Government of Nepal
Ministry of Energy, Water Resources and Irrigation
DEPARTMENT OF ELECTRICITY DEVELOPMENT
Kathmandu

PowerHouse Design Guidelines for Hydropower Projects

July 2018

FOREWORD

Hydropower projects of diverse capacities occupy a prominent position in the process of infrastructure development of the country. For this reason, hydropower projects need to be cost effective, sustainable, and environmentally and socially sound. Hence, the powerhouse design of a hydropower project demands proper planning, optimization and judicial selection of the relevant parameters, particularly in the view of topography, geology, hydrology and sediment status. In this regard, the Department of Electricity Development has felt that there is a need to maintain a uniform standard which should be compatible with the country's existing environment.

In this context, the Department has undertaken the task of formulating guidelines for the various components of a powerhouse. This work, "Powerhouse Design Guidelines for Hydropower Projects", is one of such outputs that draw upon our past experience with other projects as well as international practices and relevant literature in the area. It has hoped that the Guidelines will serve as a useful reference material for designers and developers with general guidance that should be considered while planning and designing a powerhouse.

The Department acknowledges with deep gratitude for the invaluable suggestions, comments and the endeavor of many individuals, stakeholders from governmental and non-governmental institutions, and participants of the Workshop on "Powerhouse Design Guidelines for Hydropower Projects". We also extend our thanks to the Joint Venture of Consultants; ITECO Nepal (P.) Ltd., SILT Consultants (P.) Ltd. and ERMC (P.) Ltd. for undertaking the preparation of these guidelines. Any suggestions/comments for further improvement and refinement in this Guideline will be greatly welcomed.

Mr. Nabin Raj Singh
Director General
Department of Electricity Development
June 2018

PREFACE

Introduction

The document entitled Powerhouse Design Guideline is one of a series of documents published by the Department of Electricity Development, Ministry of Energy, Water Resources and Irrigation, Government of Nepal, to establish procedural guidelines for various stages of hydropower development in Nepal. This document consists of guidelines for the design of powerhouse complex for various hydropower projects in Nepal. Powerhouse complex generally includes inlet system up to end of penstock pipe i.e. manifold, powerhouse, tailrace outlet, switchyards, workshops and quarters for the regular operations and maintenance

Development Philosophy

The guidelines presented herein have been developed along standard engineering practices by following relevant national and international acceptable Books, Manuals and Codes, incorporating considerations and requirements arising from physical and environmental conditions typical to Nepal. This development philosophy has been adopted to ensure that powerhouse development in Nepal meets the international standards.

Purpose

The guidelines provided are aimed at providing procedural guidance to agencies responsible for designing, constructing, operating and maintaining powerhouse for various hydropower projects in Nepal. These are also intended to serve as an evaluating tool for the Department of Electricity Development to monitor all engineering activities undertaken by such agencies during hydropower development.

Coverage

The guideline covers various elements to be considered for different capacity range of hydropower projects. The necessary elements covered in these guidelines are Hydrology and Hydraulics, Topographical Survey, Geology, Structure, Electrical, Electromechanical and Hydro mechanical study. The guideline clearly covers three major stages for each of the elements which are Prefeasibility, Feasibility and Detailed Design stage. It also includes the example showing sample design for a powerhouse.

Scope

The guidelines lay down overall requirements for different phases of powerhouse development. Various standard codes and suitable references have been referred for the development of the guideline.

Organization

The guidelines have been mainly divided into two parts, viz.:
Guidelines in Tabular Part
Guidelines in Theoretical Part
In tabular part, all the elements such as are Hydrology and Hydraulics, Topographical Survey, Geology, Structure, Electrical, Electromechanical and Hydro mechanical study, are briefly discussed as per the 3 stages they are developed i.e. prefeasibility, feasibility and detailed design. They are described as per the capacity range for hydropower projects. All the information is mentioned in a tabular format.
The theoretical part supplements, all the elements mentioned above in tabular part.

Applicability

The guidelines presented within apply to all government, public and private sector agencies involved in the planning, design, construction, operation and maintenance of powerhouse for various capacity range of hydropower projects in Nepal.

Principal Contributors

On behalf of Department of Electricity Development, the "*Powerhouse Design Guidelines*" has been prepared by JV of ITECO-SILT-ERMC under the Leadership of Mr. Sunil Thapa. He and his team members have made a valiant effort in completing the guideline under the stipulated time period. Additionally, DDG Mr. Sanjay Dhungel, and Er. Ashish Shrestha, on behalf of DoED, have made a major contribution in the preparation of this guideline.

Deviations

Deviations from the guidelines included in the document shall be allowed provided that the procedures of criteria used in lieu of or in addition to the provisions of the guidelines are justified in writing. Any suggested changes in the guidelines that may be necessary to incorporate in future revisions of the guidelines shall be provided to the Department of Electricity Development in writing at the following address:

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POWERHOUSE DESIGN
GUIDELINES IN TABULAR FORMAT

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LIST OF ABBREVIATIONS

A.C.	:	Alternating Current
ACI	:	American Concrete Institute
ANSI	:	American National Standards Institute
ASHRAE	:	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASCE	:	American Society of Civil Engineers
ASME	:	American Society of Mechanical Engineers
AVR	:	Automatic Voltage Regulator
BM	:	Bench Mark
CD	:	Compact Disc
DL	:	Dead Load
DoED	:	Department of Electricity Development
EIA	:	Environmental Impact Assessment
EM	:	Electro-mechanical
EOT	:	Electric Overhead Travelling
EPRI	:	Electric Power Research Institute
fps	:	Foot per second
FERC	:	Federal Energy Regulatory Commission
FS	:	Factor of Safety
GIS	:	Gas Insulated Sub station
GBR	:	Geotechnical Baseline Report
GLOF	:	Glacier Lake Outburst Flood
GNSS	:	Global Navigation Satellite System
GoN	:	Government of Nepal
GPS	:	Global Positioning System
GSU	:	Generator Step Up
HEC-HMS	:	Hydraulic Engineering Centre-Hydrologic Modelling System
HEP	:	Hydroelectric Project
HFL	:	High Flood Level
HKH	:	Hindu Kush Himalayas
HM	:	Hydro-mechanical
HVAC	:	Heating Ventilation and Air Conditioning
HV/LV	:	High Voltage/Low Voltage
IBC	:	International Building Standard

IEC	:	International Electrotechnical Commission
IEE	:	Initial Environmental Examination
IEEE	:	Institute of Electrical and Electronics Engineers
IPP	:	Independent Power Producers
ILO	:	International Labor Organization
IS	:	Indian Standard
ISC	:	International Seismological Center
ISO	:	International Organization for Standardization
kPa	:	Kilo Pascal
kV	:	kilo Volt
kVA	:	Kilo Volt Ampere
kW	:	kilo Watt
LDOF	:	Landslide Dam Outburst Flood
LIDAR	:	Light Detection and Ranging
LL	:	Live Load
MHSP	:	Medium Hydropower Study Project
MoEWI	:	Ministry of Energy, Water Resources and Irrigation
MOR	:	Moment of Resistance
MVA	:	Mega Volt Ampere
MW	:	Mega Watt
NBC	:	National Building Code
NEA	:	Nepal Electricity Authority
NIEC	:	National Earthquake Information Center
NFPA	:	National Fire Protection Association
OSHA	:	Occupational Safety and Health Administration
PIV	:	Post Indicator Valve
PVC	:	Poly Vinyl Chloride
PLC	:	Programmable Logic Controllers
PRoR	:	Peaking Run of River
psi	:	Pounds per square inch
RCC	:	Reinforced Cement Concrete
RMR	:	Rock Mass Rating
RoR	:	Run of River
RTK	:	Real Time Kinematic
RQD	:	Rock Quality Designation

SCADA	:	Supervisory Control and Data Acquisition
SL	:	Snow Load
SHP	:	Small Hydropower Project
SAP	:	Structural Analysis Programme
SPT	:	Standard Penetration Test
SWAT	:	Soil and Water Assessment Tool
TAG	:	Technical Assistance Group
TBM	:	Tunnel Boring Machine
ToR	:	Terms of Reference
UAT	:	Unit Auxiliary Transformer
UAV	:	Unmanned Aerial Vehicle
USD	:	United State Dollar
USACE	:	United States Army Corps of Engineers
USVR	:	Unites States Bureau of Reclamation
VCB	:	Vacuum Circuit Breaker
VDC	:	Village Development Committee
WECS/DHM	:	Water and Energy Commission Secretariat/Department of Hydrology and Meteorology
WL	:	Wind Load
WMO	:	World Meteorological Organization
WRD	:	Water Resource Division
WREAN	:	Western Regional Energy Agency & Network
XLPE	:	Cross Linked Poly Ethylene

1 HYDROLOGICAL STUDY AND HYDRAULIC DESIGN

1.1 Format A: Capacity Range 1-10 MW

Prefeasibility	Feasibility	Detailed design
• High flood data of river (instantaneous high flood) obtained from DHM shall be analyzed for flood frequency estimation (if available). At least 200 years return period flood shall be used for power house site selection. • For ungauged basin, WECS/DHM method shall be used for flood frequency analysis. Estimates shall be compared with other regional methods and catchment area ratio method selecting similar catchment. The selection of the design flood shall be justified if the selected method is different from WECS/DHM. • At least three cross section surveys in tailrace site shall be performed. • The historical high flood level and other high flood level shall be located in the cross-section survey. • The approximate rating curve at tailrace site shall be made for extreme flood	• All the information obtained from pre-feasibility study shall be reviewed, verified and updated. • Survey of river cross section at the same place of pre-feasibility study, shall be done, which will help to find any changes in the x-section of river. • Survey of river cross section shall be made 500 m upstream and 500 m downstream from the tailrace site. • Staff gauges shall be established, and rating curve shall be developed with necessary discharge measurements. • The glacial lake and potential hazards associated with GLOF shall be identified. (Refer to section 1.1.3.2)	• All the information obtained from pre-feasibility study and feasibility study shall be verified and updated. • Provision of measuring flow at headwork & tailrace river section shall be provided either using automated laser sensor technique or manual staff gauge reading approach or any appropriate technology.

1.2 Format B: Capacity Range 10-100 MW

Prefeasibility	Feasibility	Detailed design
• High flood data (instantaneous high flood) of a river obtained from DHM gauging stations shall be analyzed for flood frequency estimation (if available). • For ungauged basin, WECS/DHM method shall be used for flood frequency analysis. Estimates shall be compared with other regional methods and catchment area ratio method selecting similar catchment. The selection of the design flood shall be justified if the selected method is different from WECS/DHM • At least three cross section surveys in tailrace site shall be performed. • The historical high flood level and other high flood level shall be located in the cross-section survey. • The approximate rating curve at tailrace site shall be made for extreme flood.	• All the information obtained from pre-feasibility study shall be reviewed, verified and updated. For ungauged basin, hydrologic modeling shall be carried out to estimate flood. The best fitted value of flood shall be recommended. (refer section 1.1.2) • The survey of river cross section shall be made 500 m upstream and 500 m downstream from the tailrace site. • The rating curve shall be updated with updated information of gauge and precise calculation of the flood. • The glacial lake and potential hazards associated with GLOF shall be identified. (refer section 1.1.3.2) • Water surface profile modelling shall be carried out.	• All the information obtained from pre-feasibility study and feasibility study shall be verified and updated. • Power house shall be proposed at the place so that it is safe from 500 years return period flood for capacity up to 50 MW and 1000 years return period for capacity more than 50 MW and up to 100 MW. • Provision of measuring flow at headwork & tailrace river section shall be provided either using automated laser sensor technique or manual staff gauge reading approach or any appropriate technology.

1.3 Format C: Capacity Range above 100 MW

Prefeasibility	Feasibility	Detailed design
• High flood data (instantaneous high flood) of a river obtained from DHM shall be analyzed for flood frequency estimation (if available). At least 10000 years return period flood shall be used for power house site selection and PMF shall be used for storage projects. • For ungauged basin, WECS/DHM method shall be used for flood frequency analysis. Estimates shall be compared with other regional methods and catchment area ratio method selecting similar catchment. The selection of the design flood shall be justified if the selected method is different from WECS/DHM. • At least three cross section surveys in tailrace site shall be performed. • The historical high flood level and other high flood level in the cross-section survey shall be located • The approximate rating curve at tailrace site shall be made for extreme flood	• All the information obtained from pre-feasibility study shall be reviewed, verified and updated. For ungauged basin, hydrologic modeling shall be carried out to estimate flood. The best fitted value of flood shall be recommended. • The survey of river cross section shall be made 500 m upstream and 500m downstream from the tailrace site. • The rating curve shall be updated with new information of gauge and precise calculation of the flood. • The Glacial lake and potential hazards associated with GLOF shall be identified. (refer section 1.1.3.2) • Water surface profile modelling shall be carried out (Mentioned under theoretical section 1.1.1, part d).	• All the information obtained from pre-feasibility study and feasibility study shall be verified and updated. • Flood plain shall be avoided or protected well. (refer 1.1.3.1) • In case of Pelton turbine, the slope of the tailrace shall be designed in such a way that the backwater from tailrace shall not reach to the turbine. Due to the high head there will be chance of erosion on tailrace, so the tailrace floor shall be designed to resist high velocity of water. • Detailed study of river morphology shall be done to determine river course around power house site. • The power house shall be located such that it is safe from GLOF, river damming and HFL. • The draft tube of the Francis turbine shall be designed in such a way that the minimum required submergence shall be available even during the lean season to avoid the risk of cavitation. • Review of climate change scenario shall be done.

Prefeasibility	**Feasibility**	**Detailed design**
		• The fish resistance screen shall be designed so that fish cannot enter the turbine blade. The location of the screen shall be where the tailrace pipe meets the river. • Provision of measuring flow at headwork & tailrace river section shall be provided either using automated laser sensor technique or manual staff gauge reading approach or any appropriate technology.

2 TOPOGRAPHICAL SURVEY

2.1 Format A-Capacity range 1-10 MW

Study Items	Pre-feasibility Level	Feasibility Level	Detailed Study
Available Maps and Aerial Photographs	• Available largest scale contour maps and aerial photographs of the project area shall be collected and used. • The available largest scale topo-map of the project area shall be enlarged to 1:10,000 scale using photogrammetric method. • Available contour maps of the project area including their sections/ profiles shall be collected and used.	• The additional survey and mapping, e.g. setting up additional geo-technical exploration locations and seismic refraction lines shall be conducted from the recommendations made for further survey and investigation by pre-feasibility level study. • All available maps, aerial photographs, section / profiles and maps prepared during previous level of studies particularly of feasibility level survey shall be used. (refer section 2.4)	• The quality of maps and aerial photographs shall be verified.
Topographical Survey	• Cross-section survey of power house sites of the project area shall be conducted by fixing the bench marks. • Survey shall be conducted to prepare contour plan covering alternatives, powerhouse and tailrace sites.	• New control points and Bench marks shall be established. (refer to section 2.5) • Leveling and traverse survey shall be carried out for tying the control points/benchmarks with triangulation points of the national grid established by the Survey Department of GoN. • Topographical survey of the tailrace area and switchyard shall be done with 5 m contour interval and while the location of major structural components shall be done with	• Quality of survey works during feasibility study level shall be verified. • Remaining survey works, if any, shall be performed.

Study Items	Pre-feasibility Level	Feasibility Level	Detailed Study
		contour interval of 1 m. At least two most promising alternatives shall be covered by topographical survey. • River cross section survey shall be carried out at tailrace sites covering at least 500 m upstream and downstream at each site. The interval shall be 50 m to 100 m depending upon river conditions. High flood marks and existing water levels shall be shown in the cross sections. The detailed cross-section survey of cross drainage works also shall be carried out.	
Mapping and Plotting	• Contour plan in 1:10,000 scale with 5 or 10 m contour of the project area including impoundment area shall be prepared. • Cross sections of potential power house sites shall be prepared.	• Contour plan in 1:5,000 scale with 5 m contour of the whole project area shall be carried out. All the features such as rocky cliff, slide zones, cultivated land, etc., shall be shown in the contour plan. • Map in 1:1000 scale with 1 m contour interval of powerhouse sites and of canal/tunnel alignment in 1:2000 scale with 2 to 5 m contour shall be prepared. (Refer section 2.11)	• Additional mapping and plotting shall be required only if feasibility study has recommended for such works. • IS 5497:2008 can be used as guidance for topographical survey of river.

2.2 Format B - Capacity range 10-100 MW

Study Items	Pre-feasibility Level	Feasibility Level	Detailed Study
Available Maps and Aerial Photographs	• Available largest scale contour maps and aerial photographs of the project area shall be collected. • The available largest scale topo-map of the project area shall be enlarged to 1: 10,000 scale using photogrammetric method • Available contour maps of the project area including those maps/sections/ profiles shall be used.	• Topographical surveys and mapping that are expected to be carried out at feasibility level shall correspond with the requirement of feasibility level study. However, some augmentation of survey works for selected alternative may be needed, e.g., for setting up of additional geo-technical exploration locations and seismic refraction lines. These additional surveys and mapping shall be compatible with the recommendations made for further survey and investigation by pre-feasibility level study. • All available maps, aerial photographs, section / profiles and maps prepared during previous level of studies particularly of feasibility level survey shall be used. (Refer section 2.4)	• The quality of maps and aerial photographs shall be verified.
Topographical Survey	• Cross-section survey of power house sites of the project area shall be conducted along with fixing of the bench marks. • Survey works to prepare contour plan covering alternative, powerhouse and tailrace sites shall be carried out.	• The control points and new benchmarks shall be established. (Refer section 2.5) • Leveling and traverse survey for tying the control points/benchmarks with triangulation points of the national grid established by the Survey Department of GoN shall be conducted.	• The quality of survey works during feasibility study level shall be verified. • For verification, latest technologies like Differential GPS, LIDAR Survey etc. may be used.

Study Items	Pre-feasibility Level	Feasibility Level	Detailed Study
		• Topographical survey of the project area shall be carried out that includes tail race and switchyard as a whole with 5 m contour interval and of the location of major structural components with contour interval of 1 m. At least two most promising alternatives shall be covered by topographical survey. • River cross section survey shall be carried out at tailrace sites covering at least 500 m upstream and downstream at each site. The interval shall be 50 m to 100 m depending upon river conditions. High flood marks and existing water levels shall be shown in the cross sections. The detailed cross-section survey of cross drainage works shall also be carried out.	• Remaining survey works, if any, shall be conducted.
Mapping and Plotting	• Contour plan in 1:10,000 scale with 5 or 10 m contour of the project area including impoundment area shall be prepared. • Cross sections of potential power house sites shall be prepared.	• Contour plan in 1:5,000 scale with 5 m contour of the whole project area shall be prepared. All the features such as rocky cliff, slide zones, cultivated land, etc., shall be shown in the contour plan. • Map in 1:1000 scale with 1 m contour interval of powerhouse sites and of canal/tunnel alignment in 1:2000 scale with 2 to 5 m contour shall be prepared. (Refer section 2.11)	• Additional mapping and plotting will be required only if feasibility study has recommended for such works. • Latest advanced technology and mapping software may be used. (Refer section 2.12) • IS 5497:2008 can be used as guidance.

2.3 Format C - Capacity range above 100 MW

Study Items	Pre-feasibility Level	Feasibility Level	Detailed Study
Available Maps and Aerial Photographs	• Available largest scale contour maps and aerial photographs of the project area shall be collected. • The available largest scale topo-map of the project area shall be enlarged to 1: 10,000 scale using photogrammetric method • Available contour maps of the project area including those maps/sections/ profiles shall be used.	• Topographical surveys and mapping that are expected to be carried out at feasibility level shall correspond to the requirement of feasibility level study. However, some augmentation of survey works for selected alternative may be needed, e.g., for setting up of additional geo-technical exploration locations and seismic refraction lines. These additional surveys and mapping shall be compatible with the recommendations made for further survey and investigation by pre-feasibility level study. • All available maps, aerial photographs, section / profiles and maps prepared during previous level of studies particularly of feasibility level survey shall be used. (Refer section 2.4)	• The quality of maps and aerial photographs shall be verified.
Topographical Survey	• Cross-section survey of power house sites of the project area fixing the bench marks shall be conducted. • Survey shall be conducted to prepare contour plan covering alternative, powerhouse and tailrace sites.	• The control points shall be established with new benchmarks. • Leveling and traverse survey shall be conducted for tying the control points/benchmarks with triangulation points of the national grid established by the Survey Department of GoN.	• The quality of survey works during feasibility study level shall be verified. • Cross section and L-profile of river in tailrace site shall be done.

Study Items	Pre-feasibility Level	Feasibility Level	Detailed Study
		• Topographical survey shall be carried out of the project area which includes tail race area and switchyard with 5 m contour interval and of the location of major structural components with contour interval of 1 m. At least two most promising alternatives should be covered by topographical survey. • River cross section survey shall be carried out at tailrace sites covering at least 500 m upstream and downstream at each site along with detailed cross section survey of cross drainage works. The interval should be 50 m to 100 m depending upon river conditions. High flood marks and existing water levels shall be shown in the cross sections.	• The remaining survey works if/any shall be conducted. • For verification latest technologies like Differential GPS, LIDAR Survey etc. may be used.
Mapping and Plotting	• Contour plan shall be prepared in 1:10,000 scale with 5 or 10 m contour of the project area including impoundment area. • Cross sections of potential power house sites shall be prepared.	• Contour plan in 1:5,000 scale with 5 m contour of the whole project area shall be prepared. All the features such as rocky cliff, slide zones, cultivated land, etc., must be shown in the contour plan. • Maps shall be prepared in 1:1000 scale with 1 m contour interval of powerhouse sites and of canal/tunnel alignment in 1:2000 scale with 2 to 5 m contour. (Refer section 2.11)	• Additional mapping and plotting shall be required only if feasibility study has recommended for such works. • Latest advanced technology and mapping software may be used. (Refer section 2.12) • IS 5497:2008 can be used as guidance.

3 GEOLOGICAL, GEOTECHNICAL STUDY AND INVESTIGATION

3.1 Format A: Run-of-River Type, Underground/Semi Underground, Capacity Range 1-10 MW

1. GEOLOGICAL / GEO-TECHNICAL			
Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
Regional Geological Study (refer to 3.2 of section 3)	• Available literatures, topographical, geological maps and geological sections shall be collected and reviewed. • A report on regional geology and structure shall be prepared. • Maps with plan and section in 1:25,000 or 1: 50,000 based on the availability of the topographical maps shall be prepared	• Available literatures, topographical, geological maps and geological sections shall be collected and reviewed. • Reconnaissance report shall be reviewed to update and prepare a report on regional geology and structure. • Maps shall be prepared with plan and section in 1:25,000. • Structural maps shall be prepared showing major faults, folds, shear zones etc.	• Available feasibility report, topographical, geological maps, geological sections and aerial photographs shall be collected and reviewed. • Feasibility report shall be reviewed to update and prepare a report on regional geology and structure. • Maps with plan and section in 1:10,000 shall be prepared. • Structural maps shall be prepared showing major faults, folds, shear zones etc.
General Geology and Geomorphology of the Project Area (Site Specific Geology)	• A report on general geology and geomorphology of the project area shall be prepared based on the literatures and previous studies, if any.	• Report on general geology and geomorphology of the project area shall be prepared. • Maps shall be prepared with plan and section in 1:5,000 or 1: 10,000	• A report on general geology and geomorphology of the project area shall be prepared. • Maps shall be prepared with plan and section in 1:2,000 or 1: 5,000.

1. GEOLOGICAL / GEO-TECHNICAL			
Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
(Refer to 3.3 of section 3)	• A columnar section shall be prepared showing the vertical variation of geology from the project area.	• A columnar section shall be prepared showing the vertical variation of geology from the project area. • Landslide inventory map shall be prepared for the area.	• A columnar section showing the vertical variation of geology from the project area shall be prepared. • Landslide inventory map of the area shall be prepared and the vulnerability condition shall be analyzed. • A report on the ground water condition shall be done (Refer to 3.6 B).
Engineering Geological Investigation (Site Specific) (Refer to 3.4 of section 3)	• A detailed map of the Quaternary deposits shall be prepared, and stratigraphic columnar sections shall be developed. • Erosion and weathering condition of the terrain shall be Analyzed.	• A detailed geological and geo-morphological survey of. powerhouse area shall be conducted. • An inventory map of old and active landslides found in the area shall be prepared. • A detail columnar sections of the hard rock as well as Quaternary deposits shall be prepared for the project area. • A soil profile shall be prepared in the project area taking the observations at the fresh road cut sections and river cut sections.	• Prefeasibility report shall be reviewed to update the detailed geology and geomorphology study of the powerhouse. Engineering geological maps and sections in appropriate scale for design requirements or 1: 2,000 scales shall be prepared. • Engineering geological map shall contain the engineering parameters like soil type, soil depth, bearing capacity of soil, water level, gradation both in the map as well as its cross-sections.

1. GEOLOGICAL / GEO-TECHNICAL			
Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
		• Soil map shall be prepared based on genetic type like colluviums, alluviums, residual and others.	
Discontinuity Survey (Refer to 3.5 of section 3)	• Tectonic information shall be collected from the previous studies and a report on the heading of stability shall be prepared.	• A discontinuity survey shall be conducted to show the major joint sets, their orientations and stability condition in relation to the natural hill slopes. • The joint analysis shall be carried out to evaluate the stability condition of the area.	• A discontinuity survey shall be carried out such as bedding/ foliation planes, lithological contacts, major and minor joints, faults, thrusts and folds. • Discontinuity analysis shall be conducted to define major orientation and to prepare analytical result in geological format. • Rock Mass classification for each underground hydraulic structure may be prepared. • Values of RMR shall be shown on geological cross-sections. • Q-values shall be computed and the support designs shall be recommended.
Geo-physical/Hydro-geological/Geo-technical Investigation	• A list of geo-technical tests for the project shall be prepared.	• In-situ test results of the soil analysis like depth of soil in the major project components, type of soil according to Unified Soil Classification (USC) system, texture etc. shall be tabulated.	• Excavation of test pits and samples for laboratory analysis shall be done to know nature of soil at intake, desander and powerhouse sites.

1. GEOLOGICAL / GEO-TECHNICAL			
Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
(Refer to 3.6 of section 3).			• SPT and permeability tests in each test pit shall be performed to know the strength and permeable nature of soil at intake, desander and powerhouse sites. • Seismic refraction or electrical resistivity survey shall be performed for overburden thickness and nature of soil strata at intake, desander and powerhouse sites. • Laboratory analysis such as sieve and sedimentation, Atterberg limits, natural moisture content and specific gravity of collected samples for physical properties shall be performed. • The variations of soil strength in the project area shall be justified if it is significant. • Study of thin sections of the representative rocks found in the area and sedimentological studies for the loose sediments shall be done • Mineralogical tests of sediments shall be carried out

2. CONSTRUCTION MATERIAL SURVEY AND GEOTECHNICAL TESTS			
Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
		• Identification and investigation of burrow areas and quarry sites for the construction materials such as impervious soils, stones, sand and gravel etc. as required shall be carried out. • An estimation of available quantity of construction materials at each burrow area shall be prepared.	• Burrow areas and quarry sites for the construction materials such as impervious soils, stones, sand and gravel etc. as required shall be investigated. • Test pits and log showing the nature of soil at burrow locations shall be prepared for collection of samples for laboratory analysis. • Laboratory analysis shall be performed by sieving and sedimentation, Atterberg Limits, natural moisture content and specific gravity. • Available quantity at each burrow area shall be estimated to meet the requirement of the construction. • Rock block samples from each quarry site shall be collected for laboratory tests. • Laboratory tests such as uniaxial compressive strength, point load, aggregate crushing value, alkali reactivity and specific gravity etc. shall be performed on rock samples.

3. SEISMOLOGICAL STUDY (Refer to 3.8 of section 3)			
Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
Tectonic Setting	• Available Information on regional tectonics shall be discussed with illustration in a map at suitable scale.	• Available information on regional tectonics shall be used with map presentation at 1:1,000,000 or 1:2,000,000 scale.	• Regional tectonic setting of the project area and its surrounding regions shall be addressed and depicted in a map of 1:1,000,000 or 1: 2,000,000 scale with a view to indicate how and where the earthquake were generated and are likely to be generated. The major and regional existing faults around the project areas shall be shown as a source of future seismic activities. • Due to Geographical similarity with India, IS 1893 (Part 1), clause 6.4 can be referred for the calculation of Seismic coefficient.0

3.2 Format –B: Run-of-River Type, Underground/Semi-underground, Capacity Range 10-100 MW

1. GEOLOGICAL / GEO-TECHNICAL

Study Items	Prefeasibility Study	Feasibility Study	Detailed Design
Regional Geological Mapping (Refer to 3.2 of section 3).	• Available literatures, topographical, geological maps, geological sections and aerial photographs shall be collected and reviewed. • A report on regional geology and structure shall be prepared. • Maps with plan and section shall be prepared in 1:50,000 or 1: 25,000 topographical maps available.	• Available literatures, topographical, geological maps, geological sections and aerial photographs shall be collected and reviewed. • Pre-Feasibility report shall be done to update and prepare a report on regional geology and geological structure shall be reviewed. • Maps shall be drawn with plan and section based on field observation in 1:25,000 scale	• Available literatures, topographical, geological maps, geological sections and aerial photographs shall be collected and reviewed. • Feasibility report shall be reviewed to update and prepare a regional geological map of the area covering at least a 100 square kilometer and compare with the existing regional geology. • Updated maps shall be prepared with plan and section in 1:10,000 scales • Field survey shall be conducted for verification.
General Geology and Geomorphology of the Project Area (Site Specific Geology) (Refer to 3.3 of section 3).	• A report on general geology of the project area shall be prepared based on the existing literatures.	• A report on general geology and stratigraphy of the project area shall be prepared. • Maps with plan and section shall be prepared in 1:10,000 scale.	• A report on general geology and stratigraphy of the project area shall be prepared. • Maps with plan and section in 1:5,000 scale shall be prepared.

1. GEOLOGICAL / GEO-TECHNICAL			
Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
Detailed Geology and Geomorphology of particular sites (Engineering Geological Investigation). (Refer to 3.4 of section 3).	• A report on engineering geology and geomorphology covering the project site and its adjacent areas shall be prepared. Focus shall be made on the Quaternary or recent deposits along with its stratigraphy and thickness (Quaternary mapping).	• A detailed engineering geological and geo-morphological survey of powerhouse area and tailrace area shall be conducted. Map shall be prepared in 1:2000 scale considering Quaternary mapping. • Engineering geological map shall show the engineering parameters like soil type, soil depth, water condition, bearing capacity of soils, gradation etc.	• The Feasibility report shall be reviewed to update the detailed engineering geology and geomorphology of the powerhouse and tailrace access in 1:2000 scale for design requirements. • Final engineering geological map shall be prepared after proper verification survey
Discontinuity Survey (Refer to 3.5 of section 3).		• A discontinuity survey shall be conducted for the major joint sets and a summary on stability condition of the project components shall be prepared. • Stability analysis shall be performed both in rock as well as soil sloped using standard processes • Landslide and floor hazard map of the area shall be prepared.	• Discontinuity survey such as bedding/ foliation planes, lithological contacts, major and minor joints, faults, thrusts and folds, brittle shearing, fault-related indicators like fault gouge, breccia, slickensides, striations and grooves etc. shall be conducted. • A discontinuity analysis by computer or other method shall be conducted to define major orientations. Analytical results in graphical format shall also be prepared.

1. GEOLOGICAL / GEO-TECHNICAL

Study Items	Prefeasibility Study	Feasibility Study	Detailed Design
			• Rock mass classification for underground structures shall be done. • Hazard condition of the area shall be analyzed based on landslide hazard and flood hazard maps
Geo-physical/Hydro-geological/Geo-technical Investigation (Refer to 3.6 of section 3).	Appropriate geo-technical tests, sampling sites and sampling procedures shall be listed.	• Excavation shall be done at test pits and samples shall be collected for laboratory analysis to access nature of soil at powerhouse sites (a grid of 100 m x 100 m for soil samples shall be prepared). • SPT and permeability tests in each test pit shall be performed to know the strength and permeable nature of soil at powerhouse sites. • Seismic refraction or resistively survey for overburden thickness and nature of soil strata at powerhouse sites shall be performed making a close grid. Depth of investigation should be 100 m from the present surface. • Drilling and logging at powerhouse sites shall be performed.	• Drilling and logging at powerhouse sites shall be performed. Drilling shall be carried out vertical, inclined or horizontal based on the orientation of the geological strata and its structure. • Additional seismic refraction or resistively survey shall be performed to know depth to bedrock, overburden thickness and nature of soil strata at powerhouse area as well as adjacent slopes to assess the slip surface if any and depth of soils and/or characterization of bed rocks underlying the overburden. • Laboratory analysis shall be performed for soil and rock laboratory test such as (I) sieve and sedimentation, (ii) Atterberg limits, (iii) Natural moisture content and (iv)

1. GEOLOGICAL / GEO-TECHNICAL			
Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
		• Laboratory analysis such as sieve and sedimentation, Atterberg limits, natural moisture content and specific gravity shall be performed for assessment of physical properties of collected samples. • Mineralogical test of sediments is recommended to assess the quartz-grains and other hard minerals	specific gravity of collected soil samples for physical properties. • Laboratory test (i) triaxial compressive strength test (ii) uniaxial ultimate compressive strength test, (iii) point load tensile strength test, (iv) Los Angeles abrasion test (v) crushing value test (vi) Impact test (vii) specific gravity test (viii) Swelling pressure test and (ix) Alkali aggregate reaction test for rock shall be conducted. • Thin section of bed rocks (petrography) obtained from the drilling shall be studied to identify its microstructures, mineral composition, cementing materials, joint density, weathering status etc. which ultimately link to the bearing capacity of the rocks or support system. • Sedimentological test in terms of mineral composition and type is recommended.

2. CONSTRUCTION MATERIAL SURVEY AND GEOTECHNICAL TESTS (Refer to 3.7 of section 3).			
Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
		• Identification and investigation of burrow areas and quarry sites for construction materials such as impervious soils, stones, sand and gravel etc. as required shall be done. • Test pits at burrow areas shall be excavated and its log shall be prepared. Soil samples shall be collected for laboratory analysis. • Rock samples from bedrock exposures for laboratory analysis shall be collected. • Laboratory analysis for soils and rock shall be done. • An estimation of available quantity at each burrow area for the construction shall be made.	• Identification and investigation of burrow areas and quarry sites for the construction materials such as impervious soils, stones, sand and gravel etc. as required shall be done. • Construction material study reports and update for the feasibility shall be reviewed. • Additional test pits shall be excavated if required and their log shall be prepared to understand the nature of soils at burrow areas and collect samples for laboratory analysis. • Laboratory analysis shall be performed by sieving and sedimentation, Atterberg Limits, natural moisture content and specific gravity etc. for soil samples. • Rock block samples from each quarry site shall be collected for laboratory tests. • Laboratory tests such as uniaxial compressive strength, point load, Los Angeles abrasion, aggregate crushing

2. CONSTRUCTION MATERIAL SURVEY AND GEOTECHNICAL TESTS (Refer to 3.7 of section 3).			
Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
			value, alkali reactivity and specific gravity etc. tests shall be performed on rock samples. • Available quantity of construction materials of acceptable quality at each burrow area shall be estimated.

3. SEISMOLOGICAL STUDY (Refer to 3.8 of section 3)

Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
Tectonic Setting	• Background information on regional tectonics of the project area and surrounding regions shall be addressed and illustrated in a map.	• Information on tectonic features of the project area and adjoining regions representing 200 km radius shall be used and shown in a map.	• Tectonic characteristics of the project area and surrounding regions covering 200 km radius shall be stated and depicted in a map. • Information shall be specific in respect to the identification of the sources of earthquake generation and assessment of the project site in terms of seismic safety.
Aerial Photos and Remote Sensing Interpretation	• A report on the aerial photos and remote sensing methods shall be prepared. It includes the assessment of lineaments, fault scarps etc.	• General studies of aerial photos and land sat images shall be performed to review tectonics features.	• Interpretation of aerial photos and land sat images shall be critically carried out to verify and review the tectonic features of the surrounding regions including the neo-tectonics.

3. SEISMOLOGICAL STUDY (Refer to 3.8 of section 3)

Study Items	Prefeasibility Study	Feasibility Study	Detailed Design
Fault and Paleo-seismicity	• Report based on the available literatures shall be prepared.	• Information on different fault characteristics shall be presented	• Faults existent around the project area shall be stated in terms of their activity, nature such as active, capable or inactive. • Respective length, distance, return period and reoccurrence nature should be addressed. Characteristic of rupture age of the most recent deformation and consistency of the epicenters with associate fault shall be suggested. • Existing information on paleo-seismicity evidences representing pre-historic major earthquakes occurred during the past years shall be presented.

3. SEISMOLOGICAL STUDY (Refer to 3.8 of section 3)			
Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
Earthquake Catalogue and Historical and Instrumentally Recorded Earthquake	• A report on the history of earthquake and recurrence time based on the available literatures shall be prepared.	• Information on regional seismicity shall be presented and depicted in a map at suitable scale.	• The earthquake catalogue on historical and instrumentally recorded seismicity data representing magnitude 4 Richter Scale and above shall be delivered and shown in map. • For each significant event, the location, distance, recurrence, magnitude and intensity shall be reflected.
Seismic Zoning	A report showing the project location in seismic zoning map shall be prepared.		• The project area shall be represented based on the seismic zones of the country. • Characterization of various earthquake sources inherent in this zone shall be determined.

3. SEISMOLOGICAL STUDY (Refer to 3.8 of section 3)			
Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
Seismic Hazard Analysis	A report on the existing seismic hazard assessment based on the available literatures shall be done.		• Effect of earthquake at the site shall be expressed in terms of intensity or acceleration. The probable maximum earthquake which may affect an installation during its life time or the maximum earthquake likely to occur during the project life shall be addressed. • The probability of exceedance of different level of intensity or acceleration of the ground motion at the site during a particular period of time shall be expressed. • The peak ground acceleration (PGA) for Maximum Design earthquake (MDE) and Operating Basis Earthquake (OBE) shall be recommended. (Refer ER 1110-

3. SEISMOLOGICAL STUDY (Refer to 3.8 of section 3)			
Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
			2-1806, IS 13372 part 1 &2 for seismic testing and evaluation of parameter for earthquake design) • Risk assessment in consideration of ground movement, dislocation and rock shattering of fault, ground creep, landslide and rock fall due to earthquake shall be taken into account. • Seismic risks evaluation of Recent Earthquake- 2015 and its scientific findings and recommendations shall be included in the report. Seismic evaluation shall be carried out based on the vertical variation of the rock type or rock/soil interface and topographic features.

3.3 Format –C: Run-of-River Type, Underground/Semi-underground, Capacity Range above 100 MW

1. GEOLOGICAL / GEO-TECHNICAL			
Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
Regional Geological Mapping (Refer to 3.2 of section 3).	• Available literatures, topographical, geological maps, geological sections, aerial photographs shall be collected and reviewed. • A report on regional stratigraphy, geology and structure shall be prepared. • Maps shall be prepared with plan and section in 1:25,000 or 1: 50,000 based on the availability of the topographical and geological maps.	• Available literatures, topographical, geological maps, geological sections, aerial photographs shall be collected and reviewed. • Pre-Feasibility report shall be reviewed to update and prepare a report on regional stratigraphy, geology and structure. • Maps shall be prepared with plan and section in 1:25,000 based on field observation • Regional geological map shall be prepared on the basis of primary data considering an area of at least 10 km radius from project location.	• Available literatures, topographical, geological maps, geological sections, aerial photographs shall be collected and reviewed. • Feasibility report shall be reviewed to update and prepare a report on regional stratigraphy, geology and structure. • Maps shall be prepared with plan and section in 1:10,000 • Field survey shall be conducted for verification.
General Geology and Geomorphology of	• A report on general geology and	• Pre-Feasibility report shall be reviewed.	• Feasibility report shall be reviewed and a report on general geology and

1. GEOLOGICAL / GEO-TECHNICAL

Study Items	Prefeasibility Study	Feasibility Study	Detailed Design
the Project Area (Site Specific Geology) (Refer to 3.3 of section 3).	geomorphology of the project area shall be prepared. • The landslide inventory maps shall be prepared. Geomorphology shall be described in terms of slope, drainage, and aspect and land use pattern with maps.	• Report shall be made on general geology, stratigraphy, geological structure and geomorphology of the project area. • Geomorphological maps shall be prepared and text description with slope, drainage, aspect, land use, soil depth and mass movement conditions shall be prepared. • Maps with plan and section in 1:10,000 shall be prepared	geomorphology of the project area shall be prepared • Maps with plan and section in 1:5,000 shall be prepared
Engineering Geological Investigation (Site specific). (Refer to 3.4 of section 3).	• A report on geology and geomorphology of each site based on field observations shall be prepared. Emphasis shall be given to the local geological and geomorphological	• A detailed geological and geomorphological survey of powerhouse shall be conducted on recently prepared topographical maps. • The representative samples of each rock type shall be collected, both fresh and weathered and prepare thin sections	• Prefeasibility report shall be reviewed to update the detailed geology and geomorphology study of the particular sites. Additional survey of powerhouse and prepare maps and sections for design requirements in 1:2000 scale shall be prepared.

1. GEOLOGICAL / GEO-TECHNICAL			
Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
	condition of the project components.	(0.03 mm thickness) to study the petrographic as well as micro-tectonic analysis. • Engineering geological map shall show the engineering parameters like soil type, soil depth, water condition, bearing capacity of soils, gradation etc.	
Discontinuity Survey (Refer to 3.5 of section 3).	• A discontinuity survey such as bedding/foliation planes, lineation, lithological contacts, major and minor joints, faults, thrusts and folds shall be conducted. • All measured discontinuity along with location of their occurrences shall be Tabulated.	• Review and update of pre-existing reconnaissance survey shall be done. • Discontinuity survey such as bedding/ foliation planes, lineation, lithological contacts, major and minor joints, faults, thrusts and folds shall be conducted. The studies on the slickensides, step-marks, fault related striations, and other structural weaknesses shall also be carried out so that the presence of faults and shear zones will not be missed in the project area.	• Review and update of the reconnaissance survey shall be done. • Ddiscontinuity survey such as bedding/ foliation planes, lineation, fold axis, lithological contacts, major and minor joints, faults, thrusts and folds shall be carried out • D discontinuity analysis shall be conducted by computer or other method to define major orientations. Analytical results shall be prepared in graphical format.

1. GEOLOGICAL / GEO-TECHNICAL			
Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
	• A discontinuity analysis shall be conducted by computer or other method to define major orientations. Analytical results shall be prepared in graphical format.	• Discontinuity analysis shall be conducted by computer or other method to define major orientations. Analytical results shall be prepared in graphical format. • Rock mass classification shall be prepared for each underground hydraulic structure. • Landslide and flood hazard map shall be prepared for the project area.	• Rock mass classification for each underground hydraulic structure shall be prepared. • The hazard condition shall be analyzed from the hazard maps prepared and proposed for the proper mitigation measures.
Geo-physical/Hydro-geological/Geo-technical Investigation (Refer to 3.6 of section 3).	A list of necessary geo-technical test and sample collection sites and procedures shall be prepared.	• Excavation of test pits and collection of samples for laboratory analysis to access nature of soil at dam spillway, river diversion, stilling basin cofferdam, intake portal, surge-tank and powerhouse areas and tailrace sites shall be done.	• Additional seismic refraction or resistivity survey of major structures such as shall be conducted to ascertain depth of bedrock, the overburden thickness and the nature of soil strata , dam spillway, river diversion, stilling basin cofferdam, intake portal, headrace

1. GEOLOGICAL / GEO-TECHNICAL			
Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
		• SPT and permeability tests shall be performed in each test pit to know the strength and permeable nature of soil at dam spillway, river diversion, stilling basin, cofferdam, and intake portal, and surge-tank, powerhouse and tailrace sites. • Seismic refraction or resistivity survey shall be performed at location of dam spillway, river diversion, stilling basin cofferdam, intake portal, headrace tunnel, surge tank powerhouse and tailrace sites. to assess depth of bedrock, the nature of soil strata and the thickness of overburden. • Drilling and logging shall be performed in dam spillway, river diversion, stilling basin cofferdam, intake portal,	tunnel, surge tank powerhouse and tailrace sites. • Additional drilling and logging shall be performed at dam spillway, river diversion, stilling basin cofferdam, intake portal, surge tank powerhouse and tailrace sites if deemed necessary. • Permeability and grout intake tests in each drill hole shall be performed at dam, diversion, spillway, intake portal and stilling basin sites. • Based on the local geological condition and recommendation of experts, an exploratory tunnel may be drilled to obtain additional information for design and construction of the main tunnels. • Laboratory test such as (I) sieve and sedimentation, (ii) Atterberg limits, (iii) Natural moisture content and (iv)

1. GEOLOGICAL / GEO-TECHNICAL			
Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
		and surge tank powerhouse and tailrace sites. • Laboratory analysis shall be performed for soil and rock • Laboratory test such as (I) sieve and sedimentation, (ii) Atterberg limits, (iii) Natural moisture content and (iv) specific gravity (v) Proctor compaction tests shall be conducted to identify physical properties of soil samples. • Mineralogical composition of sediment shall be analyzed.	specific gravity (v) Proctor compaction tests shall be conducted on collected samples for physical properties of soil. • Laboratory test such as (i) triaxial compressive strength (ii) uniaxial ultimate compressive strength, (iii) point load tensile strength, (iv) Los Angeles abrasion, (v) crushing value, (vi) Impact value, (vii) specific gravity, (viii) swelling pressure, and (ix) Alkali aggregate reaction tests on rock samples shall be conducted. • Special tests like Hydrofracturing, Lugeon and SPT are recommended. • The thin section studies of rocks or hard sediments derived from the drill holes shall be carried out. One thin section from each 5 m depth is required for the study. If the rock succession is

1. GEOLOGICAL / GEO-TECHNICAL			
Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
			intercalated or inter-bedded, additional number of thin section studies are recommended. The study shall focus on the mineral composition, texture, micro-tectonics, weathering and alteration condition, micro-joints and fractures, grain-boundary condition and deformation status. etc. • Representative samples from each stratigraphic units or lithological type shall be collected and a report on the thin section studies shall be prepared. The studies on the mineral composition, texture, alteration, weathering status, micro-joints and fractures, grain cracking, grain-boundary deformation and micro-tectonics shall be formed. • Mineralogical test of sediments are recommended.

2. CONSTRUCTION MATERIAL SURVEY AND GEOTECHNICAL TESTS (Refer to 3.7 of section 3).			
Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
	Burrow areas and quarry sites for the construction materials such as impervious soils, stones, sand and gravel etc. as required shall be identified.	• Burrow areas and quarry sites for the quantification of construction materials such as impervious soils, stones, sand and gravel etc. shall be identified and investigated. • Test pits shall be excavated and a log of the pit shall be prepared to understand the nature of soils at burrow areas. Samples shall be collected for laboratory analysis shall be done • Collection of rock samples from bedrock exposures shall be done for laboratory analysis. • Available aggregate (fine and coarse) quantity required for construction shall be estimated at each burrow area.	• Feasibility studies shall be reviewed. • Additional burrow areas and quarry sites shall be investigated if required for the assessment of construction materials such as impervious soils, stones, sand and gravel etc. as required. • Construction material study reports and updating for the feasibility shall be reviewed. • Additional test pits shall be excavated if required and log of pit to understand the nature of soils at burrow areas. Samples shall be collected for laboratory analysis. • Laboratory analysis shall be performed by sieving and sedimentation, Atterberg

2. CONSTRUCTION MATERIAL SURVEY AND GEOTECHNICAL TESTS (Refer to 3.7 of section 3).

Study Items	Prefeasibility Study	Feasibility Study	Detailed Design
		• The petrographic studies of rocks/minerals and sediments shall be conducted to assess the weathering condition and micro-fractures present in the rocks and sediments (ref. to 3.5C of section 3).	Limits, natural moisture content and specific gravity etc. for soil samples. • Rock block samples shall be collected from each quarry site for laboratory tests and the mineralogical composition, texture, deformation status, micro-cracks and weathering status of the rocks under thin sections shall also be analyzed. • Laboratory tests such as uniaxial compressive strength, point load, Los Angeles abrasion, aggregate crushing value, alkali reactivity and specific gravity tests on rock samples shall be performed if necessary. • Available quantity of aggregate after defining the quality of the materials at

2. CONSTRUCTION MATERIAL SURVEY AND GEOTECHNICAL TESTS (Refer to 3.7 of section 3).			
Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
			each burrow area for the construction shall be estimated.

3. SEISMOLOGICAL STUDY (Refer to 3.8 of section 3)

Study Items	Prefeasibility Study	Feasibility Study	Detailed Design
Tectonic Setting	• General information on the regional tectonic situation of the project area shall be addressed and shown in a map of 1:1,000,000 or 1:2,000,000 scale.	• Information on tectonic characteristics of the study area covering 200 km radius shall be described and illustrated in map at scale 1:1,000,000 or 1:2,000,000.	• Information on tectonic setting of the study area as well as that of the surrounding regions lying within a radius of 200 km shall be provided in the map at 1:1,000,000 or 1: 2,000,000 scale in order to provide information about how and where the earthquakes were generated and are likely to be generated. • Information on the risks of the recent Earthquake (such as Gorkha earthquake 2015) shall be collected.
Aerial Photos and Remote Sensing Interpretation	• General review of aerial photos and Landsat images shall be established to assess tectonics features	• Aerial Photos and Landsat images studies information shall be used to review the neo-tectonics of the project area.	• Interpretation of aerial photos and remote sensing studies shall be critically reviewed to define the tectonic features of the project area including the neo-tectonics.

3. SEISMOLOGICAL STUDY (Refer to 3.8 of section 3)

Study Items	Prefeasibility Study	Feasibility Study	Detailed Design
Fault and Paleo-seismicity	• A report on tectonics of the area shall be prepared.	• Characteristics of faults encountered in the project area shall be discussed	• Active, capable and extinct faults occurred in the project area and surrounding regions shall be addressed in terms of length, distance, and return period and reoccurrence nature. Rupture rate of the most recent faults, present state of stress and degree of reliability and associated epicenters to the fault area shall also be suggested. • Information on paleo-seismicity of earthquakes that occurred within past 11,000 years that are useful to support the instrumental and historical major seismic data shall be established. • Field indications of the pre-historic major earthquakes shall be given.
Earthquake Catalogue and Historical and	• A report on earthquake history and earthquake frequency analysis shall be done.	• Regional seismicity shall be considered with depiction in the appropriate map	• The earthquake catalogue of historical and instrumentally recorded seismicity data of the region specifically for those above about Richter Scale shall be mentioned for assessment of seismicity

3. SEISMOLOGICAL STUDY (Refer to 3.8 of section 3)

Study Items	Prefeasibility Study	Feasibility Study	Detailed Design
Instrumentally Recorded Earthquake			of the region. For each significant event, the location, distance, reoccurrence period, magnitude and intensity shall be given and depicted in the map.
Seismic Zoning	A report shall be prepared showing the project location in seismic zonation map.		• Representation of the project area in reference to the seismic zoning of the country shall be reflected. Characterization of various earthquake sources inherent in this zone shall be established.
Seismic Hazard Analysis	A report shall be prepared on seismic hazard assessment based on available literatures.	Seismic hazard shall be assessed based on the sub-surface geological condition i.e. based on the vertical variation of lithology.	• The greatest earthquake likely to affect the construction during the life time or the maximum magnitude of earthquake anticipated to occur in a particular period shall be addressed. • The probability of exceeding different level of intensity or acceleration of the ground in the site during a particular period of time shall be expressed. Empirical formula suitable as per the

3. SEISMOLOGICAL STUDY (Refer to 3.8 of section 3)			
Study Items	**Prefeasibility Study**	**Feasibility Study**	**Detailed Design**
			tectonics of the country may be applied as necessary to determine the peak ground acceleration (PGA) for Maximum Design Earthquake (MDE) and Operating Basis Earthquake (OBE). • Risk evaluation with respect to ground motion, dislocation and rock shattering of fault, ground creep, landslide and rock fall due to earthquake shall be considered. • Due to Geographical similarity with India, IS 1893 (Part 1), clause 6.4 can be referred for the calculation of Seismic coefficient.

4 STRUCTURAL DESIGN

4.1 Format A: Capacity Range 1-10 MW

Type: Surface Powerhouse

Prefeasibility	Feasibility	Detailed design
• On the basis of available head and discharge, type of the turbine and number of unit may be decided. Simultaneously, capacity of each unit shall be estimated. • At preliminary stage dimensioning of the E/M equipment and structural component may be done by thumb rule. Based on the size and the layout of the E/M accessories, size and layout of the *Machine Hall*, *Erection Bay* and *Control Room* may be estimated. • Preliminary dimensioning of structural component shall be done by thumb rule. • Once the dimension of powerhouse is approximated, quantity of the construction materials and their approximate cost may be estimated.	• All the information obtained from pre-feasibility study shall be verified and updated. Necessary changes in the design shall be incorporated. • Size of the E/M equipment e.g. *Runner* and *Bucket (Turbine)* and size and position of *Inlet Valve* and Generator in case of Pelton turbine, shall be approximated based on the head and discharge of a single unit. Similarly, if Francis turbine is used, size of *Spiral Casing*, *Inlet Valve*, *Draft Tube* governs the size of PH. Preliminary dimensioning of electro-mechanical equipment shall be as per section 6. • Once single unit size is calculated length of *Machine Hall* can be estimated. For repair and erection purpose of E/M equipment, an additional space called *Repair Bay* shall	**<u>Planning and layout of powerhouse</u>** • All the information obtained from feasibility study shall be verified and updated. Design shall be reviewed and necessary changes shall be incorporated in detail design. • Size and layout of the E/M equipment may differ in the detail design which may affect the size of the powerhouse compared to the feasibility stage design. Size of the powerhouse shall be re-planned as per the requirement of E/M equipment. • Layout of all necessary E/M equipment and civil components may be done repeatedly which help to approximate the most economical and suitable size of powerhouse. This process includes fixing the position and size, but not limited to, *turbine, generator, tailrace channel, control room, erection bay, office rooms, general facilities rooms, doors, windows, ventilation, walls staircase, cable duct* and *emergency escape route* etc. and must be finalized prior to structural design.

Prefeasibility	Feasibility	Detailed design
	be provided which shall be at least the size of single unit. • Location of the *Control Room/Building, Repair Bay, Store, Office room/Building, Cable Trench and Tailrace Outlet* shall be fixed. • Height of the superstructure for PH, depends upon the height of the *EOT Crane*, maximum size of object to be carried by *EOT Crane and maximum level to which the object be carried*. For free movement, height of Hook, clearance required between *EOT Crane* top level and the lowest level of roof and the clearance between the bottom of the hoisted object and the any fixed object in the Machine Hall/Repair bay shall also be taken into account. • After finalizing the layout of Civil and E/M components, position of structural components like *column, beams* and *machine foundations* are fixed. Position of *doors, windows, stairs, walls*, access to *Machine Hall* and *Erection Bay and emergency exit route* should also be fixed.	• For layout of crane column reference may be taken from section 4.5.2. • For architectural requirement of powerhouse reference may be taken from section 4.26. • Construction material for various structural and non-structural element of PH shall be finalized. • C/L of *Crane Rail* track should be such that the clearance between the inner face of wall/column and the outer edge of *EOT Crane* should be at least 20cm to facilitate the maintenance of EOT crane. **<u>Design of roof</u>** • Design of roof shall be finalized prior to initialize the analysis and design of frame structure. Hence, type of the roof shall be determined first weather it is of steel truss or RCC slab. Generally, steel truss roof, being more economical and easier to construct and install, is preferred rather than RCC slab due to larger span of crane supporting columns. • Physical properties of steel members may be as per the section 4.4.1. • Imposed load on roof may be estimated according to section 4.5.4.2. • Wind load on roof and cladding wall may be estimated as per the section 4.5.4.4. • Resultant load of the roof shall be transferred to all crane column. Eccentricity of resultant of roof load

Prefeasibility	Feasibility	Detailed design
	• Stability analysis, structural analysis and design of PH may be carried out similar to the procedures given in the Detail design column.	w.r.t. to major and minor axis of column shall be identified and the moment due to the eccentricity of roof load on crane column should be taken in consideration for design of the crane column. **<u>Dead load</u>** • At first trial size of the structural elements may be provided arbitrarily according to the designer's choice. • Unit weight of the building material may be as per the sections 4.4. • Roof load should be considered as dead load. • Dead load of all structural and non-structural elements are calculated. • Weight of equipment/machinery shall be provided by E/M team are, but not limited to, as listed below; ➢ weight of turbine ➢ weight of generator unit ➢ weight of *inlet valve* ➢ Maximum wheel load of *EOT crane* Equipment weight., maximum resultant force including dynamic force and their point of application shall be provided by manufacturer. Details required for machinery/equipment load may be as recommended in section 4.3. **<u>Imposed load</u>**

Prefeasibility	**Feasibility**	**Detailed design**
		• Imposed load on the floor slab may be estimated as per the section 4.5.4.2. • Force due to *EOT crane* are considered as imposed load. • Dimensions of *EOT crane* shall be provided by manufacturer. Reference may be taken from section 4.5.4.3 for various data required for EOT crane. • Minimum load due to impact and vibration of *EOT crane* in vertical, in traverse and along rail direction shall be provided by manufacturer. In absence of authentic data, *EOT crane* load may be estimated as per the section 4.5.4.3 **<u>Seismic force</u>** • Earthquake force may be estimated according as given in section 4.5.4.6. **<u>Stability analysis</u>** • After estimation of all types of loads stability analysis of powerhouse may be carried out. Stability analysis of powerhouse may be done in accordance with the section 4.7. • Surface powerhouse should be checked for the stability in different stages of construction as per section 4-7 and table 4-1. **<u>Structural Analysis</u>** • Next step is analysis of the structural elements. Frame structure may be analyzed by using any

Prefeasibility	Feasibility	Detailed design
		computer software or may be analyzed manually. Reference may take from section 4.9. • Maximum values of design bending moment, shear force and axial forces etc. at different load combinations shall be found out and utilized for the design of the structural components. • Various Geotechnical parameters for powerhouse design can be referred from section 4.20.4 **RCC design of structure** • Reference for design of beams, columns, slab walls and foundation may be taken from section 4.11 to section 4.20. • Design of corbels for crane girder/beam may be referred from section 4.25. • Machine foundation should safely transfer the weight of machine and the additional dynamic load generated during normal operation and at emergency condition to the ground with minimum vibration. Design of block type of foundation should include ➢ Check for stability of the machine foundation in different load condition as given in section 4.20.6. ➢ Performance of the generator foundation should be checked as per the section 4.20.7.

Prefeasibility	Feasibility	Detailed design
		Analysis of block type of foundation may be done as per the section 4.20.9 • Reference may be taken from section 4.21 for reinforcement detailing. • Requirement of detail drawings of powerhouse may be in accordance with section 4.2.

4.2 Format B: Capacity Range 10-100 MW

Prefeasibility	Feasibility	Detailed design
• After selection of turbine type number of units is estimated to find the capacity of each unit. • For electromechanical work sizing of the equipment can be done by thumb rule. General planning for layout of all equipment is done to accommodate the accessories inside the powerhouse and to find the approximate size of powerhouse • Once the dimension of powerhouse is approximated, layout & planning of civil components shall be done to fix the position of columns, foundation, beams and height of powerhouse. • Selection of type of roof is also done. • Based on layout of frame, size of the beam, column and foundation	• All the information obtained from pre-feasibility study shall be verified and updated. Any change in the design shall be incorporated. • Based on the head and discharge of a single unit, size of the E/M equipment e.g. runner with bucket, dimension of penstock distributor pipe, size and position of inlet valve and turbine casing, in case of Pelton turbine, is approximated which guides to estimate the size of powerhouse. Similarly, if Francis turbine is used, size of spiral casing, inlet valve, size of draft tube governs the size of powerhouse. Preliminary dimensioning of electro-mechanical equipment shall be as per section 6. • Height of powerhouse below substructure is governed by machine height and height of *Draft Tube*. Height of powerhouse, above the *Machine Hall* mainly depends upon the height of the	**<u>Planning and layout of powerhouse</u>** • All the information obtained from feasibility study shall be verified and updated. Design should be reviewed and necessary changes should be incorporated in detail design. • Size & layout of the E/M equipment may differ in the detail design which may affect the size of the powerhouse compared to the feasibility stage design. Final size of the machinery and all auxiliaries shall be provided by the manufacturer. • Size of the powerhouse may be re-planned as per the actual size and position of machinery/equipment. This process includes fixing the position of, but not limited to, Turbine, Draft tube, Generator, Tailrace Channel, Control Room, Erection Bay, Office Rooms, general facilities rooms, doors, windows, ventilation, walls staircase, cable duct and emergency escape route etc. and must be finalized prior to structural design. • For layout of crane column reference may be taken from section 4.5.2. • C/L of Crane Rail track should be such that the clearance between the inner face of wall/column and the outer edge

Prefeasibility	Feasibility	Detailed design
is estimated and amount of reinforcement is also provided by thumb rule. • Information of geology of the powerhouse area is important parameter, at preliminary study, which will ease the foundation construction and save the cost of foundation treatment. It is recommended to select the powerhouse site with rock.	*EOT Crane*, maximum size of object to be carried by *EOT Crane* and maximum level to which the object to be carried. For free movement, height of *Hook*/*Anchor*, clearance required between *EOT Crane* top level and the lowest level of roof and the clearance between the bottom of the carried object and the any fixed object in the *Machine Hall*/*Repair bay* should also be taken into account. • Layout of all necessary E/M equipment and civil components may be done repeatedly which approximate the most economical & suitable size of powerhouse. This process includes fixing the size and position of *turbin*e, *draft tube*, *generator, tailrace channels*, *control room*, *erection bay*, *battery rooms*, *office room/building*, *General facilities rooms*, *doors*, *windows*, *ventilation*, *walls*, *staircase*, *elevator*, *cable duct/gallery* and *emergency escape route* etc. • Total numbers of floors under the ground level and height of each floors	of EOT Crane should be at least 20cm to facilitate the maintenance of EOT crane. • For architectural requirement of powerhouse reference may be taken from section 4.26. • Construction materials for various structural and non–structural element of PH shall be finalized. **<u>Design of roof</u>** • Design of roof shall be finalized prior to initialize the analysis and design of frame structure. Hence, type of the roof shall be determined first weather it is of steel truss or RCC slab. Generally, steel truss roof, being more economical and easier to construct and install, is preferred rather than RCC slab due to larger span length of crane supporting columns. • Physical properties of structural steel members may be as per the section 4.4.1. • Imposed load on roof may be estimated according to section 4.5.4.2 • Wind load may be estimated as per the section 4.5.4.4. • Resultant load of the roof shall be transferred to column. Eccentricity of resultant of roof load w.r.t. to major and minor axis of column shall be found out and the moment due to the eccentricity of roof load on crane column should be taken in consideration for design of the column/ crane column. **<u>Dead load</u>**

<table>
<tr><th>Prefeasibility</th><th>Feasibility</th><th>Detailed design</th></tr>
<tr><td></td><td>should also be finalized. Height of each floor is governed by the height of machine and auxiliaries.
• After finalizing the layout of Civil and E/M components, position of structural components like columns, beams, shear wall and foundation are decided.
• At preliminary stage, size of the crane beam, crane column and thickness of floor slab, shear walls and foundation may be provided as per the designer’s choice.
• Foundation soil/rock condition and bearing capacity should be ascertained from geological/ geotechnical report.
• All types of loads as specified in section 4.5.4 and 4.6.1 shall be estimated.
• Based on the load data stability of the powerhouse may be checked in different load conditions as per the section 4.7.
• Structural analysis and design may be carried out as the same procedure as given in the Detail design column. At feasibility stage the various data required for structural design and stability check of powerhouse may not</td><td>• At first, trial size of the structural member may be provided arbitrarily according to the designer’s choice.
• Unit weight of the building material may be as per the sections 4.4.
• Roof load should be considered as dead load.
• Information regarding static and dynamic loads and their point of application for machinery and auxiliary equipment shall be provided by manufacturer in advance are, but not limited to, as listed below.
➢ weight of Draft Tube
➢ weight of Draft Tube Gate
➢ weight of Spiral Case
➢ weight of Turbine
➢ weight of Inlet valve
➢ weight of Rotor
➢ weight of Stator and reaction at each support of the Stator
➢ maximum vertical, radial and tangential load at support of Lower Bracket and Upper Bracket
➢ weight of Generator Casing
➢ weight of EOT crane
➢ Maximum wheel load of EOT crane
Information required regarding machinery/equipment loads may be as recommended in section 4.3.</td></tr>
</table>

Prefeasibility	Feasibility	Detailed design
	be available hence the data for loads, materials and geological/geotechnical may be taken as recommended in this guideline (Theoretical) or from any other code/standard.	• Different types of load in sub structure should be as per the section 4.6. Lateral soil and water pressure which acts on shear wall should be considered as dead load. **<u>Imposed load</u>** • Imposed load on the floor slab may be estimated as per the section 4.5.4.2. • All the details of EOT Crane, weight and load direction and magnitudes shall be considered as imposed load and shall be provided by manufacturer. Reference may be taken from section 4.5.4.3 or various data required of EOT crane. • Minimum load due to impact and vibration of EOT crane in vertical, along rail track and traverse direction of rail track shall be provided by manufacturer. In absence of authentic data, EOT crane load may be estimated as per the section 4.5.4.3. • Crane load is, finally, transferred to crane girder/ beam and column. • Lateral pressure on shear wall of substructure due to surcharge should be considered as imposed/ live load. **<u>Seismic force</u>** • Earthquake force may be estimated according as given in section 4.5.4.6. **<u>Stability analysis</u>** • Stability analysis of semi-surface powerhouse may be carried out as per the section 4.7.

Prefeasibility	Feasibility	Detailed design
		• Semi-surface powerhouse should also be checked for the stability in different stages of construction as per section 4-7 and table 4-1. **Analysis of structure** • Next step would be the analysis of structural elements. Semi surface powerhouse are composed of substructure and superstructure. Analysis of powerhouse structure having multiple floors in substructure may be done either by manual calculation or by using computer software. • Structure model can be either 2d or 3d as described in section 4.9. • Maximum values of design bending moment, shear force and axial forces at different load combinations shall identified and utilized for the design of the structural components. **Design of structure** • Design of RCC structural elements for superstructure and sub structure like beam column, wall and slabs shall be done by limit state method and shall fulfill the requirements of limit sates for collapse and serviceability both. Reference for design of RCC structures by Limit State method should be as per the sections from 4.11 to section 4.20. • Design of corbel may be done as described in section 4.25.

Prefeasibility	Feasibility	Detailed design
		• Design of structural element may be carried out by Working Stress method where limit state method is not applicable. For design of RCC structures by Working Stress method reference may be taken form Annex 'B' of IS: 465-2000. • Reference may be take form section 4.21 for reinforcement detailing. • Requirements of detail drawings of powerhouse may be in accordance with section 4.2.

4.3 Format C: Capacity Range above 100 MW

Prefeasibility	Feasibility	Detailed design
• After selection of turbine type number of units is estimated to find the capacity of each unit. • Preliminary sizing of the e/m equipment can be done by thumb rule. General planning for layout of all equipment is done to accommodate the accessories inside the powerhouse and to find the approximate size of powerhouse which will give size of Powerhouse Cavern. • Geological information of the powerhouse area for an underground powerhouse is essential since total project cost is also governed by the cost of the supports required to stabilize the roof and the walls of powerhouse cavern.	• All the information obtained from pre-feasibility study shall be verified and updated. Any change in the design shall be incorporated. • Based on the head and discharge of a single unit, size of the E/M equipment e.g. runner with bucket, dimension of penstock distributor pipe, size and position of *Inlet Valve* and *Turbine Casing*, in case of Pelton turbine, is approximated which guides to estimate the size of powerhouse. Similarly, if Francis turbine is used, size of *Spiral Case, Inlet Valve* and size of *Draft Tube* governs the size of powerhouse. Reference may be taken from section 6.1 for preliminary dimensioning of powerhouse. Sometimes additional space may be provided to accommodate the E/M accessories in between the units. • Width of powerhouse depends upon the space required for Spiral Case including	**<u>Planning and layout of powerhouse</u>** • All the information obtained from feasibility study shall be verified and updated. Design should be reviewed and necessary changes shall be incorporated in detail design. • Size & layout of the E/M equipment may differ in the detail design which may affect the size of the powerhouse compared to the feasibility stage design. Size of the powerhouse may be re-planned as per the requirement of E/M equipment. This process includes fixing the position of *Turbine, Generator, Tailrace Channel, Control Room, Erection Bay, Office Rooms, general facilities rooms, doors, windows, ventilation, walls staircase, cable duct and emergency escape route* etc. and must be finalized prior to structural design. • The shape of the powerhouse cavern depends upon size and layout of the different equipment. Once the size & layout of E/M equipment is finalized, layout and size of all the civil structures are fixed and size of the powerhouse cavern is finalized. Size of the cavern also depends upon the type of the lining provided on ceiling and vertical faces of cavern. Three common types of cavern shape for powerhouse used in the past has been given in table no. 4-3.

Prefeasibility	Feasibility	Detailed design
A site with sound rock may require less support on the roof and walls whereas a site with poor geological condition may need expensive supports. • Layout and planning of civil components shall be done to fix the position of columns, shear walls, foundation, beams and height of powerhouse. • Based on the layout of civil accessories and facilities, size of the machine foundation, beams, columns and walls are estimated which will help to estimate the quantity of concrete Similarly, amount of reinforcement bar are also provided by thumb rule.	the width of wall around the Spiral Case, size of *Inlet Valve*, thickness of the walls u/s of *Inlet Valve* and additional space required at d/s of *Spiral Case* and walls thickness at d/s. • Height of powerhouse below generator floor is governed by machine height & height of *Draft Tube* in case of the Francis turbine. If vertical penton turbine is used the height depends upon the machine height and *Tailrace Pit*. *Height of superstructure may be estimated as per the section 6.1*. Total height of the powerhouse cavern thus depends upon the sum of height of substructure and superstructure including the thickness of the lining if provided. • Layout of all necessary E/M equipment and civil components of powerhouse shall be done similarly as explained in the capacity range >10<100 Mw. • Underground powerhouse should be checked for the stability for the different stages of construction.	• To fulfill the stability criteria of the machine foundation and to damp the vibrations of machine substructure is usually provided with thick RCC walls and raft foundation as in semi-surface powerhouse. Super structure of underground powerhouse may not always have RCC frame structure. Entire RCC frame i.e. columns, beams and shear walls may be omitted if favorable geological condition prevails. • For layout of crane column reference may be taken from section 4.5.2. • C/L of *Crane Rail* track should be such that the clearance between the inner face of wall/column and the outer edge of *EOT Crane* should be at least 20cm to facilitate the maintenance of EOT crane. • For architectural requirement of powerhouse reference may be taken from section 4.26. • Construction materials for various structural and non–structural element of PH should be finalized. **Design of roof** • In the underground powerhouse different types of ceiling protection work may be proposed which depends upon the geology of the site. For different types of ceiling protection reference may be taken form section 4.27.2. **Dead load** • At first trial size of the beams, columns, slab and all structural components may be provided arbitrarily according to the designer's choice.

Prefeasibility	Feasibility	Detailed design
	• Selection and design of the most suitable cavern shape is important in underground powerhouse. Three types of cavern shape have been explained in section 4.27.1. Depending upon the geology report of the site suitable shape of the powerhouse cavern shall be selected by geotechnical team. • Geological/geotechnical team shall decide the type of lining of ceiling and walls of the cavern. Different types of stabilizing methods of cavern ceiling have been given in section 4.27.2. • At preliminary stage different geological/geotechnical data required for the analysis and design of cavern may be taken from the section 3 or as suggested by the geotechnical team. • Structural analysis and design may be carried out as the same procedure as given in the Detail design column. At feasibility stage the various data required for structural design and stability check of powerhouse may not be available hence the data for loads, materials and geological/geotechnical	• Unit weight of the building material may be as per the sections 4.4. • Information regarding static and dynamic loads and their point of application for machinery and auxiliary equipment shall be provided by manufacturer/supplier in advance are, but not limited to, as listed below. ➢ weight of *Draft Tube* ➢ weight. of Draft Tube Gate ➢ weight of Spiral Case ➢ weight of Turbine ➢ weight of Stator and reaction at each support of the Stator ➢ maximum vertical, radial and tangential load at support of Lower Bracket and Upper Bracket ➢ weight of Generator Casing ➢ weight of EOT crane ➢ Maximum wheel load of EOT crane ➢ After layout planning of frame and **<u>Imposed load</u>** • Imposed load on the floor/roof slab may be estimated as per the section 4.5.4.2. • All the details of EOT Crane, weight and load direction and magnitudes shall be considered as imposed load and shall be provided by manufacturer. Reference may be taken from section 4.5.4.3 for various data required of EOT crane.

Prefeasibility	Feasibility	Detailed design
	may be taken as recommended in this guideline or from any other code/standard.	• Minimum load due to impact and vibration of EOT crane in vertical, along rail track and traverse direction of rail track shall be provided by manufacturer. In absence of authentic data, EOT crane load may be estimated as per the section 4.5.4.3. • Crane load is, finally, transferred to crane girder/ beam and column. **<u>Seismic force</u>** • Estimation of the earthquake load for this capacity range of powerhouse should be site specific. Reference may be taken from section 4.5.4.6. **<u>Stability Analysis</u>** • Stability analysis of underground powerhouse may be carried out as per the section 4.7. • Underground powerhouse should also be checked for the stability in different stages of construction as per section 4-7 and table 4-1. **<u>Analysis of structure</u>** • Next step is analysis of the structural elements. Semi surface and underground PH are composed of substructure and superstructure. Analysis of such type of powerhouse may be done either by 2D model or 3D model as described in section 4.9. • Maximum value of design bending moment, shear force and axial forces etc. at different load combinations shall

Prefeasibility	Feasibility	Detailed design
		identified and utilized for the design of the structural components. **<u>RCC Design of structure</u>** • Design of RCC structural elements for superstructure and sub structure like beam column, wall and slabs shall be done by limit state method and shall fulfill the requirements of limit states for collapse and service ability both. Reference for design of RCC structures by Limit State method should be as per the sections from 4.11 to section 4.20. • Design of corbels may be done as described in section 4.25. • Design of structural element may be carried out by Working Stress method where limit state method is applicable. For design of RCC structures by Working Stress method reference may be taken form Annex 'B' of IS: 465-2000. • Reference may be taken from section 4.21 for reinforcement detailing. • Requirements of detail drawings of powerhouse may be in accordance with section 4.2.

5 ELECTRICAL SYSTEM

Study Items	Prefeasibility	Feasibility	Detailed design
Generator, Excitation and Ancillaries	• Generator rating based on the project head, river water discharge and efficiency requirement shall be calculated.	• Generator rating based on the project head, water discharge and efficiency requirement shall be calculated and finalized. • Generator excitation system selection with the determination of generator electrical parameters shall be considered. • Generator earthing and grounding design shall be identified and completed at this stage.	• Generator layout, generator cooling, dimensioning, generator firefighting, removal of rotor for maintenance shall be designed at this stage. • Generator control, Excitation system finalization and the finalization of Generator parameters based on the Grid code and other international codes shall be finalized. • Generator neutral and earthing arrangement, generator housing and the cooling design shall be finalized. • The generator terminal leads and the bus ducts/cables shall be designed as per the current flowing through the ducts or cables. Cables and bus ducts design should be taken special consideration. Segregated, Non-segregated or the isolated phase bus duct shall be identified based on the current rating and the voltage requirement and the duct route shall be finalized. • Short circuit analysis at the MV level shall be finalized at this stage for the selection of bus bar, cables, protective equipment, circuit breakers etc.

Study Items	Prefeasibility	Feasibility	Detailed design
			• Study of Insulation co-ordination for the Generator and MV equipment for their proper selection shall be done.
Control Protection and communication	• Control room requirement and the control philosophy with the protection and communication requirement shall be identified.	• Control philosophy, protection system identification, control room layout, communication protocol and the requirement and the placement of the equipment for control, protection and communication shall be identified.	• Overall control philosophy with the detail breakdown of control arrangement for the control of powerhouse, switchyard, control or monitor of the headworks, control and monitor the interconnecting switchyard and the interconnection of control arrangement with that of Load Dispatch Center shall be addressed. • The control room arrangement with the placement of control boards, PLC equipment, control desks and SCADA computers with the provision of ventilation and air conditioning shall be considered. • The communication methodology between powerhouse, switchyard, headworks, interconnection substation, LDC has to be established and finalized. • Protection co-ordination, protection system requirement and identification, back up protection design shall be identified and addressed. Protection relays and protection switchgear selection has to be finalized.

Study Items	Prefeasibility	Feasibility	Detailed design
			• Different type of protection relays shall be identified and selected.
Heating, ventilation and Air Conditioning	.	• The heating and ventilation requirement is dependent on the powerhouse location. • Study of general heating and ventilation requirement for the type of identified powerhouse shall be considered.	• Detail heating and ventilation requirement with the consideration of heat load details from the electrical and mechanical equipment shall be determined. • The volume of air flow per second and the air entrance and exit arrangement shall be designed and calculated. • The powerhouse and electrical equipment's temperature limit shall be controlled by calculating of required HV Air Conditioning arrangement.
Transformer sizes and numbers	• Calculation of transformer size with respect to the generation capability shall be studied.	• Number, size and weight of transformer, Transformer voltage rating with respect to the interconnection and transmission line voltage rating shall be determined.	• Transformer size and number based on the project economy and transportation constraints shall be finalized. • Efficiency of transformer, transformer cooling methodology and vector group shall be designed and calculated. • Transformer placement (Indoor or outdoor) with the detail design for cooling requirement shall be designed and calculated.

Study Items	Prefeasibility	Feasibility	Detailed design
			• Transformer protection and the transformer bay requirement, transformer rails for the transformer installation, transformer size determination and the design of fire wall between transformers shall be considered and finalized. • Study of Insulation co-ordination of the transformer for their proper selection shall be done.
Switchyard equipment	• Switchyard location and voltage level shall be considered.	• While selecting Switchyard location project geology, area availability and maximum flood level shall be considered. • The switchyard voltage level, switchyard equipment identification and earthing requirement shall be studied.	• Calculation of detail earthing and lightning protection for the switchyard location shall be done. • The location of switchyard based on the project location, project geology, area availability and maximum flood level shall be finalized. • The details of each switchyard equipment, its size, equipment load, instrumentation and metering arrangement shall be finalized. • The switchyard arrangement and the arrangement of equipment on the interconnection substation along with the interconnection methodology and connecting and measuring equipment identification and details shall be finalized.

Study Items	Prefeasibility	Feasibility	Detailed design
			• For powerhouse where the space is limited, GIS (Gas Insulated substation) type of switchyard located indoors or outdoors. • The take-off yard for the transmission line can be outdoor on an open area or on the roof top of control building or the powerhouse office building, if the space limitation prevails. This type of take-off yard is generally designed for the underground powerhouse, power house with limited outdoor space and the powerhouse located on the toe of dam structure. • Study of Insulation co-ordination for the indoor and outdoor equipment for their proper selection. • Design of switchyard earthing to verify the step/touch potential and total earthing resistance of grounding mat.
LVAC requirement	• Requirement of LV AC auxiliaries and the auxiliary transformer shall be considered.	• Auxiliary transformer, LV AC auxiliary equipment, equipment control and protection should be considered. LVAC size and number on the single line diagram shall be identified.	• Details LV AC load requirement shall be calculated. • Based on that, the number and size of Auxiliary and Unit Transformers shall be finalized. • Monitoring and control of LV AC supply, the placement of LV AC equipment on the powerhouse and specific identification and

Study Items	Prefeasibility	Feasibility	Detailed design
			supply of load as per the common requirement or unit requirement shall be designed. • Arrangement of stand-by diesel generator for and its operating philosophy shall be addressed, designed and calculated. • The redundant and stand-by supply for the emergency LV AC shall be designed for the powerhouse of higher capacities. • The total installed consumption and average consumption shall be calculated for power plants larger than 10MW to select the station transformer capacity. • Short circuit analysis at LV shall be made.
DC System	• Requirement of DC system shall be identified.	• DC system requirement, identification of emergency equipment, emergency lighting arrangement, battery type and ampere hour requirement shall be considered.	• DC system design, battery size and ampere hour requirement, identification, charger design shall be done. • Emergency DC supply requirement equipment shall be identified and DC load should be calculated. • Main and redundant supply consideration and its changeover in case of emergency and maintenance shall be designed. • Battery voltage requirement for control, protection, lighting, communication shall be

Study Items	Prefeasibility	Feasibility	Detailed design
			identified and the design shall be made accordingly. • Short circuit analysis of DC shall be made.
Earthing		• Earthing requirement, earthing grid resistance and earthing of major equipment like generator, transformer, HV and MV equipment shall be studied.	• Earthing calculation shall be conducted to verify step/touch potential and total earthing resistance. • Drawings and calculation of overall powerhouse earthing system should be developed.
Power Evacuation	• Identification of transmission line voltage and nearest substation.	• Transmission line route alignment, nearest substation identification and Conductor optimization for identification of transmission voltage, number of transmission circuits and type of conductor shall be calculated and designed.	• Details of load flow, short circuit analysis and stability studies for normal and single contingency condition should be checked. • Load flow analysis, Grid Impact study, Grid Connection Agreement and Power purchase agreement should be complete at this stage.

The above described criteria are the basic design guidelines for the power house electrical system of any range and type. Specific design requirement depends on the capacity of powerhouse and design methodology along with site specific arrangement, reliability requirement and the electro-mechanical cost assessment. However, the electrical parameters and its ranges shall be based on the Grid Code developed by the NEA and shall also not deviate from the guidelines formulated by the International codes.

The substantial differences lie on ventilation, cooling requirement and the switchyard layout arrangement only, which can be easily determined by this design guidelines. The generation and transmission reliability of the power equipment with higher generation capacities and having negative impact on the revenue, due to inadvertent outage can be controlled by the placement of redundant electrical equipment and adopting reliable design philosophy.

6 ELECTROMECHANICAL AND HYDRO MECHANICAL DESIGN

S.No	Pre-feasibility Study	Feasibility Study	Detail Design
1.	• Based on the available data of design discharge and head, type of turbine, no. of units and turbine capacity shall be determined.	• Type of turbine, no. of units and turbine capacity to be used shall be verified. • Shaft alignment shall be confirmed. • Layout and positioning of units shall be determined.	**<u>Verification</u>** • Design head, discharge, type of turbine, no. of units and turbine capacity for detail design shall be verified. • Type of penstock shutoff valve shall be determined. • Maximum tailrace water level considering 100 years return period shall be fixed.
		• Tentative size of runner, spiral casing, generator, shafts as per IEC standards shall be determined. • Tentative size of runner, manifold or distributers, generators as per standard codes or accepted text books shall be determined. • The capacity and type of crane shall be estimated. • Turbine setting shall be determined.	**<u>Data from manufacturer</u>** • The size of turbine, generator, manifolds or spiral casing as per manufacturer shall be finalized. • Selection of the type of penstock shutoff valves, preparation of contract drawings and specifications. Location and space requirements shall be finalized. • The mounting dimensions and abutment structure for turbine, generators, manifolds, inlet valves, etc. shall be finalized. • The submergence of turbine from manufacturer shall be confirmed. • Limiting dimension of turbine can be finalized, which includes, elevation of centerline of distributer, elevation of lowest point of draft tube, horizontal distance from centerline to end of draft tube.

S.No	Pre-feasibility Study	Feasibility Study	Detail Design
		• Tentative dimension of powerhouse; length, width and height are shall be determined.	**<u>Layout preparation of powerhouse</u>** • Layout preparation of powerhouse from data provided by manufacturer shall be done. • Consideration should be given for the machine handling clearance between walls and units. • Location of maintenance shop shall be fixed. For small powerhouse, maintenance shop available 1-4 hr. travel time away can be utilized. • Suitable location for control room, office, etc. shall be fixed in coordination with electrical designers.
			<u>Powerhouse Crane</u> • Powerhouse bridge crane or powerhouse gantry for powerhouse shall be selected. • IS Code 3177 or EM 1110-2-4203 can be used as guidance. • No. of cranes considering lifting load, maintenance cost, hook coverage area, powerhouse structural cost, etc. shall be determined. • Layout drawing showing points at which the crane must pick up or set down materials, loading and unloading trucks, maintenance and repair areas, equipment installation points shall be prepared. • Exact dimension of EOT crane from manufacturer that includes total width, height shall be fixed.

S.No	Pre-feasibility Study	Feasibility Study	Detail Design
			• Load to be transmitted to powerhouse structure shall be calculated.
2	**Auxiliaries** • Auxiliary equipment to be used in powerhouse shall be listed out.	• Selection of auxiliary equipment to be used: ✓ Governors ✓ Oil System ✓ Compressed Air System ✓ Heating Ventilating and AC System ✓ Fire Protection System ✓ Water Supply System ✓ Dewatering and Drainage System ✓ Portable Water System ✓ Battery and Backup System ✓ Control and Protection System ✓ Communication System	• Location of auxiliary equipment according to functional requirements shall be fixed. US Corps, Engineers manual, EM 1110-2-4205 can be used as guidance. • ASHRAE Handbook can be used for the design of HVAC system. • Dewatering systems for all the components for the maintenance purpose shall be designed. • Tailrace and draft tube gate shall be designed. • Location of portable fire extinguishers, fire hose. Designing fire detection and warning systems and redundant fire protection systems shall be fixed. • Pipelines to supply clean and treated water so as to prevent scale formation and corrosion for cooling turbine bearings, wearing rings, and glands shall be designed along with • Pipelines to supply raw water for air compressor coolers and after coolers, fire protection deck washing, etc. shall be designed.

S.No	Pre-feasibility Study	Feasibility Study	Detail Design
			Final Layout of Powerhouse • Final powerhouse layout shall be prepared incorporating, all the above components, in form of drawing. Further modification can be done with coordination with structure designer.

POWERHOUSE DESIGN GUIDELINES

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1 HYDROLOGICAL STUDY AND HYDRAULIC DESIGN

1.1 Hydrological Study

Hydrological estimation including design discharge for the Powerhouse will have to be considered in the design of headwork's, intake and water conveyance system. However, for the placement of powerhouse in the safe place from the design flood, a rating curve in the upstream and downstream of the powerhouse should be developed so that Powerhouse can be safely placed from the design flood and the tail water can be discharged back to the river safely.

1.1.1 Hydrological Consideration

The extent of hydrological analysis for various level of study and range of installed capacity is clearly stated in "Guidelines for study of Hydropower Projects", 2003. However, for the placement of powerhouse, the rating curve and the design flood shall be considered as mentioned in the Tabular format (Section 1). Following aspects of hydrology shall be covered for the design of powerhouse.

a) General Climate and Hydrology

General climate and hydrology covers general information about the region, specific information about drainage basin, floods and drainage, river geometry, ground water recharge, reservoir area, other water usage, navigation and information of available meteorological and hydrological data supported by inventories. However, this information may not only be used for the design of powerhouses but should be considered for the overall project design.

b) Compilation and processing of Basic Hydrological Data

The basic/processed hydrological data should be collected and compiled. Processing of data, adjustment of records and consistency of data will be carried out and discussed. The processed data shall be compiled and furnished keeping in view the hydrological inputs required for the studies. Finally, all this data can be used to develop the rating curve at the powerhouse and tailrace site.

c) Preparation of Hydrological Inputs for studies other than Simulation

This part of the hydrology shall include the studies and their results relating to design flood, design flood level and tail water rating curve etc. Studies required for design flood for safety of structures, flood storage and flood control works, design of drainage in powerhouse area, diversion arrangements, levels for locating structures on river banks etc. shall be discussed.

d) Simulation Studies

This section shall discuss the details of the simulation studies and the conclusions derived from it. The studies carried out for the alternative measures that should be considered shall be discussed in detail explaining all the factors and assumptions that have been made. Simulation studies shall be carried out using hydrologic models such as HEC-HMS, SWAT, MIKE-BASIN etc. These may be useful for the powerhouse design to check the safety of powerhouse in case of dam breach of reservoir type of plants. Furthermore, water surface profile modeling shall be carried out to estimate high flood level upstream and downstream of the power house site

e) Consideration of Hydrologic Regime

This section shall include effect of low flows, peak flood, total runoff and sediment flows in different reaches of the river, to the project. For example, concave side of the river valley may have greater risk of sediment deposit during flash floods causing damage of power house. The information on above aspects will have to be collected/ compiled through the data inputs and studies.

1.1.2 Calculation of Flood Discharge

Using the reliable data processed as mentioned in the tabular form, flood discharge for the power house shall be calculated using the different distribution such as Normal, Log Normal, Log Pearson type III, Gamma, Weibul, Gumbel etc. The most fitted distibution (having least statistical error) shall be used.

1.1.3 Safety of the Power House

1.1.3.1 Flood Plains

The location of powerhouse should be away from the flood plain. If it is not possible to shift the location of powerhouse, river training works should be done for the protection of powerhouse.

1.1.3.2 GLOF and River Damming

GLOF hazard is becoming a prominent concern for Nepalese hydropower development as there are numerous potentially dangerous glacial lakes in the headwater regions of major river systems. In the HKH region there have been about 35 GLOF events, among which 25 GLOF events have impacted Nepal (Shrestha et. al., 2010). A sudden eruption of a glacial lake can result in a massive flow into the river system which can carry away everything in its way and hydropower projects are no exceptions to that. One typical example can be referred from Dig Tsho GLOF of Khumbu region Nepal in 1985 which caused complete destruction of a new hydropower station at Thamo and about 30 houses, and the loss of 14 bridges between Mingbo and Jubing at the downstream.

After proper calculation of flood, GLOF and proper examination of river damming, power house shall be placed safely as far as possible either adopting structural protection or avoiding the vulnerable area. In this context, the following is recommended;

- Evaluation of potentiality of GLOF hazards in the project catchment for projects above 100 MW
- Incorporation of early warning systems during the project design to secure the life of people working in the powerhouse.

1.2 Hydraulic Consideration

The formula and coefficient values for the calculation of losses can be referred from

- Design Guidelines of Water Conveyance System

- IS: 2951 (Part I) – 1965 (Reaffirmed 2003: Head loss in straight pipe due to frictional resistance
- IS: 2951 (Part II) – 1965 (Reaffirmed 2003: Head loss in valves and fittings

1.2.1 Loss in Bifurcations

The losses in bifurcations are defined as the difference between the piezometric heads immediately before and immediately after following the bifurcation (elevation of the centreline +manometric head at the centreline). Detailed loss calculation for bifurcation can be adopted from Page 429 of "High-Head Power Plants" by Emil Mosonyi.

The formula and coefficient values for the calculation of losses other than bifurcation can be referred from

- Design Guidelines of Water Conveyance System
- IS: 2951 (Part I) – 1965 (Reaffirmed 2003: Head loss in straight pipe due to frictional resistance)
- IS: 2951 (Part II) – 1965 (Reaffirmed 2003: Head loss in valves and fittings)

1.2.2 Transient analysis

The operation of the power plant involves the instantaneous closure and the opening of different valves such as butterfly valve and spherical valves etc. For the operation perspective, transient analysis shall be done. Provision of the bye pass valve in turbine or provision of surge tank in the tailrace conduit shall be determined from the transient analysis. So transient analysis in different closure time shall be done for the design of different component of the power house. Water Conveyance System Design Guidelines, 2003 (Page3-87) can be referred for the transient analysis.

1.2.3 Tailrace

After passing through the turbines, the water is discharged into the stream through a short channel called tailrace. In case of reaction turbines, the tailrace should be designed to ensure minimum tail water level required to maintain safe suction head for smooth operation of the turbine. The tailrace for Francis turbine shall be designed such that the turbine will be fully submerged during the lean period as well. This submergence varies with the draft tube type, but is usually a minimum of 300mm. Additionally, chapter 6.6.1 can be referred for the turbine setting criteria which will help for fixing the tailwater level for reaction turbines. The tailrace may be designed with gradually varying cross-sectional areas so that the tailwater elevation does not vary rapidly with large changes in flow. In case of impulse turbine, maximum water level in the tailrace should not rise to a limit that interferes with the turbine runner. For powerhouses running on relatively high discharges, common tailrace is provided for all the machines. However, for installations running on relatively low discharges and high head, separate tailrace channels are provided for individual machines. In vertical machines the bottom of the draft tube exit end happens to be much below the river bed level, where the powerhouse discharge is required to be dropped. In such a case a reverse slope not steeper than 4H to 1V is provided in the upstream reaches of the tailrace. If there is long tailrace tunnel, tailrace surge tank will be needed to neutralize the surge developed in the tailrace tunnel. The criterion for hydraulic design of surge tanks and its necessity can be referred from IS 7396 (Part 1, 2, 3 & 4). Free board will be higher up to 30 percent of the total depth because of undulating flow obtained from turbine. There are many guidelines including DoED conveyance guidelines (2006) for the design of canal/tunnel. So, the conveyance guidelines (2006) can be referred for the design of the tailrace. The fish resistance screen should be designed so that fish cannot enter the turbine blade. The fish screen shall be placed at the edge of riverbank at the tailrace. Civil Engineering Guidelines for Planning and Designing Hydroelectric Developments (ASCE), Volume 4 and IS 13877:1993 (Planning and designing of fish pass guidelines) can be referred for the design of the fish resistance screen and passes.

For the non-cascade operation hydropower project tailrace canal are reached up to the river. The turbine type of the project only affects the nature of the tailrace canal. For the cascade operation of the hydropower project, tailrace shall be designed carefully. The water level of the tailrace at upstream project affect the water level of the downstream intake level. There shall be optimum elevation difference between tailrace elevation and intake elevation of the downstream project without compromising the efficiency of the operation. We can take the example of cascade operation of Nathpa Jhakri Hydropower Project (Upstream, 1500 MW) and Rampur Hydropower Project (Downstream, 400 MW) in India. They are operating in cascade mode in the elevation difference of about 8 m where both the projects having Francis turbines. The typical powerhouse section with tailrace for francis andpelton turbine are given in Figure 1.2-1 and Figure 1.2-2 respectively.

1.2.4 Drainage Gallery in Underground Powerhouse

Drainage gallery are designed for the effective removal of the water from the underground power house. The various systems suitable for power house building may be classified as:

a) Gravity drainage system

The design criteria for gravity drainage system can be referred from IS 4721 (2000), Section 4.2,

b) Pressure drainage system,

The design criteria for pressure drainage system can be referred from IS 4721 (2000), Section 5.2,

c) Dewatering system

The design criteria for dewatering system can be referred from IS 4721 (2000), Section 6.2

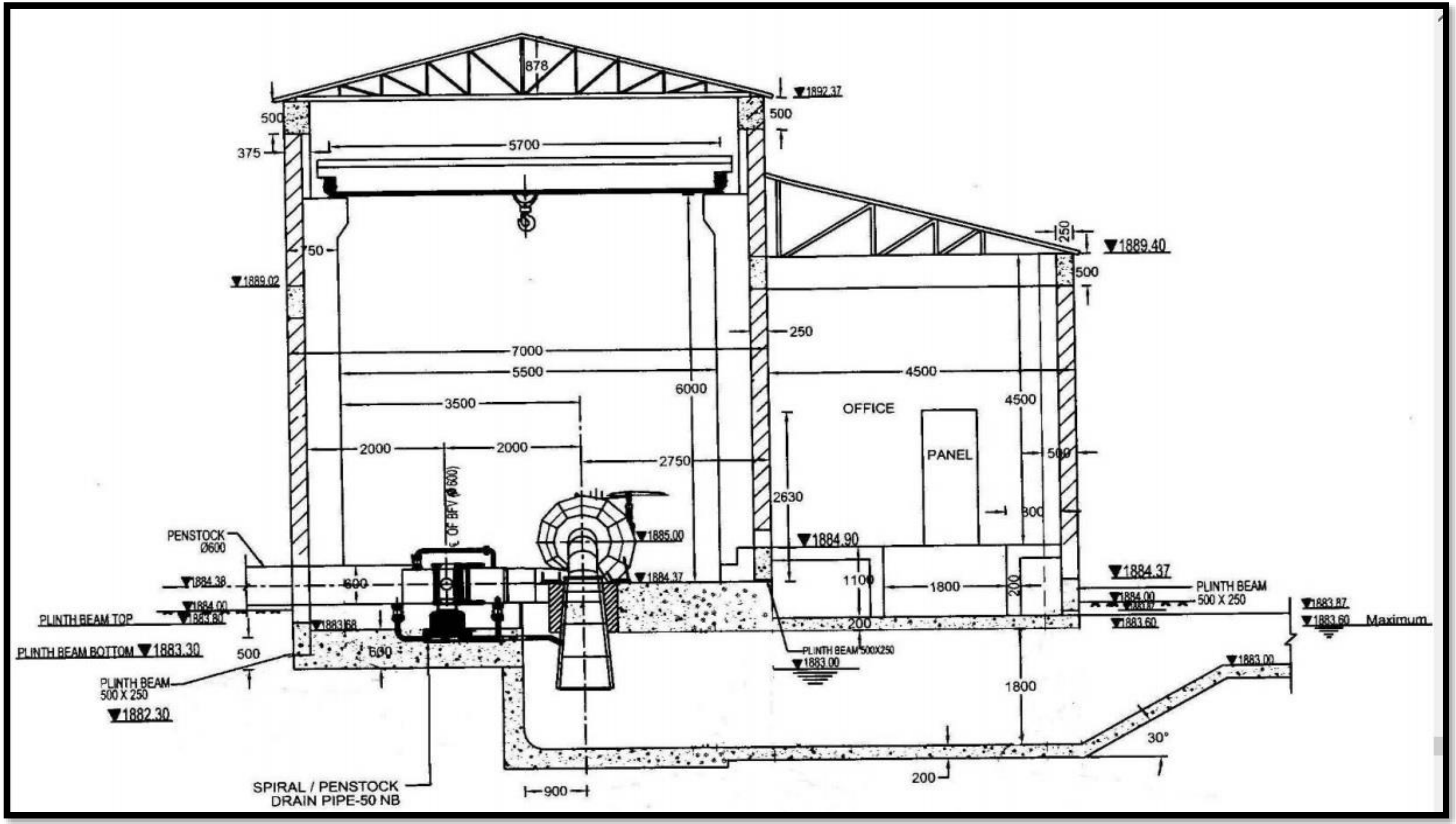


Figure 1.2-1 Typical Powerhouse section with tailrace for Francis Turbine

(Source: AHEC-IITR/MNRE/SHP Standards/Civil Works–Hydraulic and Structural Design)

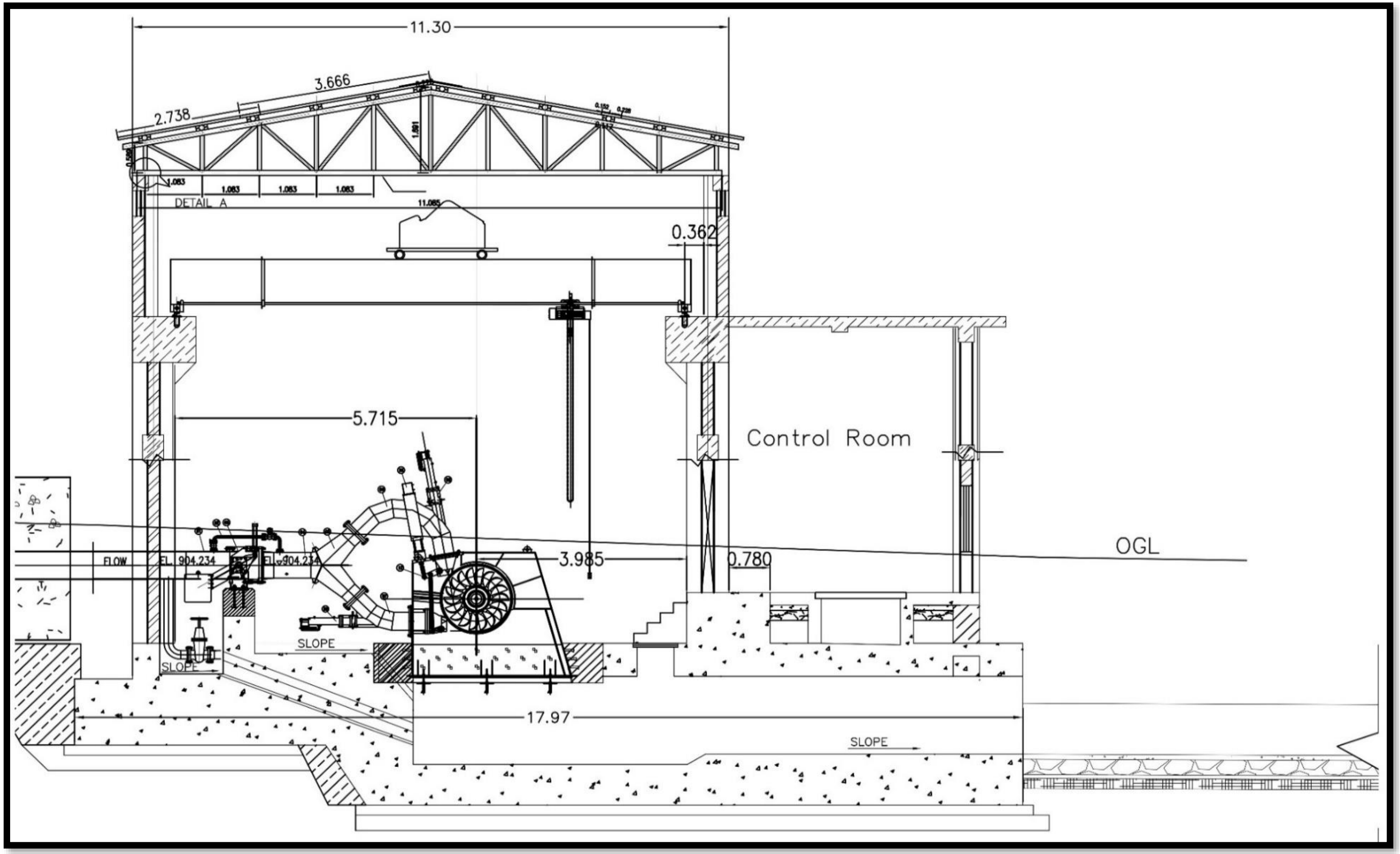


Figure 1.2-2 Typical powerhouse section with Tailrace for Pelton Turbine

(Source: AHEC-IITR/MNRE/SHP Standards/Civil Works–Hydraulic and Structural Design)

2 TOPOGRAPHICAL SURVEY

2.1 Objective of survey

Topographical surveys performed at the design stage of the powerhouse shall be aimed towards preparation of the following maps and sections of the powerhouse area:

- Engineering site plan maps;
- River profiles and cross sections

Engineering site plan maps, profiles and cross sections shall be prepared with sufficient detail to establish a sound basis for planning, engineering and design of the powerhouse.

2.2 Scope of survey

To attain the objectives of topographical surveys listed in Section 2.1, the following surveys shall normally be performed in the powerhouse area of hydropower projects:

a) Control survey;

b) Engineering site plan survey;

c) River survey.

The scope, standard procedures and accuracy requirements of these surveys are presented under "Design Guidelines of Hydropower Projects", 2003 and can be referred during the topographical survey of powerhouse. Also, IS 5497: 2008 (Guidelines for topographical survey for river valley projects) can be referred for the guiding the topographical survey of powerhouse site.

2.3 Information on Proposed Powerhouse Development

Information on the proposed powerhouse development plans shall be obtained from reports of previous studies. Depending on the stage of development of the powerhouse, such studies could include master plan, inventory, reconnaissance, pre-feasibility or feasibility studies conducted by different organizations. Information obtained from these reports shall be discussed and confirmed with the powerhouse planning and design team.

2.4 Information on Topography

Information on the powerhouse area topography shall be derived from available topographic maps, including those prepared as part of previous studies on the powerhouse. In particular, the following maps published by the Survey Department, GoN shall be referenced:

a) 1:125,000 scale district topographic maps with a 250 m contour interval;

b) 1:50,000 scale topographic maps with a 40 m contour interval;

c) 1:25,000 scale topographic maps with a 10 / 20 m contour interval.

2.5 Data and Information on Existing Ground Control

The ground control points (Benchmarks) established in the powerhouse area during previous surveys in or around the powerhouse area shall be identified, and details of their stations shall be obtained from available survey reports, D-cards and maps. However, the reliability of such information shall be checked before the control stations are used in the proposed survey. Minimum numbers of 2 control points are needed for proper survey in powerhouse area. Usually, the control points can be obtained from Department of Survey, Government of Nepal.

2.5.1 Survey Accuracy

Horizontal control surveys for different stages of powerhouse development shall conform to the survey accuracies listed in table 2.1

Table 2.1 Recommended orders of horizontal control surveys

Purpose of survey	Order
General planning and feasibility study, reconnaissance reports, generation license applications	Third Order Class II
Geotechnical investigative core borings	Fourth Order
Reservoir surveys	Third Order Class II
Site plan mapping for design memoranda, detailed design plans, contract plans and specifications	Second Order Class II

(Source: USACE EM 1110-1-1005: Topographic Survey)

The horizontal control surveys of different orders listed in table 2.2. shall satisfy the relative horizontal point closure accuracy standards specified in for checking the accuracy, the horizontal point closure shall be determined by dividing the linear distance misclosure of the survey into the overall circuit length of a traverse, loop or network line/circuit. When independent directions or angles are observed, the angular misclosure may optionally be distributed before assessing positional misclosure.

Table 2.2 Point closure standards for horizontal control survey

Order of survey	Point closure standard (ratio)
Second Order Class II	1:20,000
Third Order Class I	1:10,000
Third Order Class II	1:5,000
Fourth Order	1:2,500 to 1:20,000

(Based on USACE EM 1110-1-1005: Topographic Survey)

2.5.2 Horizontal Datum

Coordinates of horizontal control points shall be fixed in rectangular terms in grid meters in Northings and Eastings. The coordinates shall refer to the Modified Universal Transverse Mercator coordinate system used by the Survey Department (Table 2.3).

Table 2.3: Details of Modified Universal Transverse Mercator system

Spheroid	Everest Spheroid 1830
Central meridian	81°, 84° 87°, East
Latitude of origin	0° North
Scale factor at origin	0.9999
False coordinates of origin	Zero m at equator; 500,000 m at 84° East

2.6 Vertical Control Survey

Vertical control survey shall establish the elevations of control stations and benchmarks in the powerhouse area. These stations or benchmarks shall serve as points of departure and closure for leveling operations and as a reference framework for determining elevation differences in the powerhouse area.

2.6.1 Survey Accuracy

Vertical control surveys performed during different phases of powerhouse development shall conform to the survey accuracies listed in Table 2.4.

Table 2.4: Recommended orders of vertical control surveys

Purpose of survey	Order
General planning and feasibility study, reconnaissance reports, generation license applications	Third Order
Geotechnical investigative core borings	Third or Fourth Order
Reservoir survey	Fourth Order
Site plan mapping for design memoranda, detailed design plans, contract plans and specifications	Second or Third Order

(Source: USACE EM 1110-1-1005: Topographic Survey)

The vertical control surveys of different orders listed in Table 2.4 shall satisfy the relative vertical point closure standards specified in Table 2.5, where K is the length of the survey line or circuit in km. For comparison with these standards, the accuracy of a vertical control survey shall be determined by the elevation misclosure within a level section or a level loop.

Table 2.5: Point closure standards for vertical control survey

Order of survey	Point closure standard (mm)
Second Order	$\pm 6\sqrt{K}$
Third Order	$\pm 12\sqrt{K}$
Fourth Order	$\pm 24\sqrt{K}$

(Source: USACE EM 1110-1-1005: Topographic Survey)

2.7 Monumentation

Monuments for horizontal and vertical controls shall be provided in the powerhouse area to preserve their planimetric positions and elevations, respectively. These monuments shall be stable to preclude the introduction of errors in subsequent surveys that are based on them. They should also be capable of surviving the intended period of their use. These objectives shall be achieved through proper site selection, installation and documentation of the monuments.

2.7.1 Site Selection

Monuments shall be sited at appropriate locations in the powerhouse area. These locations shall be selected considering the security, functionality and stability of monuments.

a) Security

Monuments shall not be located in areas that are susceptible to damage or destruction due to construction, erosion, undercutting or collapse. River banks, flood plains and unstable areas shall be avoided. However, sites that provide natural protection or permanent and stable manmade features shall be considered for establishing monuments.

b) Functionality

Monument sites shall be readily accessible and capable of being conveniently occupied for observations. They shall be easily identifiable with reference to fairly permanent objects in their vicinity. They shall also be visible from headwork area as a large object/monument. For this purpose, areas with dense vegetation shall generally be avoided.

c) Stability

Monuments shall not be located in regions that are likely to be affected by geological and soil activities. Sites susceptible to slope instability, subsidence, frost heave, volume change and poor drainage shall be avoided. To safeguard them against subsidence and instability, monuments shall preferably be located on sound and intact bedrock in stable and firm land. Pockets of unstable ground, such as those around caverns and underground structures, and fractured, fissured and weathered bedrocks shall be avoided. Where bedrock is not available, monuments shall be established in coarse-grained soils to avoid the effects of frost heave, volume change and poor drainage commonly encountered with fine-grained soils.

Monuments shall not be placed near water reservoirs and large rivers where variable water levels can cause the ground to rise and fall due to rebound and compression of the soil. If possible, a distance of a few hundred meters between the monuments and the boundaries of these sources of ground activity shall be maintained.

Integral parts of stable manmade structures may also be used for positioning monuments. Large concrete, steel or masonry structures resting directly on bedrock, deep piles or piers shall be preferred for this purpose. Structures on other types of foundations may be chosen for monuments only if the structure’s age is more than five years. However, small structures like culverts, platforms, retaining walls, etc. shall not be used for monumentation.

2.7.2 Types of Monuments

The type of monument at a particular station shall be selected based on local site conditions. Monuments installed on rock or manmade structures and in soil shall meet the requirements discussed below.

a) Monuments on Rock and Manmade Structures

Monuments on rock or manmade structures shall be marked by drilling a 25 mm diameter, 100 mm deep hole in the rock or structure and grouting a brass nameplate on it such that its top is flashed in the surrounding. Alternatively, the monument shall be marked with a 5 mm diameter, 20 mm deep hole drilled into the rock with a circle engraved around it. For more precise work with EDM instruments, the drilled hole shall have a diameter 1 to 2 mm and a depth of 3 to 4 cm, and a copper or brass wire shall be plugged into it and made flush with the surrounding surface.

b) Monuments in Soil

Monuments in soil shall be marked by pouring fresh concrete in a 500 mm deep, 200 mm square excavation in the ground and fixing brass nameplates on its top. Alternatively, a 1 m long, 25 mm diameter pipe shall be driven vertically into the ground and its center shall be taken as the actual mark. As another option, a large stone, with a circle and dot cut on it, shall be embedded about 1 m into the ground, and a similarly marked stone with its dot aligned vertically with the dot on the lower stone shall be placed flush with the top of a 500 mm high, 3 m square surrounding platform.

2.7.3 Monument Names

Monuments shall be named based on a systematic scheme. A horizontal control monument shall be identified by an intelligible name stamped on its nameplate. The assigned name shall be concise and in itself be descriptive and/or indicative of the general location of the control point. Likewise, a vertical control point shall be identified by a number or an alphanumeric symbol stamped on the respective nameplate or inscribed on the monument.

2.7.4 Monument Documentation

Each permanent monument established in the powerhouse area shall be fully documented to record its position, description and related data. Descriptive data and other information available in the field shall be recorded at the station site, and all other applicable data shall be added as this information becomes available.

Based on the information, a description card containing the following information shall be prepared for each permanent monument:

a) Name or station designation of the monument.

b) Name of the community, town or city near the monument.

c) Name of village development committee or municipality, district and zone.

d) Month, day, and year the monument establishment.

e) Elevation of the top of the monument.

f) Exact latitude and longitude of the monument.

g) Horizontal and vertical datum referenced.

h) Order and class of accuracy of horizontal and vertical stations.

i) Type of monument and its details.

j) Description of the monument including, but not limited to, the following:

k) A short narrative providing specific directions on reaching the monument from a readily locatable landmark.

l) Exact location of the monument at the station site, with distance and direction from at least three reference objects in the immediate vicinity.

m) Vertical reference of the monument in terms of the monument's distance above, below or level with a nearby reference object or ground surface.

n) Information stamped on brass nameplates cast at the station.

o) A sketch of the monument location relative to existing physical features and reference ties.

p) Photograph of the station with surrounding area.

2.8 Engineering site plan survey

Engineering site plan survey of the powerhouse area shall be performed to determine the Planimetric location and topographic relief of features in three dimensions. This survey shall result in preparation of detailed large-scale site maps for conceiving, justifying, designing and constructing the powerhouse.

2.9 Map Scale

The scales for engineering site plans prepared during different stages of development of the powerhouse shall be selected from the range of scales recommended in Table 2.6. For a given stage of development, the smallest map scale that can provide the necessary details in an economical manner shall generally be chosen from the recommended range. However, a larger scale may be adopted if any other larger-scale map has been in use for the mapped area for the powerhouse development.

Table 2.6: Recommended scales for engineering site plans

Purpose of survey	Target map scale
Planning, feasibility study, generation license applications	1:1,000 – 1:5,000
Site plan mapping for design memoranda, detailed design plans, contract plans and specifications	1:250 – 1:500

(Source: USACE EM 1110-1-1005: Topographic Survey)

2.10 Contour Interval

Contour intervals for engineering site plans shall be selected from the ranges recommended in Table 2-7.

Table 2.7 Recommended contour intervals for engineering site plans

Purpose of survey	Contour interval (m)
Planning, feasibility study, generation license applications	0.50 – 2.00
Geotechnical investigative core borings	0.25 – 1.50
Site plan mapping for design memoranda, detailed design plans, contract plans and specifications	1

(Based on USACE EM 1110-1-1005: Topographic Survey)

For a particular stage of powerhouse development, the contour interval shall be judiciously selected considering the following factors:

a) Desired accuracy of the depicted vertical information.

b) Relief of the powerhouse area.

c) Cost of field work and fair mapping.

d) Other practical uses for the intended map.

If a specific vertical tolerance is to be satisfied, the contour interval shall be selected as a direct proportion to the tolerance (refer Table 2.9). Larger contour intervals shall be adopted for areas with steep slopes in order to make the map more legible. In flatter areas, smaller intervals that do not interfere with Planimetric details located on the map shall be chosen. Contour intervals shall be chosen to achieve economical field works and mapping without compromising on the map accuracy. For ease of mapping and legibility, intervals resulting in contours closer than 2 mm shall generally be avoided. Although the largest possible contour interval is desirable, smaller intervals may be selected if any other map uses of the mapped area are anticipated for the powerhouse development.

2.11 Mapping Standard

Engineering site plan maps prepared for different stages of powerhouse development shall conform to the horizontal and vertical mapping accuracy requirements listed in Table 2.8 and Table 2.9, respectively. In these tables, the horizontal map accuracy standards are expressed in terms of two-dimensional root mean square radial positional errors while the vertical map accuracy standards are expressed in terms of one-dimensional root mean square elevation errors. The map location and elevation tolerances in these tables are defined relative of two adjacent points within the confines of a map sheet and not to the overall powerhouse area.

Table 2.8: Recommended horizontal mapping accuracy standards

Purpose of survey	Map scale	Feature location tolerance (m)
General planning and feasibility study, generation license applications	1:1,000	0.50
	1:5,000	3.00
Geotechnical investigative core borings	1:5,000	1.50 – 3.00
	1:250	0.015

Site plan mapping for design memoranda, detailed design plans, contract plans and specifications	1:500	0.30

(Source: USACE EM 1110-1-1005: Topographic Survey)

Table 2.9: Recommended vertical mapping accuracy standards

Purpose of survey	Contour interval (m)	Feature elevation tolerance (m)
General planning and feasibility study, license applications	0.50	0.15
	3.00	0.60
Site plan mapping for design memoranda, detailed design plans, contract plans and specifications	0.25	0.003
	1	0.15

(Source: USACE EM 1110-1-1005: Topographic Survey)

For computing the accuracy of a map, at least three pairs of well-defined points within the map boundary shall be selected so that their combinations result in at least 15 error values. Points selected for this purpose shall be capable of functionally maintaining a given accuracy tolerance between themselves, e.g. adjacent property corners, adjoining buildings, bridge piers or approaches or abutments, etc. The coordinates of these points shall be obtained from scaling the finished map and from field measurements performed using survey methods superior to the methods used for constructing the map. The horizontal error shall then be obtained by taking the root mean square of the squares of the errors in latitude and departure. Likewise, the vertical error shall be computed from the root mean square of the squares of the errors in elevation.

2.12 Advanced technology in surveying

The theodolite, total station, and RTK GPS survey remain the primary methods in use. Remote sensing and satellite imagery continue to improve and become cheaper, allowing more commonplace use. Prominent new technologies include three-dimensional (3D) scanning and use of LIDAR for topographical surveys. UAV technology along with photogrammetric image processing is also appearing.

(Provisions for instrument for Cross-section survey in wide river sections)

The main surveying instruments in use around the world are the theodolite, measuring tape, total station, 3D scanners, DGPS/GNSS, level and rod. Most instruments screw onto a tripod when in use. Tape measures are often used for measurement of smaller distances. 3D scanners and various forms of aerial imagery are also used.

The gyro theodolite is a form of theodolite that uses a gyroscope to orient itself in the absence of reference marks. It is used in underground applications. The total station is a development of the theodolite with an Electronic Distance Measurement device (EDM). A total station can be used for leveling when set to the horizontal plane. After introduction of EDM, total stations have shifted from optical-mechanical to fully electronic devices.

Modern top-of-the-line total stations do not need a reflector or prism to return the light pulses used for distance measurements. They are fully robotic and can even e-mail point data to a remote computer and connect to satellite positioning systems, such as Digital Global Positioning System. Real time kinematic GPS systems have increased the speed of surveying, but they are still only horizontally accurate to about 20 mm and vertically to 30–40 mm.

Static GPS uses two receivers placed in position for a considerable length of time. The long span of time lets the receiver compare measurements as the satellites orbit. The changes as the satellites orbit also provide the measurement network with well-conditioned geometry. This produces an accurate baseline that can be over 20 km long. RTK surveying uses one static antenna and one roving antenna. The static antenna tracks changes in the satellite positions and atmospheric conditions. The surveyor uses the roving antenna to measure the points needed for the survey. The two antennas use a radio link that allows the static antenna to send corrections to the roving antenna. The roving antenna then applies those corrections to the GPS signals to calculate its own position. RTK surveying covers smaller distances than static methods. This is because divergent conditions further away from the base reduce accuracy.

Total stations are versatile and reliable in all conditions. The productivity improvements from a GPS on large scale surveys make them popular for major infrastructure or data gathering projects. One-person robotic-guided total stations allow surveyors to measure without extra workers to aim the telescope or record data. A fast but expensive way to measure large areas is with a helicopter, using a GPS to record the location of the helicopter and a laser scanner to measure the ground. To increase precision, surveyors place beacon on the ground (about 20 km apart). This method reaches precisions between 5–40 cm (depending on flight height). Surveyors use ancillary equipment such as tripods and instrument stands; staves and beacons used for sighting purposes; vegetation clearing equipment; digging implements for finding survey markers buried over time; hammers for placements of markers in various surfaces and structures; and portable radios for communication over long lines of sight.

Land surveyors, construction professionals and civil engineers using total station, GPS, 3D scanners and other collector data use Land Surveying Software to increase efficiency, accuracy and productivity.

2.13 Survey Report

Upon completion of the survey, a survey report containing the following shall be prepared:

a) Methodology of survey

b) Instruments used.

c) Description of national control points taken for reference.

d) Description of local control points.

e) Accuracy of survey.

f) Description of special points.

3 GEOLOGICAL AND GEOTECHNICAL INVESTIGATION

3.1 Introduction, Objective and Scope:

Engineering geological and geo-technical investigations are vital for the proper site selection as well as sustainable design of power house construction in hydroelectricity projects. The most adopted techniques of powerhouse construction can be grouped into three types underground, semi-underground and surface. Engineering geological investigation is necessary for the selection of suitable sites for foundation and safe from slope stability for surface construction. This investigation determines the size, type and support system especially in the case of underground constructions. It includes the proper investigation of ground as well as sub-surface by means of geological mapping, engineering geological mapping, hydrogeological mapping, geophysical investigation followed by drilling and determination of seismic parameters. It also includes the field as well as laboratory investigation of soils, rocks, aggregates and core samples used as construction materials. The aim of geo-technical investigation is to obtain the engineering geological parameters useful for support system and selection of construction materials.

Objectives:

i. Comprehensive geological and geo-technical investigation with the aim to suitable site selection for power house development from the perspective of (i) geological (ii) engineering geological (iii) hydrogeological (iv) geo-physical (v) geo-technical and (vii) seismic investigations.
ii. Investigation and selection of suitable construction materials useful for the power house construction.

Scope of the Study: The scopes of the geological and geo-technical studies are as follows:

i. Preparation of both regional as well as local geological map in various scales.

ii. Preparation of engineering geological map of the proposed site.

iii. Geophysical investigations like electrical and/or seismic methods for sub-surface ground assessment. Preparation of report with electrical and seismic profiles and recommendation of drilling sites for verification studies.

iv. Geo-technical investigation of proposed construction materials and obtaining parameters of rocks and soils useful to support designs and foundation preparation.

v. Incorporation of Seismic hazard assessment of the project area.

3.2 Regional Geological Mapping:

To assess the geological condition, knowledge of both the regional tectonics and local geology are most desirable. To understand the local geology, a broader knowledge of regional geology is advantageous. In this regard, a brief overview of geological region of the Nepal Himalaya is presented below:

The Himalaya was formed about 2 million years ago as a result of the collision and subsequent thrusting of rock masses from North to South and is still rising at a rate of 2-5 mm per year.

Penetration of Indian continent under Tibetan produced crustal shortening and slicing of the Northern margin of the Indian continent into three principal thrusts: The Main Central Thrust (MCT), the Main Boundary Thrust (MBT) and the Main Frontal Thrust (MFT).

The rocks of the Himalaya are moving upward as well as horizontally Southwards along the major thrusts. The compression resulting from the Northward movement of the Indian plate against the rigid Asian landmass has also given rise to many other faults and folds, large and small, active and inactive and of various orientations. The Himalayan rocks in general are also highly crisscrossed by joints as a result of the tectonic forces prevailing in the Himalaya.

Geologically, the Nepal Himalaya is divided into five major tectonic units as Indo-Gangatic Plain (in Nepal: the Terai Zone), the Sub-Himalayan Zone, the Lesser Himalayan Zone, the Higher Himalayan Zone and the Tethys Himalayan Zone from South to North, respectively (Gansser 1964; Hagen 1969, Fig. 3.2-1).

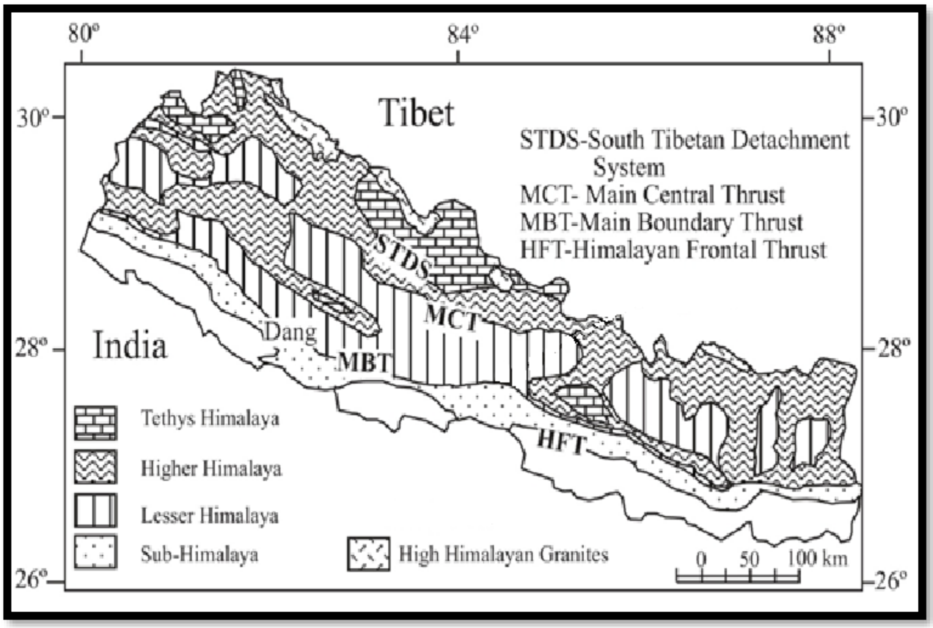


Figure 3.2- 1 Simplified geological map of the Nepal Himalaya showing major tectonic units (modified after Upreti and Le Fort 1999).

Regional Geological Mapping Techniques

Regional geological study represents the geological observation and mapping of some kilometers around the project area. It gives the idea on the regional tectonics. Such maps give the correct location and distance of adverse geological structures and lithological variation from large area. For example, how far is the MCT or MBT or any active fault from the proposed project and its adverse effects on the project in terms of local seismicity can be analyzed from regional geological map. Similarly, at and around such faults, the rocks in general are crumbled, sheared and highly shattered so that the possibility of mass movement may be high.

While preparing the regional geological map, an attempts should be made to retain the definition, classification and name of the units proposed by the previous authors. Wherever entirely different stratigraphy exists, new formations and members should be established.

Names of the new units can be given from the geographic name of the area where the unit is best exposed. One of the main tasks of the field study is to prepare the geological map in 1:25,000 scales. For this, published reports, maps and cross-sections as a part of literature review should be carried out before starting the mapping activities. For this, collection of relevant maps prepared by the Department of Mines and Geology (DMG), Departments of Geology, Tribhuvan University (e.g. Central Department of Geology, Kirtipur; Department of Geology, Tri-Chandra Campus) may be the primary source. Similarly, maps available in Central Library of Tribhuvan University, and google information of publication by national and international geo-scientists and researchers will be useful for the review processes. A review report with regional geological map should be prepared as table work before starting the field mapping. After clarifying the stratigraphy of the area, geological mapping should be started from most accessible and well-understood part of the area. The assigned area should be covered so as to cross the geological strata at maximum points traversing along all existing ridges and rivers. An attempt should be made such that each grid in the topographic map (1 km x 1 km) will contain at least 2 (two) geological study points with GPS location wherever possible. Most of the traverse lines should be selected across the strike of the strata so that boundaries of many units could be traced along the route as mentioned above. A number of sketches showing the geomorphic, petrological, and structural as well as meso-and micro-structures should be prepared in the field diary during the field investigation. High quality digital camera should be used to capture the field photographs of important features of rocks, minerals, lithological contacts and structural discontinuities.

Regional geological map is a valuable guide to interpret the seismicity of the area and seismic risk analysis processes. However, in the stage of pre-feasibility survey, regional geological map can be prepared based on the available maps and literatures (based on secondary data). But, in feasibility stage the regional geological map should be prepared on the primary data covering at least 10 km radius from the project area to all directions.

While preparing the geological map in the Sub-Himalayan terrain (Churia Range), one should be aware on the litholgoical variation to distinguish the geological units. Similarly, mapping in the Lesser Himalaya needs to interpret the lithological succession to distinguish the lithological units (successions of dolomite, quatzite are such marker litholgy). In these areas the marker lithology should be taken as the index lithology and along strike mapping is recommended to clarify the stratigraphy and hence the geological structures. However, in the terrain of the Higher Himalaya, rock types along with mineralogy as well as metamorphic index minerals in the rocks are the bases of mapping the geological units. Lithology and fossils are the marker index to map the rocks of the Tetheyan affinity.

Preparation of Geological Cross-Sections

Geological cross-sections should be made across two (or more if necessary to show the clear picture on the geological structures) parallel sections. It should be prepared manually on the graph paper. The boundaries of different formations can be projected on the vertical plane considering the apparent dip of the beds along the line of cross-section. The boundaries can be extrapolated to the depth to fit the geological structures observed on the surface. Efforts should be made to balance the length and area of units as far as possible. Final copy of cross-section can be prepared using any drawing software.

3.3 General Geology and Geomorphology (Site Specific Geology)

There is great importance of local or site geological mapping for the safe design of powerhouse. Geology can be viewed in terms of three categories: foundation, cavern stability (in the case of underground) and slope stability. Himalaya of Nepal has a complicated geological structure and there is great variation in stratigraphy. Therefore, detail study of meso-scale faults, shear zones, folds and associated joints should be considered while designing the powerhouse. Only, survey and study of master thrusts like the Himalayan Frontal Thrust (HFT), the Main Boundary Thrust (MBT) and the Main Central Thrust (MCT) is not enough for the stable designs. It should be very clear that there are large number of regional, intermediate and local faults in the Himalaya of Nepal. Most of thrusts are imbricated thrust which ultimately join to the sole thrust. The Lesser Himalayan zone clearly shows the duplex structure with the MCT as roof thrust, MBT or MFT as floor thrust and other in between as imbricated faults/thrusts. In addition, there are a number of out-of-sequence faults that they cut the older E-W trending faults differently and they are linked with the rise of the Himalaya. Some of the faults in the Himalaya are considered as active while others passive. Actually, active faults have their movement at the present days. Also, such types of faults have the tendency of significant movement during the time of earthquakes. Similarly, underground powerhouse constructed at the core of synclines or anticlines may pose difficulties in terms of stability. In powerhouse construction such types of active faults should be mapped and mentioned both in the map as well as in the reports so that the planner will think to mitigate or avoid the area. Geological condition, in this regard, can highly determines the cost of the project.

Landslide inventory mapping of the project area is the utmost importance for the safe designing of power house. A brief report on the hydrogeology is also recommended (Refer 3.6 B for details).

Local Geological variation of Nepal Himalaya: The Sub-Himalaya (Siwalik Range) has relatively simple stratigraphy with little number of folds and thrusts/faults while compared with the Lesser Himalaya. The local geology can be inferred from the regional geology to some extent in the case of the Sub-Himalaya. However, the Lesser Himalaya of Nepal shows much variation in stratigraphy, structures, and magmatism. It is a fold-and-thrust belt of the Himalaya. In addition to the master thrusts and regional thrusts of the Himalaya, a number of local faults/thrusts and shear zones exist in this zone.

Nearly vertical fault scarps are found along the southern slopes of the Siwalik hills as indicated by the tilted fans and terraces. All of the active faults have down throw sides to the south and the terraces are tilted to the north. Other active faults along the MBT and the MCT zone which is not consistent with the well-recognized south vergent thrust tectonics (e.g. MCT, MBT, and MFT) are found throughout the Nepal Himalaya (Figure 3.3-1). In addition to the East-West trending faults and thrusts, there are a number of North-South trending faults and thrusts in the Himalaya. Such type of local to semi-regional faults should be considered for designing the powerhouse in any area. Orientations of bedding, foliation and lineation should be statistically analyzed using the software DIPS 5.1. Mean values of bedding, foliation and lineation orientations can be calculated from the stereograph.

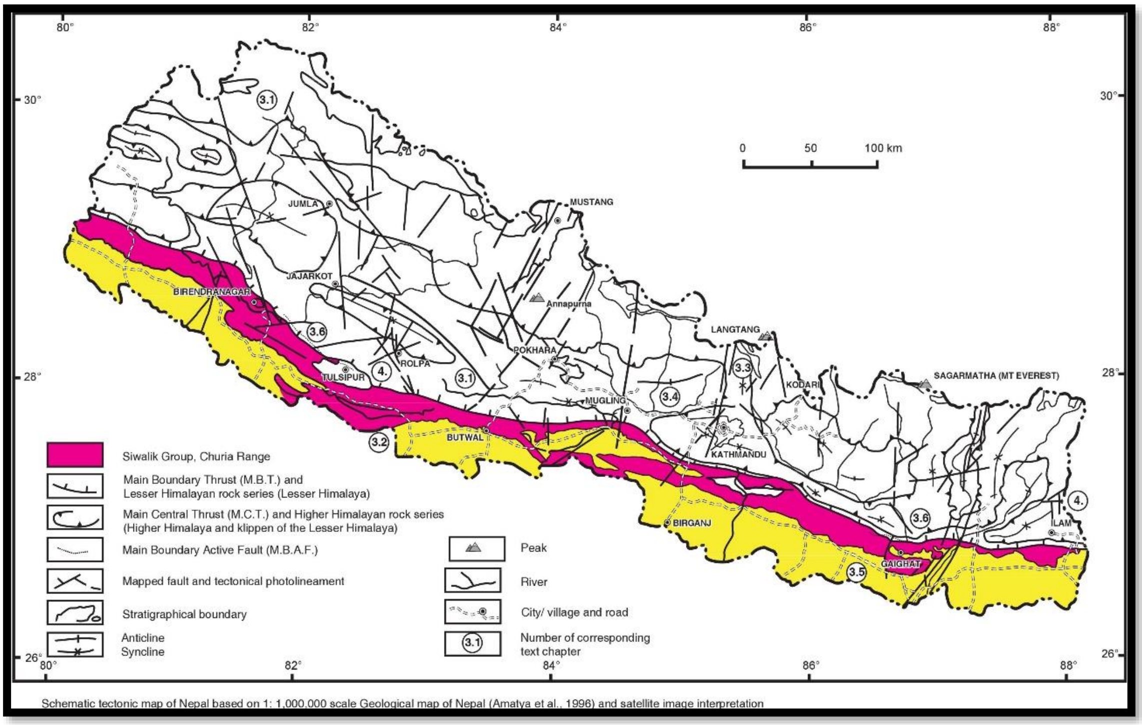


Figure 3.3- 1 Some prominent active faults of the Nepal Himalaya (After Nakata et al., 1984)

3.4 Engineering Geological Investigation (Site Specific)

Brief description of engineering geological investigation is presented as follows:

An example of study format for a small, intermediate and larger type capacity in underground powerhouse design is presented in the tabular form in geology section. This is a sample format where all types of survey and studies are included to carry out the detail engineering geological and geotechnical studies. A great concern should be whether the ground is composed of loose materials (Quaternary deposits), soft rocks, hard rocks or mixed type of lithology. A separate map of Quaternary deposits is recommended if the power house area consists of river terrace or soil deposits of various origin. A detail columnar section should be prepared to show the vertical variation of materials based on observation in river or road cut sections or other slope breakage sections. Based on the local geological condition and recommendation of site geologist, an exploratory tunnel can be constructed to investigate the sub-surface geology, characteristics and behavior of rock conditions likely to be encountered to minimize risks and verify budget cost calculations. Such type of exploratory or test tunnel provide vital data and support information for the design and construction of the main tunnels in the case of underground power-house. Geological material and structures developed in these rocks and regions greatly controls the cost and stability of the powerhouse. Moreover, the adversely oriented geological structures pose a severe problem in the construction. Therefore, there is no any alternative option except to study in detail before the project begins. Detail geological, engineering geological, geomorphological and seismic studies along with satellite images of the terrain gives the clear picture of the stability and hence the cost of the powerhouse.

Stability of the powerhouse structure is governed by three major factors from engineering geological point of view:

1. Slope stability at and around the proposed powerhouse area.
2. Ground condition especially the type of soil, depth of soil, water table, and depth of bed rock.
3. Type of rocks and discontinuities developed in the rocks i.e. rock mass properties.

A brief description of the above three points is given below:

a) In nature, slope is composed of geological materials: soil slope or rock slope or mixed type of slope. Geomorphology of slope is another aspect for its stability. There are different techniques of investigation for soil slope, rock slope or potential landslide area. Any one out of the most adopted techniques of investigation and codes or guidelines can be followed strictly for the purpose. In case of soil slope or debris slope, geophysical techniques like seismic or electrical methods should be carried out for its subsurface investigation. With the help of these methods, thickness of overburden materials as well as existing slip surface in the area can be delineated. Groundwater condition can also be assessed with the help of electrical methods like Electrical Resistivity Tomography (ERT).
b) In addition to slope, the foundation of the powerhouse area should be studied thoroughly. A geological cross-section should be prepared passing through the powerhouse area. This greatly helps to understand the hard rock geology in terms of orientation and any geological structures. With the help of geophysical methods, the depth of overburden and quality of rock mass underlying the overburden can be assessed. Drilling is recommended for the verification of geophysical investigation and surface geological mapping. However, the number and depth of drilling will be decided based on engineering geological and geophysical report by the expert.
c) In the case of soil as foundation (case of open or semi-underground powerhouse), several types of geo-technical tests should be performed to assess the bearing capacity of the soil in foundation. Investigation of engineering properties of rock mass is of great importance to make a stable cavern of underground powerhouse. Preparation of soil profile along with soil map of the proposed power house site is recommended.

Classification of Rock Mass

The most widely known engineering classifications of rocks are the RMR system of Bieniawski (1973, 1974) and the Q system of Barton, Lien and Lunde (1974). The classifications include information on the strength of the intact rock material, the spacing, number and surface properties of the structural discontinuities as well as allowances for the influence of subsurface groundwater, in situ stresses and the orientation and inclination of dominant discontinuities. These classifications were developed primarily for the estimation of the support requirements in tunnels but their use has been expanded to underground powerhouse construction. Provided that they are used within the limits within which they were developed, as discussed by Palmstrom and Broch (2006), these rock mass classification systems can be very useful practical engineering tools, not only because they provide a starting point for the design of tunnel support but also because they force users to examine the properties of the rock mass in a very systematic manner.

Palmström (1982) suggested that, when no core is available but discontinuity traces are visible in surface exposures or exploration adits, the RQD may be estimated from the number of discontinuities per unit volume. The suggested relationship for clay-free rock masses is:

$$RQD = 115 - 3.3\,J_v$$

where J_v is the volumetric joint count. It can be measured by dividing the area into several grids of 1 m^3 and counting the randomly oriented joints.

The rock mass quality (Q) is another very sensitive index and its value varies from 0.001 to 1000. Use of the Q-system is specifically recommended for tunnels and caverns with an arched roof. On the basis of the Q-value, the rock masses are classified into nine categories (Table 3.1). The Q-values will be higher where a tunnel boring machine (TBM) or a road header is used to smooth the surface of excavation. The Q-value, on the other hand, in the drill and blast method will be lower because of high over-breaks and the development of new fractures. To minimize the negative effect of blasting on Q, one can use a controlled blasting technique. The blasting effects are better in the rock masses having a Q-value between 1 and 30.

Table 3.1 Classification of Rock Mass Based on Q-Values (Barton, 1993)

Q-value	Classification
0.001–0.01	Exceptionally poor
0.01–0.1	Extremely poor
0.1–1	Very poor
1–4	Poor
4–10	Fair
10–40	Good
40–100	Very good
100–400	Extremely good
400–1000	Exceptionally good

There is no single parameter that can fully designate the properties of jointed rock masses. Various parameters have different significance, and only in an integrated form they can describe a rock mass satisfactorily. For example, there is chances to over-break the tunnel in the case of thinly bedded horizontal or nearly horizontal strata with numerous joints. Grimstad and Barton (1993) is the most adopted chart for the design of underground support system (Fig. 3.4-1). Large underground openings are called “caverns.” Caverns are generally sited in good rock masses where the rocks are massive and dry, and the ground condition would be either self-supporting or non-squeezing. To assess roof and wall support pressures the approach of Goel, Jethwa, and Paithankar (1995) can be applied for tunnels with diameters up to 12 m;

therefore, its applicability for caverns with a diameter of more than 12 m is yet to be evaluated. The modified Terzaghi's theory of Singh, Jethwa, and Dube (1995a), may also be used to estimate the roof support pressures.

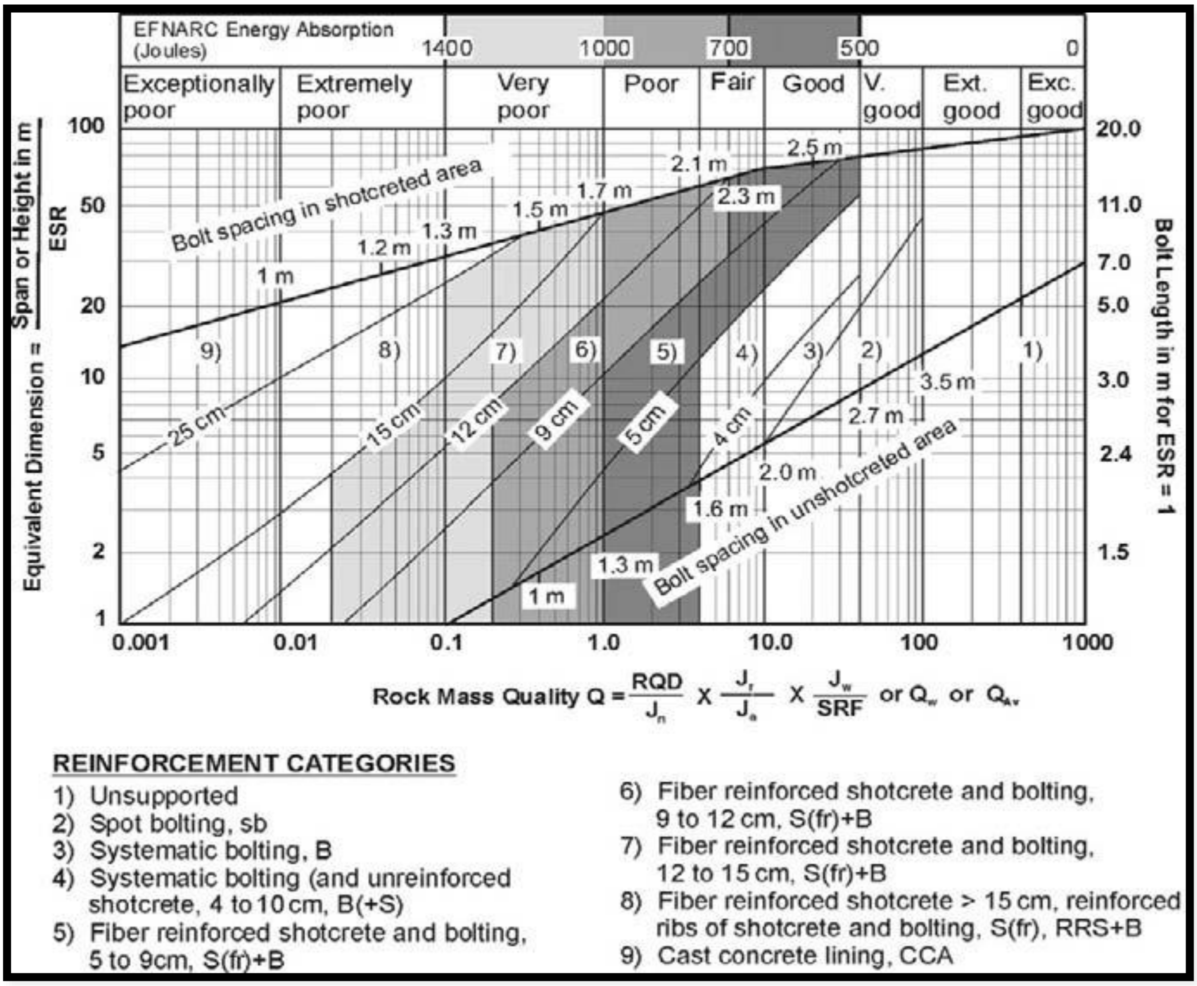
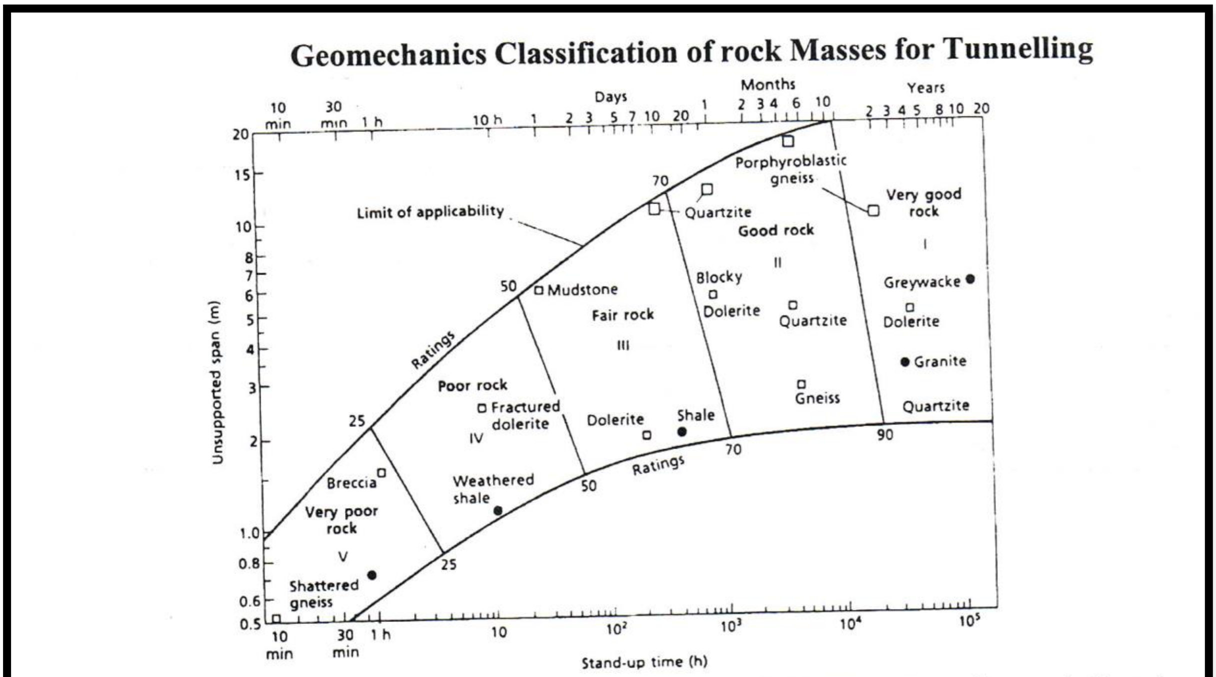


Figure 3.4- 1 Grimstad and Barton (1993) chart for the design of support

Roof support requirements (including bolt length and their spacing) can be estimated from the empirical approaches of Cording, Hendron, and Deere (1971); Hoek and Brown (1980); Barton et al. (1980); Bell (1993, Fig. 3.4-2, Fig. 3.4-3), and Barton (1998). These approaches are based on the rule of thumb and do not include the rock mass type and the support pressure for designing the bolt length. It is pertinent to note that none of these approaches, except Barton's method and the modified Terzaghi's theory of Singh et al. (1995a), provide a criterion for estimating the support pressure for caverns. The philosophy of rock reinforcement is to stitch rock wedges together and prevent them from sliding down from the roof and the walls. Empirical approaches based on rock mass classifications provide realistic bolt lengths in weak zones when compared with the results of the numerical analysis. In view of this, Singh et al. (1995b) presented approach to designing anchors/rock bolts for cavern walls in non-squeezing ground conditions.



Geomechanics classification of rock masses for tunnelling. South African cases studies are indicated by squares while those from Alpine countries are shown by dots. (After Lauffer. 1958.)

(After Bell, 1993.)

Figure 3.4- 2 Geomechanics Classification of rock masses for Tunneling

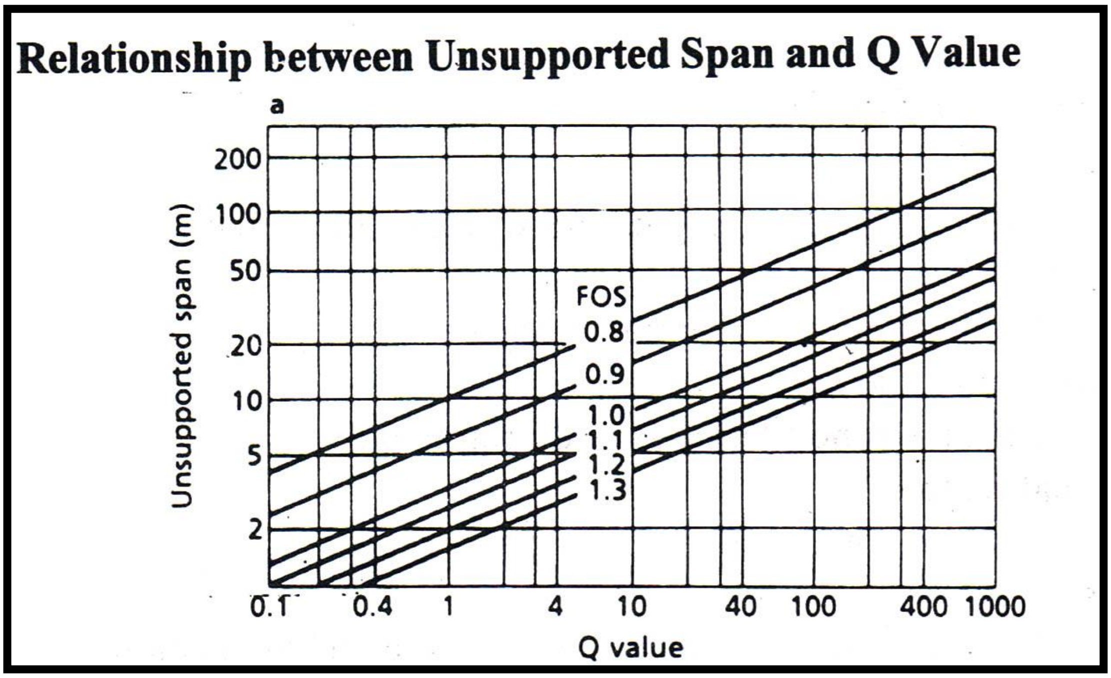


Figure 3.4- 3 Relationship between Unsupported Span and Q Value

In the Himalayan region, thin bands of weak rocks are found within good rock masses. Sometimes these thin bands are just above the roof. Separation between a stronger rock mass above and the weak bands below takes place where overall tensile stress is more than the tensile strength of the weak band. As such, longer rock bolts are needed soon after excavation to stop this separation and stabilize the roof. Thus, tensile strength needs to be estimated for the minimum value of Q in the band and the adjoining rock mass (Singh and Goel, 2011).

Engineering geological map should contain the engineering parameters like soil type, soil depth, bearing capacity of soil, water level, gradation both in the map as well as its cross-sections. Earth materials like soil, rock or debris should be differentiated in the map using suitable color or pattern as legend. For the cases of rocks, the attitudes, discontinuities, weathering grade and rock mass properties should be clearly shown in the map. At least two lines of cross-sections are recommended to show the sub-surface distribution of earth materials in the area.

3.5 Discontinuity Survey and Stability Analysis

Stability analysis should be carried out thoroughly on the slope ground focusing for the mass-movement and rock fall. The result of the analysis in the case of rocky area may have the possibilities of plane, wedge and toppling failures. Sometimes in a highly crumbled and crushed rocks, soil like failures can be analyzed. A brief description of theoretical background of various types of failures is given below (Fig.3.5-1).

Circular (rotational) Failure: It occurs along a surface that develops only partially along joints, but mainly crosses them. This failure can only happen in heavily jointed rock masses with a very small block size and/or very weak or heavily weathered rock mass. It is essential that all the joints are oriented favorably so that planar and wedge failures or toppling is not possible.

Plane Failure: This type of failure occurs mainly in stratified rocks when the strata dip towards the slope and the daylight in the slope. The plane on which sliding occurs must strike parallel or nearly parallel to the slope face. Second most important point is that the dip of strata should be smaller than the dip of the natural slope. Similarly, when we consider the friction, the failure plane must be greater than the angle of friction of this plane.

Wedge Failure: The conditions for this type of failure are (i) the line of intersection of the two planes on which sliding is to take place should be exposed to the slope, (ii) the dip of line of intersection of the two planes must be greater than the angle of internal friction.

Toppling Failure: For the case of toppling, the dip direction of natural slope and the slope of bedding, foliation or discontinuity plane should be in opposite direction and the dip amount of the discontinuity plane or bedding plane should be steeper than the natural slope.

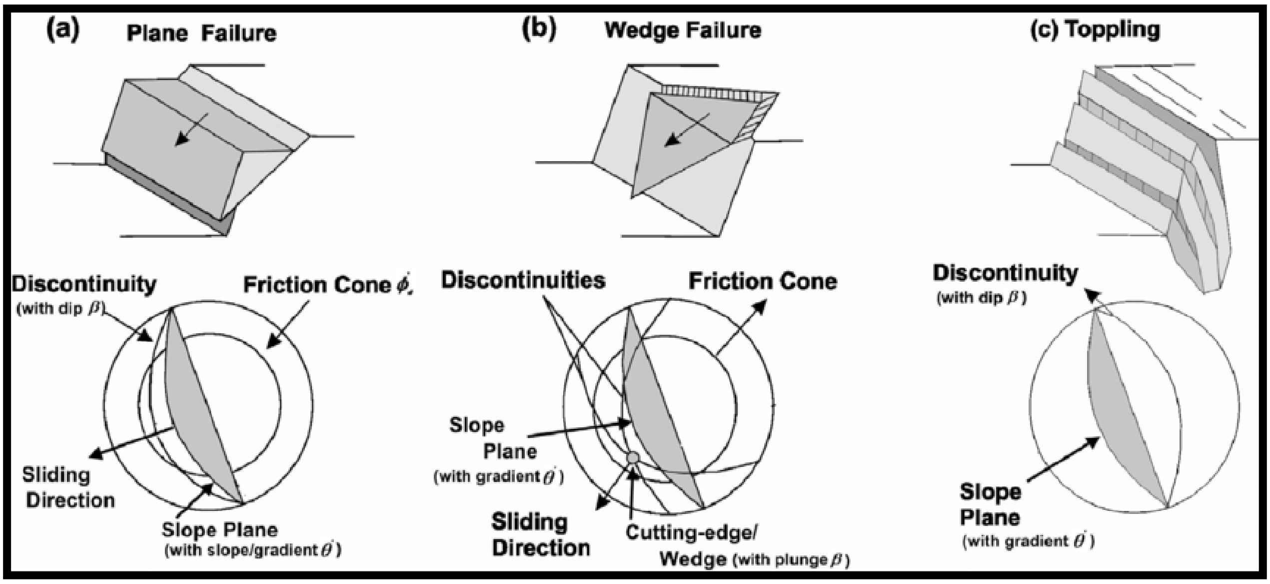


Figure 3.5- 1 Sketches show the condition of plane, wedge and toppling failures in nature.

In the case of soil slope, stability analysis either of infinite slopes or of finite slope should be calculated (Murthy, 1999). Mostly the method of slices (Bishop's method, friction-circle method, Taylor's stability numbers) can be adopted. Analysis of both natural slopes and man-made slopes are recommended from the view point of stability. The most important recommendation is to analyze the stability of both banks of river.

3.6 Geo-physical, Hydro-geological and Geo-Technical Investigation

A. Geophysical Investigation

Geophysical methods of sub-surface investigation depending upon the site condition, can be carried out by either (a) 2D Electrical Resistivity Survey or (b) Seismic Refraction Survey.

2D Electrical Resistivity Survey: 2D electrical resistivity profiling is capable of showing both lateral and vertical variation in electrical resistivity. In this method, by increasing the distance between current and potential electrodes one can get information from deeper part of the sub-surface and by shifting both current and potential electrodes along a profile it is possible to record lateral changes in electrical resistivity. The method is capable of detecting boundaries between unconsolidated material and bed rock and identifying weathered rock from fresh rock and contact between rocks of different lithology and different rock mass quality. The total length of survey will be decided by the expert after the presentation of the geological and engineering geological report based on the site condition. Processes of data acquisition, selection of equipment, data processing, analysis and interpretation procedures will be decided based on the site requirement.

(b) Seismic Refraction Survey: The refraction survey should present an evaluation of the overall sub-surface condition and layer thickness. The equipment, traverse setting, seismic spread layout, blasting materials, methodology of data analysis, interpretation will be decided by the geotechnical experts after the presentation of geological as well as engineering geological report depending upon the recommendation of the field expert and site condition.

B. Hydrogeological Investigation: It deals the study of distribution and movement of ground water in the area. Field survey is proposed to show the link between the surface water and ground water in terms of recharge, discharge and distribution of aquifer materials. Geophysical methods are recommended to locate the ground water depth and movement direction. A brief hydrogeological map should be prepared showing the distribution and movement of ground water. Hydrogeological logs should be prepared for the exact determination of depth of ground water and thickness of the aquifer.

C. Geo-technical Investigation: Systematic sampling of earth materials from the site is the pre-requisite for the testing of the materials in the lab. Samples from the surface and sub-surface are required for the test and data interpretation. The most important part is the bearing capacity evaluation. Some of the major geo-technical laboratory tests are: (i) triaxial compressive strength test (ii) uniaxial ultimate compressive strength test, (iii) point load tensile strength test, (iv) Los Angeles abrasion test (v) crushing value test (vi) Impact test (vii) specific gravity test (viii) Swelling pressure test and (ix) Alkali aggregate reaction test for rock.

Lugeon text, SPT and permeability tests are also recommended as in-situ tests. In case of large projects, hydrofracturing tests are also recommended. Geo-technical tests required for the construction materials are given in 3.7. Separate geo-technical report should be prepared covering all types of tests (both in-situ and laboratory) related to foundation designs, seepage problems, support systems and slope stability. For the detail calculation of static load, dynamic load and elastic uniform compression refer to Murthy (1999).

Core Drilling and Testing: The intent and purpose of the core drilling is to obtain the subsurface information on the foundation materials and roof condition of large caverns. Core drilling shall be conducted to obtain continuous cores with the maximum practicable amount of core recovery. Daily drilling report should be prepared in site. Three types of photographs (showing the sites before investigation, during operation and after the completion) should be included in the report. In addition to photographs, drilling work completion report from responsible site staff should also be submitted in the field investigation report (for the detail procedure see the guideline of DoED for HPP, 2003). Core samples taken from each borehole shall be placed in order in core box systematically.

Sampling for Petrographic Studies

Representative rocks of each geological units and representative core samples obtained from drilling should be collected for petrographic studies. Representative and fresh samples of average 4x2x2 inch size should be collected for thin section preparation. The sampling spacing will be varied depending upon the accessibility of outcrop and appropriate lithology. All the samples should be numbered, wrapped with paper and kept in a plastic or cloth bags to protect them from abrasion. The location of all types of collected samples will be shown in the topographical map along with the GPS coordinates.

Preparation and Study of thin sections:

Thin sections should be made parallel to the lineation and across the foliation or bedding. The number of thin section will depend on the type of lithology and stratigraphic units mapped in the field. At least two thin section of each rock type is recommended for the study. The thin sections should be studied under high resolution petrological microscope. Study should be focused on the mineral paragenesis, texture and micro-structures related to deformation. Photomicrographs can be taken from digital eye-piece camera attached with the microscope. Petrographic analysis of rocks gives the idea on the mineral composition, cementing materials that hold the grains, texture, micro-cracks, weathering status, micro-tectonics, quartz-grain structures etc. and ultimately these properties can be linked with the design parameters as well as construction material evaluation.

Similarly, sedimentological analysis should be analyzed to identify the mineral composition and hardness under the binocular microscope. Emphasis should be given to the percentage of quartz in the sediment as it has abrasive role for turbines. Sedimentological analysis should also be carried out for the determination of particle size variation in the samples.

3.7 Construction Material Survey and Geotechnical Tests

Construction Material Survey: A survey should be conducted for the identification and investigation of the burrow areas and quarry sites for the construction materials such as impervious soils, stones, sand and gravel etc. as required. For this purpose, investigation should me made based on the excavation of test pits and preparing log showing the nature of soil at burrow locations and collecting the samples for the laboratory analysis. In the case of underground power house, the laboratory tests of core samples or muck materials should be carried out to assess whether the material is suitable for construction proposes or not. The following tests are recommended for the construction materials:

Rock Samples: Performing laboratory tests such as uniaxial compressive strength, point load tests, Los Angeles abrasion, aggregate crushing value, alkali reactivity, specific gravity and petrographic analysis of each rocks types.

Fine-materials: Performing sieve and sedimentation analysis, Atterberg limits, natural moisture content and specific gravity.

Coarse Aggregates: Bulk density, Polished aggregate friction value, Particle density and water absorption, Sieve analysis, Material finer than 75 micron, Particle shape, Flakiness index, Angularity number, Fine particle size distribution, Aggregate crushing value, Wet/dry strength variation, Los Angeles Value, Soundness, Weak particles Clay and fine silt Organic impurities, Color of aggregate, Average least dimension, Resistance to wear by attrition , Unconfined compressive strength, Petrographic examination, oversize particle size distribution and shape.

Test on core Samples: point load index test, absorption and specific gravity tests, sodium sulphate soundness test, Los Angeles test and petrographic analysis.

Field Permeability Tests: Carry out test pitting and trenching in order to establish sub-surface condition at some particular locations of proposed power house area. Test pits should be excavated with minimum dimension of 1.5 x 1.5 plan area at bottom. Test trenches should be excavated to 1.0 m bottom width and required length (the length may vary from 2 m to 10 m depending upon the site condition). Geological log of all excavations should be made in the field.

Finally, evaluate the available quantity at each burrow area to meet the requirement of the construction.

3.8 Seismological Studies

This study includes the aerial photo interpretation, review of previous reports, site monitoring for impact analysis, location of liquefaction hazard area etc. Seismic hazard analysis can be carried out using both the probabilistic and deterministic methods.

From aerial photos, existing faults and lineaments can be traced out. The study of nature of fault and palaeo-seismicity is necessary for the interpretation of data. Collection of materials on seismogeology, seismic activity, modern tectonic stress field etc. within the regional scope and formulation of regional seismic structural map is the pre-requisite for the seismic evaluation. Based on the focused study on active fault and motion features, comprehensive evaluation on regional seismotectonic environment can be assessed.

Based on the collection of instrumental seismicity data from Department of Mines and Geology (DMG), Nepal and International Seismological Centre (ISC), American NEIC, British ISC etc. and by review and conversion of earthquake magnitude, regional earthquake catalog and epicenter distribution diagram can be prepared. Analysis of features of seismic activities in the region and near field region, collection of historical earthquake data and analysis of the impact of historical earthquake on the proposed engineering site are the other pre-requisites for the seismic assessment. Estimation of Peak Ground Acceleration (PGA) is the important parameter. The ground shaking caused by an earthquake varies from place to place and the hazard mapping in a region can show this variation. The hazard depends on the magnitude and locations of likely earthquakes, how often they occur and the properties of the rocks and sediments that earthquake waves travel through ground where structures are placed on. The degree of ground shaking at any place depends on the following factors:

i. Magnitude: In general, the larger the magnitude the larger is the ground shaking.
ii. Source to site distance: The shorter the source-to-site distance the larger is the ground shaking.
iii. Mechanism of faulting at the source: Degree of shaking depends on the type of faulting (e.g. thrust, normal and strike-slip etc.)
iv. Topographic effect: In general, the top of hill is shaken more than in the valley.
v. Local geological effect: Sites underlain by soft sediments e. g. sand and clay experience more shaking than on rock.
vi. Geological structures: Sometimes faults help to refract seismic waves away from their course and meet direct or other waves and interfere constructively enhancing the amplitude of the wave.
vii. Location of sites with reference to the fault plane: The degree of shaking is not same around the fault. It varies with azimuth from the fault plane.

Therefore, seismic hazard analysis of the site is necessary. Micro-seismic zonation and strong ground motion parameters should be collected for the final interpretation. Seismic coefficient of each vertical layers till the depth of 50 m should be determined based on at least one pilot drilling. Determination of seismic coefficient to surface and sub-surface power house is required.

3.9 Geological Criteria for Selection of Power House Type

Himalayan geology is termed as one of the youngest tectonic formations in the world. Tunneling in this region is hence complex in nature. The very fragile and complex geology in the region offers challenges in stability of even the best located underground structures. Tunneling in weak rock is more challenging in terms of stability and application of support. Therefore, geological investigation is vital for the selection of the location of power house in fragile and tectonically active region.

In the case of hard, massive and joint free-hard rocks, underground power house is recommended. The distribution of strata, lithology and initial geo-stress should be calculated and tabulated to determine the site condition. The excavation process and corresponding rock mass support measures are based on the discontinuities developed in the rocks and groundwater condition. For large caverns, the deformation and failure characteristics of the surrounding rock mass, the stress characteristics of anchorage structures in the cavern complex, and numerical simulations of surrounding rock mass stability and anchor support performance are the pre-requisites for the sound design. The presence of the faults not only lowers the integrity of the surrounding rock mass, but also plays a decisive role in the deformation and stability of rocks around the powerhouse. In the case of maximum deformation, multiple rock failure modes should be analyzed. Engineering measures, including the systematic monitoring and measurement of rock mass deformation, unloading relaxation, and stress monitoring in the anchorage structures, and multiple reinforcement adjustments in the surrounding support, will play an important role in the stability of powerhouse construction. In some cases, when there is problem of rock fall or slide on the surface of the slope, underground power house can be safer. Land slide-prone valleys often make a surface station unfeasible hence, underground cavern should be preferred.

In the case of weathered and jointed rocks, semi-underground power house can be constructed in the replacement of underground with due care of stability. The advantages of both surface and underground are clubbed together in a semi-underground powerhouse, provided that topography and geological conditions permits to do so. Parameters for lateral earth pressure and foundation are needed for the safety calculations of semi-underground cavern. For this, soil or rock properties from each contrast lithological or soil horizons should be tested to assure their lateral pressure and water holding properties. For the subsurface investigations, both the geophysical and drilling information are needed. In loose and fragile mass, surface power-house with good stabilization of foundation is recommended. Geophysical survey and drilling tests are recommended to get full sub-surface geological information before deciding the type and dimension of power house.

3.10 Format for Geological and Geo-Technical Baseline Report

1. Introduction:
2. Objectives:
3. Methodology (describe the methodology adopted in detail)
4. Results: (it should include the following headings)

    i. Geological Investigation (lithostratigraphy, geological structures, micro-tectonics, regional discontinuities, geological map with at least two cross-sections showing all geological units and structures)
    ii. Engineering Geological Investigation (Soil distribution map, rock mass classification, hazard assessment, ground water condition map, stability analysis).
    iii. Geo-physical and drilling report: (geophysical survey report and drilling report including geo-technical test report)
    iv. Geo-technical Investigation (geo-technical report of both construction materials and support system and foundation related parameters. Also include the permeability tests)
    v. Seismic Assessment: (historical earthquake studies, recent earthquake data base, seismic coefficients, recommendations).

5. Discussions and Conclusions: (data tabulation, data interpretation and significance for support design, foundation and construction materials)
6. References:

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4 STRUCTURAL ENGINEERING

4.1 Collection of data

Data required for the structural design of surface powerhouse can be referred from section 4.1 of IS: 4247-1993 (Part 1). However, for capacity range less than 10MW, section 4.1 (e) and (f) of IS 4247-1993 (Part 1) can be omitted.

4.2 Information regarding loads due to E/M and H/M equipment/Machines

Various information regarding loads from equipment force that should be available prior to the structural design of powerhouse are given below:

4.2.1 Equipment/machine load

a) Magnitude of load, their direction and point of application due to machines and accessories should be clearly indicated in plan and sections of drawing provided by supplier/manufacturer.
b) Information required regarding machines/equipment and their load and forces are, but not limited to, specified in section 4.2.3 of IS: 4247-1993 (Part 1).

4.2.2 Hydraulic load

Information of hydraulic load shall be specified in section 4.2.4 of IS: 4247-1993 (Part 1)

4.3 Drawings

Requirements of detail drawings of powerhouse are specified in section 4.2.1 of IS: 4247-1993 (Part 1) or in any other relevant clauses of international standard/code.

4.4 Materials

a) Definition of the characteristics strength of the material shall be as defined in section 36.1 of IS:456-2000.
b) Unit wt. of common building material shall be in accordance with IS: 875 (Part-1). For the confirmation of the unit wt. of construction material laboratory test may be carried out.

4.4.1 Structural steel

a) Specification of hot rolled structural steel for medium and high tensile strength shall conform to IS: 2062-2011.
b) Specification of steel for of ordinary quality for ordinary purposes like construction of door, window, fencing etc. shall conform to IS: 2062-2011.
c) Physical properties of hot rolled steel beam, column, channel and angle sections for structural use shall conform to IS: 808-1989.
d) Physical properties of hollow circular sections for structural purposes shall conform to IS: 1161-2014.

e) Physical properties of rectangle/square hollow sections for structural use shall conform to IS: 4923-1997.
f) Physical properties of flats and plates for structural and general engineering purposes shall confirm to IS: 1730-1989.
g) Physical properties of round and square bars for structural and general engineering purposes shall confirm to IS: 1732-1989.

4.4.2 Galvanized corrugated steel sheets

General specification for plain and corrugated roof sheet may be taken from IS: 277-2003.

4.4.3 Concrete

a) Definition of the characteristics strength of the material shall be as defined in section 6.1.1 of IS: 456-2000.
b) Grade of concrete may be designated as per the table no. 1 of IS: 10262-2009 or table no. 2 of IS: 456-2000.
c) General consideration of mix proportioning of concrete may be as given in section 9 of IS: 456-2000.
d) For capacities of powerhouse greater than 10MW, design mix of concrete should be implemented.
e) For capacities of powerhouse less than 10MW, concrete may be formed by nominal mix also.
f) IS: 10262-2009 should be used as guideline for mix proportioning of concrete.
g) Minimum grade of the concrete that should be used in structural use for construction of powerhouse should not be less than M25.
h) Specification for preparation of cement grout for embedding is specified in section 6.3 of IS: 2947-1982 (Part-1). Specification for application cement grout is specified in 6.4 of IS: 2947-1982 (Part-1).
i) Design working life of the structures should be as per section 2.6 of section 2 from Euro code EN: 1990-20002.

Physical Properties of concrete can be referred as follows:

a) Compressive strength

Refer section 6.2.1 of IS: 456-2000.

b) Tensile strength

Refer section 6.2.2 of IS: 456-2000.

c) Modulus of elasticity

Refer section 6.2.3 of IS: 456-2000.

d) Shrinkage

Refer section 6.2.4 of IS: 456-2000.

e) Creep

Refer section 6.2.5 of IS: 456-2000.

f) Coefficient of thermal expansion

Refer section 6.2.6 of IS: 456-2000.

4.4.4 Reinforcement

a) Specification of high strength reinforcement bars should be as recommended in IS: 1786-2008.
b) Specification of mild steel and medium tensile steel bars should be as recommended in IS: 432-1982.

4.5 Superstructure

The portion of surface or semi-surface powerhouse above the ground level is called super structure. The portion of the underground powerhouse above the plinth level or erection/assembly bay or generator floor of top level shall be called superstructure.

4.5.1 Types of superstructure

Types of superstructure may be categorized as given in section 6 of IS: 4247-1992 (Part 2).

4.5.2 Layout of crane columns

The column spacing is determined by considerations of economy, expediency of construction and architectural appearance. However, the spacing of the columns considerably depends upon the spacing of the machines as well as structural requirements. In order to ensure good structural design, columns should generally be avoided over beams and over openings like penstock pipe and draft tube. It is good practice to place the column either over mass concrete or over the pier of the draft tube which is connected directly to the bottom of the substructure.

Criteria for layout of columns of super structure can be referred from section 6.3 of are: 4247-1992 (Part 2).

4.5.3 Element of superstructure

a) Roof
For types, selection and general design consideration of powerhouse roof reference should be taken from section 10 of IS: 4247-1992 (Part 2).

b) Roof support
For types, selection and for general design consideration of roof support of powerhouse, reference should be taken from section 11 of IS: 4247-1992 (Part 2).

c) Gantry girder/crane beam
For types, selection and general design consideration of gantry girder, reference should be taken from section 12 of IS: 4247-1992 (Part 2).

d) Gantry/crane column
For types, selection and general design consideration of gantry column, reference should be taken from section 13 of IS: 4247-1992 (Part 2).

e) Foundation
General design consideration of powerhouse foundation for steel column and concrete column reference is recommended in section 13 of IS: 4247-1992 (Part 2).

f) Beams

General design consideration of beams / bracing members, reference should be taken from section 14 of IS: 4247-1992 (Part 2).

g) Panel wall

General design consideration for design of panel wall in powerhouse should be taken from section 15 of IS: 4247-1992 (Part 2).

h) Floors

For general consideration for layout of floors and types of floor finishes, reference should be taken from section of IS: 4247-1992 (Part 2).

4.5.4 Design loads and forces

4.5.4.1 Dead load

Dead load of the superstructure consists of wt. of the structure including but not limited to walls, finishes, handrails, rolling shutter, steel covers, stairs, false floor and ceiling.

Unit weight of different common building materials may be taken from IS: 875-1987 (part 1).

4.5.4.2 Live/Imposed load

In absence of detail load data at preliminary stage, different types of uniformly distributed loads due to imposed equipment may be taken from table no. 2 of section 4.2.2 of IS: 4247-1993 (Part 1). The final design should be based on the actual equipment load. The loading condition and data for design are given in section 4.2.2 of IS: 4247-1993 (Part 1) and can be taken from IS: 875 (Part-2)

4.5.4.3 EOT crane load

a) Data required for the crane load and crane may be as given in Annex 'A' of IS: 4247-1993 (Part 1). All the details of the EOT crane including maximum wheel load shall be supplied by supplier/manufacture.
b) Loading effect due to impact and vibration shall be in accordance with section 6.1 of IS: 875-1987 (Part-2).
c) Minimum impact allowance on crane beam/girder shall be in accordance with section 6.3 of IS: 875-1987 (Part-2).

4.5.4.4 Wind load

a) Basic wind speed shall be as recommended in NBC 104-1994.
b) Design wind speed may be estimated in per the section 6.3 of IS: 875-2015 (Part 3).
c) Design wind pressure may be estimated as per the section 7.2 of IS: 875-2015 (Part 3).
d) Wind force on individual member of building may be calculated as per the section of 7.3.1 of IS: 875-2015 (Part 3). Values of external and internal pressure coefficient may be considered as per section 7.3.1.2 and 7.3.1.3 of IS: 875-2015 (Part 3).

4.5.4.5 Snow load

Snow load may be estimated as per IS: 875-1987 (Part 4)

4.5.4.6 Seismic force

4.5.4.6.1 Design acceleration coefficient

a) Horizontal seismic coefficient

Design horizontal seismic coefficient on a structure may be calculated by two methods a) Static method b) Dynamic method.

i. Equivalent Static method

Seismic load on the superstructure may be estimated in accordance with IS: 1893-2016 or NBC 105. The design horizontal seismic coefficient A_h for a structure may be determined by using the equation given in section 6.4 of IS: 1893-2016.

$$A_h = \frac{Z}{2}\frac{S_a}{g}\ \frac{I}{R}$$

Z = zone factor, for maximum considered earthquake (MCE), table no. 3 of IS: 1893-2016.

I = post-disaster importance factor depending on the life and function of the structure, historical value or economic importance. $I/R \ngtr 1$. See section 7.2.3 and Table no. 8 of IS: 1893-2016

R = response reduction factor, see section 7.2.6 and Table no 9 of IS: 1893-2000.

S_a = spectral acceleration depends upon the period of vibration and damping. S_a /g is average response acceleration coefficient.

Value of S_a/g should found out as given in section 6.4.2 (a) or (b) of IS 1893-2016. See fig. 2 of IS: 1893-2016 for value of Sa/g for equivalent static method and response spectrum method.

Foundation soil type has been classified in three categories as per section 6.4.2.1 of IS: 1893-2016.

Soil type I – Rock or hard soils

Soil type II – Medium or stiff soils: and

Soil type III- soft soils.

To determine value of Sa/g very precisely, foundation soil should be classified correctly as given in the table no. 4 of IS: 1893-2016.

ii. Dynamic analysis method

Dynamic analysis can be performed in three ways;

i. Response spectrum method
ii. Modal time history method
iii. Time history method

For power station less than 10MW estimation of seismic force may be estimated by equivalent static method. For the entire powerhouse building greater than 10MW, in detail design, seismic force shall be estimated through dynamic analysis by using any of the methods mentioned in section 4.5.6.1 (b).

For underground structures and buildings whose base is located at depth of 30m or more, horizontal seismic coefficient shall be taken as half the value of A_h obtained for ground level.

For all power stations the zone factor Z shall be fixed to group V as categorized in IS: 1893-2016. i.e. value of z shall not be taken less than 0.36. For the power stations capacity greater than 50MW design acceleration spectrum shall be specific to the project site. However, the site-specific value of horizontal seismic coefficient should not be less than the value estimated as specified in this guideline. In such case values of horizontal seismic coefficient shall be estimated as directed in this guideline.

b) Vertical seismic acceleration coefficient

The design seismic acceleration coefficient in vertical direction shall be as given in 6.4.6 of IS: 1893-2016.

4.5.4.6.2 Permissible increment in net bearing pressure

Percentage increment in net bearing pressure and skin friction of soil for foundation shall be according as given in table no. 1 and table no. 2 of IS: 1893-2016. See notes given under the table no 1 of IS: 1893-2016.

4.5.4.6.3 Storey drift

Deformation of RC building shall be obtained from structural analysis using a structural model based on the section properties of structural elements as said in section 6.4.3 of IS: 1893-2000.

Storey drift limitation shall be limited to 0.004 times the storey height, under the action of design base shear V_B with partial factor of safety for all loads taken as 1.0, as per section 7.11.1 IS: 1893-2000.

Separation between buildings if provided gap between the two buildings shall be as requirement of section 7.11.3 of IS: 1893-2016.

4.5.4.6.4 Seismic instrumentation

Seismic instrumentation for Hydropower project may be as recommend by IS: 4967.1968.

Note: Designer may follow the standards or code of other countries also to estimate the seismic coefficient, however the estimated value of design seismic coefficient should not be less than the value of the design seismic coefficient calculated as per this guideline.

4.5.5 Force due to temperature variation

Total temperature variation in structure shall be as specified in section 8.8 of IS: 4247 (Part 2).

Design stress due to variation of temperature in the structure shall be as specified in section 8.8 of IS: 4247 (Part 2)

4.5.6 Accidental load

Accidental load shall be as described in section 6.0 of IS: 875-1987 (part 5)

Common source collision impact in powerhouse structure shall be as given in section 6.1.1 of IS: 875-1987 (part 5).

4.5.7 Vehicle impact load

Vehicle impact load shall be estimated as given in section 6.1.2 of IS: 875-1987 (part 5).

4.5.8 Crane impact load

Impact due to crane on buffer stop shall be estimated as given in section 6.1.4 of IS: 875-1987 (part -5).

4.5.9 Special loads

Loads on powerhouse other than the specified in section 4.5.4 are considered in this category. Few examples of such types of loads are listed below.

a) Load of switchyard auxiliaries should be considered during construction in connection with the structural component of powerhouse.
b) Load of transmission cable if connected to any structural component of superstructure.
c) Loads of PH outlet gate hoist arrangement, d/s of draft tube, if hoist system is supported on crane column of powerhouse. For example, in Chameliya and Kulekhani-III HEP, outlet gate hoist arrangement has been supported on crane column of powerhouse.

4.5.10 Stress

Permissible increase in stress in structural components for various load combination shall be considered as given in table no. 1 of IS: 4247-1992 (Part 2).

4.6 Sub- structure

The portion of a surface powerhouse below the ground level is defined as substructure. Substructure typically consists of valve floor, turbine floor and generator floor and machine hall floor. As per the requirement, other rooms/spaces may also be added.

4.6.1 Design loads and forces

4.6.1.1 Dead load

Dead load of the substructure consists of weight of the structure and fixed machines/equipment including but not limited to finishes, handrails, steel covers and stairs.

4.6.1.2 Live load.

Live load may be taken as specified in section 4.5.4.2 of this guide line.

4.6.1.3 Seismic load

Design seismic coefficient for substructure (below ground level) may be taken as specified in section 4.5.4.6 of this guide line.

4.6.1.4 Backfill pressure

Maximum intensity of backfill pressure in lateral direction at the required depth/ height shall be calculated by

$P_s = K_o \Upsilon_s H$

Where,

H = depth/ height of backfill

P_s = maximum pressure intensity due to backfill at height H

$k_o = 1 - \sin\phi$ = coefficient of earth pressure at rest

ϕ = angle of internal friction of soil

Υ_s = unit wt. of backfill material

4.6.1.5 Surcharge load

Lateral load due to uniformly distributed surcharge adjacent to the vertical wall is calculated by the equation given below

$P_s = K_o \sigma_s$

σ_s = surcharge pressure

4.6.1.6 Water pressure

Maximum intensity of water pressure at the required depth/ height shall be calculated by the equation given below

$P_w = \Upsilon_w H$

Where,

H = depth/ height of water

P = maximum pressure intensity at the height H

Υ_w = unit wt. of water

4.6.1.7 Shrinkage effects

Effect of shrinkage in concrete may be as described in section 6.2.4 of IS: 456-2000 and section 6.2.4 of IS: 1343-2012.

4.7 Stability analysis

Stability analysis for the powerhouse constructed on the dam body should be analyzed together with the dam body in accordance with the EM: 1110-2-2200. For all types of powerhouse constructed separately from dam, stability analysis should be checked out for sliding, overturning, bearing pressure, uplift and settlement.

Loading conditions has been recommended for stability of powerhouse as per section 6.3 of IS: 4247-1998 (Part3) as follows:

a) Normal loading conditions
   Existing normal ground water table/saturation level should be considered with normal/ minimum tail water level.
   Cases for removal equipment, being/ not being, in position with draft tube, spiral casing and penstock being empty/ full should be considered.

Crane load should be considered by assuming the crane to be moving loaded to half its capacity of stationary loaded to full capacity.

b) Extraordinary loading conditions

When seismic forces are considered, wind load and maximum flood levels, should not be considered

Combination of load and forces should be in accordance with the section 6.2 of IS: 4247 1998 (Part 3).

4.7.1 Overturning

The resultant of all the forces at foundation level under worst probable condition of loading should fall within the middle third of base. The eccentricity 'e' should be calculated to ascertain the maximum bearing pressure for all the combination of load as described in section 4.7. To find the maximum bearing pressure uplift should be neglected.

Minimum factor of safety for overturning should be as given in Table 4.1

4.7.2 Sliding/ shear friction factor

Sliding stability is based on a factor of safety (FS), a measure of resistance of a structure against sliding which should be calculated using the equation given below;

$$\mathrm{FS} = \frac{(\mathrm{W} - \mathrm{U})\tan\emptyset + \mathrm{C.A}}{\mathrm{H}}$$

Where,

C = cohesion (unit shearing strength) in KN/m^2 applied only to area in compression

A = area of base considered under compression in m^2

$\tan\phi$ = coefficient of internal friction

ϕ = the angle of internal friction of the foundation material

H = Algebraic sum of forces parallel to the plane of sliding in KN

W = algebraic sum of the normal forces to the plane of sliding in KN

U = Uplift force in KN, acts vertically upward

The value of C and ϕ vary for different foundation materials and concrete. These values should be determined by experiment for detail design. For preliminary design the values may be taken from table no. 1 of IS: 4247-1993 (Part-1).

The value of factor of safety should not be less than the values given in table no 4-1. Factor of safety against sliding is found out considering C=0.

4.7.3 Allowable bearing pressure

The allowable pressure for detail design should be identified from the actual bearing test carried out at site at the foundation level preferably under saturated condition as recommended in 6.4.4 of IS: 4247-1998 (Part 3).

The increase in permissible bearing pressure for seismic condition should be 25% to 50% depending upon the type of foundation material in accordance with table 1 of IS: 1893-2016 (Part 1).

4.7.4 Settlement

For the powerhouse founded on soil magnitude and distribution of the probable settlement should be investigated and special provisions should be made on the design of the structure to prevent such differential settlement as it may cause tilt in the turbine-generator shaft. Tilt of the turbine-generator shaft should not go beyond the permissible limit provided by the manufacturer.

a) Settlement of shallow foundations may be estimated in accordance with IS: 8009-1976 (Part-1). Permissible differential settlement of isolated footing and raft foundation may be as given in the table no. 1 of IS: 1904-1986 however tilt of turbine-generator should be within permissible limit.
b) Settlement of deep foundations may be estimated in accordance with IS: 8009-1980 (Part-2).

4.7.5 Uplift

The factor of safety against floatation shall be calculated by

$$\text{FOS} = \frac{\sum V}{U}$$

Where,

$\sum V$ = sum of all the vertical load in KN, acts vertically downward

U = Uplift force in KN, acts vertically upward.

Table 4- 1 Minimum factor of safety for Stability check of Powerhouse (constructed away from dam)

Item	Normal loading	Extreme loading
Overturning		
Construction stage	1.1	1.1
Structure complete and equipment operator	1.2	1.1
Sliding		
Construction stage	1.54	1.18
Structure complete and equipment operator	1.54	1.18
Floatation		
Construction stage	1.1	1.1
Structure complete and equipment operator	1.2	1.1

The maximum bearing pressure should be equal to or less than the allowable bearing capacity for the normal and emergency load condition.

4.8 Fire resistance

Minimum requirement of different building components for ability to withstand fire either for load bearing or non-load bearing shall be in accordance either with IS: 1642-1989 or ACI 216.1-2007.

4.9 Structural analysis of the Powerhouse

Analysis of powerhouse structural system is carried out to find the maximum values of bending moments, shear forces, axial thrust, deflection and reaction in the members of a structural system that occurs under the different load combinations.

Basis for the analysis of the reinforced concrete structure may be taken from section 22 and section 37 of IS: 456 – 2000.

Analysis of the structure may be carried out manually of by using any computer software created for analysis and design of RCC structure.

Analysis of the whole structure may be carried either by using 2D model or 3D model. Using 2D of analysis model is easier than 3D model. Furthermore, analysis of the whole structure by using 3D model is a tedious and complex process however provides more precise results comparative to 2D model of analysis.

Powerhouse substructure is quite different compared to a common RCC building in terms of shape and loading pattern. A substructure may have complex shape openings in machine foundations, spiral case and draft tube which makes distribution of stress in irregular pattern. In such situation 3d model finite element software may be used which can provide highly precise calculation of internal forces and stress at all complex location of the structure.

The stresses value during various loading condition have to be computed using available tools such as numerical approach using FEM model, analytical approach, etc. In case of underground powerhouse, numerical modeling for cavern section with stage construction needs to be carried out for proper designing of support system.

Analysis and design of the substructure may be referred from the Hand Book Hydro Electric Engineering by P.S. Nigam.

4.9.1 Numerical Modelling

The overall equivalent properties of rock masses of large size are almost not available through direct measurement. Prediction of jointed rock mass behavior of rock material, rock joints and rock masses using empirical relationships are widely used throughout the world. However, the validity of numerical modelling should be supported by physical simulation and correlation. For jointed rock masses, various types of numerical models have been developed. For rocks containing a small number of joints, joint element method can be adopted to represent discontinues planes. Modelling of densely jointed rock masses can be mainly realized by two methods. Firstly, is the approach of continuum mechanics, or the equivalence approach, such as material parameter equivalence, energy equivalence, deformation equivalence, composite equivalence, fracture mechanics and damage mechanics. The other approach is to take the rock blocks as particles of a discontinuum, where there is the study of mechanical properties of the assembly of these particles including stress, strain and stability in light of discontinuum theory, and to derive mechanical law for the blocks. Examples of this approach are the rigid block method, discrete element method and discontinuity deformation analysis method.

Finite Element Method (FEM) and Discrete Element Method (DEM) can be used for numerical calculation. Some of the commercially available software are ABACUS, ANSYS, SCIA Engineer, SAP2000, STAAD Pro, etc. There are other open source softwares such as Salome which can be used for both FEM and DEM.

4.9.2 Effective span

Effective span of the flexural member under different support conditions shall be as specified in section 22.2 of IS:456-2000.

4.9.3 Stiffness

Stiffness of the members has been specified in section 22.3 of IS: 456-2000. `

4.9.4 Structural frames

General design consideration for analysis of the structural frames has been specified in section 22.4 of IS: 456-2000.

4.9.5 Moment and shear coefficient for continuous beams

Moment and shear coefficient for continuous beam shall be as specified in section 22.5 of IS: 456-2000. Refer table no. 2 and table no. 3 of IS: 456-2000 for bending moment and shear coefficient respectively.

4.9.6 Critical sections for moment and shear

Critical sections for bending moment and shear shall be as specified in section 22.6 of IS 456-2000.

4.9.7 Redistribution of moments

Redistribution of moment shall be done as specified in section 22.7 of IS: 456-2000.

4.10 Load combination

(i) Load combination-1

$1.5\ (DL + LL) + 1.05\ (CL + CIL \pm CSL_X \pm CTL_Z)$

For all crane supporting columns and crane beams

(ii) Load combination -2

a) Case 1 Dead load, live load, earthquake load and crane load act simultaneously when crane is in operation with max load

$1.2\ (DL + LL) + 1.05\ (CL + CIL \pm CSL_X \pm CTL_Z) \pm 0.6\ EQ_X$

$1.2\ (DL + LL) + 1.05\ (CL + CIL \pm CSL_X \pm CTL_Z) \pm 0.6\ EQ_Z$

For all crane supporting columns and crane except of Erection and Repair Bay

b) Case 2 Dead load, live load, earthquake load and crane load acts simultaneously when crane is in rest (Erection and Repair Bay columns)

$1.2\ (DL + LL) \pm 1.2\ EQ_X + 1.05\ CL$

$1.2\ (DL + LL) \pm 1.2\ EQ_Z + 1.05\ CL$

For all crane supporting columns and crane beams of Erection & Repair Bay

(iii) Load combination -3

$1.2\ (DL + LL) \pm 1.2\ EQ_X$

$1.2\ (DL + LL) \pm 1.2\ EQ_Z$

$1.5\ DL \pm 1.5 EQ_X$

$1.5\ DL \pm 1.5\ EQ_Z$

$0.9 DL \pm 1.5\ EQ_X$

$0.9 DL \pm 1.5\ EQ_Z$

(iv) Load combination -4

$1.2\ DL + 1.2\ EL$

$0.9\ DL + 1.2\ EL$

(v) Load combination -5

$1.0\ DL + 0.35 LL + 0.35 CL + 1.0\ AL$

Where,

DL: dead load

LL: live load

CL: maximum wheel load of crane when trolley is at minimum distance from one side of wheel or rail

at rest position

EQ: earthquake load (x and z denotes respective direction)

EL: erection load

AL: accidental load

CIL: crane impact load in vertical direction

CSL: crane surge load acts in transverse direction of rail

CTL: tractive force acts along the direction of rail

Note: x and z represents the respective direction of force

Reference: Reinforced Concrete Limit State Design

Accidental torsion analysis must be carried out for all buildings in both the orthogonal directions even for symmetric buildings along with the earthquake analysis. When the lateral load resisting elements are not oriented along the orthogonal horizontal directions, the structure shall be designed for the effects due to full design earthquake load in one horizontal direction plus 30 percent of the design earthquake load in the other direction. e.g.

$\pm$ EQx $\pm$ 0.3EQz or

± EQz ± 0.3EQx

When response from the three earthquakes components are to be considered, the responses due to each component may be combined using the assumption that when the maximum response from one components occurs, the response from the other two components are 30 percent of their maximum.

± EQx ± 0.3EQz ± 0.3EQy

± 0.3EQx ±EQz ± 0.3EQy

± 0.3EQx ± 0.3EQz ± EQy

4.11 Design of RCC structure (Limit state method)

Purpose of RCC design, method of design and design process may be referred from section 18 of IS: 456.

Safety and serviceability requirement for limit state design of the structure may be as specified in section 35 of IS: 456-2000.

4.11.1 Characteristics strength of material

Reference shall be taken from section 36.1 of IS: 456-2000.

4.11.2 Characteristics loads

Reference shall be taken from section 36.2 of IS: 456-2000.

4.11.3 Design values

a) Design strength of material shall be as per section 36.3.1 of IS: 456-2000.
b) Design load should be as per section 36.3.2 of IS:456-2000.

4.11.4 Partial safety factors

4.11.4.1 Partial safety factors for loads

Partial safety factor for loads shall be as said in section 36.4.1 of IS: 456-2000.

4.11.4.2 Partial safety factor for material

a) Partial safety factor for loads shall be as said in section 36.4.2 of IS: 456-2000.

4.11.5 Limit state of collapse

Reference may be taken from section 35.2 of IS: 456-2000.

4.11.5.1 Flexure

a) Assumptions for the design of Limit State of collapse for flexural member should be referred from section 38 of IS: 456-2000.
b) Moment of resistance of singly reinforced rectangular section should be calculated as given in section G-1.1 of Annex G of IS: 456-2000.
c) Moment of resistance of doubly reinforced rectangular section should be calculated as given in section G-1.2 of Annex G of IS: 456-2000.

d) Similarly, MOR of T-section/ flanged section should be calculated as given in section G-2 of Annex G of IS: 456-2000.

4.11.5.2 Compression

a) Assumption for design of compression members in limit state design should be as per specified in section 39.1 of IS: 456-2000.
b) All compression members shall be designed for minimum eccentricity in accordance with the section 39.2 and 25.4 of IS: 456-2000.
c) Axially loaded short columns should be designed as per section 39.3 of IS: 456-2000. Reference may be taken from section 3.1 and example 5, page no. 99 of SP 16-1986 for design of a short column under axial load.
d) Compression members subjected to axial load and uniaxial moment should be designed as per the section 39.5 of IS: 456-2000. Reference may be taken from section 3.2 and example 6, page no. 103 of SP 16-1986 for design of a short column under axial load and uniaxial bending.
e) Members subjected in combined axial load and biaxial bending should be designed as per the section 39.6 of IS: 456-2000. Reference may be taken from section 3.3 and example 8, page no. 105 of SP 16-1986 for design of a short column under axial load and biaxial bending.
f) A slender compression member should be designed as per the section 39.7 of IS: 456-2000. Reference may be taken from section 3.4 and example 9, page no.106 of SP 16-1986 for design of a slender column under axial load and biaxial bending.
g) A circular compression members should be designed as per the section 39.4 of IS: 456-2000. Reference may be taken from example 7, page no.103 of SP 16-1986 for design of a circular column.

Note: Design of compression members under axial load and uniaxial bending and biaxial bending may be done using the interaction diagrams given in SP 16.

4.11.5.3 Shear

(i) Shear strength of flexural members

a) Nominal shear stress (τ_v) in a rectangular section of uniform depth should be calculated using the equation given in the section 40.1 of IS: 456-2000.
b) Nominal shear stress (τ_v) in a rectangular section of varying depth should be calculated using the equation given in the section 40.1.1 of IS: 456-2000.
c) The design shear strength (τ_c) of concrete in rectangular concrete section without shear reinforcement should be taken form table no. 19 of IS: 456-2000.
d) When τ_v exceeds τ_c shear reinforcement should be provided as per section 40.4 of IS: 456-2000.
e) When τ_v is less than τ_c given in Table no. 19 of IS: 456-2000, minimum shear reinforcement shall be provided in accordance with section 26.5.1.6 of IS: 456-2000.
f) Under no circumstances, even with shear reinforcement, nominal shear stress (τ_v) in beam shall exceed $\tau_{c\,max}$ given in table no. 20 of IS: 456-2000.

(ii) Shear strength of members under axial compression

a) For members subjected to axial compression P_u, the design shear strength of section shall be as per section 40.2.2 of IS: 456-2000.

Note: Characteristic strength of the stirrup reinforcement shall not be taken greater than 415 N/mm².

4.11.5.4 Torsion

Design of torsion for reinforced concrete member shall be in accordance with section 41 of IS 456.

4.11.6 Limit state of serviceability

Reference may be taken from section 35.3 of IS: 456-2000.

4.11.6.1 Deflection

a) Deflection limit of a flexural member may be calculated as per the section 23.2 of IS: 456-2000. Refer clause 24.1 of IS 456-2000.
b) Deflection of a flexural member may be calculated as per the Annex C of IS: 456-2000.

Also, refer section 42 of IS: 456-2000.

4.11.6.2 Cracking

a) General design consideration for cracking in concrete structure shall be as described in section 35.3.2 of IS: 456-2000.

4.11.6.2.1 Flexural member

a) Limiting value of crack in flexural member shall be as per section 35.3.2 of IS: 456-2000.
b) Width of the crack flexural member shall be calculated using the formula given in annex F of IS: 456-2000.

Also, refer section 43.1 of IS: 456-2000.

4.11.6.2.2 Compression member

Cracks in compression member may be checked as per the conditions specified in section 43.2 of IS: 456-2000.

4.12 Design of beam

General design consideration should be as per section 23 of IS: 456-2000.

4.12.1 Limit state of collapse

a) Design of singly reinforced beam for flexure may be done as per section 4.11.5.1 (b).
b) Design of doubly reinforced beam flexure may be done as per section 4.11.5.1 (c).
c) Design of singly and doubly reinforced beam for shear may be done as per section 4.11.5.3.
d) Design of singly and double reinforced beam for torsion may be done as per section 4.11.5.4.

4.12.2 Limit state of serviceability

a) Deflection limit of singly and doubly reinforced beam should be as per section 4.11.6.1 (a)
b) Limiting value of crack for singly and doubly reinforced beam should be as per section 4.11.6.2.1.

4.13 Design of flanged beam

4.13.1 Limit state of collapse

Design of Flanged beam for flexure should be done as per section 4.11.5.1 (d)

Design of Flanged beam for shear should be done as per section 4.11.5.3

4.13.2 Limit state of serviceability

a) Deflection limit of flanged beam should be as per section 4.11.6.1 (a)
b) Limiting value of crack for flanged beam should be as per section 4.11.6.2.1.

4.14 Deep beams

Special design requirement for the design of deep beams should be referred from section 29 of IS: 456-2000.

4.15 Slab

General consideration for the design of solid slab should be referred from the section 24 of IS: 456-2000.

4.15.1 One-way slabs

Flexural and shear design for one-way slab may be done in the same manner as that of beam design given in section 4.11. A one-way slab continuous over supports shall be designed according to the provision applicable to continuous beams having width equal to one meter.

4.15.2 Two-way slabs, spanning in both directions

a) Simply supported two-way slab

In simply supported slab edges tends to lift off its support when load is applied.

$M_x = \alpha_x w l_x^2$

$M_y = \alpha_y w l_x^2$

α_x and α_y are bending moment coefficient for two-way simply supported slab given in table no. 27 of IS: 456-2000.

M_x and M_y are moments on strips of unit width spanning l_x and l_y respectively.

w in the total design UDL on slab.

l_x the length of shorter span and l_y is the length of longer span.

b) Restrained two-way slab

The maximum bending moments per unit width in a slab are given by the following equations:

$M_x = \alpha_x \, w \, l_x^2$

$M_y = \alpha_y \, w \, l_x^2$

Where,

α_x and α_y Bending moment coefficient for two-way simply supported slab given in table no. 26 of IS: 456-2000.

M_x and M_y are moments on strips of unit width spanning l_x and l_y respectively

w in the total design UDL on slab.

l_x the length of shorter span and l_y is the length of longer span.

4.15.3 Design of slab

4.15.3.1 Limit state of collapse

a) Design of two-way slab for flexure may be done as per section 4.11.5.1 (b)
b) Design of two-way slab for shear may be done as per section 4.11.5.3

4.15.3.2 Limit state of serviceability

a) Deflection limit of two-way slab should be as per section 4.11.6.1 (a)
b) Limiting value of crack for two-way slab should be as per section 4.11.6.2.1.

4.16 Design of column

General consideration for the design of the compression members may be referred from the section 25 of IS: 456-2000.

Also refer "SP: 16 design aids for reinforced concrete to IS: 456-2000".

4.16.1 Limit state of collapse

Design of compression member shall be as per section 4.11.5.2

Compression member may be check for shear as per section 4.11.5.3 (ii)

4.16.2 Limit state of serviceability

Cracks due to bending in compression member shall be checked from section 4.11.6.2.2

4.17 Stairs

General design requirement for design of RCC stairs shall be in accordance with the section 33 of IS: 456-2000.

4.18 RCC wall

RCC wall in powerhouse are provided for different purpose. It may be provided for partition of rooms, cable shaft/gallery, elevator shaft, special shear wall, as basement wall in semi surface PH and as vault wall in underground PH.

4.18.1 Special shear wall

Design of special shear wall to take lateral load due to earthquake should be in accordance with the section 10 of IS: 13920-2016.

4.18.2 Basement/substructure wall

In semi surface PH Valve floor, Turbine floor and generator floor are located below ground level hence it is necessary to protect the floors by provision of RCC wall. Functions of substructure wall are;

a) To protect the percolation of ground water inside the powerhouse substructure.
b) To take the lateral load due to backfill, water table and surcharge.
c) Substructure wall may also be used to bear the load from super structure, floor loads of sub structure and transfer safely to foundation.

Design of wall may be carried out either by limit state method or working stress method. Basement walls should be checked for;

a) flexural strength, as described in section 4.11.5.1

b) axial compressive strength, as described in section 4.11.5.2

c) shear strength, as described in section 4.11.5.3

Furthermore, the Basement walls in semi surface PH are subjected to both vertical and horizontal wall hence recommended to check design as per section 32 of IS: 456-2000 also.

4.19 Foundation

a) Refer IS: 6403 for bearing capacity of soil of shallow foundation.
b) Method of sub surface investigation for foundation should be in accordance with IS: 1892-1979.
c) Refer IS: 1888-1982 for methods of load test on soils.
d) Refer IS: 1904 for general requirement for design and construction of footing in soil.
e) Refer IS: 2911 for design and construction of pile foundation.

4.19.1 Design of Isolated footing

Basis for the structural design of the isolated footing may be in accordance with the section 34 of IS: 456-2000.

4.19.1.1 Limit state of collapse

a) Bending moment at any section of footing shall be calculated as per the section 34.2.3.1 of IS: 456-2000.
b) Design of footing for flexure may be done as per section 4.11.5.1 (b).

4.19.1.2 Design for shear

The shear strength of footing is governed by the more sever conditions of 4.19.1.2 (a) and 4.19.1.2 (b).

a) Design for shear strength of footing in one-way action shall be checked as per the section 4.11.5.3. Critical section in one-way shear is considered at a distance equal to effective depth (d) of the footing from the face of column/pedestal in accordance with section 34.2.4.1 (a) of IS: 456-2000.

b) Two-way action of the footing shall be checked as per the section 31.6 & section 34.2.4.1 (b) of IS: 456-2000. Critical section for two-way shear is considered at a distance equal to half the effective depth of footing from the periphery of column/ pedestal.

Permissible shear stress in footing of a foundation shall be checked as per the section 31.6.3 of IS 456.

4.19.2 Raft Foundation

Reference should be taken form IS: 2950 for design and construction of raft foundation.

4.19.3 Pile Foundation

Reference should be taken form IS: 2911 for design and construction of pile foundation.

4.20 Generator Foundation

4.20.1 Rotating machinery

Unbalanced forces in rotating machines are created when the mass centroid of the rotating part does not coincide with the center of rotation. This dynamic force is a function of the shaft mass, speed of rotation and the eccentricity. The eccentricity should be minor under manufactured condition when the machine is well balanced, clean, and without wear or erosion. Changes in alignment, operation near resonance, blade loss, and other malfunctions or undesirable conditions can greatly increase the force applied to its bearings by the rotor.

Hydro turbines and generator falls under the rotating type of rotating machinery

4.20.2 Type of generator/turbine foundation

a) Block foundation

Block foundation is commonly used in horizontal axis Pelton and Francis turbine. Reference can be taken form section 4.20.9.

b) Barrel foundation

Barrel type of support is used in vertical axis turbine. Barrel support may either be constructed in circular or polygonal shape.

Reference can be taken form section 4.2 (a) and 4.2 (b) of IS: 7207-1992. For more information, reference can be taken from chapter ‘29’ of ‘Hand Book of Hydro Electric Engineering’ by P.S. Nigam

c) Framed foundation

For more information, reference can be taken from chapter ‘29’ of ‘Hand Book of Hydro Electric Engineering’ by P.S. Nigam

4.20.3 Machine data

a) Loading diagram of the machine showing magnitude and direction of all loads, including dynamic load
b) Speed of the machine
c) Outline dimension of the foundation

d) Mass moment of inertia of the machine components

4.20.4 Geotechnical data

4.20.4.1 Allowable bearing pressure

Reference can be taken from IS: 6403 for bearing capacity of soil of shallow foundation.

4.20.4.2 Dynamic properties of soil

Dynamic properties of foundation soil like Poisson's ratio (ν) and shear modulus (G) should be known in advance to calculate the stiffness (k) of foundation soil. Correlation of different soil parameters required for dynamic analysis of machine foundation has been given under section 4.20.9.

Different parameters required for dynamic analysis of Machine/Generator foundation can be identified by soil test in accordance with IS: 5249-1992.

a) Poisson's ratio (ν)

Poisson's ratio is used to calculate the soil stiffness and damping of foundation soil. It's varies from 0.25 to 0.35 for cohesionless soil and 0.35 to 0.45 for cohesive soil. In absence of specific data designer may take Poisson's ration as 0.33 for cohesionless soil and 0.40 for cohesive soil for feasibility stage design. However, for final design Poisson's ratio should be identified specific to the site.

b) Dynamic shear modulus (G)

Dynamic shear modulus is a soil parameter influencing the dynamic behavior of the soil-foundation system.

c) Damping of soil (ζ)

Damping is a phenomenon of energy dissipation that opposes the free vibration of a system.

4.20.5 Loads on machine foundation

4.20.5.1 Dead load (DL)

Dead load includes the self-wt. of the foundation, machine and auxiliaries

4.20.5.2 Operating load (OL)

Operation load supplied by the machine manufacturer includes friction force, power torque, thermal elongation forces and piping forces

The normal torque (NT) (drive torque) applied to the foundation as a static couple in the vertical direction acting about the c. of the shaft of the generator. The magnitude of the normal torque calculated by the following formula as given in section 3.2.1.5 of ACI: 351.3R-2004.

$$NT = 9950 \frac{P_s}{f}$$

Where,

NT = normal torque, N-m;

P_s = power being transmitted by the shaft at the connection, kilowatts; and

f = operating speed, rpm.

4.20.5.3 Dynamic load of machine

Dynamic load in the generator occur during the operation of the machine; result either from the forces generated by unbalance or inertia of moving parts, or both. The magnitude of these dynamic loads primarily depends upon the machine's operating speed, the type size, weight and arrangement (position) of moving parts within the casing.

4.20.5.3.1 Normal machine unbalance load (NUL)

$$F_o = \frac{m e_m \omega^2 \sin\omega t}{1000}$$

$$F_o = \frac{m Q \omega \sin\omega t}{1000}$$

$$Q = e_m \omega$$

Where,
F_o = dynamic force amplitude (zero-to-peak), N;
m = rotating mass, kg;
e_m = mass eccentricity, mm;
ω = circular operating frequency of the machine (rad/s);
Q = balance quality grade in mm/s. Refer table no. 4-2

Table 4- 2 Balance quality guide for different rotor types

Balance Quality Guide	Product of e.ω, mm/s	Rotor types- general examples
G1600	63(1600)	Crankshaft/drives of rigidly mounted, large, two-cycle engines
G630	2.5 (630)	Crankshaft/drives of rigidly mounted, large, four-cycle engines
G250	10 (250)	Crankshaft/drives of rigidly mounted, fast, four-cylinder diesel engines
G100	4 (100)	Crankshaft/drives of fast diesel engines with six or more cylinders
G40	1.6 (40)	Crankshaft/drives of elastically mounted, fast four-cycle engines (gasoline or diesel) with six or more cylinders
G16	0.6 (16)	Parts of crushing machines; drive shaft (propeller shafts, cardan shafts) with special requirements; crank shaft/ drivers of engines with six or more cylinders under special requirements
G6.3	0.25 (6.3)	Parts of process plant machines; centrifuge drums, paper machinery rolls, print rolls; fans; flywheel; pump impellers; machine tool and general machinery parts; medium and large

Balance Quality Guide	Product of e.ω, mm/s	Rotor types- general examples
		electric armatures (of electric motors having at least 80 mm shaft height) without special requirement
G2.5	0.1 (2.5)	Gas and steam turbines, including marine main turbines; rigid turbo-generator rotors; turbo- compressors; machine tool drives; medium and large electric armatures with special requirements; turbine driven pumps
G1	0.04 (1)	Grinding machine drives
G0.4	0.015 (0.4)	Spindles, discs, and armatures of precision grinders

References

Section 3.2.2.1b & 3.2.2.1c of ACI: 351.3R-2004
Annex B of IS: 2947-2992 (Part 3)
Annex 'C' of IS: 5249-1992

4.20.5.3.2 Load at emergency condition

a) **Loss of blade unbalance (LBL) or bearing failure load (BFL)**
b) **Short circuit forces (SCF)**

The short-circuit moment (torque) affects the foundation via the generator or motor casing in the form of opposite pairs of vertical forces, the moment vector being parallel to the shaft axis. The resulting displacements and loads can be calculated as a function of the excitation/time relationship or by using the equivalent-load method. If the machine manufacturer has not specified the short-circuit moment, M(t), as a function of time, analysis may be based on the following equation for three-phase machines:

$$M(t) = Ae^{-t/0.4}\sin\omega t - Be^{-t/0.4}\sin 2\omega t - Ce^{-t/0.4}$$

Where,
ω = angular frequency of the mains
A, B, C = coefficients specific to generator design
The following function is generally supplied by machine manufacturer. In absence of the vendor supplied data, the following information may be used to find value of M(t).
A = 10 times normal power torque
B = 5 times normal power torque
C = normal power torque
Sometimes only the equivalent static force is provided which makes the design of foundation highly rigid which increase the foundation cost. It is recommended to perform the dynamic analysis of the foundation.
References:
DIN 4024 (Part 1)

Annex B of IS: 2947-2992 (Part 3)

4.20.5.4 Temperature load in foundation (TLF)

a) Uniform temperature change
b) Temperature gradient

4.20.5.5 Seismic load (EQF)

Acceleration coefficient for seismic design of foundation may be taken as explained in section 4.5.4.6.

4.20.6 Load combinations for design of Generator foundation.

a) Operating condition

DL+OL+NUL+TLF

b) Short circuit condition

DL+OL+NUL+TLF+SCF

c) Loss of blade condition/ Bearing failure condition

DL + OL + TLF + LBL/BFL

d) Seismic condition

DL+OL+NUL+TLF

4.20.7 Limitation of vibration

Reference: ACI: 351.3R-2004

4.20.7.1 Machine limits

The vibration limits applicable to the machine are normally set by the equipment manufacturer or are specified by the equipment owner. The limits are usually predicated on either limiting damage to the equipment or ensuring proper performance of the equipment.

For rotating equipment (fans, pumps, and turbines), the normal criterion limits vibration displacements or velocities at the bearings of the rotating shaft. Excessive vibrations of the bearings increase maintenance requirements and lead to premature failure of the bearings. Often, rotating equipment has vibration switches to stop the equipment if vibrations become excessive.

ISO 10816-1 identifies four areas of interest with respect to the magnitude of vibration measured:

Zone A: vibration typical of new equipment;

Zone B: vibration normally considered acceptable for long-term operation;

Zone C: vibration normally considered unsatisfactory for long-term operation; and

Zone D: vibration normally considered severe enough to damage the machine

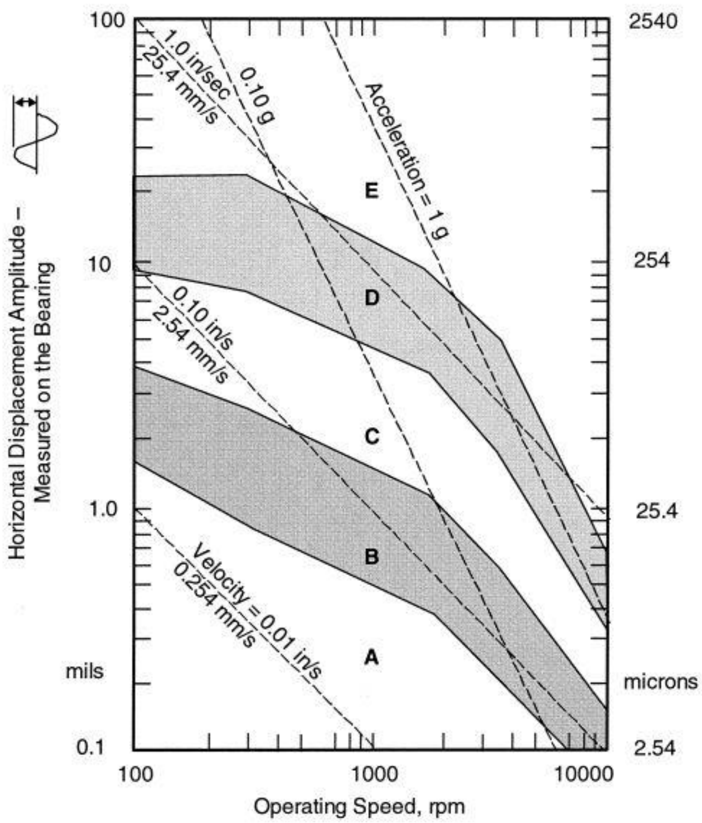


Figure 4.20- 1 Vibration criteria for rotating machinery (Blake 1964, as modified by Arya, O'Nill, and Pincus 1979)

A: No faults, Typical new equipment

B: Minor faults, Correction wastes dollars

C: Faulty, correct within 10 days to save maintenance dollars

D: Failure is near, Correct within two days to avoid breakdown

E: Dangerous, shut it down to avoid danger

4.20.7.2 Physiological limits

The modified Reiher-Meister figure (barely perceptible, noticeable, and troublesome) is also used to establish limits with respect to personnel sensitivity, as shown in figure 4.20-2.

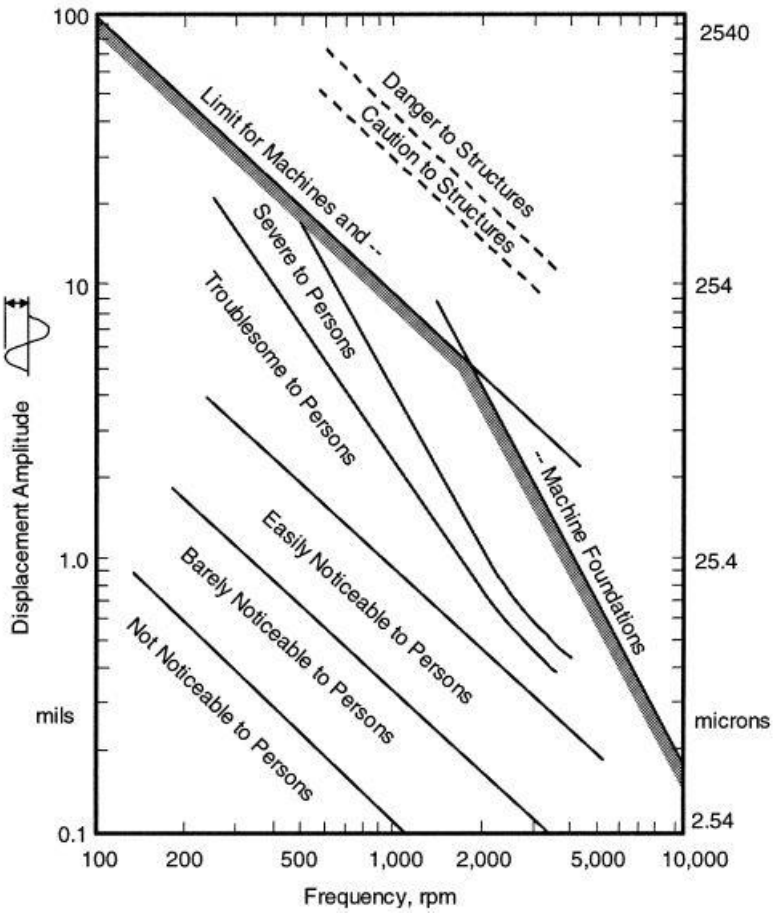


Figure 4.20- 2 Reiher-Meister Chart (Richart, Hall and Woods 1970)

Reference: ACI: 351.3R-2004

4.20.8 Preliminary dimensioning of Generator foundation

1. A block-type foundation resting on soil should have a mass minimum 2 to 3 times the mass of the supported machine for centrifugal machines.
2. The top of the block is usually kept at 30cm above the finished floor or pavement elevation to prevent damage form surface water runoff.
3. The vertical thickness of the block should not be less than 60cm, or as dictated by the length of anchor bolts used. The vertical thickness may also be governed by the other dimensions of the block in order that the foundation is to be considered rigid. The thickness is seldom less than one fifth the least dimension or 1/10 of the largest dimension.
4. The foundation should be wide to increase damping in the rocking mode. The width should be at least 1 to 15 times the vertical distance from the base to the machine centerline.
5. The length L is determined according to (1), provided that sufficient plan area is available to support the machine plus 30cm clearance from the edge of the machine base to the edge of the block for maintenance purpose. The length L and width B of the foundation are adjusted so that the center of gravity of the machine coincides with the center of gravity of the foundation. The combined center of gravity should coincide

with the center of resistance provided by the soil. The eccentricity of the foundation system along x-x and y-y shall not exceed 5 percent of the length of the corresponding side of the contact area. In addition, center of gravity of machine and foundation shall be if possible below the top of the foundation block.

4.20.9 Analysis of Block Type Machine Foundation using Mass Spring Dashpot method

Block foundation are commonly used in surface powerhouse with horizontal axis turbines.

Block foundation should be analyzed for six modes of vibration (Fig. 4.20-3).

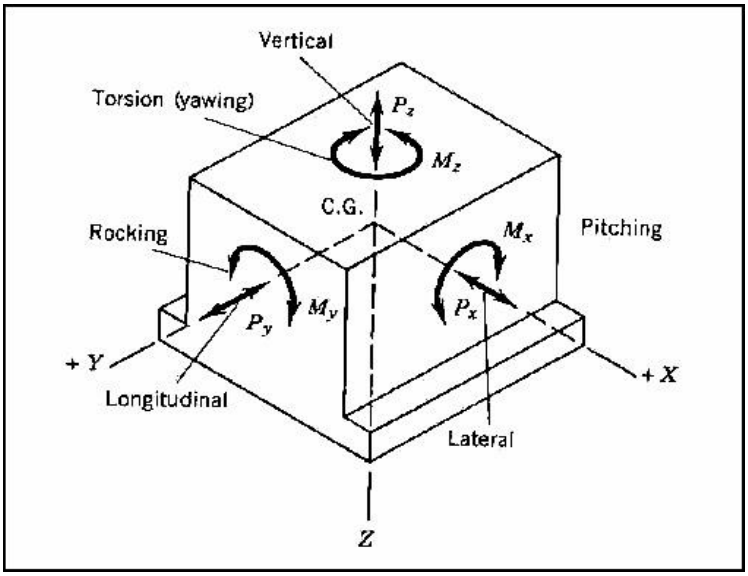


Figure 4.20- 3 Block foundation showing six-modes different of vibration

Vertical mode of vibration

Equivalent radius of the circular base for given rectangular foundation,

$$r_z = \sqrt{\frac{A}{\pi}}$$

Soil spring constant,

$$K_z = \frac{4 * G * r_z}{1 - \nu}$$

Natural frequency of the foundation system,

$$\omega_{nz} = \sqrt{\frac{K_z}{m}}$$

Frequency ratio,

$$\beta_z = \frac{\omega}{\omega_{nz}}$$

Where,

A = area of the rectangular base of foundation

G = dynamic shear modulus of soil

ν = Poisson's ratio of soil

ω = angular frequency of the machine

M = mass of foundation + machine

i. Constant force type of excitation

a) At operating frequency

Amplitude of vertical displacement at operating frequency,

$$A_{z\,o} = \frac{\frac{P_z}{K_z}}{\sqrt{[1-\beta_z{}^2)]^2+[2\zeta\beta_z]^2}}$$

b) At Resonance condition

Amplitude of vertical displacement at resonance,

$$A_{z\,r} = \frac{P_z}{K_z} * \frac{1}{2\zeta\sqrt{1-\zeta_z{}^2}}$$

and

$$DMF = \frac{1}{2\zeta\sqrt{1-\zeta_z{}^2}}$$ = Dynamic Displacement / Static Displacement

where,

P_z = amplitude of vertical external force

ζ = damping coefficient

DMF = Dynamic magnification factor

ii. Rotating mass type of excitation

i. At operating frequency

Amplitude of vertical displacement at operating frequency,

$$A_{z\,o} = \frac{\frac{M_e * e}{m}(\beta_z)^2}{\sqrt{[1-(\beta_z)^2]^2+[2\zeta\beta_z]^2}}$$

ii. At resonance Condition

Amplitude of vertical displacement at resonance,

$$A_{z\,r} = \frac{(\frac{M_e * e}{m})}{2\zeta\sqrt{1-\zeta^2}}$$

where

M_e = unbalanced eccentric mass

e = eccentricity

Sliding Mode of Vibration

Equivalent radius of the circular base for given rectangular foundation,

$r_x = = \sqrt{\frac{A}{\pi}}$

Soil spring constant,

$k_x = \frac{32(1-\nu)}{7-8\nu} * h * r_x$

Natural frequency of the foundation system,

$\omega_{nx} = \sqrt{\frac{K_x}{m}}$

Frequency ratio,

$\beta_x = \frac{\omega}{\omega_{nx}}$

Where,

H = height of foundation

i. Constant force type excitation

a) At operating frequency

Amplitude of horizontal displacement at operating frequency,

$$A_{x\,o} = \frac{\frac{P_x}{k_x}}{\sqrt{\left[1-\beta_x{}^2\right]^2 + [2\zeta\beta_x]^2}}$$

where,

P_x = amplitude of externally applied horizontal force in x direciton

b) At resonance condition

Amplitude of horizontal displacement at resonance,

$$A_{x\,r} = \frac{\frac{P_x}{k_x}}{2\zeta\sqrt{1-\zeta^2}}$$

ii. Rotating mass type of excitation

a) At operating frequency

Amplitude of horizontal displacement at operating frequency,

$$A_{x\,o} = \frac{\frac{M_e * e}{m}(\beta_x)^2}{\sqrt{\left[1-\beta_x{}^2\right]^2 + [2\zeta\beta_x]^2}}$$

b) At resonance condition

Amplitude of horizontal displacement at resonance,

$$Ax_r = \frac{\left(\frac{M_{e*e}}{m}\right)}{2\zeta\sqrt{1-\zeta^2}}$$

Where,

Rocking mode of Vibration

Equivalent radius of the circular base for given rectangular foundation,

$$r_\psi = 4\sqrt{\frac{16ab^3}{3\pi}}$$

Soil spring constant,

$$k_\psi = \frac{8Gr_\psi{}^3}{3(1-\nu)}$$

Mass moment of inertia of foundation block about y axis,

$$M_{m\psi} = \pi r_\psi{}^2 h \frac{\gamma}{g}\left(\frac{r_\psi{}^2}{4} + \frac{h^2}{3}\right)$$

Natural frequency of the foundation system,

$$\omega_{n\Psi} = \sqrt{\frac{k_\psi}{M_{m\psi}}}$$

Frequency ratio,

$$\beta_\Psi = \frac{w}{w_{n\Psi}}$$

i. Constant force type excitation

a) At operating frequency

Amplitude of angular displacement about y axis at operating frequency,

$$A_{\Psi o} = \frac{\frac{M_\psi}{k_\psi}}{\sqrt{[1-\beta^2]^2+[2\zeta\beta]^2}}$$

b) At resonance Condition

Amplitude of angular displacement about y axis at resonance,

$$A_{\Psi r} = \frac{\frac{M_\psi}{k_\psi}}{2\zeta\sqrt{1-\zeta^2}}$$

Where,

M_ψ = externally acting dynamic moment about y axis

ii. Rotating mass type excitation

a) At operating frequency

Amplitude of angular displacement about y axis at operating frequency,

$$A_{\Psi o} = \frac{\frac{M_e*e*z}{M_{m\psi}}\beta_\psi{}^2}{\sqrt{\left[(1-\beta_\psi{}^2\right]^2+(2\zeta\beta_\psi)^2}}$$

a) At resonance Condition

Amplitude of angular displacement about y axis at resonance,

$$A_{\Psi r} = \frac{\frac{M_e*e*z}{M_{m\psi}}}{2\zeta\sqrt{1-\zeta^2}}$$

Where,

M_e = Unbalanced mass rotating about y axis

e = eccentricity of unbalanced mass

z = h/2 (in standard practice h is taken half of height of foundation)

Torsional / Yawing Mode of Vibration

Equivalent radius of the circular base for given rectangular foundation,

$$r_\phi = \sqrt[4]{\frac{16ab(a^2+b^2)}{6\pi}}$$

Soil spring constant,

$$K_\phi = \frac{16}{3} * G * r_\phi{}^3$$

Mass moment of inertia of foundation block about z-axis,

$$M_{m\phi} = \frac{1}{2}\pi * r_\phi{}^4 * h * \frac{\gamma_c}{g}$$

Natural frequency of the foundation system,

$$\omega_{n\phi} = \sqrt{\frac{k_\phi}{M_\phi}}$$

Frequency ratio,

$$\beta_\phi = \frac{w}{w_{n\phi}}$$

i. Constant force type excitation

a) At operating condition

Amplitude of Angular displacement about z axis at operating frequency,

$$A_\theta = \frac{\frac{T_\phi}{k_\phi}}{\sqrt{[1-\beta^2]^2+[2n\beta]^2}}$$

b) At resonance condition

Amplitude of angular displacement about z axis at resonance,

$$A_\theta = \frac{\frac{T_\phi}{k_\phi}}{2\zeta\sqrt{1-\zeta^2}}$$

4.20.10Final design of foundation block

The final dimensioning of block foundation shall include the static and dynamic analysis of the foundation system and shall consider

a) Dimensioning of foundation by empirical rules
b) The bearing pressure due to dead load and imposed load
c) The natural frequency of the foundation system for the six modes of vibration
d) The relation between the exciting frequency and the natural frequency of the system
e) Amplitude shall be calculated for six modes of vibration
f) Influence of water shall also be considered

4.21 Detailing of reinforcement

a) Format of structural drawing may be in accordance with the section 3 of SP 34.
b) General requirement of reinforcement detailing may be as specified in section 4 of SP 34.
c) Bending of reinforcement bar may be in accordance with the section 5 of SP 34.
d) Detailing of reinforcement bar for foundation may be as specified in section 6 of SP 34.
e) Detailing of reinforcement bar for column may be as specified in section 7 of SP 34.
f) Detailing of reinforcement bar for beam may be as specified in section 8 of SP 34.
g) Detailing of reinforcement bar for floor slab may be as specified in section 9 of SP 34.
h) Detailing of reinforcement bar for stairs may be as specified in section 10 of SP 34.
i) Detailing of reinforcement bar for deep beam may be as specified section 11.1 of section 11 of SP 34.
j) Detailing of reinforcement bar for RCC wall may be as specified section 11.2 of section 11 of SP 34.
k) Detailing of reinforcement bar for RCC cantilever retaining wall may be as specified section 11.3 of section 11 of SP 34.
l) Detailing of reinforcement bar for machine foundation may be as specified section 11.8 of section 11 of SP 34.
m) For welding in mild steel reinforcement bars reference may be taken IS: 2751-1979 or Appendix ‘A’ of SP 34
n) Detailing of reinforcement for concrete corbels may be as specified in section 7.7 of SP 34.
o) Ductile detailing of reinforcement of different components of RCC building for earthquake resistance construction, may be as recommended in IS: 13920-2016.

4.21.1 Development length

a) Development length of reinforcement may be as given in section 26.2.1 of IS: 456-2000.
b) Design bond stress in limit state method for plain bars shall be as given in section 26.2.1.1 of IS: 456-2000.

4.21.2 Anchoring of reinforcement

Anchoring of the reinforcement may be as given in section 26.2.2 of IS 456-2000.

4.21.2.1 Anchoring in tension

a) Anchoring of deformed bars without end anchorage
b) Anchoring of bars with bend and hooks

Bend and hooks of reinforcement bars shall conform to IS: 2502.

4.21.2.2 Anchoring in compression

Anchoring reinforcement in compression shall be as per section 26.2.2.2 of IS: 456-2000.

4.21.2.3 Anchoring shear reinforcement

Anchoring of shear reinforcement and stirrups shall be as per section 26.2.2.6 of IS: 456-2000.

4.21.2.4 Bearing stress at bends

Bearing stress at bends of reinforcement shall be as per the section 26.2.2.5 of IS: 456-2000.

4.21.3 Nominal cover to reinforcement

a) Nominal cover to reinforcement shall be in accordance with the section 26.4 of IS: 456-2000.
b) Nominal cover to meet durability requirement may be as given in table no. 16 of IS: 456-2000.
c) Nominal cover to meet specified period of fire resistance may be as given in table no. 16A of IS: 456-2000.

4.21.4 Curtailment of tension reinforcement in flexural members

Curtailment of tension reinforcement may be as given in section 26.2.3 of IS: 456-2000.

4.21.5 Splicing of reinforcement

a) Only lap splicing and mechanical splicing (splicing by coupler) of reinforcement shall be permitted in construction of powerhouse structure. End bearing splicing and weld splicing shall not be permitted in structural member of powerhouse.
b) Requirement of lap types of splicing of reinforcement shall be as specified in section 26.2.5 of IS: 456-2000.
c) Specification of mechanical splicing (coupler) shall conform to IS: 16172-2014.

4.21.6 Spacing of reinforcement

Spacing of reinforcement bars may be as recommended in section 26.3 of IS: 2000.

4.22 Requirement of reinforcement for structural members

4.22.1 Beam

a) Tension and compression reinforcement

a) Minimum and maximum area of tension reinforcement shall be as per section 26.5.1.1 of IS 456-2000.
b) Maximum area of compression shall be as per section 26.5.1.2 of IS 456-2000.

b) Side face reinforcement

Side face reinforcement shall be provided as per section 26.5.1.3 of IS: 456-2000.

c) Transverse reinforcement

Transverse reinforcement in beam shall be provided in the form of shear and torsion reinforcement as said in section 26.5.1.4. of IS: 456-2000.

d) Shear reinforcement

a) Maximum spacing of shear reinforcement shall be as specified in section 26.5.1.5 of IS: 456-2000.
b) Minimum shear reinforcement shall be as per the section 26.5.1.6 of IS: 456-2000.

e) Torsion reinforcement

Distribution of torsion reinforcement as per section 26.5.1.7 of IS: 456-2000.

4.22.2 Slabs

Minimum area of reinforcement in slabs shall be as per section 26.5.2.1 of IS: 456-2000.

Maximum diameter of reinforcement in slab shall be as per section 26.5.2.2 of IS: 456-2000.

4.22.3 Columns

a) Longitudinal reinforcement

Provision of longitudinal reinforcement is column shall be in accordance with the section 26.5.3.1 of IS: 456-2000.

b) Transverse reinforcement

Transverse reinforcement is column shall be provided as guided in section 26.5.3.2 of IS: 456-2000.

4.22.4 Assembly of reinforcement

Assembly of reinforcement may be as specified in the section 12 of IS: 456-2000.

4.23 Joints in powerhouse

a) Location and design of joints in surface powerhouse may be as recommended in IS: 4461-1998
b) Common types of joints provided in building may be as recommended in IS: 3411-1968.
c) Special type of joints which are provided in the substructure to protect the percolation of water inside powerhouse and can take the water pressure also, may be as recommended in the IS: 3370-2009 (Part 1).
d) Refer section 27 of IS 456 for general deign consideration for provision of joints in building.

4.24 Instrumentation

4.24.1 Measurement of settlement and tilt of structure

Settlement and tilt of the structure may be checked by periodic survey of different points of the structure. If high accuracy of tilt measurement is required, special tilt measuring instruments should be installed. Different types of instruments to measure tilt of a structure are described in section 9 of section 4 of EM: 1110-2-4300.

4.24.2 Verification of position of structure

Position of powerhouse may be checked and verified at required interval of time. Verification of the position may be done either by using Total Station or Theodolite survey.

4.24.3 Measurement of machine vibration

Practice of installation, maintenance and observation of the vibration studies instruments may be as recommended in IS: 14793-2000.

4.25 Corbels

This section has been extracted from 'Design of RCC structure' by A.K. Jain.

4.25.1 Introduction

A corbel is a short cantilever projection which supports a load bearing member. The distance between the point of application of the load and the face or root of the corbel is less than the effective depth of the root of the corbel. Moreover, depth at the outer edge of the corbel is not less than one-half of the depth at the support of the corbel as shown in Fig. 4.25-1.

The ratio of the distance of the point of application of load from the support 'a' to the effective depth of the member supporting the load 'd' is referred to as the a/d ratio or shear span/depth ratio. When the ratio a/d is less than 2, the load is transferred to the support through strut action rather than through flexure. This is similar to the truss action in simple beam near the support.

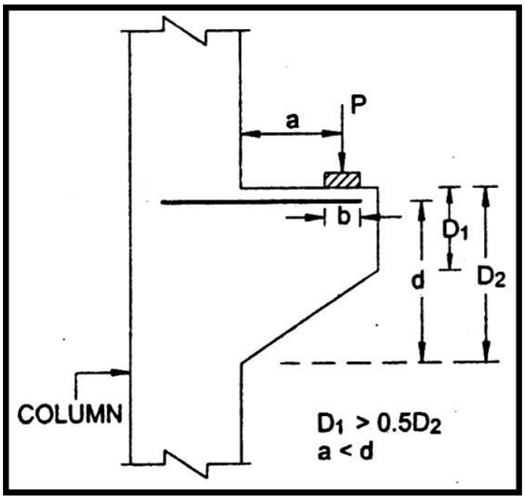


Figure 4.25- 1 Corbel or Bracket

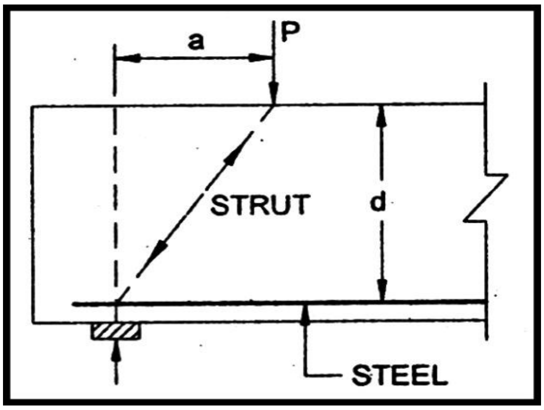


Figure 4.25- 2 Load near support

4.25.2 Assumptions

a) A corbel is designed for the limit state of collapse.
b) The concrete and reinforcement in the corbel are designed on the basis of the analogy, that is, simple strut and tie system.
c) The resistance provided to the horizontal force should be greater than one-half the design vertical load on the corbel.
d) The compatibility of strains between the strut and tie should be satisfied as root of the corbel.

4.25.3 Truss Analogy

Lever arm of the stress block in a corbel can be determined using the truss analogy shown in Fig. 4.25-3. By triangle of forces, using Lame's theorem

$$\frac{P}{\sin(\pi-\theta)} = \frac{F_r}{\sin(90°+\theta)} = \frac{F_c}{\sin 90°} \quad \ldots\ldots (4.129)$$

$$\frac{P}{\sin\theta} = \frac{F_r}{\cos\theta} = F_c \quad \ldots\ldots (4.130)$$

Tension force FT = P cot θ = $P\frac{a}{z}$ …… (4.131)

Compression force Fc = P cosec θ = $\frac{\sqrt{a^2+z^2}}{z} P$ …… (4.132)

Lever arm z = d-0.42x or x= 2.38 (d-z)

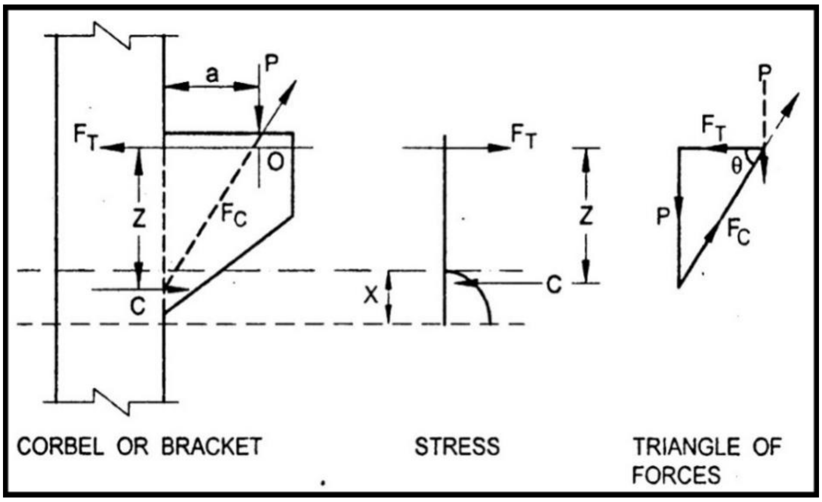


Figure 4.25- 3 Truss analogy in corbel

The force of compression in concrete is also given by

$$Fc = 0.36\ \sigma_{ck}\ b\ (x\text{-}\cos\theta)$$

$$Fc = 0.36\ \sigma_{ck} b2.38\ (d\text{-}z)\ \frac{a}{\sqrt{a^2+z^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (4.133)$$

$$0.86\ \sigma_{ck}\ bd\ (1\text{-}\ \frac{z}{d})\ \frac{a}{\sqrt{a^2+z^2}} = \frac{\sqrt{a^2+z^2}}{z} P$$

$$0.86\ \sigma_{ck}\ bd\ (1\text{-}\ \frac{z}{d})az = (a^2+z^2)\ P \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (4.134)$$

Let,

$$\frac{P}{0.86\ \sigma_{ck} bd} = \alpha \text{ and } \frac{a}{d} = \beta$$

$$\alpha(a^2+z^2) = (1\text{-}\ \frac{z}{d})az$$

$$\alpha(\frac{a^2}{d^2} + \frac{z^2}{d^2}) = (1\text{-}\ \frac{z}{d})\ \frac{a}{d}\frac{z}{d}$$

$$\frac{z^2}{d^2} - \left(\frac{\beta}{\alpha+\beta}\right)\frac{z}{d} + (\frac{\alpha}{\alpha+\beta})\beta2 = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (4.135)$$

For given values of α and β, the values of z/d can be calculated.

4.25.4 Detailing of Reinforcement of Corbel

a) The main tension reinforcement should not be less than 0.4% of the cross-section area at the face of the supporting member.

b) The maximum tension reinforcement should not exceed 1.3% of the cross-section area at the face of the supporting member.

c) The tension reinforcement should be anchored at the front face of the corbel either by welding it to a traverse bar of equal strength (Fig. 4.25-4) or, by bending bars to form loops. In any case, the bearing area of the load should not project beyond the straight portion of the bars forming the main tension reinforcement.

d) When the corbel is required to resist a horizontal force applied to the bearing plate because of shrinkage and temperature changes, additional tension reinforcement should be provided to transmit this force in its entirety. This reinforcement should be welded to the bearing plate and adequately anchored.

e) Theoretically compression reinforcement is not required. However, where the main tension bars at the front face of the corbel are welded to a transverse bar, nominal compression steel to anchor the stirrups is provided.

f) Alternatively, all main tension bars are bent back to form loops to act as compression steel.

g) Shear reinforcement is provided in the form of horizontal stirrups distributed in upper two thirds of the effective depth of the corbel at the column face.

h) The area of shear reinforcement should be at least 50% of the area of the tension reinforcement and should be adequately anchored.

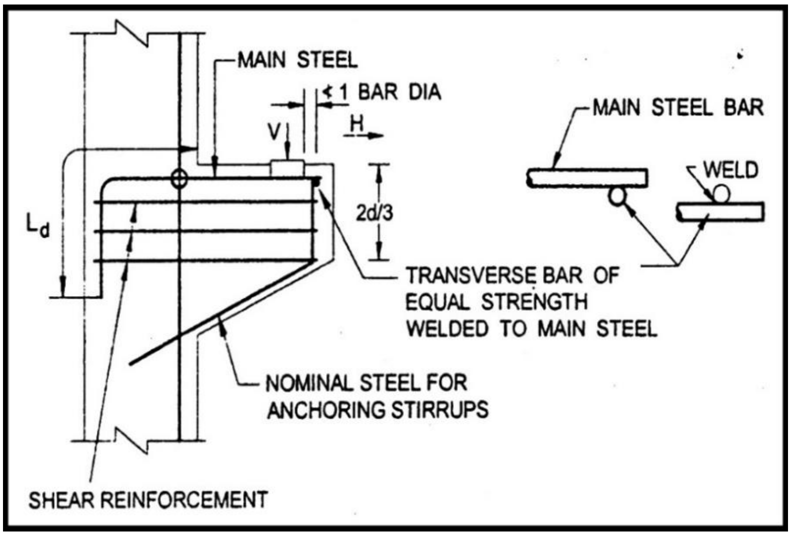


Figure 4.25- 4 Typical concrete barrel type of foundation

4.26 Architectural Requirement

The exterior design should utilize scale, proportion, rhythm and composition to achieve aesthetically pleasing structure which fits in with its natural surroundings. The exact size and location of openings should be determined from the standpoint of aesthetics after the structural, mechanical and functional requirements have been investigated. Selection of the final powerhouse design should be made after a careful study of at least three designs having basically different exterior treatment. Exterior details should include roofing, decks, walls, entrances, fenestration, draft tube deck, stairs and railings and skylights.

The Interior Design shall include Visitors' facilities, Control room facilities, generator room and auxiliary spaces along with personnel facilities. The designer should use their knowledge of equipment and materials to achieve simplicity and first-cost economy consistent with utility, safety, aesthetics, and low maintenance costs.

The architectural design of the powerhouse should be thoroughly discussed in a design memorandum. General and specific consideration that influenced the exterior design and type of construction should be provided by the architect considering the aesthetic view of powerhouse. The method of determining the amount of space allotted for public use and for offices should also be explained.

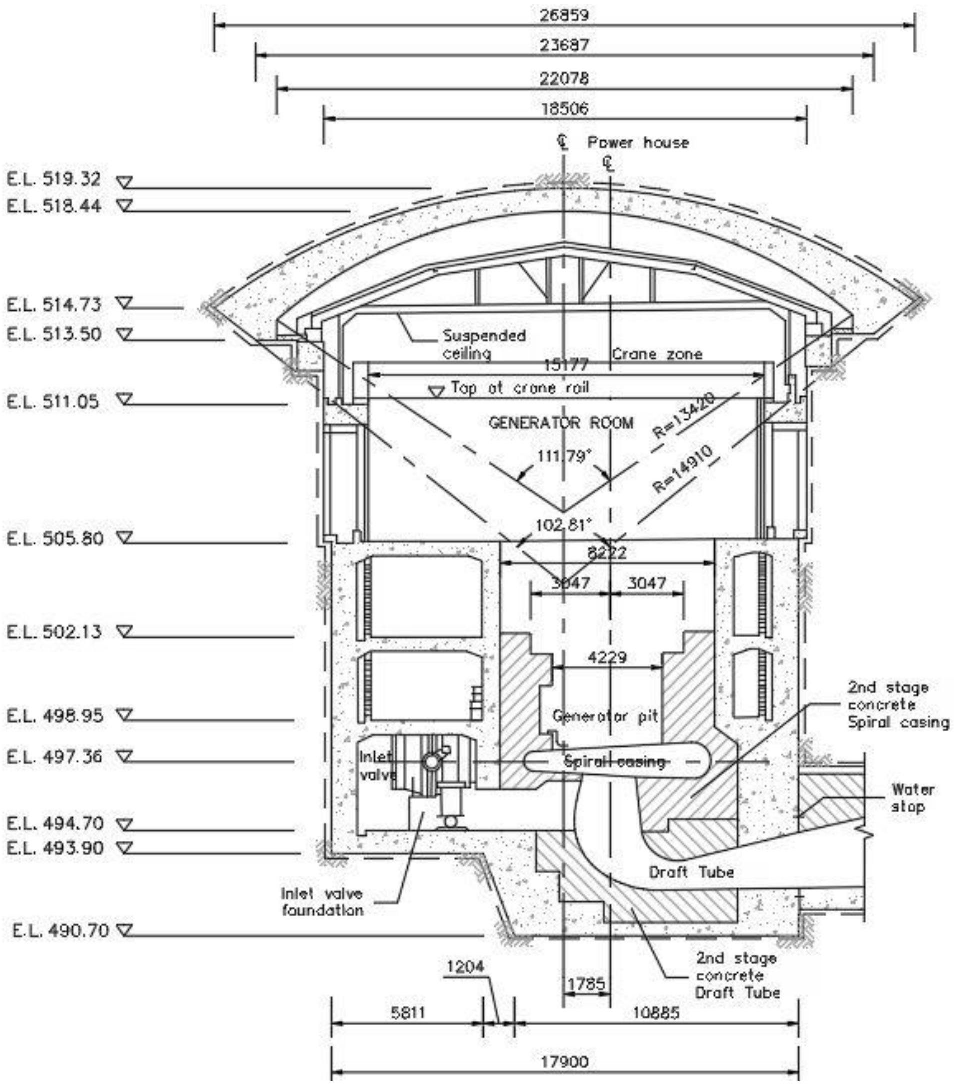
The detailed information regarding Architectural requirements can also be referred from Chapter 3 of EM 1110-2-3001, Planning and Design of Hydroelectric Power plant Structures by U.S. Army Corps of Engineers.

4.27 Underground powerhouse

4.27.1 Shape

The shape of the cavern is governed by the geology of the site. Three major shape of underground powerhouse cavern are given below (Table 4.27-1):

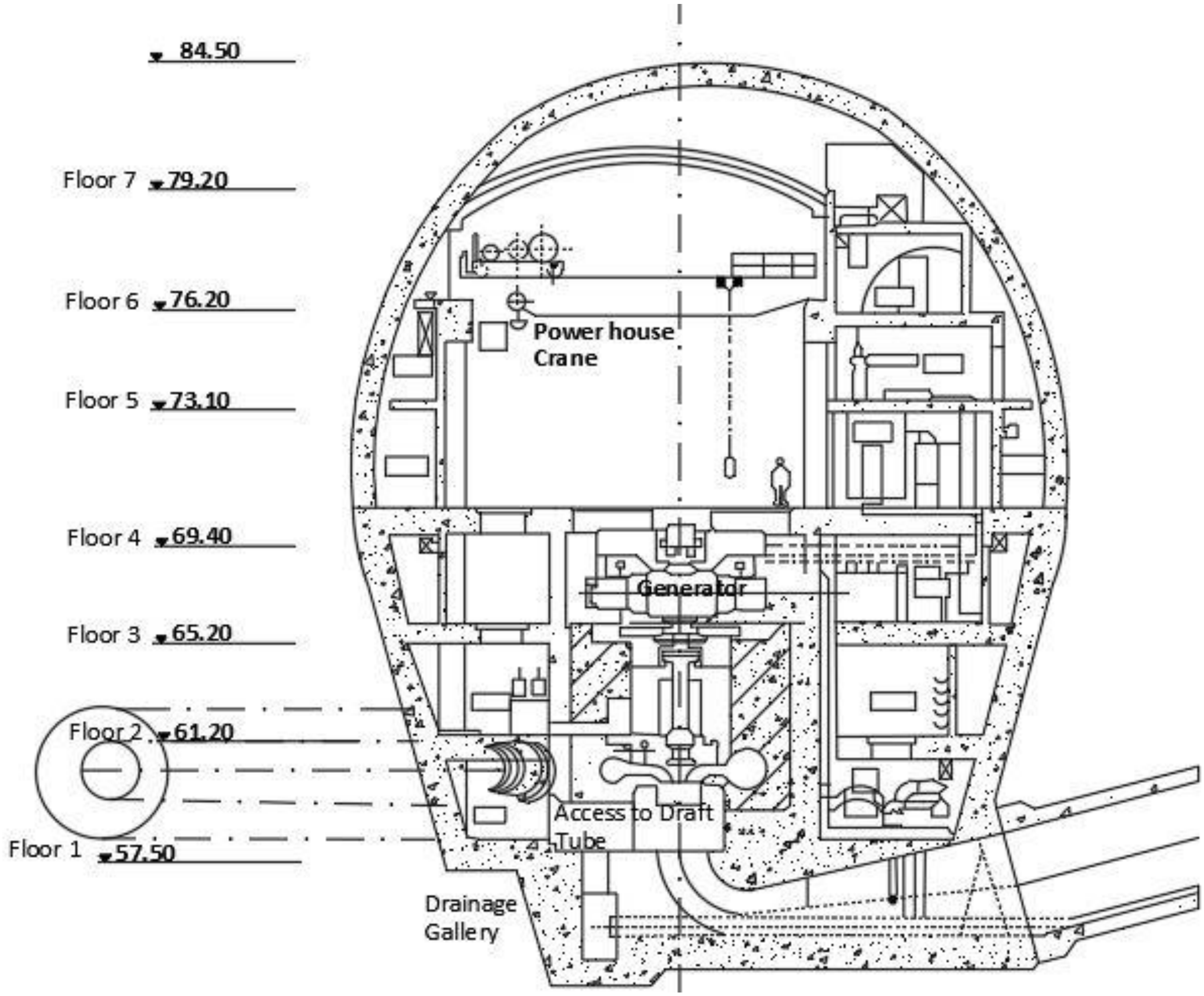
Figure 4.27- 1 Major Cavern Types of Underground Powerhouse

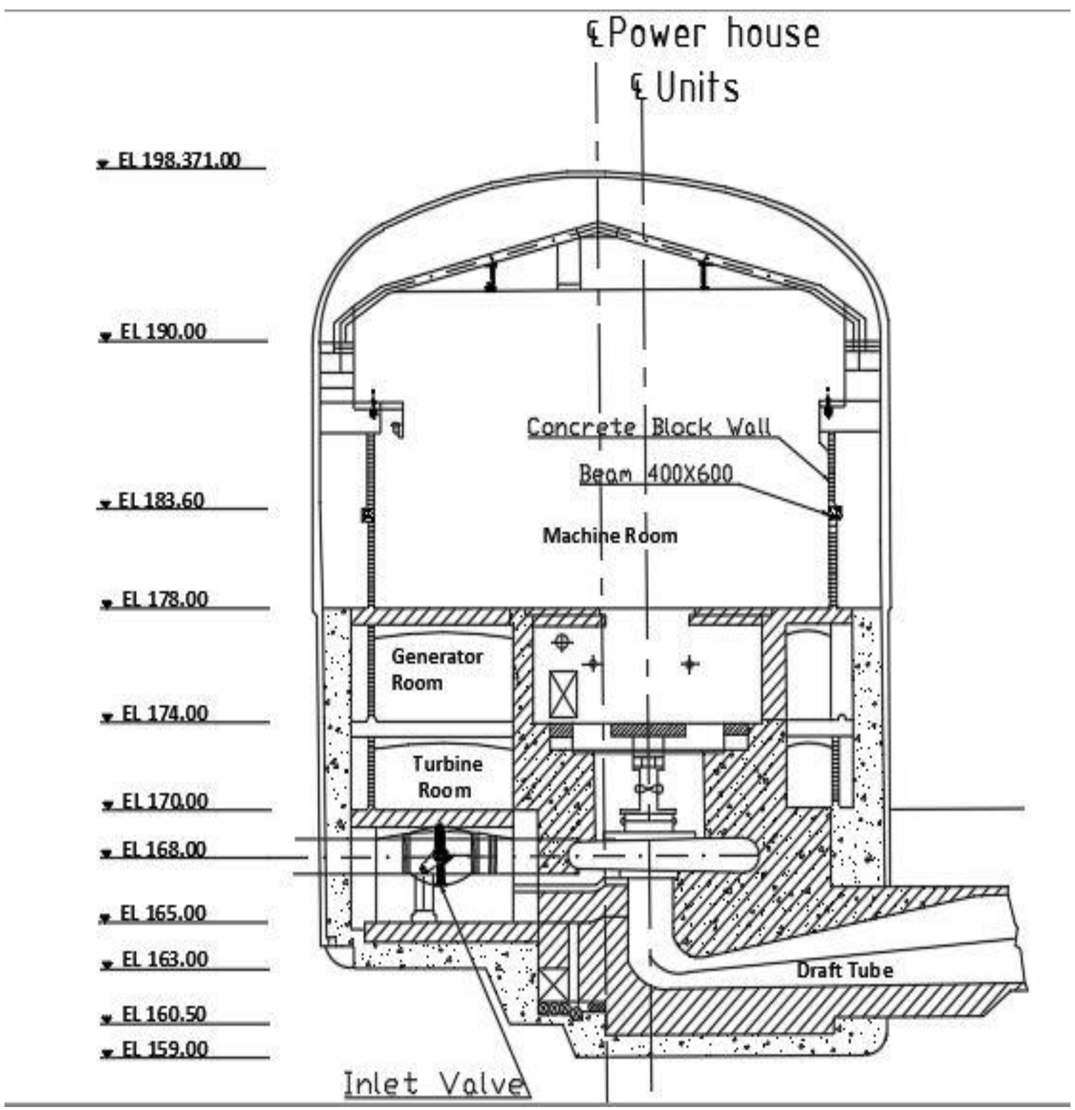
<table>
<tr>
<td>Mushroom Type</td>
<td>


</td>
<td>
Many past projects have applied.

Main body excavation after arch concrete can be safely proceeded by down-drilling bench cut method.
Rock pressure in upper part of cavern is supported is supported by concrete arch.
Sectional area required for cavern is medium among alternatives.

</td>
</tr>
</table>

Egg /Elliptical Type		• The cavern shape is designed to fit the surrounding rock in-situ stresses and therefore is most stable in view of rock mechanics. • -Sectional area required for cavern is big among alternatives due to enlarged and curved sidewalls. • -This type is suitable for rather soft rock strata and high horizontal to vertical stress ratio exceeding 1.0.

D-shape Type		• Rock pressure in upper part of cavern is supported by arch action reinforced with shotcrete and PS anchor without arch concrete. • Sectional area required for cavern is minimized due to vertical wall massive with massive rock strata. • This type is suitable for massive rock strata.

4.27.2 Underground PH Cavern Roof

The cavern ceiling should be formed with a curvature adapted to the stress configuration in the rock to favor a self-supporting arch.

Even in excellent rock a lining or under-roof shall be provided because of following reasons;

1. To ensure safe working conditions for operators
2. To prevent damage to equipment from accidental rock fall
3. To collect and lead seepage of water to the drainage system

4.27.2.1 Compact Concrete Arch

Such concrete arches are usually designed to carry specified load of the overlying rock and retain pieces of rock, provided there is continuous contact between concrete (Fig. 4.27-2). The voids/space between the concrete and the arch is filled with grouting in second stage. The line of thrust will run inside the arch and no structural reinforcement is needed. Such type of thick concrete support is constructed if the rock if of less reliable character or if the cavern area contains moisture. The thickness of concrete arch depends upon the assumed rock load, the shape of the cavern and the quality of the concrete used.

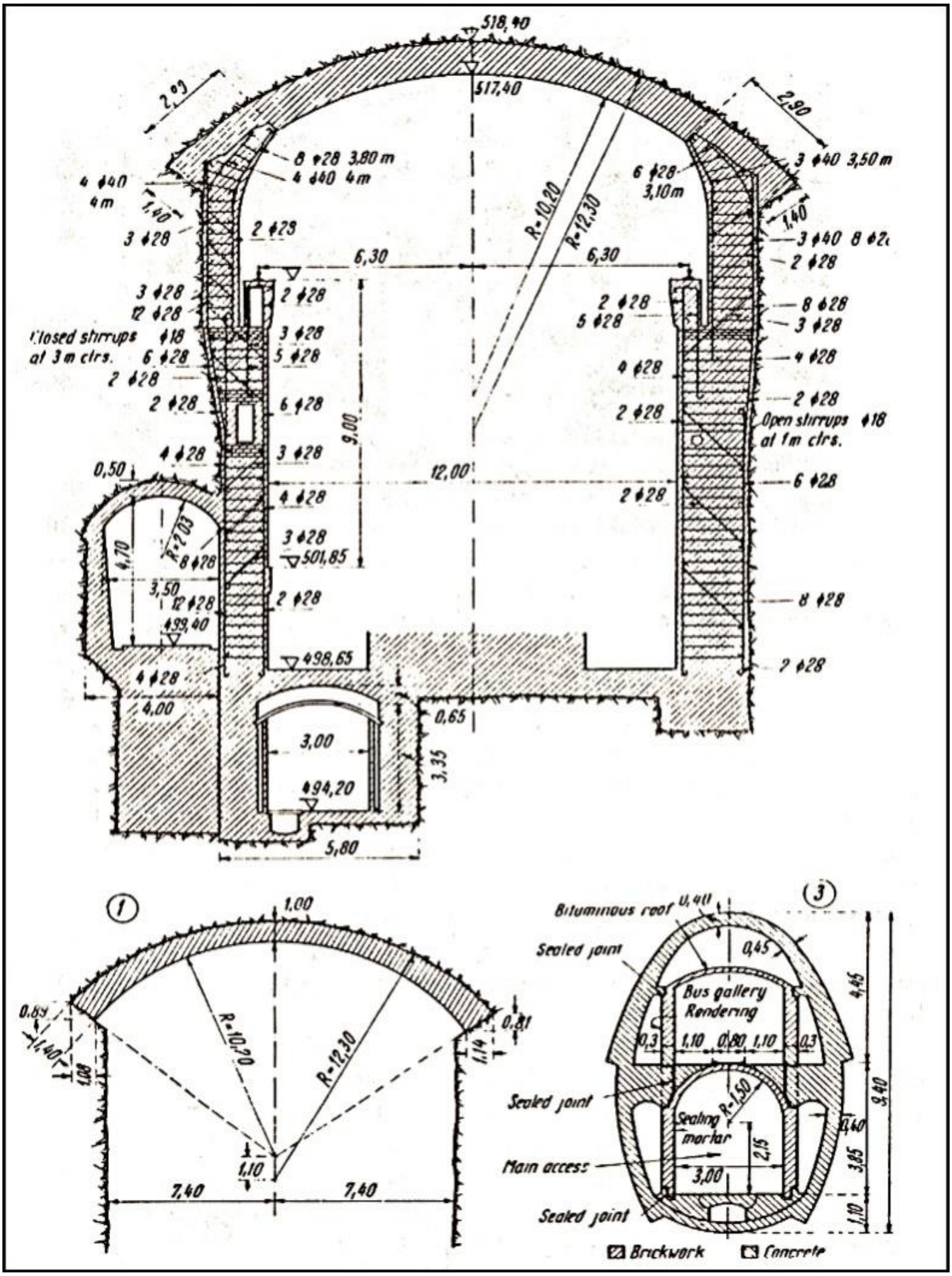


Figure 4.27- 2 Section of a Powerhouse showing Thick Concrete Arch

4.27.2.2 Free Span Concrete Arch

The thin reinforced concrete arch is designed assuming only to intercept falling minor rock. The arch is subjected to self-weight only but is also designed for concentrated loads caused by possible smaller downfall of rocks.

The free span arch is most feasible in shallow seated caverns in good quality rock where small temporary support is needed during excavation hence the permanent support of the ceiling is limited to rock bolting and SFRS both. Top heading of the cavern is somewhat widened with slightly inclined walls to create competent abutments for the arch. In some cases, the design has been reinforced at intervals with ribs directly supporting the rock ceiling.

For practical reasons and to control cracks due to shrinkage of concrete, the arch will be divided in 8-12 m long sections by construction joints. A strong watertight membrane on top of the arch will prevent seepage through cracks, and there is no need for a light suspended ceiling under the arch. Concentrated seepage from the rock is collected in pipes and led to the drainage system.

The distance from the arch to the rock ceiling is typically 1.5-2.0 m to facilitate works like easy access for later inspection, removal of minor rock fall and repair of the sealing membrane.

A typical free span arch is shown in fig. 4.27-3 and fig.4.27-4 show the water proofing and construction joint in the arch.

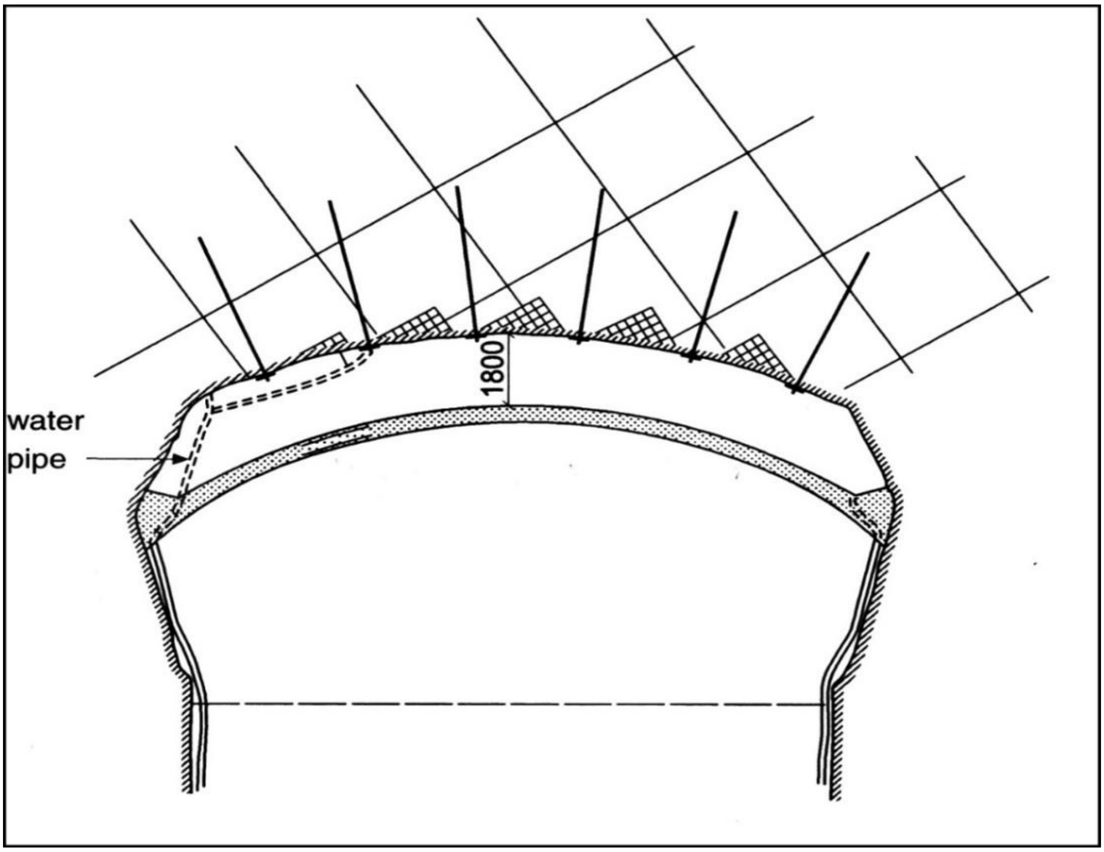


Figure 4.27- 3 Free span concrete arch

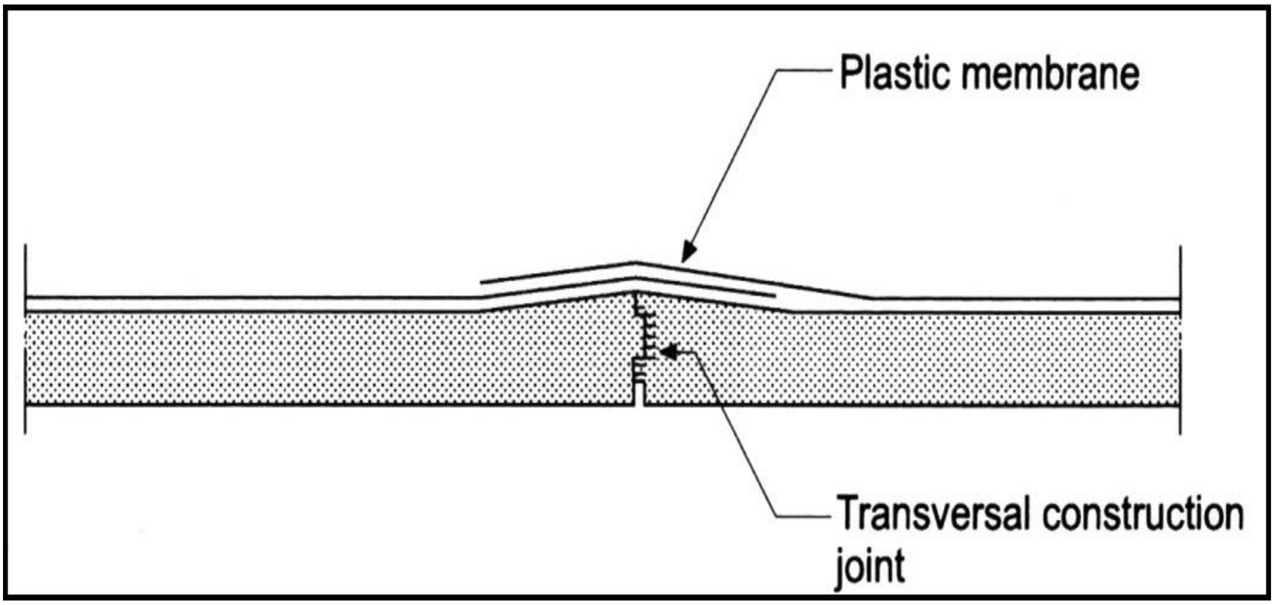


Figure 4.27- 4 Water proofing and construction joint in free span concrete arch.

4.27.2.3 Fiber Reinforced Shotcrete Arch with Suspended Light ceiling

Steel fiber significantly improves the mechanical properties of the shotcrete, like strain energy, bending strength and adhesion. This is utilized in the concept of the steel fiber reinforced shotcrete arch as shown in figure 4.25-5 and 4.25-6.

Support by shotcrete or rock bolting and shotcrete in combination after each round of blasting has proved effective to secure safe working conditions under such conditions. This temporary support makes out the first stage in building up the permanent arch structure.

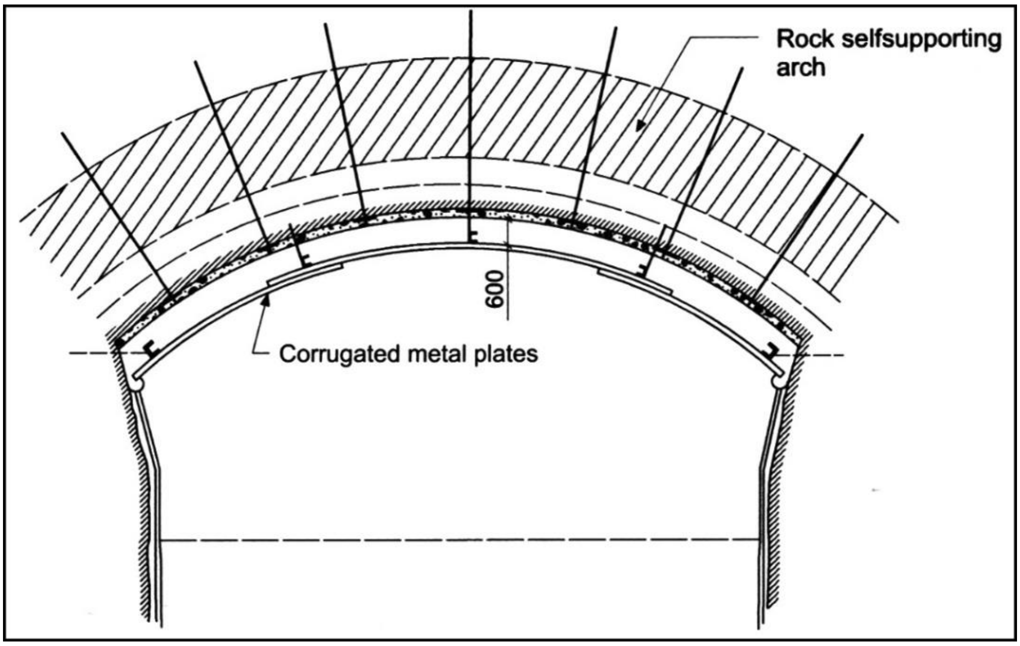


Figure 4.27- 5 Typical SFRS arch with suspended light ceiling for collection of water seepage

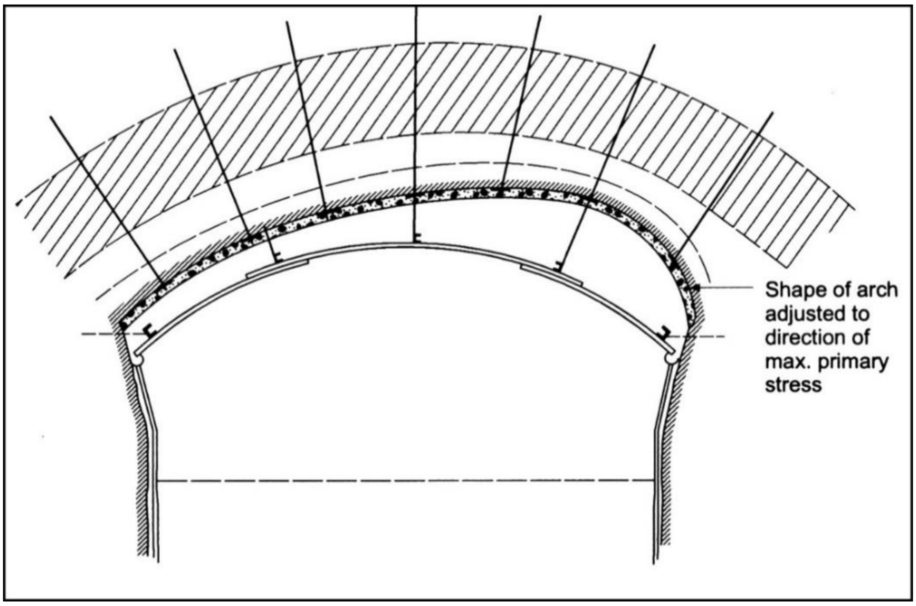


Figure 4.27- 6 Typical SFRS arch with suspended light ceiling for collection of water seepage

The structural principle of the shotcrete arch is to control the stress release near the surface, establish a stable self-supporting arch in the rock mass above, and anchor the stressed zone by rock bolts to the stable rock mass and its principles are illustrated in Fig. 4-10 and Fig 4-11. This shotcrete arch is different from a cast-in-place massive arch of conventional concrete, which is regarded as an independent supporting structure subjected to load from overlying rock.

4.27.3 Cavities

Reference has been taken from IS: 9120-1979.

4.27.3.1 Layout of Cavities

Depending upon the geology and rock strata, approach and access facilities and arrangement of auxiliary openings hence a number of layouts are possible. The various arrangements given below serve as a broad guideline for initial planning of the underground power station may be considered.

a) Parallel Arrangement: The Valve house, Machine hall and transformer hall are situated in parallel independent cavities. Service bay and control room may be located in line with machine hall. Although, this arrangement limits the size of individual cavities and leads to a greater safety in case of fire hazards or pipe bursts, the volume of excavation increases and separate erection cranes are required in the parallel cavities.

b) Linear Arrangement: The Valves, Machine hall, Transformers, Service Bay and Control room are all located in one single large cavity. The new tension cables from the units to transformer may be taken along the walls of machine hall and no separate bus bar gallery is needed. This arrangement limits the span in the cavity.

c) Composite Arrangement: The Control valves, generating unit and transformers are all located in the machine hall cavity, valves located on the upstream side and the transformers on the downstream side. This arrangement reduces the length of the low-tension cables to a minimum, a single crane serves all the purposes and only one access gallery is required.

d) Perpendicular and Skew Arrangement: Transformers may be located at right angles or skew to the machine hall.

4.27.3.2 Rock Cover

Effective rock cover below the line of slumping should be provided depending upon the condition of rock. Reference may be taken from Fig. 9-1 and Fig. 9-1 of chapter 9 of EM: 1110-2-2901. Exploratory drilling shall be made during feasibility study which shall be made to the powerhouse foundation (draft tube) level. The rock cover (on top of the arch crown) should be at least 3 times the width of powerhouse. The rock cover thus calculated should not be alluvium/colluvium or other loose material. For large underground powerhouses (>50 MW), test adit may be recommended.

Additionally, adequate rock cover between two cavities shall be provided depending upon the quality and the strength of the rock in which the cavities are located. Reference may be taken from section 8 of IS: 9120-1979.

4.27.3.3 Roof and Wall Support

Underground power stations are usually located in competent rock not requiring extensive or expensive supporting arrangements. Roof support to the main cavity may take form of Plain concrete arch, RCC arch, Steel ribs or Rock Bolting.

The wall support treatment is totally based on quality of the rock.

5 ELECTRICAL SYSTEM

5.1 Selection of Major Electrical Equipment in Hydro powers

5.1.1 Generator

5.1.1.1 kW Rating:

The kilowatt rating of the generator should be compatible with the kW rating of the turbine. For any turbine type, however, the generator should have sufficient continuous capacity to handle the maximum kW available from the turbine at 100-percent gate without the generator exceeding its rated name plate temperature rise. In determining generator capacity, any possible future changes to the project, such as raising the fore bay (draw down) level and increasing turbine output capability, should be considered.

5.1.1.2 kVA rating and Power Factor:

kVA and power factor is fixed by consideration of interconnected transmission system and location of the power plant with respect to load centre. These requirements include a consideration of the anticipated load, the electrical location of the plant relative to the power system load centers, the transmission lines, substations, and distribution facilities involved. A load flow study for different operating condition would indicate operating power factor, which could be specified.

As per the Grid Code of Nepal Electricity Authority, generators shall maintain power factor between 0.85 lagging and 0.95 leading. Specifying a lower power factor results in an increased capability to supply reactive power to the system but requires a generator with a larger MVA rating. The formula shown below determines the capacity of Generator in hydropower plants.

Generator kVA = (Turbine output in kW * Generator efficiency) / Generator Power Factor

5.1.1.3 Determination of the weight of Generator Rotor:

Weight of Generator in the powerhouse is required in determining the structure of the powerhouse machine hall and also in determination of the maximum lifting capacity of the Overhead crane. The weight of the Generator rotor as mentioned in the Water Power Development (Emil Mosonyi) can be reliably estimated from the following empirical formula:

Wr (tons)= $50\,\frac{kVA\ rating\ of\ Generator^{0.74}}{Synchronous\ speed^{0.37}}$

This equation can be applied for rotor

Revolving with a speed exceeding 90rpm and

Having standard magnitude of GD^2

The transportable weight of the generator rotor has to be verified from the manufacturer and shall be within the transportation limit of Nepalese Road network.

5.1.1.4 Generator Rated Voltage

Followings are recommended rated voltages for generators of different rated output.

• Up to 500 KW	415 V
• 501 to 2500 KW	3.3 KV
• 2501 to 5000 KW	6.6 KV or 11 kV
• More than 5000 KW	11 KV

Voltages above 13,800 V may be desirable in machines of large capacity. Such large machines are usually connected directly to their own step-up transformers, and voltage is selected on the basis of economic and technical considerations.

5.1.1.5 Parameters for Generator selection

a) Horizontal or vertical

b) Rated Capacity at rated voltage and rated power factor

c) Maximum (continuous) capacity at rated voltage and rated power factor

d) Rated generation voltage

e) Rated frequency

f) Overload capacity

g) Rotational Speed

h) Speed rise and runaway speed

i) Noise level

j) Insulation and Temperature rise of Stator and Rotor

k) Guide and Thrust Bearing configuration

l) Bearings temperature rise

m) Efficiency and output guarantees

5.1.1.6 Guidelines for Generator Protection

The Fault Clearance Time for a fault on the Generator's System shall not be longer than 120 ms for 132 kV and 220 kV and 150 ms for 66kV systems.

A circuit breaker fail protection shall be provided for the Generator.

In the event the primary protection system fails to interrupt the fault within the prescribed Fault Clearance Time, the breaker fail protection shall operate and interrupt the fault current within 200 ms of fault occurrence.

Each Generating Unit shall be provided with protection against loss of excitation.

Each Generating Unit shall be provided with protection against pole slipping.

Protection shall be provided on each Generating Unit against over current, earth fault, out-of-step and frequency.

Other protection requirements shall be as per Best Industry Practice.

5.1.1.7 Voltage and Frequency variation:

The Grid of Nepalese power system is considered to be in the Normal state when:

a) The System Frequency is within the limits of 49.5 Hz and 50.5 Hz;

b) The voltage at all Connection points is within the limits of 0.95 and 1.05 of the nominal value;

The Grid of Nepalese power system is considered to be in the Alert state when:

a) The System Frequency is outside the limits of 49.5 Hz and 50.5 Hz but within the limits of 48.75Hz and 51.25Hz;

b) The voltage at all Connection points is outside the limits of 0.95 and 1.05 of the nominal value but within 0.9 and 1.1 of the nominal value

These things are to be considered during designing the voltage and frequency variation limits of the hydro generators.

5.1.1.8 Operational Requirements of the Large Generators

Generating Units shall be equipped with Automatic Voltage Regulators. Power System Stabilizer, if provided, shall be tuned properly in consultation with the System Operator.

Each Generating Unit shall be capable of delivering continuously its active power output as guaranteed in the Generator's Declared Data within the Grid frequency range of 49.5-50.5 Hz. Any decrease in the Active Power output outside this frequency range shall not be more than the proportionate value of Grid frequency decay.

Each Generating Unit shall be capable of generating its active power and reactive power outputs, as guaranteed in the Generator's Declared Data, within the voltage variations of +/- 10% during normal operation.

Each Generating Unit shall be capable of generating its active power output, as guaranteed in the Generator's Declared Data, within the limits of 0.85 lag and 0.95 lead at the Generating Unit's terminals, in accordance with its Reactive Power Capability Curve.

All Generating Units shall remain in synchronism for at least fifteen (15) seconds in the event the Grid frequency varies in the range of 47.5-52.5 Hz, unless the Generator decides that it may damage the Generating units.

Generators shall have the capability to operate in Island mode and operate in this mode as and when instructed by the System Operator.

Generating Units shall be capable of picking up minimum 5% additional load over the maximum continuous ratings for five (5) minutes or the limit specified by their manufacturers.

Generator shall be responsible for providing protection against Grid Frequency excursion outside the range of 47.5-52.5 Hz, and the Generator shall have to drop the Generating Unit(s) from the Grid and operate in the Island Mode.

Generating Units shall be synchronous generators; induction generators shall not be permitted by the Grid Code of NEA.

Generating Units shall be capable of contributing to Frequency Control by continuous regulation of the active power.

Generating Units shall be fitted with a fast-acting automatic generation control system, with an overall speed-droop characteristic of five (5) percent or less to provide Frequency Control during normal operating conditions.

The Generating Unit, when it becomes isolated from the Grid, shall provide Frequency Control to the resulting Island Grid.

The Power Plant Owner shall be responsible for conducting system studies to determine protection settings. Each and every piece of electrical Equipment must be covered by protection.

5.2 Excitation System

5.2.1 Types of Excitation System

These two types of excitation systems are widely used and have to be mentioned during the excitation system selection of hydropower.

a) Brushless excitation system

b) Static excitation system

The excitation system should also have features which will enable the alternator to operate.

a) In isolation (solo)

b) Parallel with other alternators

c) Parallel with the grid

5.2.1.1 Guidelines for Excitation Control System

Generating Units shall be capable of contribution to Voltage Control by continuous regulation of the reactive power supplied to the Grid or, in the case of Embedded Generating Units, to the User System. Generating Units shall be fitted with a continuously acting automatic excitation control system to control the terminal voltage without instability over the entire operating range of the Generating Units. Generators shall provide power system stabilizers, if results of Impact Studies conducted by the System Planning Department demand it. The Generators shall have Black Start Capability as mentioned in the Grid Code.

5.3 Cables/Metal Enclosed Bus bar from Generator Terminal

The power generated from the Generator terminal can be transferred up to the Transformers either through the cables or Metal Enclosed bus bar.

5.3.1.1 Cables

The rating of cables shall be capable to transfer the maximum full load current generated from the Hydro Generator. Cables are of two types based on the insulation of the conductor.

<u>PVC Cable</u>

These cables are suitable for use where the combination of ambient temperature and temperature rise due to load results in conductor temperature not exceeding the following condition given in table 5-1.

Table 5- 1 Normal and short circuit condition temperature of PVC cable

Type of PVC Cable	*Normal Continuous Operation*	*Short Circuit Condition*
General Purpose	70°C	160°C
Heat Resisting	85°C	160°C

Cross linked polyethylene insulated PVC sheathed (XLPE) cables

These cables are suitable for use where combination of ambient temperature and temperature rise due to load results in conductor temperature not exceeding 90°C under normal operation and 250°C under short circuit conditions.

The both type of cables are armoured, unarmoured, single, twin, three, four and multicore cables for electric supply and control purposes. The conductors used in cables are composed of plain copper or aluminum wires. Type of cables shall be selected as per the plant's requirement.

Minimum Permissible Bending Radius for Cables

Installation radius should be as large as possible. However, the minimum installation radius for cables as recommended in IS 1255 – 88 are given in table 5-2.

Table 5- 2 Minimum installation radius for cables

Voltage Rating	*Single Core*	*Multi Core*
Up to 1.1kV	15D	12D
Above 1.1 to 11kV	15D	15D

Where, D is the Diameter of the Cable

Determination of the size of the Cable

Following parameters should be considered while deciding the size of the cable

- Voltage of the system
- Whether cable is to be used in earthed or unearthed system.
- Current – direct or alternating
- Short circuit current of the system
- Ambient temperature
- Method of laying – in air, duct or in ground
- Number of cables grouped together and their spacing

- Thermal resistivity of soil for cables land directly in soil
- Depth of lying of cables in ground

Cables may be appropriate for some small generators or in installations where the transformer is located in the plant's switchyard. In the latter situation, economic and technical evaluations should be made to determine the most practical and cost-effective method to make the interconnection

5.3.1.2 Metal Enclosed Busbar

i. Non-segregated-phase buses:

This bus arrangement is normally used with metal-clad switchgear and is available in ratings up to 4000 A (6000 A in 15 kV application) in medium voltage application.

ii. Segregated phase buses:

This bus arrangement is available in the same voltage and current ratings as non-segregated phase bus, but finds application where space limitations prevent the use of isolated phase bus or where higher momentary current ratings than those provided by the non-segregated phases are required.

iii. Isolated phase buses:

Bus systems are available in both continuous and non-continuous housing design. Isolated phase bus is available in ratings through 24000A and is associated with installations using station cubicle switchgear.

Following parameters should be considered while designing the bus bar

a. Rated current
b. Rated voltage
c. Rated frequency
d. Rated short-circuit current
e. Material
f. Derating conditions
g. Temperature rise during short circuit conditions
h. Oscillations
i. Bending load on insulators
j. Insulations requirements
k. Spacing of support insulators
l. Clearance between phases and between phase and earth
m. Creepage distance

5.4 Transformers

When selecting the transformer for a hydroelectric plant, number of factors, namely operating condition, available transporting facility, methods of cooling, insulating level, per cent of impedance, voltage regulating at different power factors, losses at different power factor loads, weights and dimensions, cost etc. are taken into consideration.

The size of transformer depends on the size of the generating units. The KVA capacity of the three phase transformer must be the same as that of the generator/generators to which it is connected. If a bank of three single phase transformers is used (one in each phase); the KVA capacity of each single phase transformer must be one third (1/3) of the KVA of the generators/generator connected. Also, the physical size and weight of transformer is dependent on the cooling mechanism selected, which finally depends on the location of the transformer and accessibility of the power plant. Following scheme can be adopted during selection of Generator Transformer.

5.4.1 Generator Transformer Scheme Selection

In order to supply electrical energy generated from the generator to the high voltage transmission system, three different generator-transformer schemes are possible. They are:

a) Unit generator-transformer scheme: (Refer Figure 5.4-1)

b) Generator bus scheme 1 (Refer Figure 5.4-2)

c) Generator bus scheme 2 (Refer Figure 5.4-2)

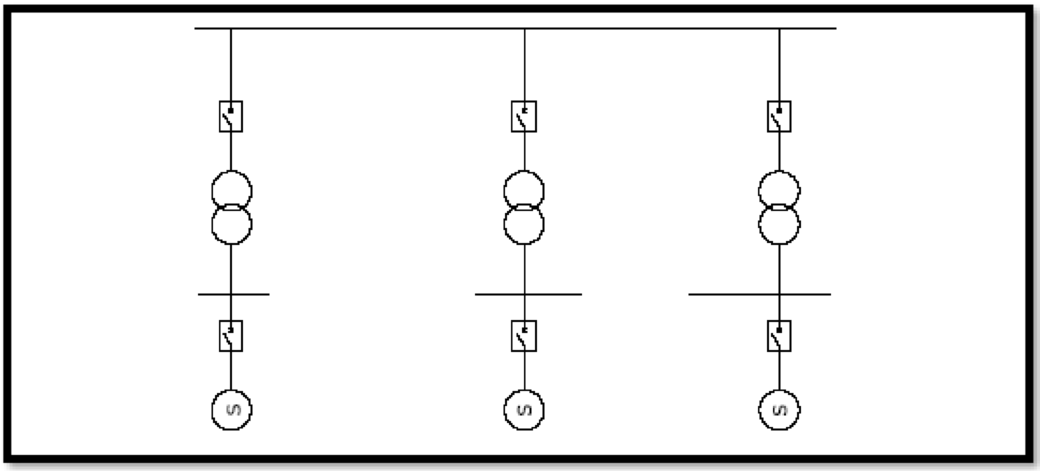


Figure 5.4- 1 Unit Generator- Transformer Scheme

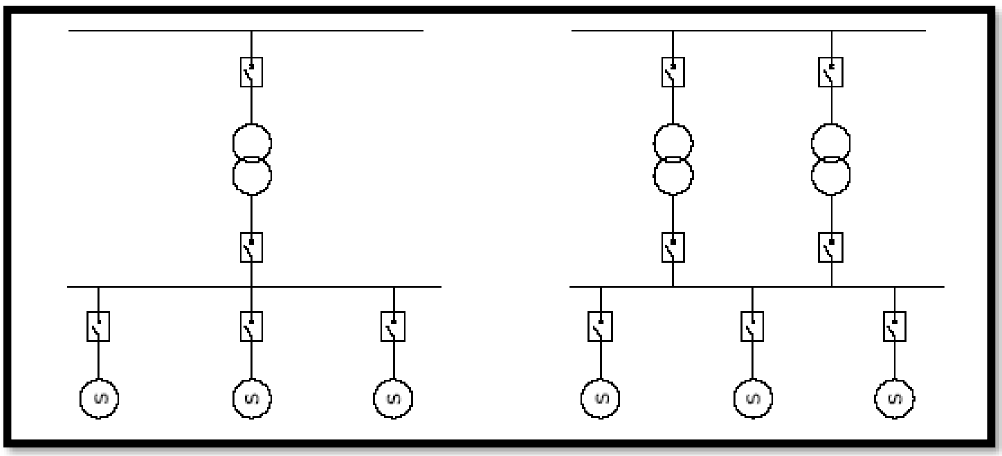


Figure 5.4- 2 Generator Scheme Bus 1 & 2

In each of the schemes listed above, there can be either single phase transformer banks or three phase transformers. Design issues involved in selecting generator-transformer schemes are:

- General Issues:
  a) Initial investment cost
  b) Reliability and cost of outage
  c) Stability of the system and effect of a single outage
- Technical Issues:
  a) Transportation weight of transformer and road capacity
  b) Single phase or three phase transformer and spare
  c) Breaker capacity at MV/HV level
  d) Short circuit level in each of the scheme
  e) Protection scheme and complexity
  f) Subsequent effect of MVCB layout and station service scheme

5.4.1.1 Unit Generator-Transformer Scheme:

This is a conventional scheme preferred for medium sized power plants in a small power system where the plant size is significant for the system. With the use of individual transformer for each generator unit, unit protection of generator and transformer becomes easy. Overall protection system becomes simple and easy to locate the faults. The fault level at the generator bus is less as compared to other schemes. This scheme makes maintenance outage simpler to arrange. In case of fault in a unit, other units can run independent of others and the plant's availability is higher. It requires higher number of switchgear compared to generator bus scheme 1.

5.4.1.2 Generator Bus Scheme 1:

In this scheme, all the generators are connected to the common generator bus and the power is evacuated through single step up transformer. The fault level at generator bus is very high in this scheme as a result the cost of generator circuit breakers becomes very high. Although it requires less number of switchgears, the loss of a transformer bank would result in loss of total power. Maintenance outage of the transformer results in loss of whole plant. Hence, for large plants this scheme is not preferred.

5.4.1.3 Generator Bus Scheme 2:

This scheme uses two transformers to evacuate total power from the common generator bus. Protection system is complex and disturbances of one generator can trip other units too. The fault level at the generator bus is high due to common connection of all the generators. It requires higher number of switchgear than other schemes. During the fault in a transformer and its regular maintenance, half of the power is lost.

5.4.2 Transformer Cooling

The methods of cooling transformers differ and affect its rating, performance and size. The type of cooling is determined by the size, location and the rating of the transformer. The Table 5.3 below depicts the selection of cooling medium for the power transformers. The cooling system shall be carefully studied and indicated during the detail design phase.

Table 5- 3 Selection of cooling medium for the power transformers

Types of cooling	Description
Air Natural (AN)	The ambient air is used for cooling. This method is useful for oil less transformer and is generally used for small transformers below 25 KVA.
Oil Natural Air Natural (ONAN)	Natural (ONAN) Transformers are fitted with panel Type radiators for oil natural circulation.
Oil Natural Air Forced (ONAF)	The panel type radiators are provided with cooling fans. Fans are switched on during heavy Loads.
Oil Forced Air Forced (OFAF)	The oil is circulated through coolers. The coolers have Cooling fans to exchange heat form oil to air.
Oil Forced Water Forced (OFWF)	The heat is exchanged from oil to cooler water. Both oil and cooling water are circulated through heat Exchanger. These are mostly used in underground type power houses.

5.4.3 Guidelines for Connecting the Transformer to Grid

- If the Generator is connected to the Grid, the high voltage side of the transformer shall be connected in Wye with neutral brought out for earthing.
- Differential scheme shall be provided for all size of transformers of capacity higher than 5MVA with over current and earth fault as backup.
- Over-current and earth-fault relays shall be provided for all capacity transformers with directional features for parallel transformer operations.
- Restricted earth-fault relays shall be provided for all transformers with capacity equal to or higher than 30 MVA.
- Other protection requirements regarding gas-operated relays, and oil and winding temperature protection shall be as per Best Industry Practice.
- Step-up power transformer voltage level shall be studied to verify expected voltage regulation for all cases of system (p.f -0.95 lead to 0.85 lag and bus voltage +0.1 to -0.1 pu at HV bus)

5.4.4 Unit Auxiliary and Station Transformers

The number of unit auxiliary transformers (UAT) is one or two depending upon the capacity of unit. The number of station transformers depends on the total number of generators in a power station. It is normal practice to provide one station transformer up to two units and two station transformers for two to five units.

The capacity of the unit auxiliary transformers is based on the total actual running auxiliary load of the particular unit with a 10% margin. The total installed consumption and average consumption should be calculated for power plants larger than 10MW to select the station transformer capacity.

The UATs are connected in delta/ star or delta/ delta. In case of delta/ star, the star neutral is earthed through a resistor.

The HV and LV terminals of the UATs should be suitable for bus duct or cable connection. The underground power house generally has dry type Unit Auxiliary and Station Transformer. The surface and sub-surface powerhouse can have dry type or oil filled Unit Auxiliary Transformer depending upon the project economy and the reliability concern.

5.5 Control System

The main control systems in a hydroelectric power plant (hydro plant) are associated with the start and stop sequences for the unit, and for control of real power, voltage, and frequency.

The control of a power plant or the equipment in the plant can be defined by identifying a type of control from each of three categories. The three categories of control are location, mode, and supervision. The control philosophy of the power plant has to be developed based on these categories.

Table 5- 4 Summary of control hierarchy for hydroelectric Power plants (IEEE Std. 1010-1987)

CONTROL CATEGORY	**SUB CATEGORY**	**REMARKS**
Location	Local	Control is local at the controlled equipment or within sight of the equipment
	Centralized	Control is remote from the controlled equipment, but within the plant.
Mode	Off-site	Control location is remote from the project
	Manual	Each operation needs a separate and discrete initiation; could be applicable to any of the three locations

	Automatic	Several operations are precipitated by a single initiation; could be applicable to any of the three locations
Operation (Supervision)	Attended	Operator is available at all times to initiate control action
	Unattended	Operating staff is not normally available at the project site

For larger, power plants computer-based start/stop sequencing is cost-effective, reliable, and easy to maintain, compared to older electromechanical relay systems. Some engineers may not be comfortable with full computer automation of the start/stop sequencing. In these cases, the start/stop sequencing can be made more conservative by containing breakpoints in the sequencing to allow for operator intervention or permissive action.

Examples of some of the equipment controlled and monitored during the start/stop sequence are as follows:

a) Intake gate or inlet valve;
b) Governor hydraulic oil system;
c) Gate limit position;
d) Gate position;
e) High pressure oil system for the thrust bearing;
f) Mechanical brakes;
g) Cooling water system;
h) Excitation equipment;
i) Unit speed;
j) Protective relaying status;
k) Unit alarms;
l) Unit breaker status.

Black start capability (i.e., starting the plant without normal station service power) for restoring the plant, and ultimately the power system, is vital.

The capability to start a unit under black start conditions is usually a function of the physical devices in the power plant rather than the automation system. An auxiliary power system, such as an emergency generator or station batteries, must be available to provide power to the unit's auxiliary systems in the power plant to ensure a black start will be successful. Black start facilities shall be adopted as mentioned in the Grid Code of NEA.

A number of the functions available at the unit local control system may be made available at the centralized control location. The extent of duplication between centralized and local control functions will depend on the operating philosophy of the utility or owner and the capability of the plant data network. Typical unit control functions able to be initiated at the centralized control location are as follows:

a. Automatic start and synchronization;

b. Automatic stop;
c. Emergency shutdown;
d. Speed setpoint;
e. Power setpoint;
f. Voltage and reactive power set point.

Raw data collected by the computer system is necessary for the generation of reports that are used for operations and maintenance decisions. For larger power plants, the multi-tasking capabilities of the computer shall provide report generation capability while accomplishing real-time control and monitoring of plant functions. Computer-based documentation capabilities shall include the following:

a. Sequence-of-events recording: Inputs (events) are scanned and time-tagged to the nearest millisecond to provide after-the-fact information to analyze faults and other high-speed events.
b. Automated operator's log: Hourly, daily, and weekly electrical and mechanical data, traditionally logged manually by the operator, can be recorded automatically.
c. Historical data recording: Important data are recorded in such a way as to permit analysis of plant operation over various cycles of operation. Such data can be used to improve the computer control. For example, optimum efficiency algorithms that control plant operation in response to dynamic plant and power system conditions can be developed or improved by studying the historical data records.
d. Trend reporting Data is reported for trends in equipment operation that indicate problems that may need maintenance attention. Also, water and power data can be analyzed for trends that may be useful for system operation or planning.

5.5.1 Typical Control Parameters

The table 5-5 below shows the typical parameters necessary to implement automated control of hydroelectric plants (IEEE Std. 1249-1996):

Table 5- 5 typical parameters necessary to implement automated control of hydroelectric plants (IEEE Std. 1249-1996)

CONTROL ACTION	INPUTS	OUTPUTS
Unit Start/Stop	Gate limit	Brake release
	Gate position	Gate operator
	Breaker status	Cooling water valve
	Governor hydraulics	Exciter start circuit
	Unit speed	unit selection
	Unit protective relays	breaker trip/close
	Generator voltage	
Unit synchronizing	Unit speed	Breaker select
	Gate position	Breaker closing
	Gate limit	unit select
	Breaker status	Power adjust
	Generator voltage	Voltage adjust
	Bus voltage	
AGC	Unit status	Unit selection
	MW	Power adjust
	MVar	
	Unit protective relays	
	Set point	
Synchronous Condensing	Draft tube depression	Power adjust
	MW	Excitation
	MVar	Draft tube depression
		Unit selection
Turbine Optimization	Head	Gate operator
	Blade angle	Power adjust
	Gate position	Unit selection
	MW head	
	MVar	
	Flow	
Trashrack control	Differential pressure	Trashracking system
		Power adjust
		Gate operator
Black start	Protective relays	Generator start
	Bus voltages	Unit synchronizing
	Generator status	Breaker close (dead bus)
	Breaker status	Power adjust
	Generator voltage	Voltage regulator
	Unit power	Unit selection
		Breaker selection
Base load control	Unit status	Power adjust
	MW	Gate operator
	MVar	Unit selection
	Gate position	
	Gate limit	
	Set point	
Voltage Control	Unit status	Voltage regulator
	Breaker status	Unit selection
	MW	
	MVar	
	Bus voltage	
	set point	
	Generator voltage	
Remedial action schemes	RAS initiation	Breaker trip
	Generator selection	Breaker selection
	Breaker status	
	Unit status	
	System frequency	
Forebay selective withdrawal	Water temperatures	Gate operator
	Gate position	Unit select

5.6 Protection System

Protection is a vital section in the Electrical design of a power plant. The relaying used for protecting the electrical equipments is varied dependent upon the size and type of generator.

The following protection devices shall be considered as the minimum requirement at Hydroelectric Project

Generator:

1. Generator differential protection
2. 100% stator earth fault protection
3. Rotor earth fault protection
4. Negative phase sequence protection
5. Loss of excitation protection
6. Generator overvoltage protection
7. Voltage control overcurrent protection
8. Reverse power protection
9. Under voltage protection
10. Under/over frequency protection
11. Field winding overload protection
12. Stator winding overload protection
13. Loss of synchronism

Main Transformer:

1. Transformer differential protection
2. Overcurrent earth fault protection
3. Restricted earth fault protection
4. Thermal overload protection
5. Over flux protection
6. Breaker failure protection

Transmission line and HV Cable

1. Line/Differential Protection
2. Distance Protection
3. Breaker failure protection
4. Synchro check relay
5. Directional overcurrent/earth fault relay

Relay operating characteristics and their setting must be carefully coordinated in order to achieve selectivity. The aim is basically to switch off only the faulted component and to leave the rest of the power system in service in order to minimize supply interruptions and to assure stability.

5.7 Earthing System

The principle objective of powerhouse grounding/earthing system is to carry electric currents into earth under normal and fault conditions without exceeding operating and equipment limits or adversely affecting continuity of service and to assure that a person in the vicinity of grounded facilities is not exposed to the danger of electric shock.

After preliminary layouts of the dam, powerhouse, and switchyard have been made, desirable locations for two or more ground mats can be determined. Grounding conditions in these areas should be investigated, and the soil resistance measured. IEEE 81 outlines methods for field tests and formulas for computing ground electrode resistances.

The measured soil resistivity obtained by field exploration is used to determine the amount of ground grid necessary to develop the desired ground mat resistance. The resistance to ground of all power plant, dam, and switchyard mats when connected in parallel should not exceed, if practicable, 0.5 ohm for large installations. For smaller installations it can be 1 ohm.

The earthing mat designed at the power house and switchyard is purely governed by the maximum fault level. The earthing mat should be designed in such a way that even in worst condition the touch and step potential should not exceed the permissible value. The conductor used for risers and the mat should take account of maximum fault current.

The grounding system shall be designed to keep rise in touch and step voltages in and around switchyards where operators are likely to be present within acceptable safety limits specified by IEEE standard.

Special design of the grounding system shall be considered in case of powerhouse housing GIS (Gas Insulated Substation) equipment.

5.8 Medium Voltage Switchgears

Metal-clad switchgear with draw-out type circuit breakers are in common practice for medium-voltage application. The draw-out type circuit breakers eliminate the need of isolators during the maintenance of circuit-breaker. Metal-clad enclosure provides necessary safety and connection facilities between the circuits.

The circuit-breakers have no specified continuous over-current capability. When selecting a circuit-breaker therefore, the rated normal current should be such as to make it suitable for any load current that may occur in service. Where intermittent over-currents are expected to be frequent and severe, the manufacturer should be consulted.

The values of rated normal current should be selected for R 10 series as, specified below in table 5-6.

Table 5- 6 Standard Current Ratings

Standard Current Ratings (A)									
1	1.25	1.6	2	2.5	3.15	4	5	6.3	8
10	12.5	16	20	25	31.5	40	50	63	80
100	125	160	200	250	315	400	500	630	800
1000	1250	1600	2000	2500	3150	4000	5000	6300	8000
10000	12500	16000	20000	25000	31500	40000	50000	63000	80000
100000	125000	160000	200000	*(Source: - IEC 60059)*					

5.9 Rated Voltage

The rated voltage of a circuit breaker corresponds to the highest system voltage for which the circuit breaker is intended for use. The standard values of rated voltages shall be selected as are given in table 5-7.

Table 5- 7 Standard values of rated voltages

Nominal System Voltage kVrms	Rated Voltage of Circuit Breaker kVrms
.240	.264
.415	.440
3.3	3.6
6.6	7.2
11	12
22	24
33	36
66	72
132	145
220	245
400	420
500	525
750	765

(Source: - Guidelines for electrical designs of SHP plants including switchyard, Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee)

5.9.1 Rated Short Circuit Breaking Current

The rated short-circuit breaking current is the highest short-circuit current which the circuit breaker shall be capable of breaking under the conditions of use and behavior prescribed in this standard in a circuit having a power-frequency recovery voltage corresponding to the rated voltage of the circuit-breaker and having a transient recovery voltage equal to the rated specified value.

For three-pole circuit-breaker the a.c. component relates to a three phase short circuit. The r.m.s. value of the a.c. component of the rated short-circuit breaking current shall be selected from the following values and shall meet the utility requirements:

6.3 kA; 8 kA; 10 kA; 12.5 kA; 16 kA; 20 kA; 25 kA; 31.5 kA; 40 kA; 50 kA; 63 kA; 80 kA; 100 kA

5.9.2 Rated Short Circuit Making Current

The circuit-breaker should be able to close without hesitation as contacts touch. The circuit-breaker should be able to withstand the high mechanical forces during such a closure. These capabilities are proved by carrying out making current test. The rated short-circuit making current of a circuit-breaker is the peak value of first current loop of short-circuit current (Ipk) which the circuit-breaker is capable of making at its rated voltage.

The rated short-circuit making current should be at least 2.5 times the r.m.s. value of a.c. component of rated breaking current.

5.9.3 Rated operating sequence

The opening sequence denotes the sequence of opening and closing operations which the circuit-breaker can perform under specified conditions. The operating mechanism experiences severe mechanical stresses during the auto-reclosure duty. This shall be clearly indicated during detail design phase. As per IEC, the circuit-breaker should be able to perform the operating sequence as per one of the following two alternatives:

(i) O – t – CO – T – CO

Where,

O	opening operation
C	closing operation
CO	closing followed by opening
t	3 minutes for circuit-breaker not to be used for rapid auto-reclosure
t	0.3 second for circuit-breaker to be used for rapid auto-reclosure.
T	3 minutes

Note – Instead of T = 3 minutes, other values: T= 15 seconds (for voltages less than or equal to 52 KV) and T = 1 minute are also used for circuit breakers intended for rapid auto reclosing.

(ii) CO – t’ – CO

Where,

t’ = 15 second for circuit-breaker not to be used for rapid auto-reclosure.

5.10 High Voltage Switchyard Equipment

The transmission voltages of INPS are 33kV, 66kV, 132kV, 220kV and 400kV. The equipment installed in the HV switchyard shall match with the transmission line voltage and selected accordingly. The voltage of take-off yard at the power station shall correspond with the interconnecting sub-station at the connection point. The interconnecting sub-stations are selected considering the Load Flow analysis, distance from the Power Plant and are fixed during the Grid Connection Agreement made with the utility. The arrangement of equipment at the takeoff yard and interconnecting equipment depends on the number of transmission lines adopted for power evacuations.

In case of underground power house; the powerhouse having very less area for outdoor switchyard or the power house/interconnection substation located in the polluted area, GIS (Gas Insulated Substation) shall be considered in the feasibility/ design phase. The design associated with the placement of GIS in the powerhouse or any other area, requirement of its earthing and cable terminating from GIS to take off yard shall be clearly indicated.

The major equipment installed in the take-off yard and interconnection substations are listed below but shall not deviate from the utility requirement:

a) Power Transformers
b) Lightning Arrestor/ Surge Arrestor
c) Current Transformers
d) Voltage Transformers
e) Disconnecting Switches with or without earthing
f) Circuit Breakers
g) Main meters and Check meters
h) Cables
i) Gantry
j) Busbars

i. Lightning Arrestors

The lightning arrestors/surge arrestors shall be suitable for a nominal system of 3 phase, 50Hz solidly grounded system. Lightning arrestors shall be provided at entry points of the overhead transmission lines and close to the power transformers. The active part of the lightning arresters shall be accommodated in porcelain insulators, which are suitably reinforced to prevent explosion of an arrester. Pressure relief device shall be provided for the safe discharge of internal pressure. The lightning arresters shall be mounted on galvanized steel structure. Terminal connectors for both line and ground terminals shall be furnished.

ii. Disconnecting Switches

The disconnecting switches shall be designed for the 50Hz, 3 phase systems. The disconnecting switches shall be able to carry the rated current continuously and rated short time current for three seconds without exceeding the temperature limit specified in the relevant standard. The disconnecting switches shall be capable of withstanding the dynamic and thermal effects of maximum possible short circuit current at the point of its installation. The grounding switch shall be capable of making to a dead short circuit without damage of the equipment or endangering operator.

iii. Main Meter and Check Meter

Meters shall be of three-element, 3-phase, 4-wire, Wye-connection, bi-directional digital type, having facility for local and remote communication. The transmission medium may be of any type but shall be free of data loss during transmission.

The minimum standard of accuracy of Meters shall comply with the latest IEC standards and be as follows:

i. For Generators, including IPP's, with total installed capacity exceeding 5MW, the accuracy shall be 0.1;

For Generators, including IPP's, with total installed capacity equal to or less than 5MW, the accuracy shall be 0.2; and

The burden of meters shall be maintained between 25% and 100% of rated values.

The meter shall display KW and cumulative Demand, KWh, KVA, KVAh and KVARh with the features of adjustable time-of-use, maintenance records, recordable load profile, pulse output, and down loading facilities in local and remote mode.

iv. Current Transformers and Voltage Transformers for main meter and check meter

The minimum standard of accuracy of the voltage transformer for main and check meter shall conform to the latest relevant IEC Standard and be as follows:

i. For Generators, including IPP's, with total installed capacity exceeding 5MW, the accuracy shall be 0.2;

For Generators, including IPP's, with total installed capacity equal to or less than 5 MW, the accuracy shall be 0.5; and

The neutrals of the voltage transformer shall be solidly grounded and the secondary shall be suitable for a 3-phase, 4-wire Y-connection.

The rated secondary voltage of the voltage transformer shall be 110 volts

The Check Meter shall be supplied from a secondary core separate from the one feeding supply to the main Meter.

The minimum standard of accuracy of the current transformer shall conform to the latest relevant IEC Standard and be as follows:

i. For Generators, including IPP's, with total installed capacity exceeding 5MW, the accuracy shall be 0.2;

For Generators, including IPP's, with total installed capacity equal to or less than 5MW, the accuracy shall be 0.5;

The rated secondary current of the current transformer shall be one (1) ampere.

The Check Meter shall be supplied from a secondary core separate from the one feeding supply to the Main Meter.

However, since NEA being the sole purchase of the generated power, the energy meter should comply with the Grid code of NEA

v. Circuit Breakers

The circuit breakers shall be suitable for 3 phase, 50 Hz. The circuit breakers could be installed outdoor or indoor as per the requirements. All coils and the spring charging motor shall be suitable for 110V DC or 220V DC. Any auxiliary equipment shall be suitable for 3 phase-4 wire, 50 Hz, 400/230V AC. The circuit breakers used for the switchyard and interconnection application could be VCB or SF6 depending upon the transmission/interconnection voltage. A circuit-breaker with another combination of the rated values should not be outside the IEC Standard for circuit-breakers. Coordinated values of rated voltages, short-circuit breaking currents and rated normal currents of circuit breaker shall be selected from the tables shown below (Table 5-8; 5-9):

Table 5- 8 Co-ordination of rated values for circuit-breakers

Co-ordination table of rated values for circuit-breakers									
Rated voltage U (KV)	Rated Short-Circuit breaking current Isc (KA)	Rated normal current I_n (A)							
3.6	10	400							
	16		630		1250				
	25				1250	1600		2500	
	40				1250	1600		2500	4000
7.2	8	400							
	12.5	400	630		1250				
	16		630		1250	1600			
	25		630		1250	1600		2500	
	40				1250	1600		2500	4000
12	8	400							
	12.5	400	630		1250				
	16		630		1250	1600			
	25		630		1250	1600		2500	
	40				1250	1600		2500	4000
	50				1250	1600		2500	4000
17.5	8	400	630		1250				
	12.5		630		1250				
	16		630		1250				
	25				1250				
	40					1600		2500	
24	8	400	630		1250				
	12.5		630		1250				
	16		630		1250				
	25				1250	1600		2500	
	40					1600		2500	4000
36	8		630						
	12.5 16		630		1250				
	25		630		1250	1600			
	40				1250	1600		2500	
						1600		2500	4000
52	8			800					
	12.5				1250				
	20				1250	1600	2000		
72.5	12.5 16			800	1250				
	20			800	1250				
	31.5				1250	1600	2000		
					1250	1600	2000		

Note: - The values of the rated voltage are those given Sub- clause 4.1.1 of IEC publication 694 for Series I. The values of the short circuit breaking current and normal current are selected from those given in sub- clauses 4.101.1 & 4.4.

Table 5- 9 Co-ordination of rated values for circuit-breakers

Co-ordination of rated values for circuit-breakers							
Rated voltage U (KV)		Rated short-circuit breaking current I_{sc} (KV)		Rated normal current I_n (A)			
123	12.5	800	1250				
	20		1250	1600	2000		
	25		1250	1600	2000		
	40			1600	2000		
145	12.5	800	1250				
	20		1250	1600	2000		
	25		1250	1600	2000		
	31.5		1250	1600	2000	3150	
	40			1600	2000	3150	
	50				2000	3150	
170	12.5	800	1250				
	20		1250	1600	2000		
	31.5		1250	1600	2000	3150	
	40			1600	2000	3150	
	50			1600	2000	3150	
245	20		1250	1600	2000		
	31.5		1250	1600	2000		
	40			1600	2000	3150	
	50				2000	3150	
300	16		1250	1600			
	20		1250	1600	2000		
	31.5		1250	1600	2000	3150	
	50			1600	2000	3150	
362	20				2000		
	31.5				2000		
	40			1600	2000	3150	
420	20			1600	2000		
	31.5			1600	2000		
	40			1600	2000	3150	
	50				2000	3150	4000
525	40				2000	3150	
765	40				2000	3150	

Note: - The values of the rated voltage are those given Sub- clause 4.1.2 of IEC publication 694, omitting 100 KV. The values of rated short circuit breaking current and rated normal current are selected from those given in sub- clauses 4.101.1 & 4.4.

5.11 Power Evacuation and Transmission Line design

In order to design Transmission line, take-off yard and facilities at the interconnecting substation different option of transmission line route alignment and connecting substations has to be identified. Proper identification of indoor or outdoor substation has to be made and the design has to be performed accordingly. Power generated from generating stations shall be evacuated through nearby substation or the substations identified by the Power flow studies. The power evacuation study comprises of:

1) Identification of the nearest substation for the evacuation of generated power.
2) Conductor and Transmission line optimization for selecting the type of conductor used in transmission line, number of circuits and the transmission voltage.
3) Power flow and the Grid Impact study.
4) Grid Connection Agreement with the power purchaser (Nepal Electricity Authority).

The Transmission line design shall be done taking into consideration that the Transmission loss does not exceed 4.5% of the Received Energy.

The minimum protection scheme for short 132 kV lines shall consist of pilot wire differential or current differential through fiber optics or directional comparison relays with over-current and earth fault relays as backup.

The minimum protection scheme for long 132 kV lines shall consist of one protection distance relay and carrier transfer trip with over-current and earth-fault relays as backup. The distance protection scheme shall be of the permissive under-reaching or blocking scheme with protection zones 2 and 3 delayed trip. The distance protection relays shall have in-built facilities for fault locator, event recorder and disturbance recorder.

Out of step relays shall be provided with both primary and backup protection to check operation of relays due to power swing.

Each relay line terminal shall be provided with circuit breaker-failure protection for each circuit breaker.

Each line terminal breaker shall include single-pole tripping and three-pole tripping with single shot auto-reclosure.

The maximum permissible loading of Transmission line and sub-stations as declared by the Grid Code of Nepalese Power system shall be as follows:

A) For Normal Conditions
    a. Transmission Line Loading: <100% of the thermal capacity of line @85°C
    b. Transformer Loading: <100% of the rated transformer capacity.
B) For Single Outage Conditions
    a. Transmission Line Loading: <120% of the thermal capacity of line @85°C
    b. Transformer Loading: <120% of the rated transformer capacity.
C) For severe Outage Conditions
    a. Transmission Line Loading: <120% of the thermal capacity of line @85°C
    b. Transformer Loading: <120% of the rated transformer capacity.

Power Evacuation analysis with connecting sub-station options and voltage and conductor optimization, and evacuation analysis without violating N-1 contingency till second substation (for >50MW), till first subsequent substation for <=10MW and as per guidelines of the utility shall be followed for the planning studies.

6 ELECTROMECHANICAL AND HYDRO MECHANICAL DESIGN

6.1 Size of Powerhouse:

Size of the powerhouse should be fixed on the basis of relevant input and output parameters i.e.

Input Parameters:

a. Type of Powerhouse
   Type of powerhouse should be selected as per the topographical and geological condition at the site.
b. Type of turbine
   Selection of turbine should be made as per guidelines given in IS 12837:1989 or equivalent relevant code.
c. Turbine Orientation (Horizontal/Vertical)
d. Design Discharge (Max/Min.)
   Design discharge should be taken as per "Guideline for Study of Hydropower Projects, 2003" and depending up on the available hydrograph of the river; the design discharge (Q35, Q40, Q50, etc.) has to be selected.
e. Number of units.
   Optimization study should be carried out considering the hydrological, sedimentology report so that the generation of electricity can be continuous for at least single unit during the dry period and maintenance work can be carried out effectively
f. Tail water Level
   This plays an important role in case of francis or Kaplan turbine
g. Rated/ Design Head.
h. Max/Min. Head
i. Arrangement of runner removal
j. Location of MIV.
k. Location of Control Panels
l. Location of Transformers and switchyards

Output Parameters:

Following are the output parameters, necessary for dimensioning powerhouse

a. Speed (Specific speed, runner speed)
b. Suction head
c. Turbine center line
d. Runner dimension
e. Draft tube dimensions in case of Francis Turbine.
f. Spiral casing dimensions/ distributor dimensions.
g. Number of jets and diameter of jet in case of pelton turbines.
h. MIV specification
i. Generator dimensions
j. Thrust and loads

k. Spacing between units
l. Length, width and height of powerhouse

IS 12800.1.1993 can be used for preliminary dimensioning and layout of powerhouse. However, the final dimensioning should be verified after getting the exact dimension of machinery for the suppliers.

The overall dimension of powerhouse depends up on the dimension of the turbine, draft tube scroll-case, generator, number of units, size of erection bay, size of equipment in control room and the length required for the EOT crane to handle the last unit. The example for overall dimensioning can be found in the IS 12000.1.1993 and also chapter 57 Preliminary powerhouse design from the text book "Water Power Development by Emil Mosonyi, volume 1" can be used.

IS 7326:1992 (part 1, 2 and 3) can be used for main inlet butterfly valves design and selection

6.2 Preliminary dimension of main equipment

Powerhouse can be divided into three areas: unit bays, erection bay and service areas. In order to determine the size of unit bays, we need to determine numbers of unit, select the type of turbine and generating sets.

6.3 Selection of turbine type

The selection of turbine is decisive process based on principle site characteristics; design discharge, head and also flow variations and part load characteristics of turbine.

The most common types of turbine used in present context are as follows:

a) Impulse turbine: High head and low discharge
b) Reaction turbine: Low / medium head and high / medium discharge

The most important factor for selection of turbine is determining its specific speed. For that, rotational, or design speed should be finalized.

The rotational in r.p.m (n) = $\frac{60*f}{p}$

Where,

f = frequency in cycle per second.

p = number of pair of poles.

Now, the specific speed can be calculated as,

$$n_s = \frac{\sqrt{p * 1.358}}{H^{5/4}}$$

Where,

n_s = Specific speed of turbine in revolution per minute.

p = turbine output in kW

H = rated head in meters

The following figure shows the various turbines as the function of head and specific speed. Preliminary selection of turbine type can be done based on the figure 6.3-1.

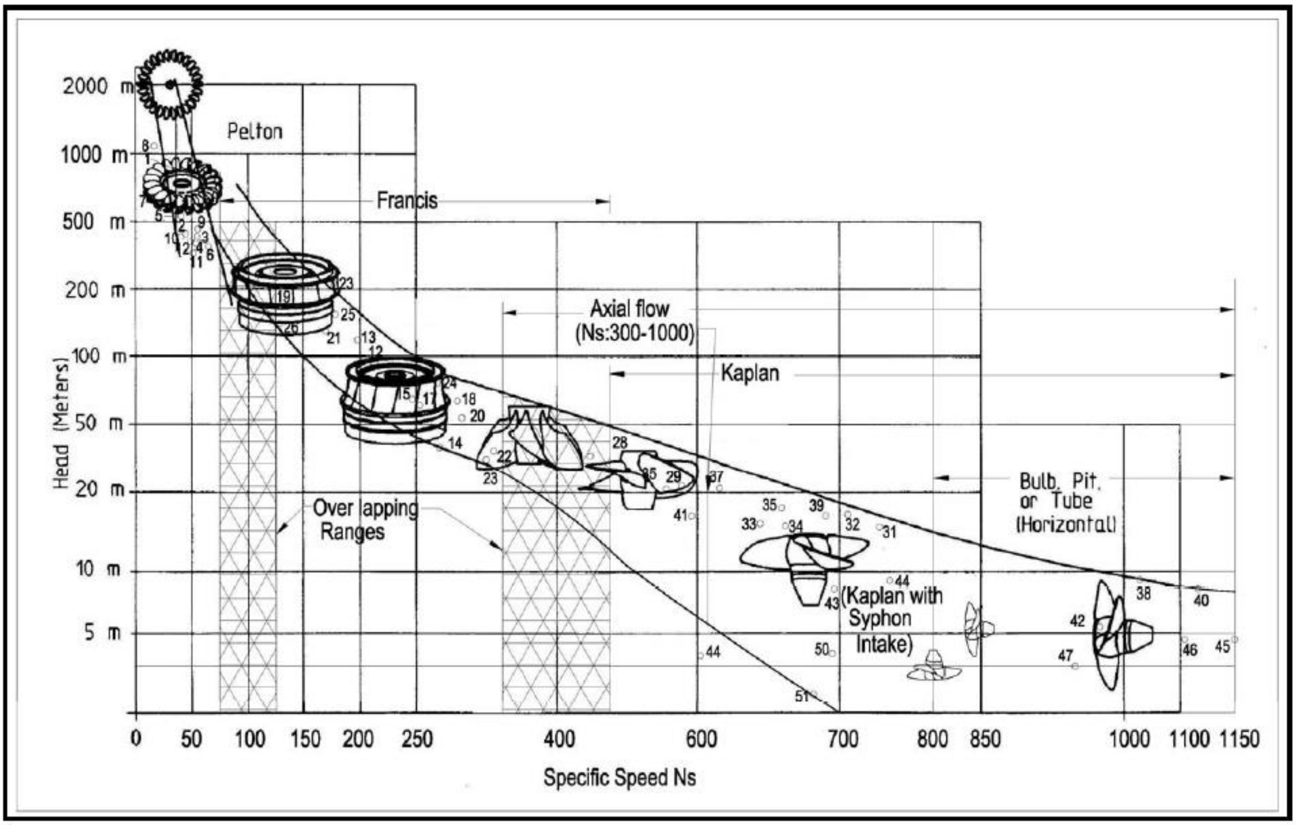


Figure 6.3- 1 Head Vs Specific Speed

(Source: The Guide to Hydropower Mechanical Design. ASME)

If the specific speed falls in overlapping ranges, selection of turbine should be done on the basis of following parameters:

a. Efficiency curves.

   Francis turbine has better efficiency curves than Pelton turbines.

b. Head variation.

   Pelton turbine is sensitive to head variation.

c. Operating conditions.

   Francis turbine performs better in part load conditions.

d. Turbine setting.
   Setting of Francis turbine can be below or above minimum tailrace water level whereas setting of Pelton is above. In case of Francis turbine additional head can be gained by increasing the setting height of turbine below the minimum tailrace water level.

e. Excavation.
   Setting for Francis is deeper than Pelton which require greater excavation for surface power house.

f. Size of unit and powerhouse size.

   Spacing between units is greater in Pelton which leads to wider & large power house.

g. Cost of generator.

   Cost of generator is higher for Pelton than Francis because of lower speed.

h. Maintenance.

   Easier & less expensive maintenance in Pelton.

6.4 Number of units

The capital cost per kW for a hydroelectric power plant of a given capacity decreases with a fewer number of units. Multiunit plants can efficiently meet large variations of load by varying the number of units in service to assure operation in the high-efficiency range. The service bay and plant equipment such as cranes, air compressors, oil handling equipment, etc. are smaller and can be used more efficiently. No doubt, single unit plants have lower operating and maintenance cost because there are fewer machines to service, but the service equipment must be larger and more expensive.

The cost for generator, turbine, governor and transformers decreases with increase in unit size. But, this may be offset by smaller service equipment and cheaper foundation for the small units.

Moreover, transporting the bigger units is a tedious task in Nepal due to its geographical difficulties. Thus, the number of units can best be determined by a careful weighing of the foregoing limitations and criteria.

6.5 Pelton Turbine

6.5.1 Shaft Alignment

The vertical shaft alignment allows use of multi-jet wheels (4 to 6 jets) which leads the increment of specific speed hence there is decrement of turbine size. Furthermore, it entails the possibility of reducing cavern width therefore, for larger units, vertical alignment is preferred.

The horizontal shaft alignment permits the use of only 1 or 2-jets. Recently few manufacturers have supplied horizontal turbine with three jets (as shown in figure 6.5-1). Hence, horizontal shaft is preferred for smaller and medium sized units.

Figure 6.5- 1 3-Jets Horizontal Shaft Pelton Turbine

(Photo Courtesy Sikles Hydropower Project)

6.5.2 Jet Diameter

The jet diameter can be determined as;

$$d_j = \sqrt{\frac{4 * Q}{z * \pi * v_1}}$$

Where,

d_j = Diameter of jet.

Q = Design discharge.

z = number of jet.

v_1 = jet velocity

$= \varphi \sqrt{2gH_n}$ [m/sec]

φ = velocity coefficient and ranges from 0.97 to 0.98.

g = acceleration due to gravity.

H_n = Design Head

Peripheral Velocity of turbine wheel can be determined as:

$speed\ ratio\ (k_u) = \frac{u}{v_1} = 0.45\ to\ 0.48$

Where,

u = peripheral velocity

v_1 = jet velocity

Pitch circle diameter of the turbine can be determined as:

$D = \frac{60\,u}{\pi n}$

Where,

u = peripheral velocity.

n = rated speed.

The jet ratio of pelton turbine should with this limit, i.e.

$9 < \frac{D}{d_j} < 15$

For safely avoiding damages from cavitation pitting and droplet erosion, actual pitch circle diameter should not fall below the limiting value. Typical wheel dimension of pelton runner is given in figure 6.5-2.

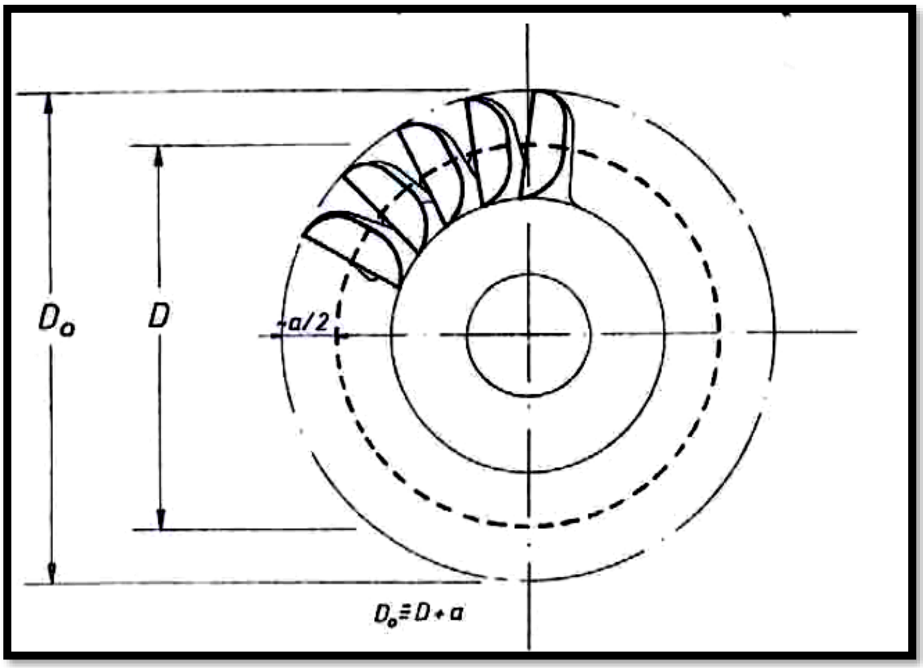


Figure 6.5- 2 Pelton wheel dimension

(Source: Emil Mosonyi, Water Power Development, Vol. 2/B, High Head Power Plant, 1991)

6.5.3 Pelton Turbine Arrangement

For vertical shaft arrangements,

the housing diameter can be estimated as;

$$L=0.78+2.06\,D_0$$

The roof height of the housing can roughly be valued at

$$h_R \approx 0.45\,D_0\,[m]$$

The setting height for the machine is obtained as,

$$h_s = (0.5\,to\,1) + 0.5D_o\,[m]\,9$$

The setting height should be high enough to avoid the back splash or foam reaching the runner.

Similarly, for horizontal shaft machine, the setting height of machine axis is

$$h_s = (0.5\,to\,1) + D_o - b/2\,[m]$$

Where,

b is bucket width.

The width of turbine pit should be approximately 4 times the bucket diameter.

Similarly, the width of the tail water flume may be determined as;

$$B_t = 1.5 + 0.75\,D_o\,[m]$$

The water depth, H_t in the wheel pit and in tail water flume is determined from discharge Q, flume width B_t and prescribed flow velocity v_t.

$$H_t = \frac{Q}{v_t B_t}\ [m]$$

Flow velocity can be presumed as 1 m/s for the first phase of planning. Figure 6.5-3 shows the setting out of pelton turbine.

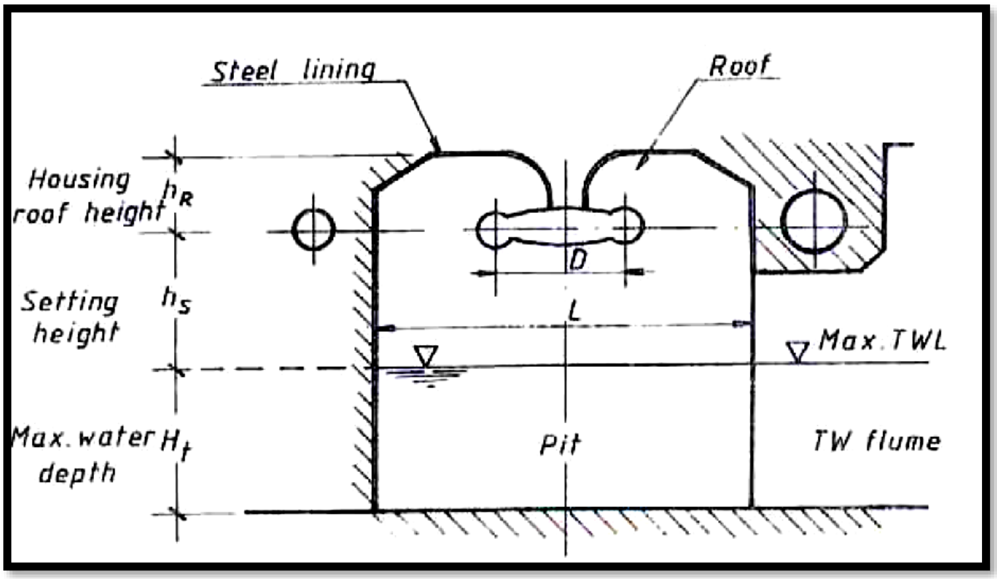


Figure 6.5- 3 Setting of Pelton turbine

(Source: Emil Mosonyi, Water Power Development, Vol. 2/B, High Head Power Plant, 1991)

6.5.4 Distributer of Pelton Turbine

The full size of the manifold as shown in figure 6.5-4 can be determined from the empirical relation;

$$M = 2 + 2.8D_0 \ [m]$$

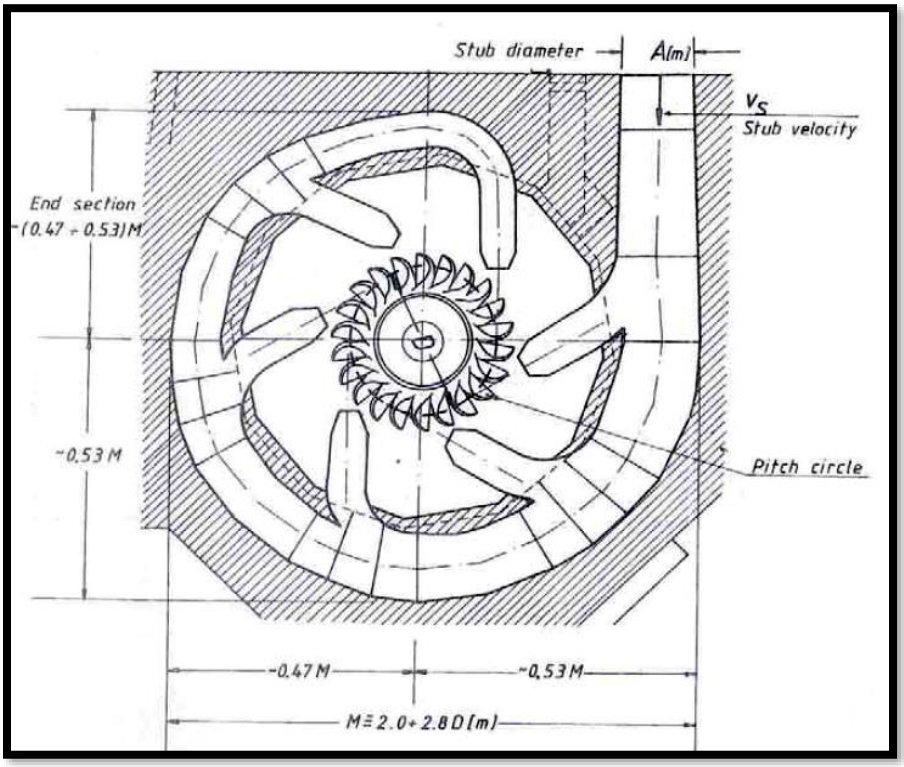


Figure 6.5- 4 Layout of distributor of Pelton turbine

(Source: Emil Mosonyi, Water Power Development, Vol. 2/B, High Head Power Plant, 1991)

The stub velocity can be determined as;

$$v_s = \frac{\sqrt{H_n}}{2.5} \ [m/\sec]$$

and stub area is

$$A = 1.13\sqrt{\frac{Q}{v_s}} \ [m]$$

6.5.5 Weight of Pelton Runner

The estimation of Pelton runner weight varies largely concerning upon no. of jets and other design considerations. However, order-of-magnitude estimation can be done from the equations as follows.

The full weight of horizontal shaft 1, 2- jet turbine can be obtained as;

$$G \approx \frac{35{,}000\,N}{H_n^{3/2}} [tons]$$

(Source: Emil Mosonyi, Water Power Development, Vol. 2/B, High Head Power Plant, 1991)

Where,

N = rated turbine output in megawatts,

H_n = rated head in meters, and

G = result in metric tons.

Similarly, for the vertical axis multi jet turbine, it is given as,

$$G = \frac{H_n}{\sqrt{N}} + \frac{2500\,N}{H_n^{\;1.2}}\ [tons]$$

(Source: Emil Mosonyi, Water Power Development, Vol. 2/B, High Head Power Plant, 1991)

For detail calculations it is suggested to use Emil Mosonyi, Water Power Development Volume 1 and 2 or any standard codes or best practice.

6.6 Francis Turbine

6.6.1 Turbine setting

The setting of reaction turbine should such that the problem of cavitation is avoided. The setting height is driven by the formula,

$$Hs = Ha - Hv - \sigma H$$

Where,

Hs is suction head

Ha= atmospheric pressure in meters

Hv=Water vapour pressure at the maximum expected temperature

σ = Thoma's cavitation coefficient

H = total net head (in meter)

The typical setting of Francis turbine is given in figure 6.6-1 and horizontal shaft arrangement is given in figure 6.6-2.

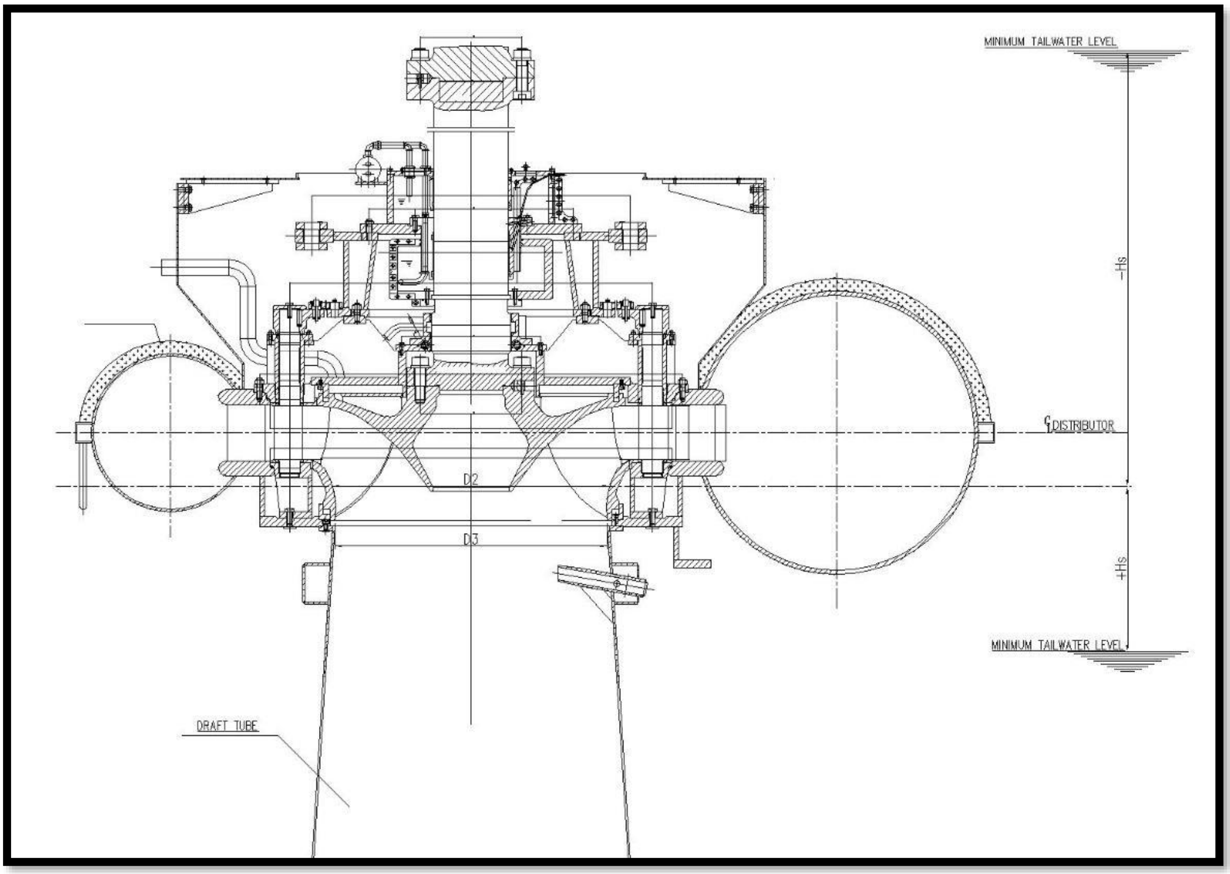
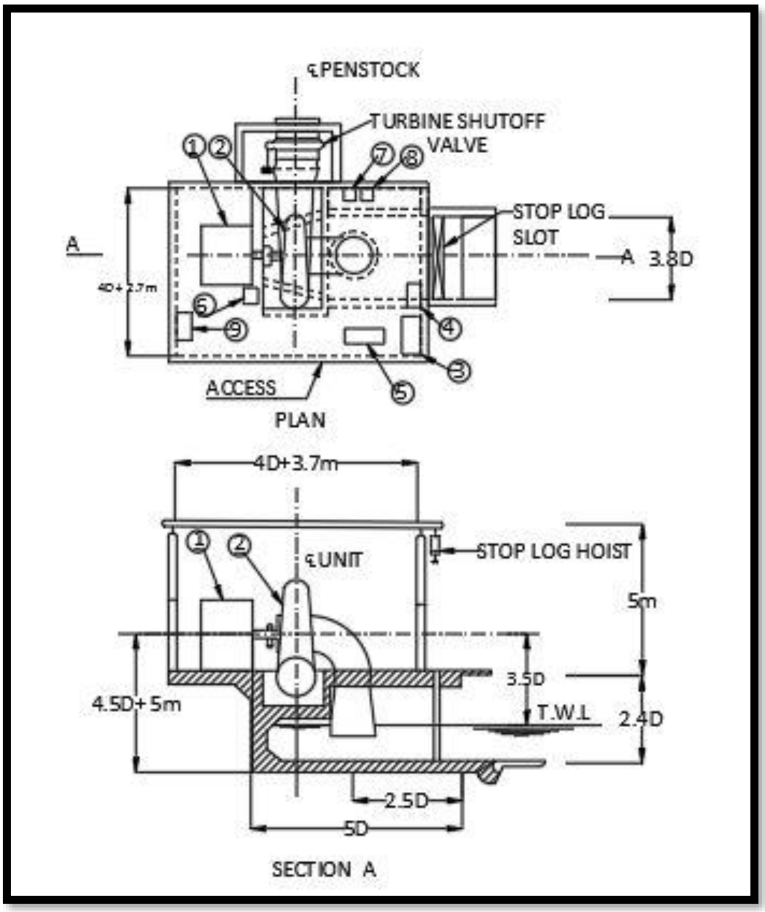


Figure 6.6- 1 Setting of Francis Turbine



Equipment

1 Generator

2 Turbine

3 Governor

4 Generator breakers

5 Control Panel

7 Cooling Pumps

8 Sump Pumps

Air Compressor and tank

Figure 6.6- 2 Horizontal Shaft Arrangement of Francis Turbine

(Source: IS: 12800(Part-3)-1991)

Positive value of obtained suction head indicates the setting above tailrace level and negative value indicates setting below tailrace water.

Calculation of suction head based on vapour pressure and thoma cavitation coefficient can be performed using international codes such as IS 12800 and USBR Engineering Monograph No. 20. Comparison of setting height for pelton and francis turbine is graphically represented in figure 6.6-3.

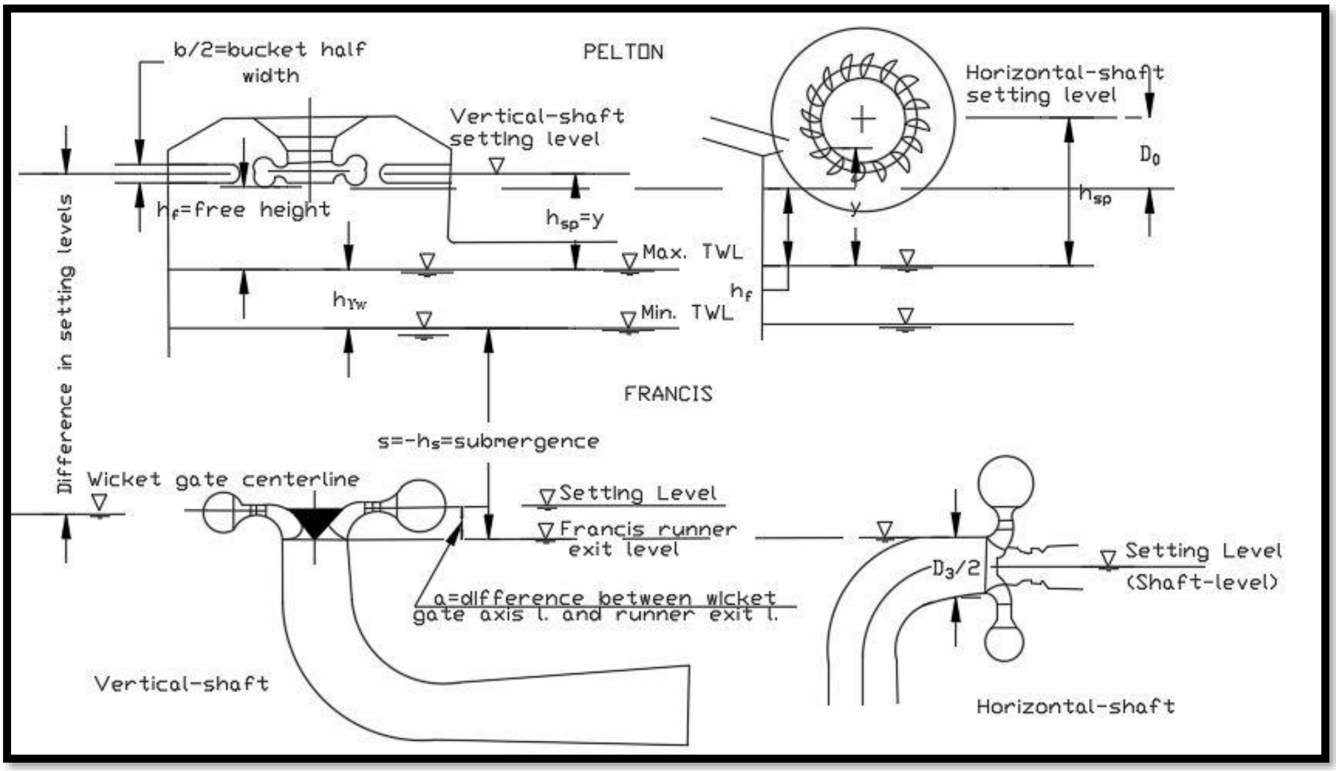


Figure 6.6- 3 Comparison of setting height of Francis and Pelton turbines

(Source: Water Power Development, Emil Mosonyi)

6.6.2 Runner

The major dimensions of Francis runner can be determined from IS 12800 or as per other standard codes and best practice.

6.6.3 Turbine weight

The preliminary weight of Francis runner can be determined from IS 12800 or as per other standard codes and best practice.

6.6.4 Draft Tube

The dimension of draft tube is mainly governed by the diameter of the runner. The design of the draft tube should be such that the total losses in draft tube and exit losses should be economically minimum. The major dimensions of draft tube can be determined from IS 12800 or as per other standard codes and best practice.

6.6.5 Air gap diameter

Air gap diameter (D_g) should be sufficient to allow the turbine runner top cover to pass through the stator bore. D_g depends on maximum permissible stresses in rotor parts and rims which depend on peripheral velocity on runway speed. IS 12800 or as per other standard codes and best practice can be used to determine air gap diameter.

6.7 Weight of Generator Rotor:

The preliminary weight of generator rotor can be determined from IS 12800 or as per other standard codes and best practice.

6.8 Layout of powerhouse

6.8.1 Position of unit bays and erection bays

Unit bay is the main feature, consisting unit turbine and generator set, about which other areas are grouped. Hence, size and layout of power depends on arrangement of multiple unit bays. Unit bays may be arranged in single row or multiple rows. If the site condition doesn't favor all the units in the same row, which increases powerhouse length, the units can be arranged in two rows making same elevation level of turbine but varying outlet of draft tube.

6.8.2 Dimension of Powerhouse

The dimension of powerhouse depends on;

a. Unit bays
b. Erection bay
c. Service areas

6.8.2.1 Unit bays

Unit bays consist of main components of generating units. As already stated, size of unit bay depends upon size of turbine and generators. One more element affecting the size is spiral casing which is the one covering more floor area in each unit bays.

6.8.2.2 Erection Bay

Erection bay can be placed either at end or in the center of a multi-unit hydro plant. In underground plants it is usually near the access tunnel. It is continent to keep level of erection bay same as generator floor.

6.8.2.3 Service Areas

Service areas include offices, control and testing rooms, storage rooms, maintenance shop, auxiliary equipment room, and rooms for special uses. The offices are frequently located on upper floors, and the control room and other service rooms on lower floors.

6.8.3 Spiral Casing

There are two types of spiral casing; metallic and concrete spiral casing. For the height above 30m, metallic spiral casing is used. The major dimensions of spiral casing can be determined from IS 12800 or as per other standard codes and best practice.

- **Distance Between Units**

To determine the center distance between two units, the above space determining components should be drawn in plan. The outer diameter of generator barrel should be determined by adding 0.5 to 1.5m in size of inner diameter of generator barrel. After then, a clearance space of 1.5m to 2m should be added to each side of extremities to determine unit bays space.

Major dimensions can be determined from IS 12800 or as per other standard codes and best practice.

- **Erection Bay**

In general, the length of erection bay should be located at the end of the generator room, at the same floor level if possible. The length of erection bay should be at least the size of one-unit bay.

- **E.O.T. Crane**

The length of EOT crane track should be such that it should allow crane to handle equipment of all the units.

The safe working load of E.O.T crane should be at least 125% of maximum load to be handled. The following codes can be referred for design and selection of EOT and gantry cranes:

IS:3177-1999- Code of practice for Electrical Overhead Traveling Cranes and Gantry Cranes

IS: 807- Structural design of crane

6.8.4 Powerhouse Length

The overall length of powerhouse should be

L= No. of units times unit spacing + Length of erection bay + Length required for EOT crane to handle last unit which is usually 3-5 m.

Reference of IS 12800 or as other standard codes and best practice can be taken.

6.8.5 Powerhouse Width

In the drawing of plan showing space determining components, the powerhouse downstream superstructure column should be in distance of 2 to 5 m. Whereas in the upstream side, provision should be made for;

a) Clearance of about 1.5 to 2m for concrete the upstream of scroll case

b) Gallery of 1.5 to 2m width for approaching the draft tube manhole.

c) Main inlet valve is accommodated as per IS 7326.

d) A clearance of 1.5 to 2m is required for pressure relief valve in scroll casing.

Reference of IS 12800 or as other standard codes and best practice can be taken.

6.8.6 Height of Powerhouse

The height of powerhouse from base of draft tube to centerline of spiral casing is obtained from IS 5496 and the height of powerhouse from centerline to the top of generator is obtained as;

Height= Length of stator frame + Height of load bearing bracket + (5.5 to 7m depending upon the size of machine)

The height of machine hall above the top bracket depends on the EOT crane level and clearance required between the ceiling and the top of crane which are determined according to clearance required for moving major items of equipment like runner, generator, shaft, main transformer with bushing, tanking of transformers. The height of the power house ceiling above the highest level of EOT crane hook may vary from 4 to 6 m.

Reference of IS 12800 or as other standard codes and best practice can be taken. (*A Detailed Example of Dimensioning of Powerhouse is presented in Annex 1)*

6.9 Hydro-mechanical components

6.9.1 Guard/Penstock Inlet Valve/ Gate:

When the headrace tunnel (or pipe/canal) is very long, the water flowing into the penstock cannot be stopped without dewatering them. In order to avoid this situation a valve or gate is provided immediately downstream of surge tank. This will allow to do repair and maintenance works in penstock and turbine inlet valve without dewatering headrace tunnel (or pipe/canal).

If such gate/valve is meant for closure in emergency closure they are called penstock guard valve/gate. They are meant for sudden closure in case of rupture of penstock pipe downstream of it.

Closure time for Guard Valve should be 10-12 seconds and opening time should be 120-180 seconds.

6.9.2 Penstock bifurcation:

Wherever, there are multiple generating units in powerhouse, separate manifolds are required for each unit. If the penstock length is less, separate penstock pipes can be managed for each manifold. However, when the penstock length required is large, it becomes economical to use branches; bifurcation or trifurcation. In order to minimize the head loss in bifurcations, the branch angle should be limited within 45° to 60°. Beyond this range, there is significant increase is head loss.

6.9.3 Turbine Inlet Valve:

The turbine inlet valve is required at the powerhouse at the end of the penstocks. The purpose of this valve is to provide emergency shutoff in case of flooding-type failure, loss of speed control, and maintenance of turbine.

For operational and maintenance flexibility separate inlet valve for each unit should be used. The design head should include water hammer effect in case of emergency closure of valve.

Turbine inlet valve body should be designed to avoid abrupt changes in velocity. Size of the valve should normally be the same as that of inlet diameter of the spiral case/distributor. However, reduction in the size can be considered taking into consideration the extra head loss in the reducer and expander. Water passage may be so shaped so as to give either constant velocity or to give a gradual increase in velocity in the direction of flow. Minimum loss of head should be kept in view while designing.

Turbine inlet valve normal opening time should be 60-120 seconds, normal closure time should be 60-100 seconds and emergency closure time should be 10-12 seconds.

Most commonly used closure valves are discussed below:

- **Butterfly Valves:**

Butterfly valves are used for closure service involving heads up to 122 meters and inlet diameters up to 9 meters.

- **Spherical Valves:**
  Spherical valves are used for closure service involving heads up to 1,200 meters and inlet diameters up to 4.6 meters.

Standard Size and design considerations of Spherical Valves and Butterfly Valves can be selected as per IS: 7332.1 (1991) and IS: 7326.1 (1992) respectively or as per standard codes or best practice.

6.9.4 Draft tube gate

Draft tube gate is required to stop the tailrace water from entering the turbine section during maintenance of turbine and draft tube. The gates may either be just downstream of the main powerhouse wall or at the end of the draft tube. Draft tube is incorporated with Francis turbine so there is draft tube gate whereas draft tube is not incorporated with Pelton turbine so there is no draft tube gate.

7 AUXILIARIES

7.1 Governors

The governors should be located of the turbine floor. The governor operating requirements and characteristics will be determined from the electrical, mechanical and hydraulic characteristics of generator, turbine and penstock.

7.1.1 System Pressures

The nominal pressure of governor - servomotor systems in selected from a series of standard pressures ranging from 2067-6890 kPa. Since turbine contracts are normally scheduled in advance of governor contracts, the nominal pressure will have to be determined before the governor specifications is prepared.

7.1.2 Oil Heaters

The minimum ambient temperature may be of significance in determining the need for oil heaters if oil of higher viscosity than standard turbine oil will be used in the governor system. If oil heaters are used, care must be taken to ensure that the surface temperature of the oil heater does not cause any chemical change of the oil, such as chemical breakdown.

7.1.3 Pressure Tank

The pressure tank for the governor should be located with the shortest and most direct lines practicable from the tank to the actuator and servomotors in order to minimize pressure losses.

7.1.4 Maximum runaway speed

The maximum runaway speed to be specified should be based on the turbine model test results.

7.1.5 Brake air valve

The air pressure for the brake air valve should normally be specified at a nominal 689kPa. If there is a reason to expect the service air will be controlled to a higher pressure, the powerhouse construction contract should require a pressure-reducing valve in the brake system air supply.

7.2 Oil system

Generally, two systems; governor lubrication oil and insulating oil are required for powerhouses. Insulating oil is used for transformer and circuit breakers. Design should be based on the complete separation of two oils including purifying and storing.

Oil storage room should be located at a low elevation in the powerhouse. Purification equipment should be managed in same room is desirable to simplify CO_2 fire protection. A provision of personal emergency escape door should be made.

Clean and dry insulating oil tank should be provided with capacity of minimum 110 % of oil required to fill the largest transformer and each clean dry governor oil tanks should hold a minimum of 110% of the oil required to fill the governor system and all the bearings of the largest generator- turbine unit.

7.3 Compressed Air System

Compressed air system is required for operation and to facilitate repair and maintenance. Service air, brake air and governor air are the three systems needed in all powerhouses. Compressors should be heavy duty, water cooled and flood lubricated. Compressor room should be located in a noncritical noise area on a solid foundation free from vibration having adequate ventilation for temperature control and compressor intake. Service air, brake air, and governor air comprise, all three systems are needed in all powerhouses. Some powerhouse will require a draft tube water depression system in addition. Reliability, flexibility, and safety are prime design considerations.

7.3.1 Service Air System

The service air system is a nominal 700-kPa (100-psi) system providing air for maintenance and repair, control air, hydro pneumatic tank air, charging air for the brake air system, and in some cases, air for ice control bubblers.

7.3.2 Brake Air System

The brake air system comprises one or more semi-independent storage and distribution installations for providing a reliable supply of air to actuate the generator braking systems. Air is supplied from the service air system, stored in receivers, and distributed through the governor actuator cabinets to the generator brake systems.

7.3.3 Governor Air System

The governor air system provides the air cushion in the governor pressure tanks. When the governor system is to be placed in operation, the pressure tank is filled approximately one-fourth full with oil, and the tank is then pressurized to governor-operating pressure from the governor air system. The governor pressure tank size and operating pressure will be determined by the turbine servomotor volume.

7.3.4 Draft Tube Water Depression System

A draft tube water depression system is required in plants with submerged turbine or pump-turbine runners where planned operations include the operation of one or more main units for synchronous condenser operation, motor starting for pumping, or spinning reserve. The system function is to displace and maintain draft tube water to a level below the turbine runner permitting the runner to turn in air.

7.4 Heating Ventilating and AC system

Powerhouse heating, ventilating and air conditioning are required to maintain temperature and air quality conditions suitable for operating equipment, plant personnel and visitors. Heating sources may be generator cooling water, solar heat, outside air, pool water, electricity, oil-gas, etc. Maintaining required conditions for operating equipment is essential under all weather conditions at the site. Personnel and visitor design conditions are also important, but temporary deviations under weather extremes can be tolerated and should be reflected in the design.

7.4.1 Design Conditions

Assumed design conditions, both outside and inside the powerhouse, have major effects on system adequacy, construction costs, and operating costs since they influence the type of equipment provided. Sufficient engineering time for research and coordination of available data is essential to a practical design. The external conditions include Weather, Water Temperatures, Ground and Rock Temperatures while the internal conditions include Temperature-humidity and Ventilation. All these factors must be considered during the design.

7.4.2 Design Sections

The design should be conservative while providing acceptable operation with nominal decreases in operating efficiency and average maintenance. Unnecessary compilations to achieve ideal conditions under all operating extremes should be avoided. Heat gains from lights and equipment should be included in both heating and cooling load requirements with due reward for both initial and long -range plant operations.

7.5 Fire Protection System

Powerhouses are generally low fire hazard structures with special installed fire protection usually limited to the four specific hazards: oil storage and purification rooms, paint and flammable storage room, main power generators, and transformers. The principal fire protection for all other areas and hazards are portable extinguishers and fire hoses. Manned fire hoses are not generally required on as the first line fire protection because of the potential damage to equipment inherent in powerhouses. The deck washing systems provided in all powerhouses offer limited fire protection in most areas. NFPA Standard 851 and ETL 1110-2-311 provide guidance for fire, protection for hydroelectric generating plants, and hydroelectric power plants, respectively. Fire protection systems using Halons are prohibited.

7.6 Water Supply System

The water supply system should provide water for generator air coolers, bearing coolers, turbine bearing coolers, wearing rings and glands, transformer cooling, fire protection, domestic water, air conditioning systems, and compressors and after coolers.

7.7 Dewatering and Drainage System

Dewatering and drainage system provides the means for dewatering main unit turbines and their associated water passages for inspection and maintenance purposes as well as the collection and disposal of all powerhouse leakage and wastewater other than sanitary. The safety of personnel and plant is of vital concern in this system and should have continuing priority throughout the design.

7.7.1 Dewatering System

The principal volumes to be dewatered in all powerhouses are the spiral case and draft tube. In addition, there is usually a considerable volume downstream of the head gates or the penstock valve. Some projects include extensive fish passage facilities with large volumes of water in pumps, channels, and conduits to be dewatered.

7.7.2 Drainage System

The drainage system handles three general types of drainage as follows; rain and snow water from roofs and decks, leakage through structural cracks and contraction joints, and wastewater from equipment. Discharge is to tail water either by gravity or by pumping from a drainage sump.

7.8 Portable Water System

Portable water system is required for drinking, washing and sanitation. Possible source of portable water includes wells, surface supply etc. The supply chosen for the portable water system should meet the standards for bacteriological quality, physical, chemical and radiological characteristics.

7.9 Battery and Backup System

Stationary battery or batteries each complete with battery charger, distribution board and control gear are to be provided for generating equipment's operation, control, and protection and for switching equipment and shall have sufficient capacity for the present scope of works.

The battery located in a battery room shall be connected to the distribution board and battery charger. AC supply shall be connected to battery system from low tension panel by suitable sized PVC cable.

Engine generator set are provided as an emergency power source in case of station service power failure. The requirements for an emergency engine generator are dependent on the reliability of station service power. However, it is justified in case of plants without station service generators.

The location of engine generator set should be decided considering access, space for maintenance, noise, ventilation, exhaust piping, fuel piping, humidity and temperature. Hence, a location within powerhouse structure with dependable, controlled temperature conditions and moderate noise isolation from the main working areas and occupied areas is preferred.

7.10 Control and Protection System

Generator and turbine control equipment are to be located in their respective floors. Whereas, supervisory and telecommunication equipment is adjusted in available floor.

7.11 Communication System:

Reliable communication system that are required for operation of power house are voice communication, dedicated communication system for SCADA, circuit types of line protective relaying and telemetering etc. Additionally, the available communication media can be leased telephone lines, metallic cable power, power line carrier, radio frequency communication, micro wave (MW) communication system, fiber optics and satellite communication. The following documents can be referred for the detailed information on communication system:

- ANSI/IEEE 1010-1987
- US Army of Engineers Engineering Manuals
- Relevant National/International Standards

8 MAINTENANCE SHOP

Maintenance shops are provided to facilitate preventive maintenance and to use moderate repair capacity. The intent is that each powerhouse has the capability to take care of the average work promptly and efficiently. The maintenance shop layout should provide adequate space and power for both initial and future requirements of installed and portable equipment. However, the workshop inside powerhouse can be omitted if well-equipped workshop is available near to the powerhouse and equipment transport is easy.

8.1 Shop Room

The shop room should be located close to the erection bay and preferably on the same floor. The location should facilitate the convenient transporting of tools, equipment and materials. The shop area should be enough for dismantling and reassembly, safe and effective movement of personnel.

8.2 Equipment Selection

Various equipments are required to be placed within the maintenance shops. The equipment may vary depending upon the size, location, availability and cost.

8.2.1 Shop layout

Machines should be located to provide good access for placing parts and materials in each machine. Repair oriented shops normally require more free area around machines than production shops where specific operations can be scheduled. Power should be provided for all fixed machines to be installed and for portable tools at benches and assembly areas.

9 OCCUPATIONAL HEALTH AND SAFETY

Labor Act, 2017 requires employer of any industrial entity to provide conducive working environment by making adequate and appropriate arrangements to protect health and safety of workers at workplace. Hydropower station (powerhouse) involves potential risks for the health and lives of persons as well as for the environment. Therefore, a particularly high level of safety is required for such plants. The implementation of such high safety standards in power plants begins with ensuring the powerhouse design incorporates all aspects of health and safety of the people working inside the powerhouse in a long term perspective. When designing and implementing a hydropower station, required standard of workplace health and safety and the scope of work necessary to achieve that standard have to be duly and thoroughly considered.

Safety systems for hydropower plants can be complex and sophisticated, but simple systems can also be robust – it all depends on the specific requirements of the facility in question (Canning A., 2015). The designer should have the clear understanding of the relevant legislations, building codes and other specific codes pertaining to safeguarding health and safety of the personnel inside a powerhouse.

A preliminary assessment on potential hazards of a powerhouse system and potential risks of such hazards would be necessary to understand what is required to be incorporated in the design such that a powerhouse could be made free from recognized hazards that are causing or are likely to cause death or serious physical harm to anybody inside a powerhouse.

9.1 Drainage, Dewatering and Flood Protection

IS 4721:2000 "code of practice for drainage and dewatering of surface/underground hydroelectric power station" can be referred for the design of drainage systems (both pressure and gravity) and dewatering systems for both surface and underground powerhouse.

- Gravity Drainage System is applicable in order to drain leakage water from penstock coupling, generator coolers, scroll case liner, turbine cover, transformer coolers, drainage from formed drains at expansion/contraction joints, compressor cooling water, air conditioning cooling water, ventilation cooling water (for underground power house), hydrant firefighting systems and for other discharges intermittent in character to drain these waters into either a tailrace or a drainage pipe laid outside the power house building or a sump within the power house building from which the water is pumped either to the tailrace or to a drainage. It is though desirable to adopt both the alternatives in any power house building to keep the amount of pumping from the sump, at minimum.
- The pressure drainage system is to be provided independent for each unit of the power house in order to drain cooling water from the bearings, generator, transformer and ventilation cooler of each unit to various outlets above maximum tail water level. This system is subject to the losses in pipes and should be designed to run full at all times. In case of underground power houses, cooling water shall be discharged into draft tube directly.

- Provision of pumps should be considered in order to dewater the penstock, scroll case, draft tube and discharges into a tailrace or collection gallery through embedded pipes, when required.

Powerhouse flooding can be caused due to;

- Failure of drainage pumps which can lead to a slow increase in the water level and eventual flooding of the station.
- A plant failure and leakage that drainage pumps cannot manage and eventually cause rapid flooding of the station.

The powerhouse design shall incorporate;

- Flood protection schemes so as to automatically close intake gates or valves in order to keep turbines operating to drain the headworks and penstocks of water to control flooding,
- Automatic systems to stop the plant operation before the water levels become critical.
- An alarm system to inform powerhouse workers on flood situation and evacuation requirements
- Proper drainage and dewatering system in order to sufficiently drain out the water continuously

9.2 Electrical Safety

Electric arrangements in any entity shall consider its adequacy for intended purpose and more importantly its safe and efficient use. Powerhouse electric design shall confirm with NBC 207: 2003 “Electrical Design Requirements for Public Buildings”. Furthermore, the National Electrical Safety Code of the IEEE code can be referred for designing electrical installations in powerhouse building.

9.3 Fire Safety

9.3.1 General

The following are the common fire hazards in a power station;

- Unsafe conditions such as electrical short–circuit, earth fault, overheating in electrical circuits and electrical contact getting stack up, hot surface or excessive heating due to friction or lack of cooling, leakage of inflammable gas or liquid, accumulation of static charges etc.
- Unsafe acts such as smoking in "No Smoking" area, bad housekeeping causing scattered combustible materials, openly storing combustible materials or storing them near a heat source, carrying out spark generating activities such as gas cutting, welding splatters etc. close to combustible materials

Common fire risk areas in a powerhouse complex are;

- Oil filled transformers,
- Battery rooms,
- Cable galleries, electrical cables and switchgears

- Control room,
- Store room,
- Fuel storage room, and
- Air cooled generators.

There are five classes of fire and a powerhouse is susceptible to all of these classes. Table 9.1 provides details on classes of fire with their respective definitions, sources and preferred put off agent.

Table 9. 1 Classes of Fire

Fire Class	**Definitions**	**Source of Fire**	**Preferred Extinguishing Agent**
Class A	Ordinary Combustibles	Wood, fabric, paper, trash and plastics etc.	Water or mono-ammonium phosphate
Class B	Flammable liquid or gas	Petroleum based oils and paints, kerosene, gasoline, butane, propane etc.	
Class C	Electrical Component/Energized equipment	Motors, appliances and transformers etc.	Nonconductive chemicals
Class D	Combustible metals	Titanium, Magnesium, Aluminium, Potassium etc.	Dry powder agent
Class K	Cooking fire	Greases, cooking oils, vegetable and animal fats etc.	Wet chemical fire extinguisher

9.3.2 Fire Protection

- Fire safety in a powerhouse can be ensured through an integral approach of;
- prevention,
- detection, signaling and alarming,
- suppression and
- emergency evacuation for life system safety.
- At the detailed design stage of the project, a separate fire protection design analysis shall be carried out.

The fire protection design analysis shall incorporate a minimum of following considerations;

a. Identify applicable codes and standards relating to fire protection and life safety. A list of relevant codes and standards are provided hereunder in Table 9-2 for reference, however, these are not the exclusive ones. The designer, on the basis of his experience and specific requirements of the project under development can refer to other available relevant codes.

b. Carry out analysis of available building codes
c. Classify occupancy
d. Analyze requirements for fire walls, fire barriers, partitions, smoke partitions, compartmentalization and special hazard protection as well as fire resistance rating.
e. Assess requirements for protection of horizontal and vertical penetrations and openings as well as the associated fire resistance rating.
f. Study requirements on separation from hazards
g. Discuss means of egress provisions and components considering occupant load, exit capacity, exit width, travel distance, common path of travel, dead end corridors etc.
h. Calculate fire flow requirements, water supplies and distribution network for fire protection, location of fire hydrants
i. Location of Post Indicator Valves (PIVs) and other control or isolation valves.
j. Carry out analysis of automatic sprinkler sand suppression systems and protected areas with supporting calculations on system performance requirements such as hydraulic analysis of water demand, agent concentration and quantity.
k. Analyze requirement of stand pipe systems
l. Analyze requirement of portable fire extinguishers
m. Assess requisite of fire detection systems in view of the type of detection and type and location of detectors
n. Assess requisite of fire alarms system in terms of type, locations and mass notification arrangements.
o. Discuss smoke management or control methods
p. Assess requirements for fire department access

Table 9. 2 Fire protection systems related codes and standards

Codes	Description
Nepal National Building Codes	
NBC 107:1994	Provisional Recommendations for Fire Safety
NBC 206:2003	Architectural Design Requirement
NBC 207:2003	Electrical Design Requirements for Public Buildings
Unified Facilities Criteria, USA	
UFC 3-600-01	Fire Protection Engineering for Facilities
National Fire Protection Authority, USA	
NFPA 851	Recommended practice for fire protection for hydroelectric generating plants and high voltage direct current converter stations
NFPA 10	Standard for Portable Fire Extinguishers, 2002 edition.
NFPA 11	Standard for Low, Medium, and High Expansion Foam, 2005 edition.
NFPA 12	Standard on Carbon Dioxide, Extinguishing Systems, 2000 edition.

NFPA 12A	Standard on Halon 1301 Fire Extinguishing Systems, 2004 edition.
NFPA 13	Standard for the Installation of Sprinkler Systems, 2002 edition.
NFPA 14	Standard for the Installation of Standpipe and Hose Systems, 2003 edition.
NFPA 15	Standard for Water Spray Fixed Systems for Fire Protection, 2001 edition.
NFPA 16	Standard for the Installation of Foam Water Sprinkler and Foam Water Spray Systems, 2003 edition.
NFPA 17	Standard for Dry Chemical Extinguishing Systems, 2002 edition.
NFPA 20	Standard for the Installation of Stationary Pumps for Fire Protection, 2003 edition.
NFPA 22	Standard for Water Tanks for Private Fire Protection, 2003 edition.
NFPA 24	Standard for the Installation of Private Fire Service Mains and Their Appurtenances, 2002 edition.
NFPA 25	Standard for the Inspection, Testing, and Maintenance of Water - Based Fire Protection Systems, 2002 edition.
NFPA 30	Flammable and Combustible Liquids Code, 2003 edition.
NFPA 30A,	Code for Motor Fuel Dispensing Facilities and Repair Garages, 2003 edition.
NFPA 31	Standard for the Installation of Oil Burning Equipment, 2001 edition
NFPA 51B	Standard for Fire Prevention During Welding, Cutting, and Other Hot Work, 2003 edition.
NFPA 72	National fire alarm and signalling code, 2016 edition.
NFPA 75	Standard for the Protection of Information Technology Equipment, 2003 edition.
NFPA 80	Standard for Fire Doors and Fire Windows, 1999 edition.
NFPA 80A,	Recommended Practice for Protection of Buildings from Exterior Fire Exposures, 2001 edition.
NFPA 90A	Standard for the Installation of Air Conditioning and Ventilating Systems, 2002 edition.
NFPA 90B	Standard for the Installation of Warm Air Heating and Air - Conditioning Systems, 2002 edition.
NFPA 101	Life Safety Code, 2003 edition.
NFPA 110	Standard for Emergency and Standby Power Systems, 2002 edition.
NFPA 204	Standard for Smoke and Heat Venting, 2002 edition.
NFPA 750	Standard on Water Mist Fire Protection Systems, 2003 edition.

NFPA 780	Standard for the Installation of Lightning Protection Systems, 2004 edition.
NFPA 1221	Standard for the Installation, Maintenance, and Use of Emergency Services Communications Systems, 2002 edition.
NFPA 1901	Standard for Automotive Fire Apparatus, 2003 edition.
NFPA 1971	Standard on Protective Ensemble for Structural Fire Fighting, 2000 edition.
NFPA 2001	Standard on Clean Agent Fire Extinguishing Systems, 2004 edition.
Institute of Electrical and Electronics Engineers (IEEE), USA	
IEEE 484	Recommended Practice for Installation. Design and Installation of Large Lead Storage Batteries for Generating Stations and Substations, 2002.
Indian Standard Codes	
SP7:2016	National Building Code of India 2016 (NBC 2016) Volume 1 and Volume 2, Bureau of Indian Standards
IS 10386: 2003 (first revision Feb 2015)	Construction, operation and maintenance of river valley projects- Safety Codes, Part 7 Fire Safety Aspects

Some of the general design considerations to be followed for designing fire protection in a powerhouse structures are as follows;

- Storage rooms for oils, fuels, lubricants, chemicals (such as paints, varnishes, lacquers, thinners etc.) should be located in an isolated area from any potential sources of fire and sparks. Such storage area should be provisioned with ventilation such that any vapour can escape easily from the confinement.
- Suitable clearance distance should be provided between the combustible materials and heating devices as well as hot water pipes.
- Provide with sand, pebbles or other non-flammable slab coverings in the cable trenches containing electrical cables inside powerhouse. Specify requirement of flame retardant cables.
- Provide oil trapping mechanism in oil storage rooms and equipment and oil filled machines and equipment to prevent spread of spilled oil
- Excessive heating of the motors can be prevented by using over-current and under-voltage protection.
- While designing electrical layout, control cables and power cables should be sufficiently separated and locating the cables possible source of fire hazards as well as minimizing vertical stacking of the power cables. For an example, physical separation between the cable trays should range between 2.5 and 4.5 times the width of the tray in vertical direction and 1 to 1.5 times in a horizontal direction. For example, to prevent

propagation, 0.6-meter-wide trays should be vertically separated from each other by 1.5-2.75 meter and horizontally by 0.6-0.9 meter.

- Cable size selection should consider permissible maximum temperature it can withstand (IS 1255:1965)
- Provide fire sealing/fire barrier using non-combustible materials to provide fire-stopping to prevent fire spread from one compartment to another.
- A lightning arrester shall be provisioned in the highest part of every building (Surface and Semi-surface powerhouse buildings in this case) and it shall be connected by a conductor to an earth rod buried in the earth. The lightning arrester shall be so located that as much as possible of the building lies inside the surface of an imaginary cone having a vertex angle of 45 degrees and its apex at the top of the arrester (NBC 107:1994).
- A means of isolation of possible fire and smoke in the power plant should be provided. Ventilation systems should be designed or modified to evacuate smoke and toxic particles to allow for emergency access and egress. Fire barriers and smoke control barriers should be provided to prevent the transmission of the fire and smoke from one area to another.
- CO_2 systems should be provided for the generator, oil storage and purification rooms, and flammable storage rooms. Water deluge systems should be provided for large outdoor oil filled transformers when the transformer is located on or adjacent to the structure. Halon systems may be provided for control rooms, computer rooms and record storage rooms. Water suppression systems for oil filled pipe cable, cable galleries or tunnels, and spreading rooms.
- Sufficient means of access and egress should be provided to allow the rapid evacuation of all occupants in the event of fire.

9.4 First Aid

A first-aid room should be planned adjacent to the control room, if practicable, or otherwise on either the office or locker floor level. This room should contain a first-aid cabinet, a cot, and a lavatory and should have rubber or vinyl-plastic tile floor and cove base, painted walls, and ceiling. The door should be wide enough to accommodate a stretcher.

9.5 Emergency Evacuation for Life Safety

The life safety design requirements for all structures including the hydroelectric powerhouse share the same goal i.e. getting the building occupants out of the building in a safe and orderly fashion in case of emergency before conditions in the building become dangerous. Therefore, powerhouse designer shall consider the following;

- All powerhouses should have at least one or more independent ways of exit during the time of crisis (regardless of the nature of the crisis) in order to ensure all the personnel inside the powerhouse can be able to get out of the powerhouse complex safely. If one route becomes inaccessible, an alternative emergency escape route should always be available. The escape route should lead the people in crisis to an emergency assembly point/area into an open area with sufficient lightings. Hence, the powerhouse layout shall incorporate sufficient area for such an assembly point which shall be located outside of the powerhouse complex/building ensuring minimal or no risks during any crisis situation

- Adequate lighting is essential for emergency escapes.
- OSHA (Occupational Safety and Health Act of 1970) also provides information regarding the exit routes, maintenance, emergency action plans and fire prevention plans
- NBC 206:2003 *Architectural Design Requirements* provides general design guidelines for exit requirements (in form of a continuous and unobstructed means of egress to a public way such as intervening doors, passages, lobbies, ramps, staircases, courts and balconies as well as a horizontal exit into another building at the approximately the same level) and other associated features such as lightings and ventilation in such exits.
- Furthermore, Chapter 10 of International Building Code (IBC, 2012) Chapter 10- Means of Egress, the 2015 International Fire Code (Chapter 10) and NFPA 101- Life Safety Code can be referred to understand emergency evacuation requirements (in form of exit access, exit and exit discharge) in a building.

9.6 Ventilation

(Adopted from IS 4720: 1982 “” *code of practice for ventilation of surface hydel power station*)

Due consideration should be given to the ventilation requirements in designing surface, semi-surface as well as underground powerhouses. Ventilation arrangements are required for the purpose of;

- Preventing temperature stratification
- Removing contaminated air
- Removing waste heat from generators
- Providing cooling/heating of the building
- Providing clean air
- Furnishing outside air necessary for human comfort

Ventilation in surface power stations by natural means alone using gravity may be sufficient in some stations to meet the above-mentioned purposes. Where these purposes cannot be met by natural ventilation, forced ventilation or combination of the two with heating and cooling systems (where necessary) can be provisioned to ensure flow of clean air to reach various premises in the power stations to maintain satisfactory thermal environment.

Ventilation can be arranged through;

- *Natural Ventilation* by provisioning of adequate windows and ventilator (for Surface Powerhouse). IS 4720:1982 sets minimum area of windows and ventilators to be provided in a powerhouse building to be one-tenth of the floor area
- *Forced Ventilation* to be designed ensuring the inlet capacity 10 percent more than the exhaust fan capacity.

9.7 Lighting

(Adopted from IS 4720: 1982 “” *code of practice for amenities in hydroelectric power station*)

Adequate illumination should be provided in different locations of the power house to meet the requirements of service units housed therein. Illumination facilities should, as far as possible, should be in harmony with the general architecture of the structure. In the event of sudden failure of electric supply, it is necessary to have provision for emergency lighting at key points (including the egress). Main emergency lighting shall be fed from ac supply wherever emergency station generator is available and arranged to be automatically switched on to dc supply in case of failure of ac supply. IS 4720: 1982 “” *code of practice for amenities in hydroelectric power station*) can be referred for guidelines (codes) on selection of lighting fixtures, required illumination level at different places in a powerhouse building and wiring requirements.

9.8 Noise Control

(Adopted from IS 4720: 1982 “” *code of practice for amenities in hydroelectric power station*)

The turbine floors of hydroelectric power stations and especially of those with half embedded scroll case are generally quite noisy. In order to maintain comfortable working conditions, following measures should be employed:

a. Control-room, telephone-room, office, etc., should be segregated from the machine hall by providing sound-proof partitions;
b. Control-room, telephone-room, offices, corridors, etc., may be provided with rubberized floor tiles and acoustic tiles in the false ceilings; and
c. Air intake and exhaust openings provided for ventilation should be large enough to keep the noise level low.

9.9 Water Supply and Sanitary Arrangements

(Adopted from IS:10824-1984 “” code of practice for amenities in hydroelectric power station)

The arrangement of water supply shall be made according to the requirements of various equipment, size of the power station and the toilet facilities provided therein as well as considering the requirement for various purposes such as cooling, firefighting, toilet flushing and drinking water purposed.

Adequate toilet facilities with effective sewer systems (through a well laid out system of sanitary pipes and drains to a septic tank of suitable capacity) has to be incorporated in the powerhouse building design to serve the personnel working inside the power station and those visiting from outside.

Apart from IS: 10824-1984 and other applicable international codes, the designer shall also refer to NBC 208:2003 *Sanitary and Plumbing Design Requirements* to consider design requirement for water supply and sanitary arrangements in a powerhouse building.

9.10 Seismic Alarm Tripping Device

It is recommended to consider adequate allowance for seismic forces in the design of hydroelectric power houses in view of preventing the plant to operate after a minimum threshold value of seismic waves for safety of plant and personnel. To automatically trip off the generators in the powerhouse in an event of an earthquake an instrument, "*Seismic Alarm Tripping Device*" may be installed which causes tripping off the generating units when seismic waves induced by an earthquake exceed a pre-set threshold value (frequency). Furthermore, with signaling (in form of light indicators and audible sirens), it can help people in the vicinity to take necessary precautions for the safety of human life and equipment. IS 10824: 1984 *Code of Practice for Amenities in Hydro Electric Projects* Appendix A) provides details on typical seismic alarm tripping device and their maintenance.

10 PUBLIC SAFETY

Hydropower plants and the associated facilities nearby may consist of conditions which could be conducive to accidents that could have implications to public safety causing injuries or death. It is the foremost responsibility of the project developer to operate and properly maintain projects for the protection of life, health, and property. Therefore, identification of hazards associated with powerhouse operations to the general public should be carried out during the design after which measures to prevent those hazards or nullify potential health and safety impacts of such hazards should be incorporated in the design.

Many hazardous aspects of projects are not present at all times; therefore, it is important to consider the full range of plant operations that could cause hazardous conditions. Peaking operations are more hazardous than run-of-river operations, since tailwaters are normally calm and low flows occur between periods of generation. When generation begins, the tailwaters could rise rapidly and become swift and hazardous in a very short time. Tailrace areas are particularly dangerous when spillway gates are opened quickly and without warning, discharging flows into dry or calm areas below spillways. Remote operation or automation of hydro projects may increase the chances of accidents at the projects by eliminating the observations, judgements, and warnings of an operator. Therefore, un-manned, remotely-controlled facilities may require more access control provisions, lighting arrangement and warning signage and symbols adequately warn and protect the public (FERC 1992).

While potential hazards of a powerhouse operation to publics may be specific for each projects as each project is unique in terms of their layout and design, some of the most common hazards to the general public due to operation of a powerhouse are;

- Accidental drowning in the reservoir (as considered to be an integral component of a powerhouse to be built in the reservoir toe)
- Electrocution in unprotected switchyard or substation as well as electric shock hazards associated with high voltage power lines
- Hazards associated with sudden release of tailrace discharge to the people at the downstream shoreline at or near the tailwater areas
- Slips and falls causing drowning in tailrace canals

Each project should be reviewed for public safety needs on a case-specific basis. It is extremely important to assess the number and type of public safety measures at any project based on the public use patterns at a project (FERC 1992). In view of the hazards which are mentioned above, the powerhouse design should incorporate following necessary design measures;

- *Access Control or Restriction*

Hazard prone areas should be restricted for public access for which the design should include adequate restriction features in form of gates, fences and barricades wherever required. Entry to powerhouse complex should be restricted by provisioning gates. Switchyard and substations, tailrace canals, reservoir shorelines should be provided with fences with sufficient heights to restrict public entry to the area.

- *Warning Devices*

(1) Audible warning devices, together with signs to explain their meaning should be provided at projects with sudden changes in operation that result in large flows and rapidly changing tailwater levels.

(2) Clearly visible and legible warning signs at an appropriate distance should be provisioned adequately in reservoir area, powerhouse intake area (reservoir), tailwater area, hazardous spillway location, tailrace canal, switchyard and substation area and other potential hazard prone areas. Such warning sign should be in language that is understood by general public and should contain information of the possible hazard at that particular location in form of pictures and texts. Such signage should be integrated with adequate lighting arrangements to ensure night time visibility.

- *Trashrack*

Powerhouse intake shall be provisioned with trash racks. IS 11388: 2012 "*Recommendations for design of trashracks for intake*" can be referred for the design of trash racks.

- *Escape structure*

Escape devices such as safety ropes, escape nets, escape ladders or suspended cable should be provisioned at least every 100 m interval in steep-sided concrete lined tailrace canals.

- *Powerlines*

Determination of safe height of powerlines (i.e. minimum vertical clearance) should consider factors affecting powerlines sagging. The minimum clearance required for powerlines of different voltages can be referred from IEEE C2: *National Electrical Safety Code, Part 2 "Safety Rules for Overhead Lines".*

- *Lighting*

Spillways, intake areas, tailrace areas and reservoir shorelines should be provisioned with adequate lighting arrangements (i.e. perimeter lighting) for ensuring night time visibility of the hazard prone areas and the warning signage placed in these areas.

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- *IS: 3844 Code of Practice for installation of internal fire hydrants in multi-storied buildings*
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ANNEXES

ANNEX 1

SAMPLE OF POWERHOUSE DESIGN

TABLE OF CONTENTS

LIST OF FIGURES

SAMPLE OF POWERHOUSE DESIGN

1. OVERALL DIMENSIONING OF POWER HOUSE

1.1 POWERHOUSE WITH FRANCIS TURBINE

1.1.1 DATA

i. Type of Machine: Francis Turbine
ii. Total Number of Machines: 4
iii. Unit Capacity: 100 MW
iv. Maximum Head: 105 m
v. Rated Head: 100 m
vi. Minimum Head: 75 m
vii. Barometric Pressure at Power House site: 10 m
viii. Vapour Pressure at Power House site: 0.4 m
ix. Power Factor: 0.9

1.1.2 SYNCHRONOUS SPEED

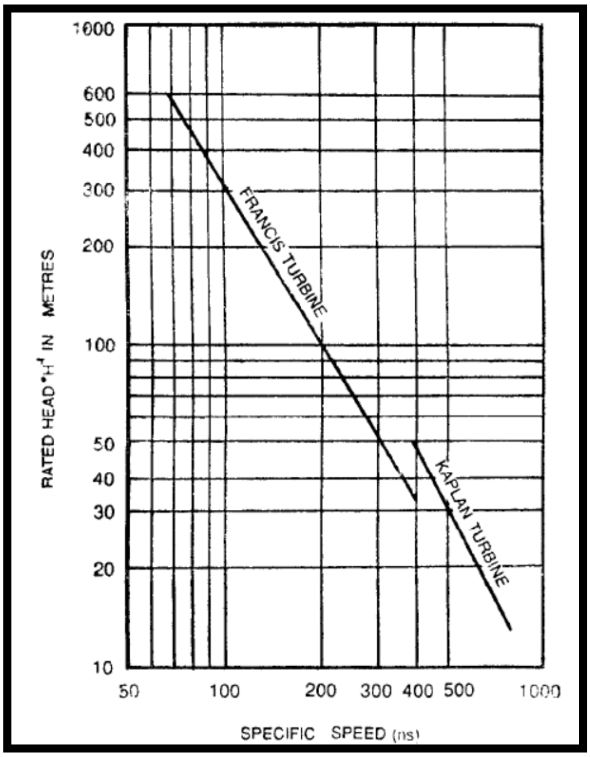


Figure-1. 1 Relationship between specific speed and rated head (Source: IS 12800)

From the above figure, specific speed of machine can be taken as 205.

We know, Synchronous speed of machine = $\frac{n_s H^{5/4}}{\sqrt{P \times 1.358}}$ (IS 12800)

Where,

n_s= 205 RPM, H= 100 m and P = 100 x 1000= 10^5 kW

Therefore, trial Synchronous speed of machine = $\frac{205 \text{ x } 100^{5/4}}{\sqrt{10^5 \times 1.358}}$ ≈ 176 RPM

Synchronous speed for 18 pairs of poles = $\frac{60 \text{ x } 50}{18}$ = 166.7 RPM

Synchronous speed for 16 pairs of poles = $\frac{60 \text{ x } 50}{16}$ = 187.5 RPM

Assuming the head variation from the rated head is more than 10%, lower synchronous speed i.e. 166.7 RPM is adopted.

Therefore, corrected specific speed = $\frac{166.7 \sqrt{10^5 \times 1.358}}{H^{5/4}}$ = 194 RPM

1.1.3 TURBINE SETTING

We know, $H_s \leq H_b - \sigma H - H_v$

Where,

H_b = 10 m

H_v = 0.4m

σ = Thoma's coefficient= 0.12; for specific speed of 194 (from figure -1.2)

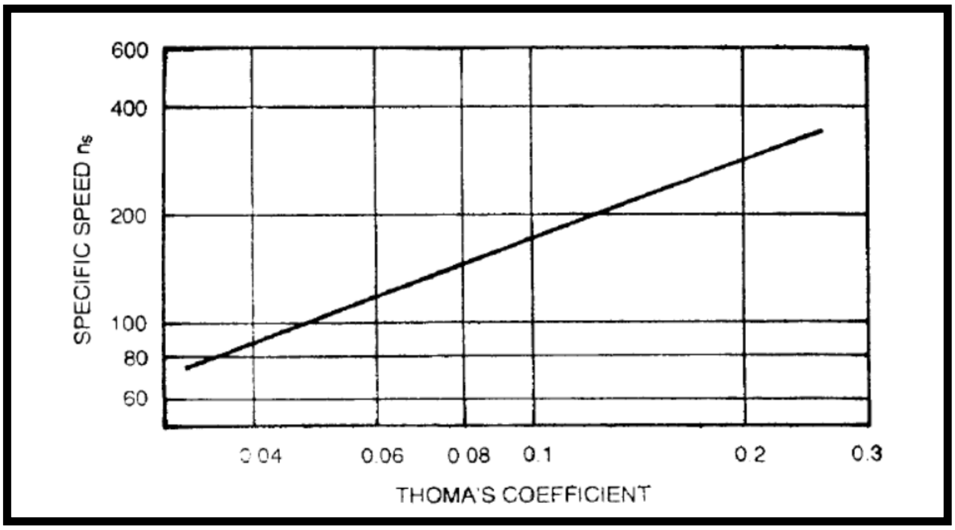


Figure-1. 2 Specific Speed Vs Thoma's Coefficient (Source: IS 12800)

Therefore,

$H_s \leq$ 10 - 0.12 x 105 – 0.4 m

≤ - 3.0 m

With the further margin of 0.5 meter, the center of line of distributor should be set 3.0 + 0.5 = 3.5 meter below minimum tailrace level.

1.1.4 SIZE OF RUNNER

Discharge diameter, $D_3 = \frac{60(2gH)^{0.5}K_u}{\pi n}$ (IS 12800 (Part-2): 1989)

Where,

H = 105 m

N = 166.7

K_u = for specific speed of 194 = 0.71 from figure -1.3 below,

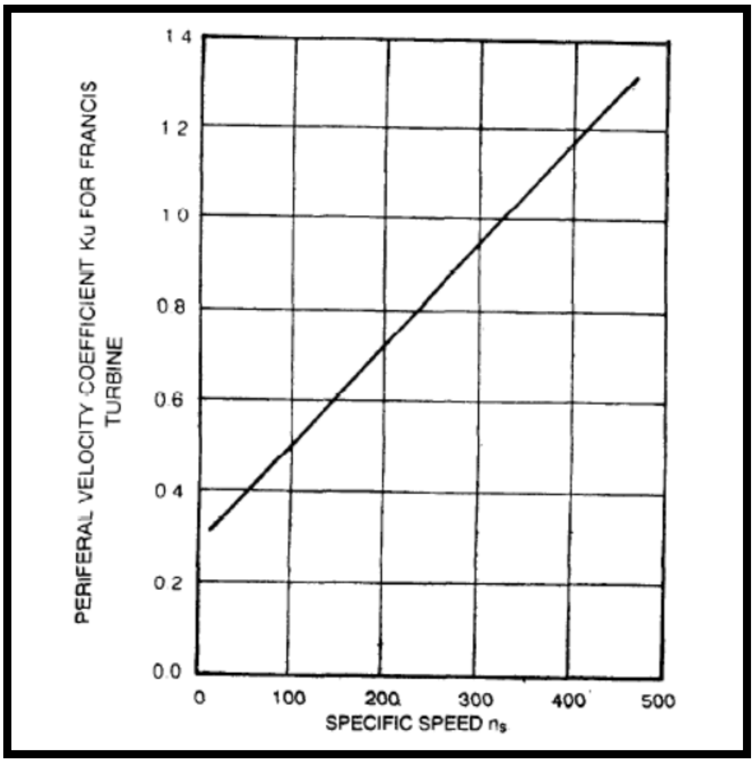


Figure-1. 3 Relationship between specific speed (n_s) and peripheral velocity coefficient K_u for Francis Turbine

(Source: IS 12800)

Therefore,

$$D_3 = \frac{60(2\times9.81\times105)^{0.5}\times0.71}{3.14\times166.7}$$

= 3.69 m, say 3.7 meters.

1.1.5 DIMENSIONS OF SPIRAL CASE

As the gross head above the turbine is more than 30 meters, metallic spiral casing should be used. The main dimensions of spiral casing can be determined in accordance to figure 6-22 to 6-26 and 6-27.

A = 1.1 x 3.7 = 4.07 m

B = 1.39 x 3.7 = 5.14 m

C = 1.57 x 3.7 = 5.81 m

D = 1.74 x 3.7 = 6.44 m

E = 1.29 x 3.7 = 4.77 m

F = 1.65 x 3.7 = 6.11 m

G = 1.38 x 3.7 = 5.11 m

H = 1.2 x 3.7 = 4.44 m

I = 0.235 x 3.7 = 0.87 m

L = 0.98 x 3.7 = 3.63 m

L = 0.61 x 3.7 = 2.26 m

1.1.6 SIZE OF DRAFT-TUBE

The various dimensions of the draft-tube are in accordance with IS: 5496:1969 and should be as below:

Height of draft-tube at exit end,

H = 0.94 D_3 to 1.32 D_3

As the specific speed of the turbine is on the lower side, 'h' will be on the higher side.

Taking, h = 1.25 D_3 = 1.25 * 3.7 = 4.65 m

Depth of draft tube 'H_1' for Francis Turbine = 2.5 to 3.0 D_3

Taking, H_1 = 2.75 D_3 = 2.75 x 3.7= 10.2 m

Length of draft-tube L = 4 to 5 D_3

Taking, L = 4.5 D_3 = 4.5 x 3.7 = 16.70 m

Clear width 'B' of the draft-tube at exit end = 2.6 to 3.3 D_3

Taking, B = 3 D_3 = 3 * 3.7 = 11.0 m

Since the width of the draft tube is excessive, a pier of 1.5 meters width should be introduced in the center of the draft-tube. The total width of draft-tube will thus be 12.5 m.

Since, Power in kW = 9.81 * Q * H * η

Where,

Q = discharge in cumecs,

H = rated head in meters,

η = efficiency of machine

Assuming the efficiency of machine to be 0.9,

$Q = \frac{100\times1000}{9.81\times100\times0.9}$ = 113.5 cumecs.

Therefore, velocity at exit end of draft-tube,

$V_e = \frac{113.5}{4.65*11}$ = 2.219 m/sec

In accordance to IS 5496: 1969, minimum submergence at the outlet end of the draft-tube should be greater than 0.3 meters, or

$$\frac{V_e^2}{2g} \text{ i.e. } \frac{(2.219)^2}{2*9.81} = 0.251 \text{ m (Say 0.3 m)}$$

Keeping bed slope 1 vertical to 10 horizontals at the bottom of the draft-tube, the exit end of draft-tube will be 1.67m above the bottom of draft-tube.

Therefore, the top of exit end of draft-tube will be 1.67 + 4.65 = 6.32 m above the bottom of the draft-tube.

Since height of draft-tube below center line of guide apparatus itself is 3.5 m below minimum tail water level, the top of the exit end of the draft-tube will be (3.5 + 10.2 – 6.32) = 7.38 m below the minimum tail water level, which is in order.

1.1.7 GENERATOR PARAMETERS

Air Gap Diameter 'Dg'

Total number of pair of poles = 18

Rated kVA of generator = 100,000/0.9 = 111,000

Following IS 12800 guidelines, Dg = 8.1 m

Outlet core diameter, D_0 = Dg (1 + π/2p) = 8.1 (1 + 3.14/ (2 * 18)) = 8.807 m (say 8.8m)

Stator frame diameter, $D_f = D_0 + 1.2 = 8.8 + 1.2 = 10$ m

Inner diameter of generator barrel, $D_b = D_f$ + 1.6 to 2.0 m = 10 + 1.8 = 11.8 m

Core length of stator 'Lc' = $\frac{W}{K_0 D_g^2\, n}$

Where,

W = 111,000 kVA

$K_0 = 6.6$

Dg = 8.1 m

n = 166.7 RPM

Therefore,

$L_c = \frac{111,000}{6.6\times 8.1^2 \times 166.7}$ = 1.54 m (say 1.5 m)

Length of stator frame, $L_f = L_c$ + (1.5 to 1.6) = 1.5 + 1.5 = 3.0 m

Axial hydraulic thrust $P_H = KD_3^2 H_{max}$ in tones.

Where,

K = 0.19

$D_3 = 3.7$ m

$H_{max} = 105$ m.

Therefore,

$P_H = 0.19 \text{ x } 3.7^2 \text{ x } 105$ = 273 tonnes.

Weight of generator rotor, W_B = 225 x 1.5 tonnes = 338 tonnes.

Weight of turbine runner = 23 tonnes

Weight of load bearing bracket = Total weight of rotating parts + axial thrust

= 338 + 23 +273

= 634 tonnes.

Let there be 6 arms in the bearing bracket.

Load on each arm = $\frac{634}{6}$ = 105.7, say 106 tonnes.

Height of load bearing bracket, $h_j = K\sqrt{D_t}$ for suspended type construction, and

$= K\sqrt{D_g}$, for umbrella type construction

Where,

K = 0.85 (IS 12800 (Part-1):1993, 5.7.1)

Therefore,

$h_j = 0.85\sqrt{10} = 2.64$ for suspended type construction, and

$= 0.85\sqrt{8.1} = 2.42$ for umbrella type construction.

1.1.8 OVERALL DIMENSIONS OF POWER STATION

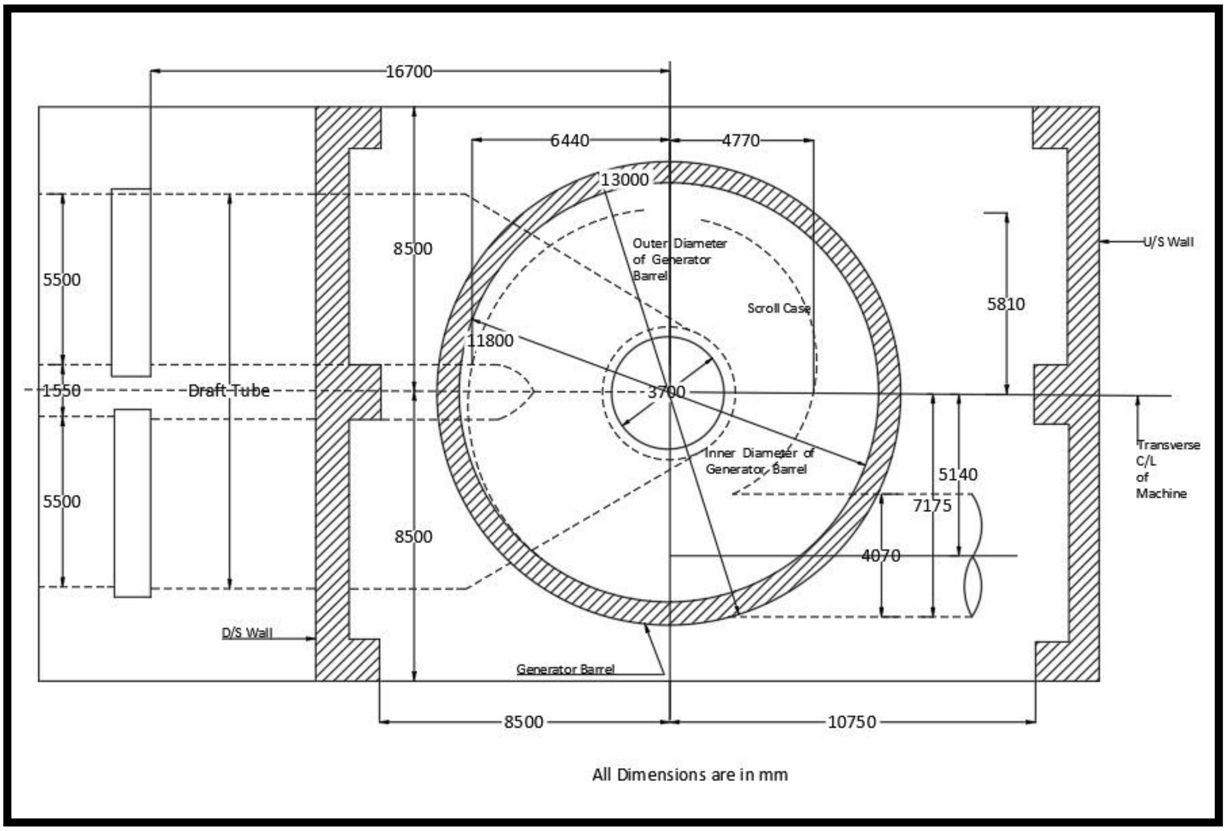


Figure-1. 4 Plan Showing Main Dimensions of Unit Bay

(Source IS 12800 (Part-1):1993)

Figure 1.4 is drawn in accordance to **6.8** of main report, the extremities of scroll case/draft-tube/generator in longitudinal direction are at 7.115m on spiral inlet side and 6.5 m on opposite side of the transverse center line of the machine. Adding 1.5 to 2 meters to these dimensions, the size of the unit bay is in longitudinal direction or unit spacing work out to be 17 meters.

Length of erection bay = 0.7 to 1.5 times the unit bay size = 1 x 17 = 17 m.

Space required for the E.O.T crane to hand the last unit will depend upon the number and size of the crane. For preliminary purpose assuming it to be 3 to 5 meters (4 meters in the present case).

Total length of power station = 4 x 17 + 17 + 4 = 89 m.

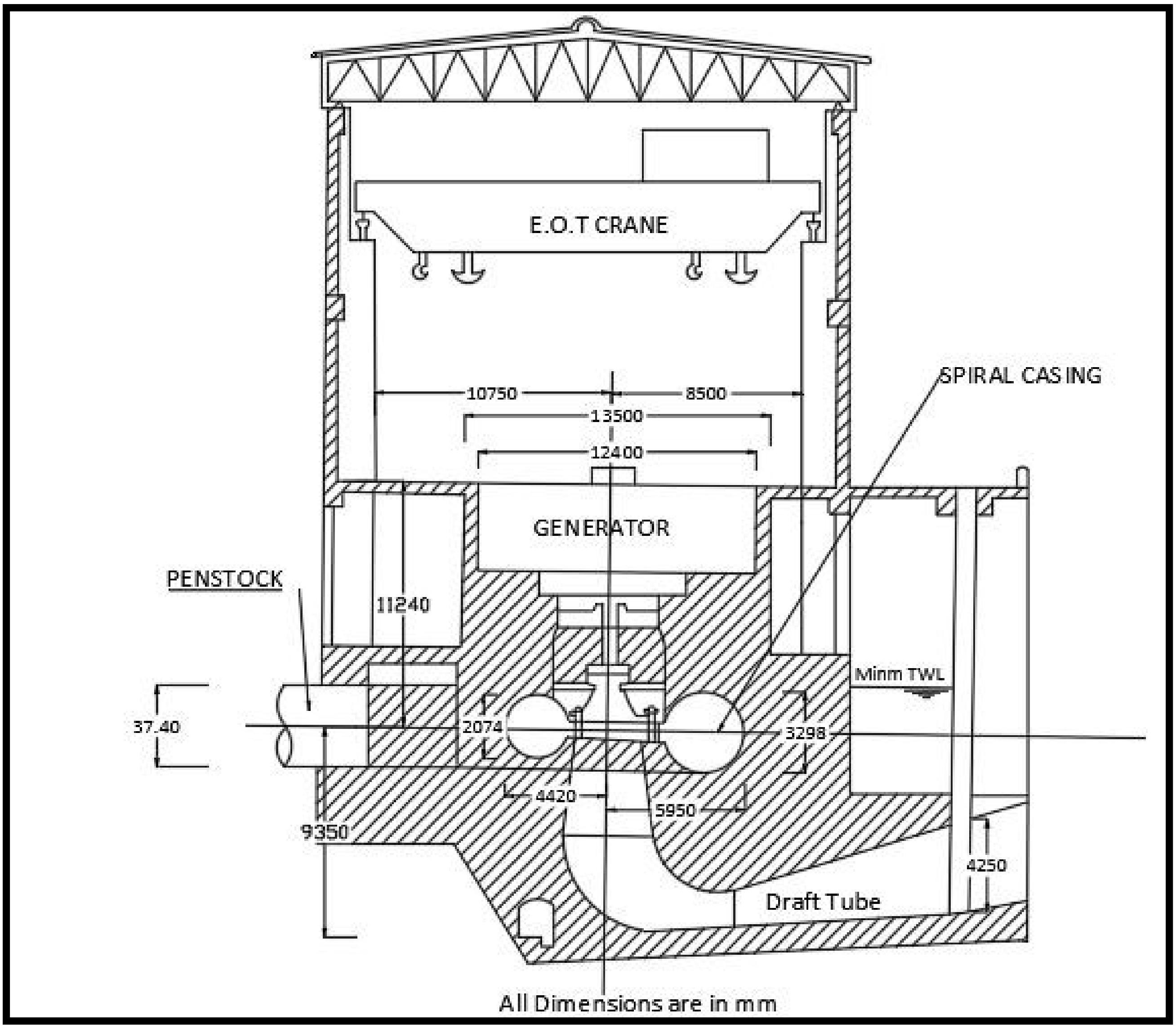


Figure-1. 5 Cross Section of Power House

(Source IS 12800 (Part-1):1993)

The distance of the inner face of downstream columns from the longitudinal center line of machine works out to be 6.5 + (1.5 to 2.0, Say 2.0) = 8.5 m

Distance of the inner face of upstream columns from the longitudinal center line of machine = 6.5 (extremity of draft-tube/ scroll-case/ generator barrel) + 4.00 (For accommodating control valve; the same space can also be used for approaching draft-tube) = 10.5 m

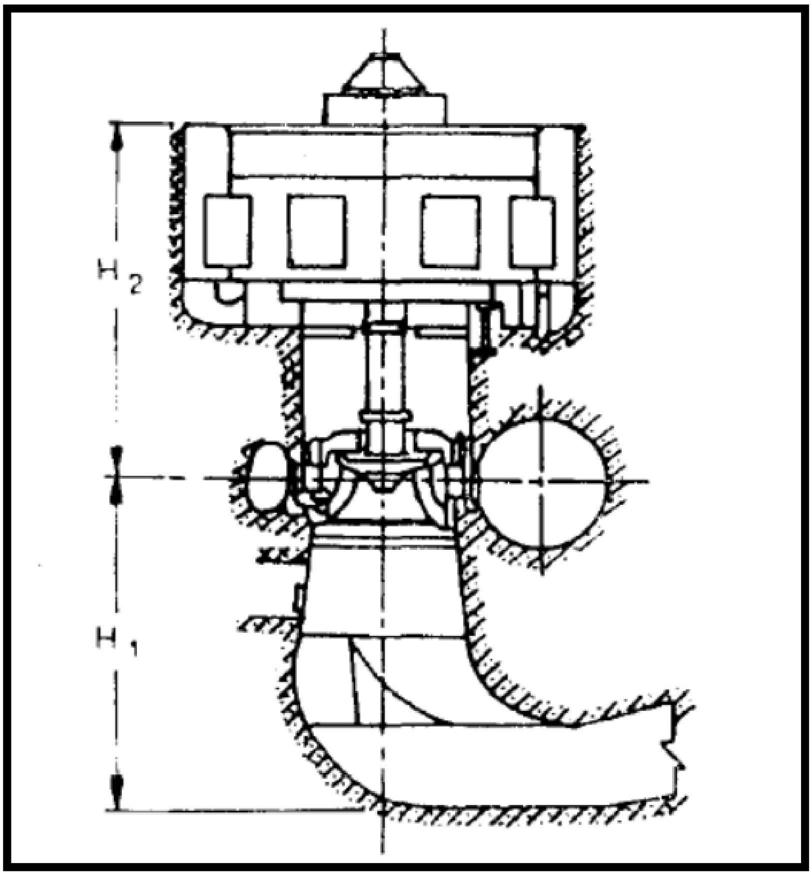


Figure-1. 6 Cross Section through Generating Unit

(Source IS 12800 (Part-1):1993)

From figure -1.6,

Total height of machine = $H_1 + H_2$

From the size of draft-tube as already calculated above, $H_1 = 10.2$ m

$H_2 = L_f + h_j + K$ (Refer main report section 6.8.6)

K = 5.5 to 7.0, say 6.0 m.

$H_2 = 3 + 2.69 + 6 = 11.69$ m.

Therefore, Total height of machine = 10.2 + 11.69 = 21.89 m.

Total height of machine hall will depend upon type of foundation, height of E.O.T crane, size of assemblies, and type of roof and can be determined accordingly.

1.2 POWERHOUSE WITH PELTON TURBINE

1.2.1 TURBINE SELECTION

Data Input:

Design Discharge (Q) = 0.656 m^3/s

Net Head (H)= 719.6 m

No. of unit (n) = 2

Efficiency (η) = 0.9

Discharge per unit (q) = Q/n = 0.328 m^3/s

Speed in RPM (N) = 1000 RPM

Now,

Specific Speed, $N_q = N.\frac{\sqrt{q}}{H^{0.75}}$ = 4.12 RPM

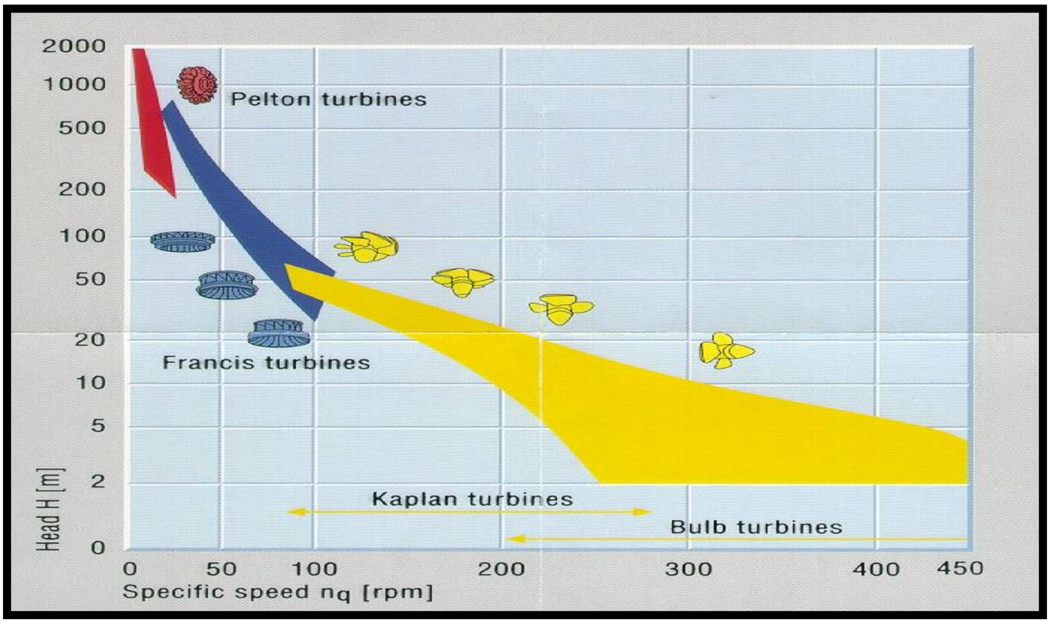


Figure-1. 7 Selection of turbine depending up on head and specific speed

From the figure-1.7, the selected turbine is Pelton turbine.

Also,

Speed Number, $\Omega = \bar{\omega}.\sqrt{\bar{Q}}$

Where, $\bar{Q} = \frac{Q}{\sqrt{2gH}}$ and $\bar{\omega} = \frac{\omega}{\sqrt{2gH}}$ $(Q\ is\ taken\ for\ discharge\ per\ unit)$

Here,

ω = 2πN/60 = 104.72 rad/s

$\bar{Q}$ = 0.003 m^2

$\bar{\omega}$ = 0.88 m^{-1}

Now,

Ω = 0.05 nearly equals to 0.1

Then, from the figure-1.8, the turbine to be selected in Pelton turbine.

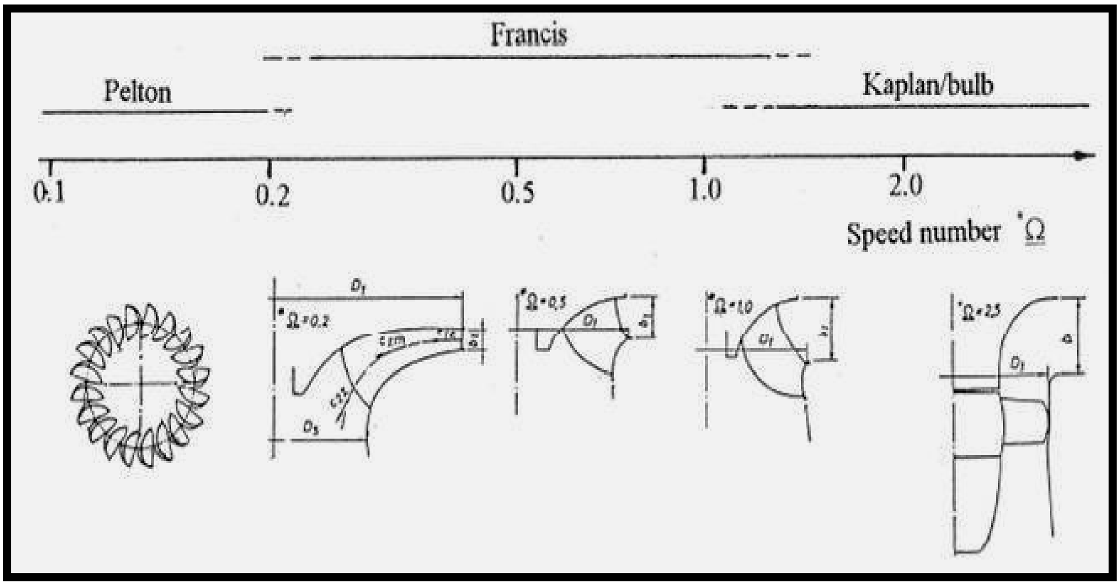


Figure-1. 8 Relationship between speed number and type of turbine selection

1.2.2 DESIGN OF PELTON TURBINE

Speed Ratio (k) = 0.48 (assumed) (0.43<k<0.48)

Jet ratio (m) = D/d_s= 10 (assume)

No. of jets = 1

Coefficient of discharge(C_d) = 0.98

Frequency (f) = 50Hz

Circumferential velocity (u_1) = $k\sqrt{2gH}$ = 57.03 m/s

Velocity of jet at inlet (v_1) = $C_d\sqrt{2gH}$ =116.45 m/s

Diameter of jet (d_s) = $\sqrt{\frac{4q}{\pi v_1}} = 0.06m$

Diameter of wheel (D) = m.d_s = 10 x 0.06 = 0.60m

Number of Bucket (z) = 0.5m + 15 = 20

Now,

Rotational Speed (N) = $\frac{60u_1}{\pi D} =$ 1815.32 RPM

No. of Poles (P) = 3000/N = 1.65

Increasing the value,

Take No. of poles (P) = 2

So, Rotational Speed (N) = 3000/P = 1500 RPM

Then, Diameter of Wheel (D) = $\frac{60u_1}{\pi N} =$ 0.73 m

Jet ratio (m) = 0.73/0.06 = 12.17 (Which is greater than assumed ratio i.e. 10)

OK

Width of Bucket = 3*Diameter of jets = 3 x 0.06 = 0.18 m

Depth of Bucket = 0.8* Diameter of jets = 0.8 x 0.06 = 0.05 m

Length of Bucket = 2.6* Diameter of jets = 2.6 x 0.06 = 0.156 m

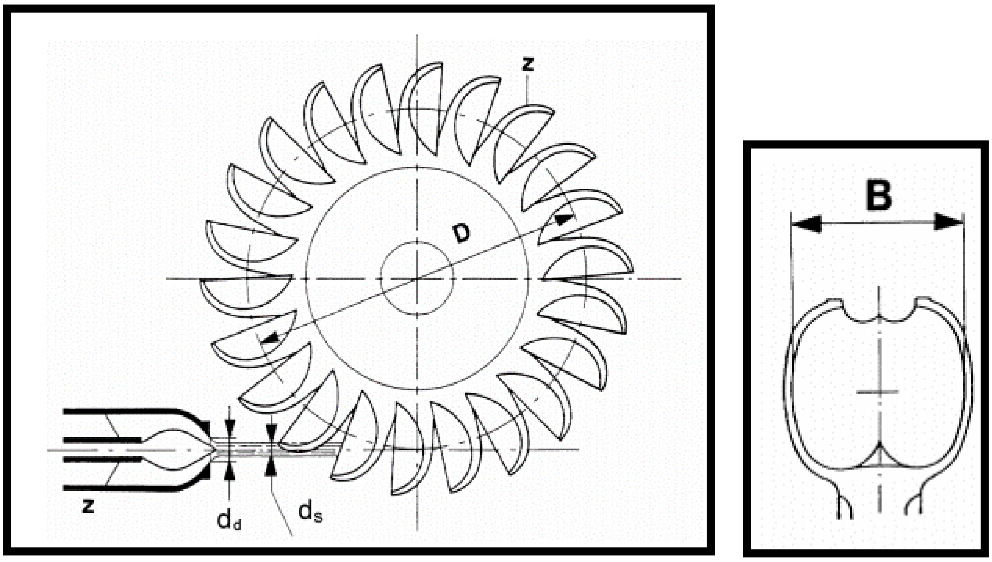


Figure-1. 9 Typical layout of pelton runner, inlet jet and bucket

1.2.3 PRELIMINARY DIMENSION OF POWER HOUSE

For Horizontal Shaft Pelton turbine with:

Diameter of turbine (D): 0.73 m

No. of units: 2

Size of machine hall (for each unit):

Length, L = 4D+2.7 = 4 x 0.73 + 2.7 = 5.62 m

Breadth, B = 5D+2.5 = 5 x 0.73 + 2.5 = 6.15 m

Total length of machine hall = 2 x 5.62 = 11.24 m

Total breadth of machine hall = 6.15 m

Size of erection bay:

Length = 4D+2.7 = 5.62 m

Size of control bay:

Take, length = 5m

Therefore,

Total length of powerhouse = 11.24 + 5.62 + 5 = 21.86 m

Total width of powerhouse = 6.15 m

Note:

The final dimensions of the powerhouse are fixed based on the arrangement of the electrical and electromechanical equipment. Therefore, it is always recommended to consult Electromechanical Department for finalizing the size of powerhouse and proceeding to the analysis and design part.

2. DESIGN OF POWERHOUSE STRUCTURAL MEMBERS

After the dimensioning of the powerhouse, the arrangements for the structural members are made based on the requirements and their analysis and designs are done. Various components like roof truss, beam, column, corbel, slab, machine foundations and tailrace channels etc. are required in design of any powerhouse.

Initially, the loadings on various components are determined from the available theories and then the analysis is done to determine the internal forces acting on members. Then, the members are designed so as to resist the forces acting on them. The analysis of the structure is done using any available Finite Element (FE) software.

In this example, a surface type powerhouse with two units of Pelton turbine is taken for the design. The plan and sections of powerhouse is shown in figure-2.1 and figure-2.2 respectively. The dimensions of the powerhouse shown below are obtained as discussed in Section 1, with further help from the Electromechanical Department. The succeeding sections will discuss the design of each components of the powerhouse.

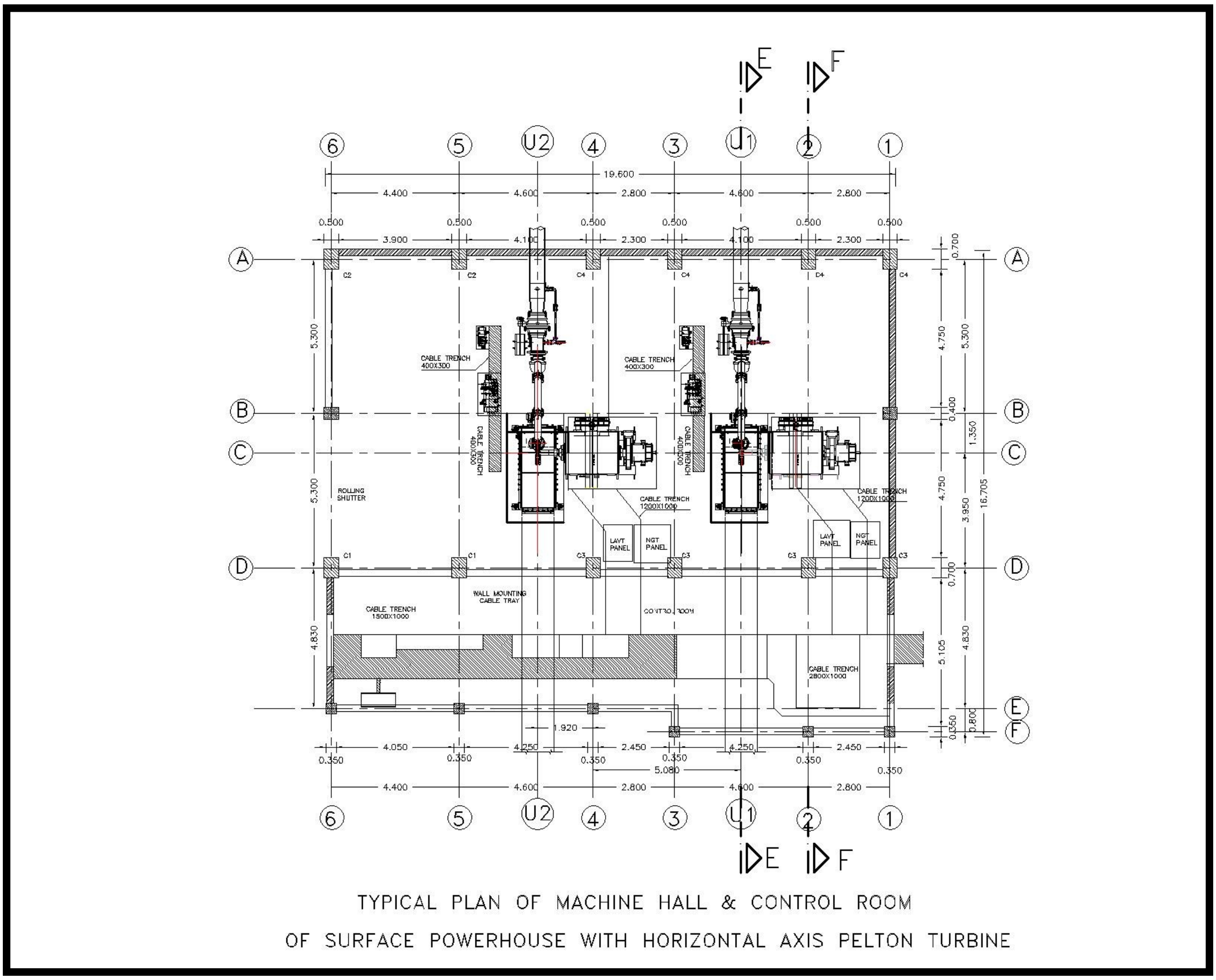


Figure-2. 1 Plan of the powerhouse

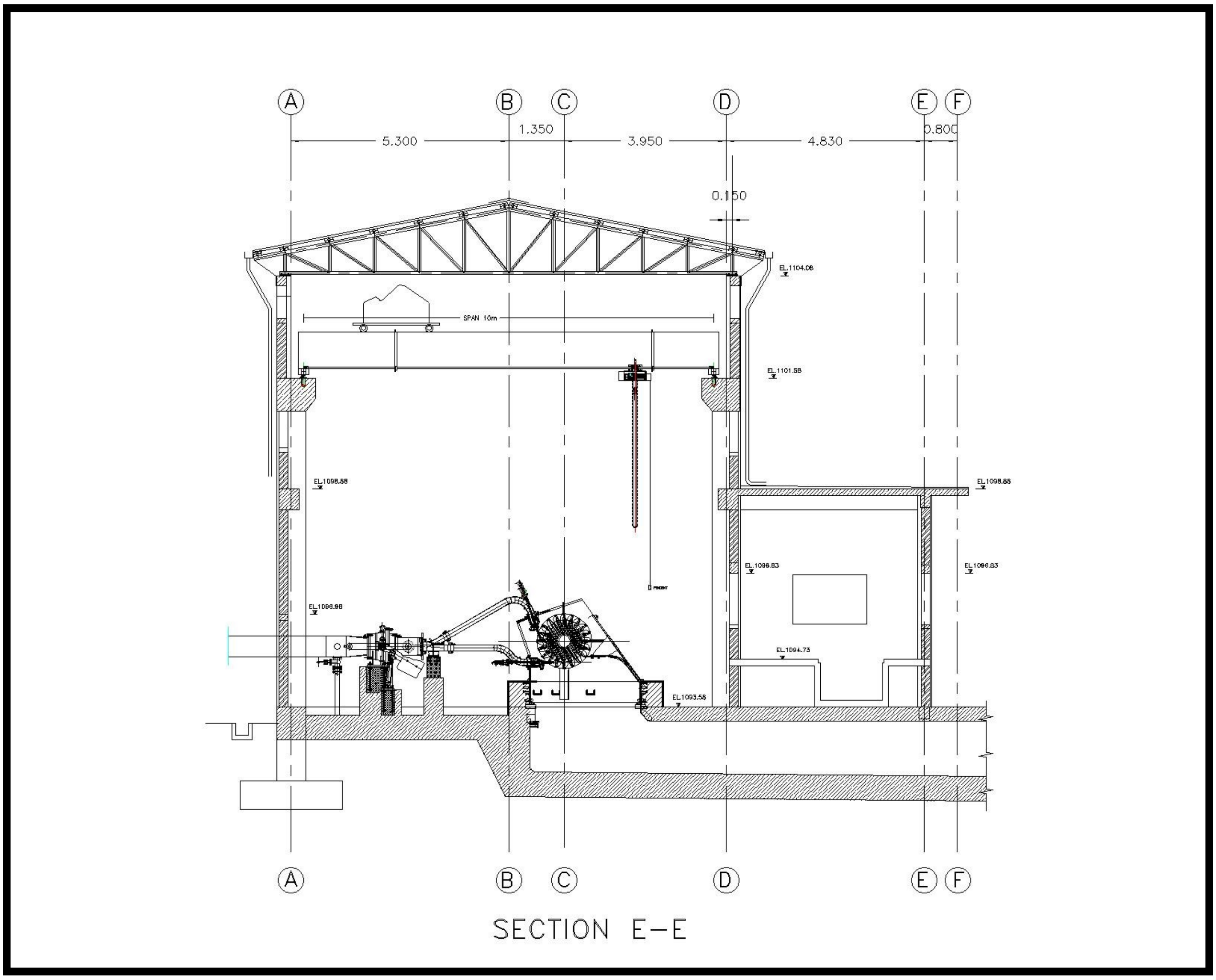


Figure-2. 2 Powerhouse section at turbine unit

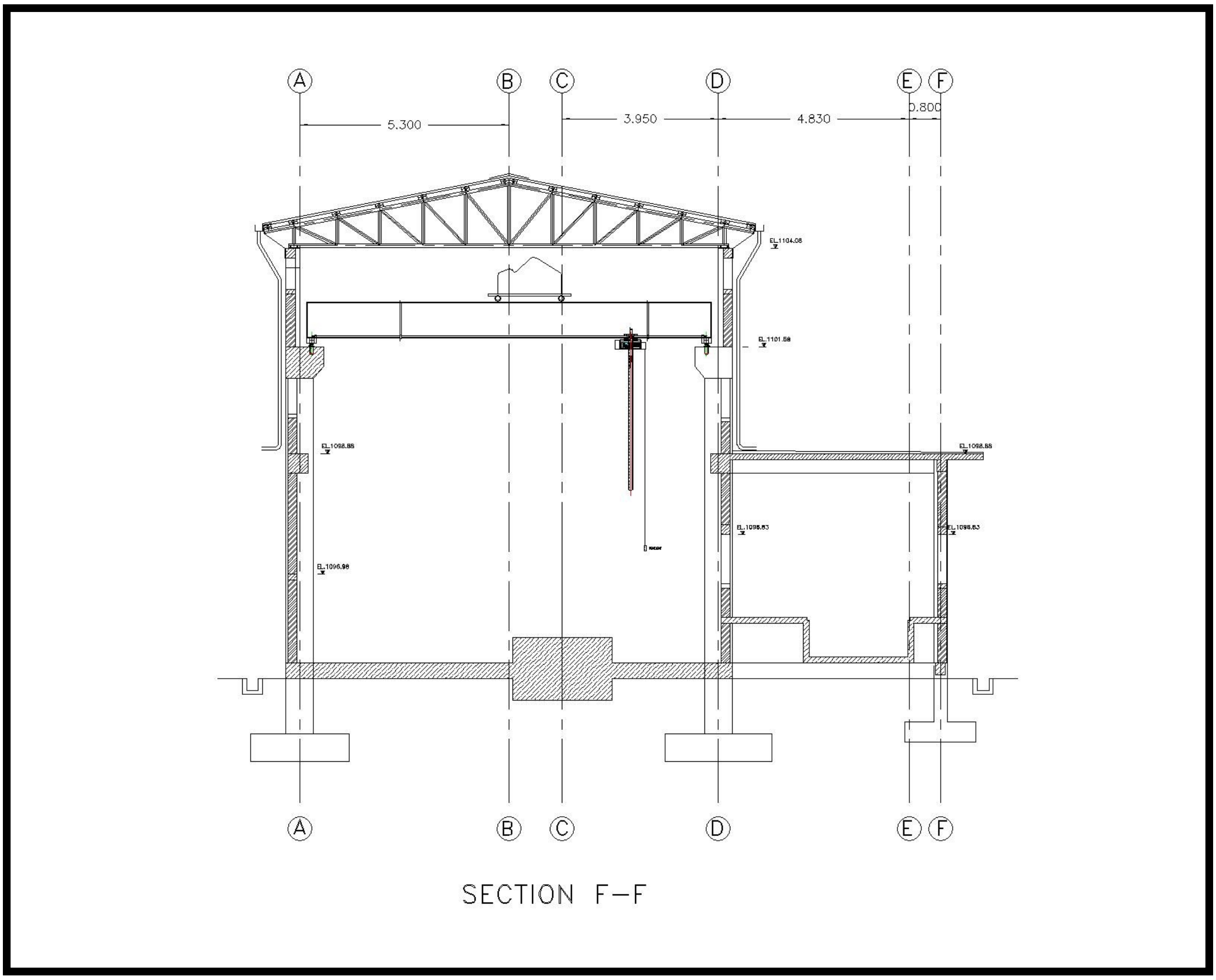


Figure-2. 3 Powerhouse section at generator unit

2.1 DESIGN OF ROOF TRUSS

Wind Load Calculation and Design of Purlins:

Grade of steel tubular pipe used	Yst24		As per IS: 1161-2014
Purlin size NB 90M , OD 101.6mm			
Unit wt of material			
CGI sheet	0.056	KN/m^2	(for 0.55mm thick corrugated sheet)
CGI sheet	0.078	KN/m^2	40% increased due to lapping of CGI sheet and water proofing material (may be changed as per designer's choice)
Wt of purlin NB 90M , 101.6mm	9.63	Kg/m	IS: 1161-1998
	0.0963	KN/m	
1. DEAD LOAD			
Truss Spacing	4.600	m	

Spacing of purlins at middle nodes		1.110	m	
Spacing of purlins at end node		0.666	m	
Roof slope		11	Degree	
		0.192	rad	
Self-weight of Purlin			KN/m	
Weight of CGI Sheet at intermediate node	a	0.400	KN	
Wt. of CGI sheet at support node	b	0.320	KN	
Wt. of CGI sheet at far end of rafter	c	0.240	KN	
Wt. of purlin	d	0.443	KN	
Total dead load on truss at intermediate nodes	W_1	0.928	KN	(a+d)*1.1 *Note: 10% wt. increased due to cleat plates and bolts*
UDL on at intermediate purlin	W_{1UDL}	0.202	KN/m	(W_1+W_p)*1.1/spacing of purling
Total dead load on truss at support node	W_2	0.796	KN	(0.5*(b+c)+d)*1.1
UDL on purlin at support node	W_{2UDL}	0.173	KN/m	
Total dead load on truss at far end node of rafter	W_3	0.619	KN	(0.5*c+d) * 1.1
UDL on purlin node at far end node	W_{3UDL}	0.135	KN/m	

2. LIVE LOAD

Minimum imposed load for roof where access not provided		0.75	KN/m^2	IS 875
Live load as per IS 875 for roof slope >10°		0.730	KN/m^2	X= 0.75-0.02*(11°-10) refer IS 875
Live load on intermediate purlin		0.795	KN/m	= X*cosθ*spacing of purlin
Live load on truss at intermediate node		3.659	KN	= 2/3*0.581*cosθ*spacing of purlin*spacing of truss
Live load on purlin at support		0.636	KN/m	
Live load on truss at support node		2.927	KN	
Live load on purling at far end node		0.239	KN/m	
Live load on truss at far end node		1.098	KN	

3. WIND LOAD

Note: Wind load has been calculated as per IS: 875 – 1987 (Part-3. Wind load may be calculated as per IS: 875 – 2015 (Part -3) or any other standard or code also.

$P_z = 0.6\, V_z^2$

Where,

$V_z = K_1 * K_2 * K_3 * V_b$

V_b = basic wind speed in m/s

k_1 = Probability factor (or risk coefficient)
k_2 = Terrain, height and structure size factor
k_3 = Topography factor

a) Calculation of Probability factor (Risk coefficient), K_1

Basic wind speed		47	m/s
Assumed life span		100	yrs
Risk coefficient	k_1	1.07	IS 875-1987 (Part 3), Table 1

b) Calculation of Terrain, height and structure size factor, K_2

Width of building	w	11.2	
Length of building	l	21.5	
Height of building	h	12.5	
Class of building		B	Since largest dimension of the structure is within 20m to 50m
Terrain category		2	PH structure is in the river bank which has scattered obstruction with height less than 10m
	K_2	1	From table no. 2 of IS: 875-1987 (Part-3)

c) Calculation of Topography factor, K_3

Value of K_3 is determined as given in Appendix C of IS: 875-1987 (Part-3).
Value of K_3 varies from 1 to 1.36

	K_3	1.105		
Design wind velocity	V_z	55.570	m/s	($V_z = K_1*K_2*K_3*V_b$)
Design wind pressure	$P_z = 0.6\ V_z^2$	1852.845	N/m^2	
	P_z	1.853	KN/m^2	
Height to width ratio of building	h/w	1.116	m	0.5 < h/w < 1.5

External Pressure Coefficient (C_{pe})

Wind ward	Lee ward	1/4 th of L	1/2 of L	
0	0	90	90	Wind angle
EF	GH	EG	FH	Face
-1.01	-0.59	-0.8	-0.6	Cpe

Internal Pressure Coefficient (C_{pi})

Assuming the building to be of medium permeability

Cpi	0.2	-0.2

= Cpe+Cpi	-0.81	-0.39	-0.6	-0.4
= Cpe-Cpi	-1.21	-0.79	-1	-0.8

Wind pressure

-1.501	-0.723	-1.112	-0.741	KN/m^2
upward	upward	upward	upward	
-2.242	-1.464	-1.853	-1.482	KN/m^2
upward	upward	upward	upward	

Design wind load intensity	2.2419	KN/m^2	upward
Wind load on intermediate purlin	2.489	KN/m	

Wind load on intermediate nodes of truss		11.447	KN	upward
Wind load on purlin at support		1.991	KN/m	
Wind load on support node of truss		9.158	KN	
Wind load on purlin at far end		0.747	KN/m	
Wind load on truss at far end node		3.434	KN	

4.Design of purlin

Permissible bending stress in extreme fibers in tension and compression as per IS:806-1968

Grade	F_b	
	kgf/cm^2	N/mm^2
YSt 21	1400	137
YSt 24	1655	162
YSt 32	2050	201

Selected material for design of Purlin and Truss: YSt 24

a) Case-1 (DL+WL)

NB 90M, 101.6mm Dia.

Modulus of section	$Z_{x/y}$	28800	mm^3	
Dead load	W_d	0.202	KN/m	vertical
Total vertical load	W_2	0.152	KN/m	(Wind load + dead load is considered 33% less effective)
Wind load	W_1	-1.871	KN/m	Perpendicular to CGI sheet
Mx = $(w_1+w_2*\cos\theta)*L*L/10$	M_x	3644300	Nmm	
My= $(w_2*\sin\theta)*L*L/10$	M_y	61217.4	Nmm	
Maximum stress at extreme fibre = $M_x/Z_x+M_y/Z_y$	σ_{bc} or σ_{bt}	128.66	N/mm^2	
	σ_{bc} or σ_{bt}	128.66	N/mm^2	<162 N/mm^2 OK

b) Case-2 (DL+LL)

NB 90M, 101.6mm Dia.

Modulus of section	$Z_{x/y}$	28800	mm^3	
Dead load	W_d	0.202	KN/m	vertical
Live load	W_l	0.795	KN/m	vertical
Total vertical load	W_2	0.997	KN/m	
Wind load	W_1	0	KN/m	Perpendicular to CGI sheet
Mx = $(w_1+w_2*\cos\theta)*L*L/10$	M_x	2071035	Nmm	
My= $(w_2*\sin\theta)*L*L/10$	M_y	402568.4	Nmm	
Maximum stress at extreme fibre = $M_x/Z_x+M_y/Z_y$	σbc (σbt)	85.89	N/mm^2	<162 N/mm^2 OK

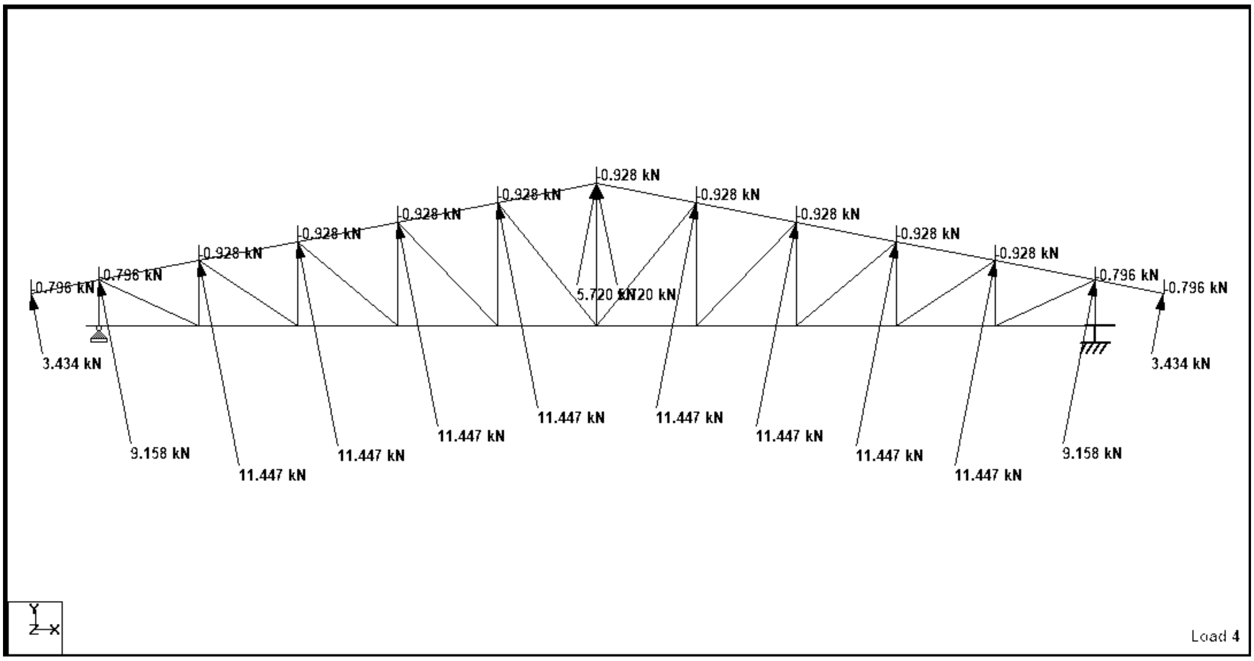


Figure-2. 4 Dead load+Wind load FBD

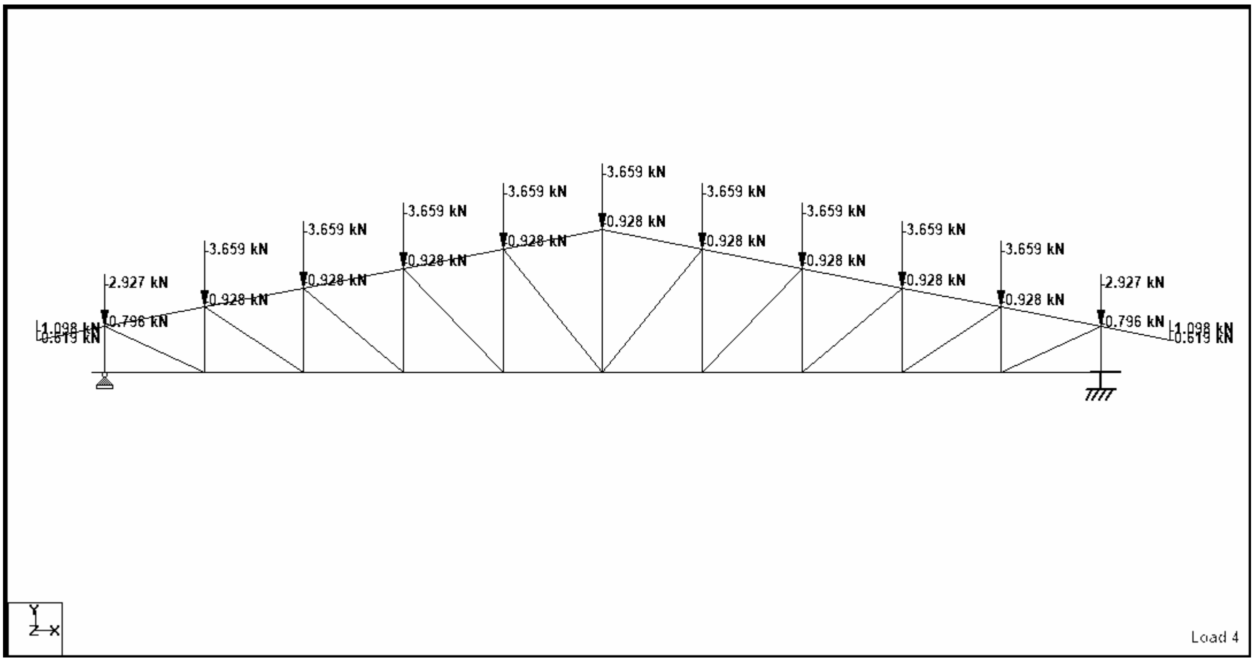


Figure-2. 5 Deal load+Live load FBD

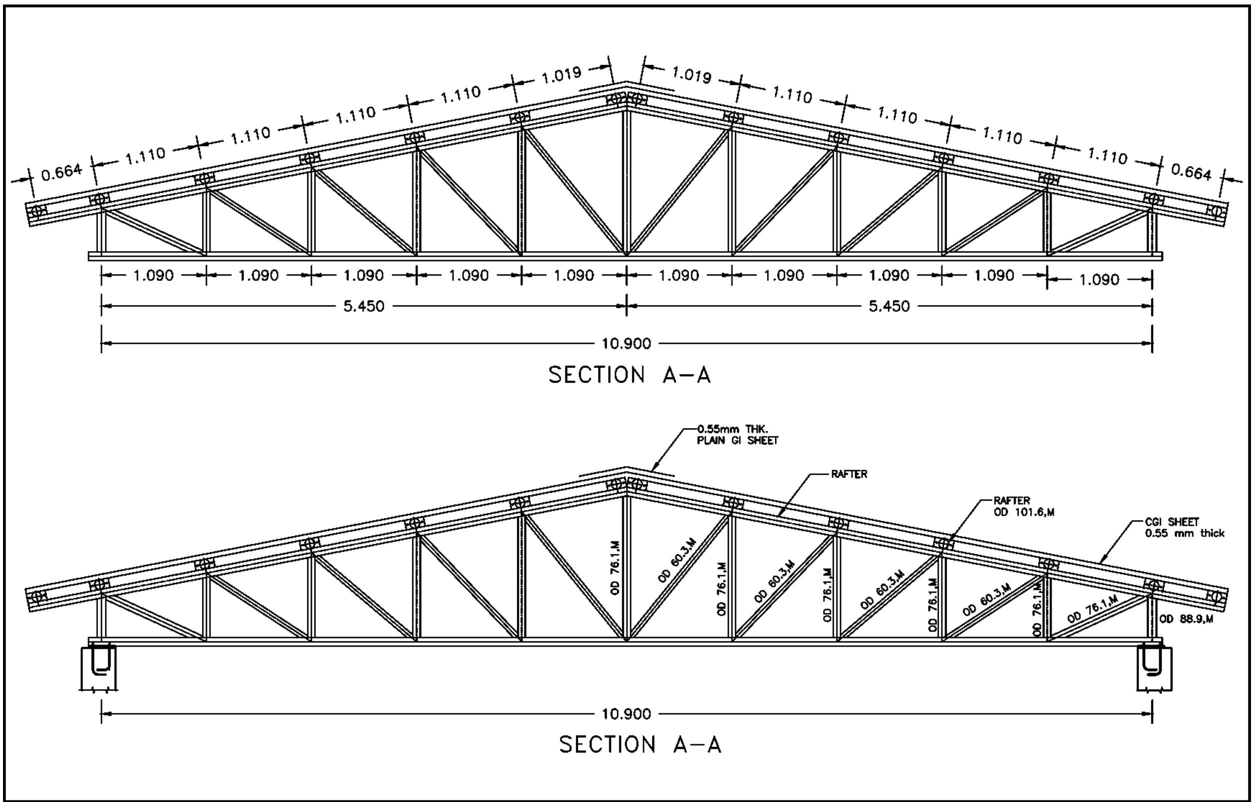


Figure-2. 6 Roof truss detail

Design of Truss member for Dead load+ Live load

-

Note:

1. Structural analysis has been carried out by using computer software.
2. Structure design code IS: 800, 802
3. Physical properties of structural member (hollow structural pipes) shall be according to table no. 1 of IS: 1161-1998
4. Joints between each member are assumed fixed

Youngs' modulus of elasticity	***E =***	200000	N/mm^2	
Yield stress of steel, YSt 25 (IS :806-1968)	***Fy =***	240	N/mm^2	Minimum (guaranteed) yield strength of structural member shall not be less than $240N/mm^2$
Imperfection factor which is taken as	***N =***	1.4		
Elastic critical stress in compression	***fcc***			

$$f_{cc}= \pi.\pi.E/(l_e/r)^2$$

$$\sigma_{ac} = 0.6*f_{cc}*f_y/((f_{cc})^n+f_y)^n)^{1/n}$$

Permissible stress σ_{ac} & σ_{at} in the structural member of Grade Yst 240

1) In axial compression		Refer IS: 806 - 1968, table 2	
2) In axial tension	1500	kgf/cm^2 ($147N/mm^2$)	Refer IS 806 - 1968, table 1

Slenderness ratio for main tension member must not exceed 180 (refer IS: 800 1984, 802)

S.no.	Beam no.	Length (l)	Outer dia. (D)	Member type	Load type	Axial force	Section area (A)	Effective length (le)	Radius of gyration (r)	Slenderness ratio (le/r)	Permissible compressive & tension stress (σ_{ac}) (from attached taable)	Actual stress on the member	Safe load	FOS	Remarks	fcc (calculated from above formula)	Permissible compressive stress (σ_{ac})	Remarks	Unit wt./ m	Wt. of member
		m	mm			(DL+LL) KN	mm^2	m	mm	(r= diameter of pipe)	N/mm^2	N/mm^2	KN			N/mm^2	N/mm^2		kg/m	kg
1	1	0.500	88.90	M	C	27.254	1070	0.500	30	16.7	139	25.471	148.5	5.4	OK	7106.12	143		8.36	4
2	2	0.712	76.10	M	C	14.84	820	0.712	25.7	27.7	134	18.098	109.6	7.4	OK	2571.79	140		6.24	4
3	3	0.924	76.10	M	C	8.341	820	0.924	25.7	36.0	130	10.172	106.4	12.8	OK	1527.05	137		6.24	6
4	4	1.136	76.10	M	C	2.83	820	1.136	25.7	44.2	126	3.451	103.2	36.5	OK	1010.27	132		6.24	7
5	5	1.348	76.10	M	T	-1.713	820	1.348	25.7	52.5	147	-2.089	120.5	70.4	OK				6.24	8
6	6	1.560	76.10	M	T	-11.199	820	1.560	25.7	60.7	147	-13.657	120.5	10.8	OK				6.24	10
7	7	1.348	76.10	M	T	-1.713	820	1.348	25.7	52.5	147	-2.089	120.5	70.4	OK				6.24	8
8	8	1.136	76.10	M	C	2.83	820	1.136	25.7	44.2	126	3.451	103.2	36.5	OK	1010.27	132		6.24	7
9	9	0.924	76.10	M	C	8.342	820	0.924	25.7	36.0	130	10.173	106.4	12.7	OK	1527.05	137		6.24	6
10	10	0.712	76.10	M	C	14.84	820	0.712	25.7	27.7	134	18.098	109.6	7.4	OK	2571.79	140		6.24	4
11	11	1.199	76.10	M	T	-34.064	820	1.199	25.7	46.7	147	-41.541	120.5	3.5	OK				6.24	7
12	12	1.090	88.90	M	T	0.031	1070	1.090	30	36.3	147	0.029	157.3	5073.9	OK				8.36	9
13	13	1.090	88.90	M	T	-31.687	1070	1.090	30	36.3	147	-29.614	157.3	5.0	OK				8.36	9
14	14	1.090	88.90	M	T	-44.776	1070	1.090	30	36.3	147	-41.847	157.3	3.5	OK				8.36	9
15	15	1.090	88.90	M	T	-48.224	1070	1.090	30	36.3	147	-45.069	157.3	3.3	OK				8.36	9
16	16	1.090	88.90	M	T	-46.557	1070	1.090	30	36.3	147	-43.511	157.3	3.4	OK				8.36	9
17	17	1.090	88.90	M	T	-46.557	1070	1.090	30	36.3	147	-43.511	157.3	3.4	OK				8.36	9
18	18	1.090	88.90	M	T	-48.224	1070	1.090	30	36.3	147	-45.069	157.3	3.3	OK				8.36	9
19	19	1.090	88.90	M	T	-44.776	1070	1.090	30	36.3	147	-41.847	157.3	3.5	OK				8.36	9
20	20	1.090	88.90	M	T	-31.686	1070	1.090	30	36.3	147	-29.613	157.3	5.0	OK				8.36	9
21	21	1.090	88.90	M	T	0.031	1070	1.090	30	36.3	147	0.029	157.3	5073.9	OK				8.36	9
22	22	1.110	88.90	M	C	31.542	1070	1.110	30	37.0	132	29.479	140.8	4.5	OK	1441.87	136		8.36	9

S.no.	Beam no.	Length (l)	Outer dia. (D)	Member type	Load type	Axial force	Section area (A)	Effective length (le)	Radius of gyration (r)	Slenderness ratio (le/r)	Permissible compressive & tension stress (σ_{ac}) (from attached taable)	Actual stress on the member	Safe load	FOS	Remarks	fcc (calculated from above formula)	Permissible compressive stress (σ_{ac})	Remarks	Unit wt./ m	Wt. of member
		m	mm			(DL+LL) KN	mm^2	m	mm	(r= diameter of pipe)	N/mm^2	N/mm^2	KN			N/mm^2	N/mm^2		kg/m	kg
23	23	1.110	88.90	M	C	45.493	1070	1.110	30	37.0	132	42.517	140.8	3.1	OK	1441.87	136		8.36	9
24	24	1.110	88.90	M	C	49.131	1070	1.110	30	37.0	132	45.917	140.8	2.9	OK	1441.87	136		8.36	9
25	25	1.110	88.90	M	C	47.529	1070	1.110	30	37.0	132	44.420	140.8	3.0	OK	1441.87	136		8.36	9
26	26	1.110	88.90	M	C	43.007	1070	1.110	30	37.0	132	40.193	140.8	3.3	OK	1441.87	136		8.36	9
27	27	1.110	88.90	M	C	43.007	1070	1.110	30	37.0	132	40.193	140.8	3.3	OK	1441.87	136		8.36	9
28	28	1.110	88.90	M	C	47.529	1070	1.110	30	37.0	132	44.420	140.8	3.0	OK	1441.87	136		8.36	9
29	29	1.110	88.90	M	C	49.131	1070	1.110	30	37.0	132	45.917	140.8	2.9	OK	1441.87	136		8.36	9
30	30	1.110	88.90	M	C	45.493	1070	1.110	30	37.0	132	42.517	140.8	3.1	OK	1441.87	136		8.36	9
31	31	1.110	88.90	M	C	31.542	1070	1.110	30	37.0	132	29.479	140.8	4.5	OK	1441.87	136		8.36	9
32	32	0.764	88.90	M	T	-0.338	1070	0.764	30	25.5	147	-0.316	157.3	465.4	OK				8.36	6
33	33	1.302	60.30	M	T	-15.466	641	1.302	20	65.1	147	-24.128	94.2	6.1	OK				5.03	7
34	34	1.429	60.30	M	T	-4.526	641	1.429	20	71.5	147	-7.061	94.2	20.8	OK				5.03	7
35	35	1.574	60.30	M	C	2.303	641	1.574	20	78.7	108	3.593	69.0	29.9	OK	318.70	100		5.03	8
36	36	1.734	60.30	M	C	6.855	641	1.734	20	86.7	101	10.694	64.8	9.5	OK	262.60	92		5.03	9
37	37	1.734	60.30	M	C	6.855	641	1.734	20	86.7	101	10.694	64.8	9.5	OK	262.60	92		5.03	9
38	38	1.574	60.30	M	C	2.303	641	1.574	20	78.7	108	3.593	69.0	29.9	OK	318.70	100		5.03	8
39	39	1.429	60.30	M	T	-4.526	641	1.429	20	71.5	147	-7.061	94.2	20.8	OK				5.03	7
40	40	1.302	60.30	M	T	-15.467	641	1.302	20	65.1	147	-24.129	94.2	6.1	OK				5.03	7
41	41	1.199	76.10	M	T	-34.063	820	1.199	25.7	46.7	147	-41.540	120.5	3.5	OK				6.24	7
42	42	0.764	88.90	M	T	-0.338	1070	0.764	30	25.5	147	-0.316	157.3	465.4	OK				8.36	6
43	43	0.103	88.90	M		0	1070	0.103	30	3.4									8.36	1
44	44	0.134	88.90	M		0	1070	0.134	30	4.5									8.36	1
45	45	0.500	88.90	M	C	27.254	1070	0.500	30	16.7	139	25.471	148.5	5.4	OK	7106.12	143		8.36	4
																				344

Design of Truss member for Dead load+ Wind load

Youngs' modulus of elasticity	***E***	200000	N/mm^2	
Yield stress of steel, Yst 25 (IS:806-1968)	***fy***	240	N/mm^2	Minimum (guaranteed) yield strength of structural member shall not be less than 240N/mm^2
Imperfection factor which is taken as	***n***	1.4		
Elastic critical stress in compression	***fcc***			

Structure design code IS: 800, 802

Properties of structural member shall be according to IS: 1161-1998

$$f_{cc}=\pi.\pi.\ E/(l_e/r)^2$$

$$\sigma_{ac} = 0.6*f_{cc}*f_y/((f_{cc})^n+f_y)^n)^{1/n}$$

Permissible stress σ_{ac} in the structural member of Grade Yst 240

1) In axial compression **Refer IS 806 - 1968, table 2**

2) In axial tension 1500 kgf/cm^2 (147N/mm^2) **Refer IS 806-1978, table 1**

Slenderness ratio for main tension member must not exceed 180 (refer IS 800 1984, 802)

S.no.	Beam no.	Length (l)	Outer dia. (D)	Member type	Load type	Axial force	Section area (A)	Effective length (le)	Radius of gyration (r)	Slenderness ratio (le/r)	Permissible compressive & tension stress (σ_{ac}) (from attached taable)	Permissible stress on each members increased by 33%	Actual stress on the member	Safe load	FOS	Remarks	fcc (calculated from above formula)	Permissible compressive stress (σ_{ac}) (calculated from above formula)	Remarks
		m	mm			(DL+WL) KN	mm^2	m	mm	(r= diameter of pipe)	N/mm^2		N/mm^2	KN			N/mm^2	N/mm^2	
1	1	0.500	88.90	M	T	-54.51	1070	0.500	30	16.7	147	196	50.944	209.2	3.8	OK			
2	2	0.712	76.10	M	T	-30.33	820	0.712	25.7	27.7	147	196	36.988	160.3	5.3	OK			
3	3	0.924	76.10	M	T	-16.598	820	0.924	25.7	36.0	147	196	20.241	160.3	9.7	OK			
4	4	1.136	76.10	M	T	-5.209	820	1.136	25.7	44.2	147	196	6.352	160.3	30.8	OK			
5	5	1.348	76.10	M	C	4.124	820	1.348	25.7	52.5	122	162	5.029	133.0	32.2	OK	717.49	125	
6	6	1.560	76.10	M	C	24.705	820	1.560	25.7	60.7	118	157	30.128	128.7	5.2	OK	535.73	118	
7	7	1.348	76.10	M	C	4.126	820	1.348	25.7	52.5	122	162	5.032	133.0	32.2	OK	717.49	125	
8	8	1.136	76.10	M	T	-5.207	820	1.136	25.7	44.2	147	196	6.350	160.3	30.8	OK			
9	9	0.924	76.10	M	T	-16.596	820	0.924	25.7	36.0	147	196	20.239	160.3	9.7	OK			
10	10	0.712	76.10	M	T	-30.33	820	0.712	25.7	27.7	147	196	36.988	160.3	5.3	OK			
11	11	1.199	76.10	M	C	68.615	820	1.199	25.7	46.7	125	166	83.677	135.9	2.0	OK	906.90	130	
12	12	1.090	88.90	M	C	0.664	1070	1.090	30	36.3	132	175	0.621	187.6	282.545	OK	1495.27	137	
13	13	1.090	88.90	M	C	64.564	1070	1.090	30	36.3	132	175	60.340	187.6	2.906	OK	1495.27	137	
14	14	1.090	88.90	M	C	89.949	1070	1.090	30	36.3	132	175	84.064	187.6	2.086	OK	1495.27	137	
15	15	1.090	88.90	M	C	95.769	1070	1.090	30	36.3	132	175	89.504	187.6	1.959	OK	1495.27	137	
16	16	1.090	88.90	M	C	91.21	1070	1.090	30	36.3	132	175	85.243	187.6	2.057	OK	1495.27	137	
17	17	1.090	88.90	M	C	91.21	1070	1.090	30	36.3	132	175	85.243	187.6	2.057	OK	1495.27	137	
18	18	1.090	88.90	M	C	95.77	1070	1.090	30	36.3	132	175	89.505	187.6	1.959	OK	1495.27	137	
19	19	1.090	88.90	M	C	89.952	1070	1.090	30	36.3	132	175	84.067	187.6	2.086	OK	1495.27	137	
20	20	1.090	88.90	M	C	64.569	1070	1.090	30	36.3	132	175	60.345	187.6	2.906	OK	1495.27	137	

S.no.	Beam no.	Length (l)	Outer dia. (D)	Member type	Load type	Axial force	Section area (A)	Effective length (le)	Radius of gyration (r)	Slenderness ratio (le/r)	Permissible compressive & tension stress (σ_{ac}) (from attached taable)	Permissible stress on each members increased by 33%	Actual stress on the member	Safe load	FOS	Remarks	fcc (calculated from above formula)	Permissible compressive stress (σ_{ac}) (calculated from above formula)	Remarks
		m	mm			(DL+WL) KN	mm^2	m	mm	(r= diameter of pipe)	N/mm^2		N/mm^2	KN			N/mm^2	N/mm^2	
21	21	1.090	88.90	M	C	0.671	1070	1.090	30	36.3	132	175	0.627	187.6	279.598	OK	1495.27	137	
22	22	1.110	88.90	M	T	-66.742	1070	1.110	30	37.0	147	196	62.376	209.2	3.134	OK			
23	23	1.110	88.90	M	T	-96.066	1070	1.110	30	37.0	147	196	89.781	209.2	2.178	OK			
24	24	1.110	88.90	M	T	-104.47	1070	1.110	30	37.0	147	196	97.636	209.2	2.002	OK			
25	25	1.110	88.90	M	T	-102.252	1070	1.110	30	37.0	147	196	95.563	209.2	2.046	OK			
26	26	1.110	88.90	M	T	-94.18	1070	1.110	30	37.0	147	196	88.019	209.2	2.221	OK			
27	27	1.110	88.90	M	T	-94.179	1070	1.110	30	37.0	147	196	88.018	209.2	2.221	OK			
28	28	1.110	88.90	M	T	-102.251	1070	1.110	30	37.0	147	196	95.562	209.2	2.046	OK			
29	29	1.110	88.90	M	T	-104.471	1070	1.110	30	37.0	147	196	97.636	209.2	2.002	OK			
30	30	1.110	88.90	M	T	-96.069	1070	1.110	30	37.0	147	196	89.784	209.2	2.178	OK			
31	31	1.110	88.90	M	T	-66.747	1070	1.110	30	37.0	147	196	62.380	209.2	3.134	OK			
32	32	0.764	88.90	M	T	-0.163	1070	0.764	30	25.5	147	196	0.152	209.2	1283.4	OK			
33	33	1.302	60.30	M	C	29.978	641	1.302	20	65.1	116	154	46.768	98.7	3.3	OK	465.77	114	
34	34	1.429	60.30	M	C	7.632	641	1.429	20	71.5	112	149	11.906	95.7	12.5	OK	386.66	107	
35	35	1.574	60.30	M	T	-6.323	641	1.574	20	78.7	147	196	9.864	125.3	19.8	OK			
36	36	1.734	60.30	M	T	-15.592	641	1.734	20	86.7	147	196	24.324	125.3	8.0	OK			
37	37	1.734	60.30	M	T	-15.591	641	1.734	20	86.7	147	196	24.323	125.3	8.0	OK			
38	38	1.574	60.30	M	T	-6.325	641	1.574	20	78.7	147	196	9.867	125.3	19.8	OK			
39	39	1.429	60.30	M	C	7.629	641	1.429	20	71.5	112	149	11.902	95.7	12.6	OK	386.66	107	
40	40	1.302	60.30	M	C	29.975	641	1.302	20	65.1	116	154	46.763	98.7	3.3	OK	465.77	114	
41	41	1.199	76.10	M	C	68.613	820	1.199	25.7	46.7	125	166	83.674	135.9	2.0	OK	906.90	130	
42	42	0.764	88.90	M	T	-0.163	1070	0.764	30	25.5	147	196	0.152	209.2	1283.4	OK	3043.59	141	
43	43	0.103	88.90	M			1070	0.103	30	3.4									
44	44	0.134	88.90	M			1070	0.134	30	4.5									
45	45	0.500	88.90	M	T	-54.508	1070	0.500	30	16.7	147	196	50.942	209.2	3.8	OK	7106.12	143	

2.2 DESIGN OF ROOF SLAB OF CONTROL BUILDING

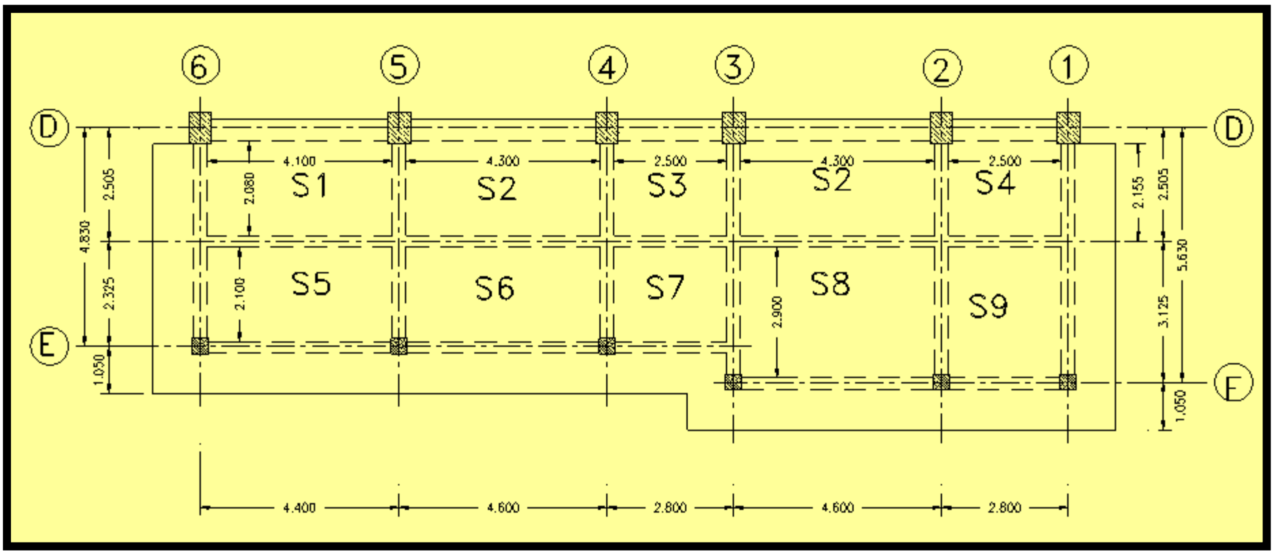


Figure-2. 7 Slab layout plan above control room

Unit wt. of RCC concrete	γ_c	25	KN/m^3
Unit wt. of water proofing concrete PCC		24	KN/m^3
Unit wt. of plaster over PCC		20.4	KN/m^3
Thickness of RCC Slab		150	mm
Thickness of Waterproofing concrete		60	mm
Thickness of Plaster above water proofing		15	mm
Self wt. of slab		3.75	kN/m^2
Wt. of water proofing concrete		1.44	kN/m^2
Wt. of plaster		0.306	kN/m^2
Total dead load	DL	5.496	kN/m^2
Live load	LL	2.5	KN/m^2

(live load on roof shall be not be less than $1.5kN/m^2$. Refer may be taken form table no. 2 of IS: 4247-1993.

DL+LL		7.996	kN/m^2
Partial factor of safety	Υ_m	1.5	
Assume diameter of bar	Φ	10	mm
Clear concrete cover	c_c	25	mm
Grade of reinforcement bar	f_y	500	N/mm^2
Grade of concrete	σ_{ck}	25	N/mm^2

Slab Types

Slab No.	Type of Panel
S1	Two adjacent edge discontinuous (One long edge continuous)
S2	One way slab
S3	One long edge discontinuous
S4	Two adjacent edge discontinuous (One long edge continuous)
S5	Two adjacent edge discontinuous (One long edge continuous)
S6	One way slab
S7	One long edge discontinuous
S8	One long edge discontinuous
S9	Two adjacent edge discontinuous (One long edge continuous)

Design of slab S1 (Two-way slab):

<table>
<tr><th>Calculation</th><th>Reference</th></tr>
<tr><td>Clear span:
Short span = 2.08 m
Long span = 4.175 m
Overall depth of slab (D) = 150 mm
Effective depths:
dx = 150-25-10/2 = 120 mm
dy = 150-25-10-10/2 = 110 mm
Effective span:
Short span (L_x) = 2.08 + 120/1000 = 2.20 m
Long span (L_y) = 4.175 + 110/1000 = 4.295 m
Aspect ratio, L_y/L_x = 1.952</td><td></td></tr>
<tr><td>Total working load (w) = 7.996 kN/m^2
Total factored load (w_u) = 1.5 x 7.996 = 11.994 kN/m^2
Consider 1m width of slab</td><td></td></tr>
<tr><td>Design moments:
$M_x = \alpha_x w L_x^2$ and $M_y = \alpha_y w L_x^2$
<table>
<tr><th></th><th>α_x</th><th>α_y</th><th>M_x (kN.m)</th><th>M_y (kN.m)</th></tr>
<tr><td>Negative moment at continuous edge</td><td>0.091</td><td>0.047</td><td>5.28</td><td>2.73</td></tr>
<tr><td>Positive moment at mid-span</td><td>0.069</td><td>0.035</td><td>4.01</td><td>2.03</td></tr>
</table></td><td>Table 26, IS 456:2000</td></tr>
<tr><td>Check for effective depth:
For Fe500 grade steel,
$$\text{Effective depth required, d} = \sqrt{\frac{M_u}{0.133 f_{ck} b}} = \sqrt{\frac{5.28 \times 10^6}{0.133 \times 25 \times 1000}}$$
$$= 39.85\ mm$$
Provided effective depth = 120 mm > 39.85 mm (OK)</td><td></td></tr>
<tr><td>Reinforcement calculation:
$$M_u = 0.87 f_y A_{st} d \left(1 - \frac{A_{st} f_y}{b d f_{ck}}\right)$$
Ast,x:
B.M = 5.28 kN.m , Ast = 103 mm^2
B.M = 4.01 kN.m , Ast = 78 mm^2
Minimum A_{st} required = 0.12 % of bD = 180 mm^2
Provide dia. of bar = 10mm
Spacing of bar (S) = 78.5/180 x 1000 = 436mm
Maximum spacing is least of following:
i) 3d = 360 mm</td><td>Clause 26.5.2.1, IS: 456-2000</td></tr>
</table>

ii) 300 mm Adopt spacing of 150mm C/C Area of steel provided = 523.33 mm^2 % tension steel provided = 0.44% Ast,y: B.M = 2.73 kN.m , Ast = 58 mm^2 B.M = 2.03 kN.m , Ast = 43 mm^2 Minimum A_{st} required = 0.12 % of bD = 180 mm^2 Since, area of steel required for both direction is same, similarly, Provide dia. of bar = 10mm Adopt spacing of 150mm C/C Area of steel provided = 523.33 mm^2 % tension steel provided = 0.44%	Clause 26.3.3, IS: 456-2000
Check for shear: Along short span: Design Shear force (V_u) = $0.6w_uL_x$ (For continuous slab) Then, V_u = 15.8 kN Nominal shear stress (τ_v) = V_u/(bd) = 0.132 N/ mm^2 For p_t = 0.44% & M25 concrete, τ_c = 0.458 N/ mm^2 For slabs, permissible shear stress (τ_c') = k τ_c Where, k = 1.3 τ_c'= 1.3 x 0.458 = 0.595 N/mm^2 > τ_v (OK) Along long span: $V_u = 0.6w_uL_y$ = 30.91 kN Nominal shear stress (τ_v) = V_u/(bd) = 0.26 N/ mm^2 τ_c = 0.458 N/ mm^2 τ_c'= 0.595 N/mm^2 > τ_v (OK)	From Table 19, IS: 456-2000 Clause 40.2.1.1, IS: 456-2000
Check for deflection: $Allowable\ \frac{L}{d} = Basic\ \frac{L}{d} \times \alpha_1 \times \alpha_2 \times \alpha_3$ Basic L/d = 20 Modification factor for tension reinforcement: A_{st} required = 180 mm^2 A_{st} provided = 523.33 mm^2 Steel stress of service = $0.58f_y \frac{A_{st,required}}{A_{st,provided}} = 100\ N/mm^2$ Modification factor, α_1 = 2 Modification factor for span, α_2 = 1 Modification factor for compression reinforcement, α_3 = 1 Therefore, Allowable L/d = 20 x 2 x 1 x 1 = 40 mm Actual L/d = 4.295 x 1000/120 = 35.79 mm < 40 mm (OK)	Clause 24.1, IS: 456-2000 Figure 4, IS: 456-2000,

In similar way, other two-way slabs (S3, S4, S5, S7, S8 and S9) can be designed.

Design of slab S2 (One-way slab):

Calculation	**Reference**
Clear span of slab = 2.08 m Overall depth of slab (D) = 150 mm Effective depths: d = 150-25-10/2 = 120 mm Effective span, L = 2.08 + 120/1000 = 2.20 m	
Total working load (w) = 7.996 kN/m^2 Total factored load (w_u) = 1.5 x 7.996 = 11.994 kN/m^2 Consider 1m width of slab	

Design moment: $M_u = \alpha w_u L^2$ α = 1/10 Therefore, M_u = 1/10 x 11.994 x 2.20^2 = 5.81 kN.m	Table 12, IS: 456-2000
Check for effective depth: For Fe500 grade steel, $\text{Effective depth required, d} = \sqrt{\frac{M_u}{0.133 f_{ck} b}} = \sqrt{\frac{5.81 \times 10^6}{0.133 \times 25 \times 1000}}$ $= 41.80\ mm$ Provided effective depth = 120 mm > 41.80 mm (OK)	
Reinforcement calculation: $M_u = 0.87 f_y A_{st} d \left(1 - \frac{A_{st} f_y}{b d f_{ck}}\right)$ Main bar: B.M = 5.81 kN.m , Ast = 113 mm^2 Minimum A_{st} required = 0.12 % of bD = 180 mm^2 Provide dia. of bar = 10mm Spacing of bar (S) = 78.5/180 x 1000 = 436mm Maximum spacing is least of following: i) 3d = 360 mm ii) 300 mm Adopt spacing of 150mm C/C Area of steel provided = 523.33 mm^2 % tension steel provided = 0.44% Distribution bar: Ast = 0.12% of bD = 180 mm^2 Provide dia. of bar = 10mm Adopt spacing of 150mm C/C	Clause 26.5.2.1, IS 456:2000 Clause 26.3.3, IS 456:2000
Check for shear: Design Shear force (V_u) = $0.6 w_u L_x$ (For continuous slab) Then, V_u = 15.8 kN Nominal shear stress (τ_v) = V_u/(bd) = 0.132 N/ mm^2 For p_t = 0.44% & M25 concrete, τ_c = 0.458 N/ mm^2 For slabs, permissible shear stress (τ_c') = k τ_c Where, k = 1.3 τ_c'= 1.3 x 0.458 = 0.595 N/mm^2 > τ_v (OK)	From Table 19, IS 456:2000 Clause 40.2.1.1, IS 456:2000
Check for deflection: $\text{Allowable } \frac{L}{d} = \text{Basic } \frac{L}{d} \times \alpha_1 \times \alpha_2 \times \alpha_3$ Basic L/d = 20 Modification factor for tension reinforcement: A_{st} required = 180 mm^2 A_{st} provided = 523.33 mm^2 Steel stress of service = $0.58 f_y \frac{A_{st,required}}{A_{st,provided}} = 100\ N/mm^2$ Modification factor, α_1 = 2 Modification factor for span, α_2 = 1 Modification factor for compression reinforcement, α_3 = 1 Therefore, Allowable L/d = 20 x 2 x 1 x 1 = 40 mm Actual L/d = 2.20 x 1000/120 = 18.33 mm < 40 mm (OK)	Clause 24.1, IS 456:2000 Figure 4, IS 456:2000,

In similar way one-way slab S6 can be designed.

2.3 DESIGN OF CRANE BEAM

Referring to Figure 2.1, the crane beam lies in grid A-A and D-D of the powerhouse. For the design of crane beam, the location of wheel load is important so that maximum bending moment and shear forces are generated in the member. In this example, three load cases for wheel load are taken as seen in Figures below. The frame is analyzed for the combination of dead load & crane load along with respective partial factor of safety, using the structure analysis software. The bending moment and shear force diagram for various load combinations are shown in Figures below.

Calculation for maximum wheel load

Total nos. of wheels = 4

Wt. of crane bridge girder = 250 KN

Hoist capacity = 250 KN

Wt. of trolley = 50 KN

Minimum distance of hoisted load from left or right wheel (x) = 1.2m *(should be provided by manufacturer)*

Load Case-1 Maximum load when crane is in rest position & trolley is near to one of the supports.

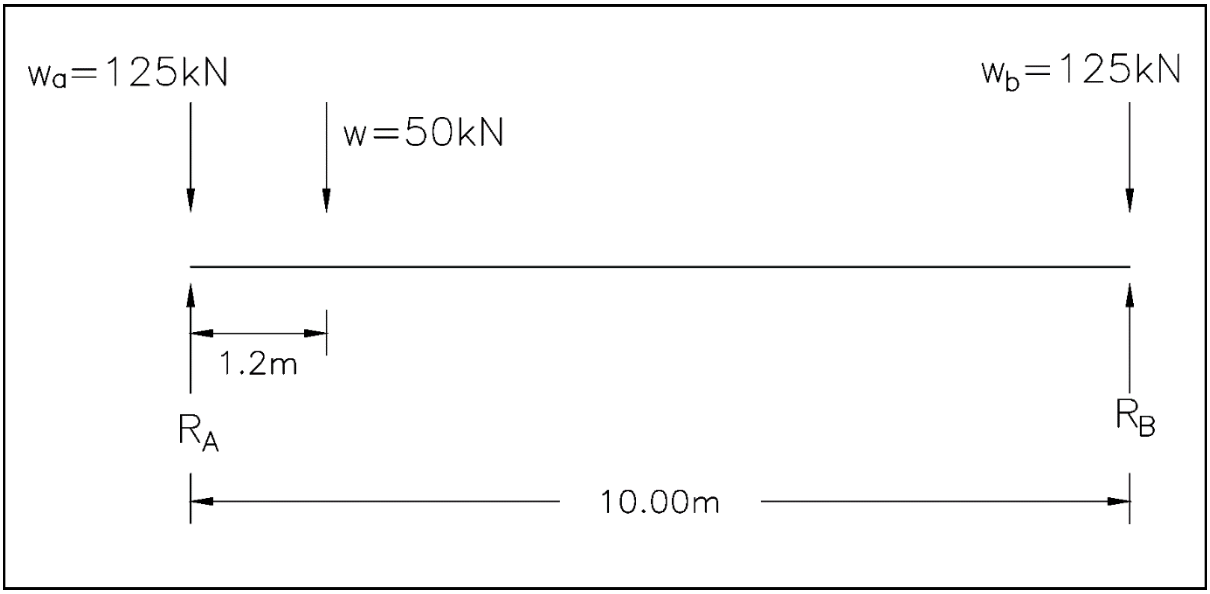


Figure-2. 8 EOT crane load -1, FBD

Load at normal condition (when crane is rest in position) = 250+50 = 300 KN

R_a = 169 KN

R_b = 131 KN

Maximum load per wheel = 169/2 = 84.5KN

Minimum load per wheel = 131/2 = 65.5

Load Case -2 Maximum load when crane is carrying maximum load & trolley is near to one of the supports.

Minimum impact load on crane column/beam/girder due to EOT crane in powerhouse shall be as per clause 6.3 of IS: 875-1987 (Part 2).

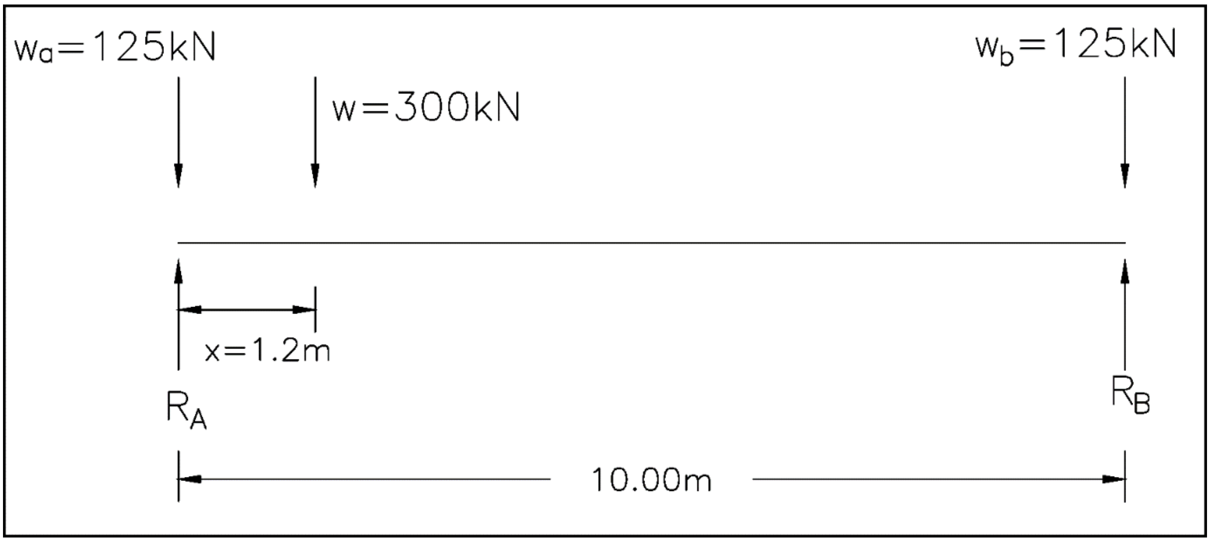


Figure-2. 9 EOT crane load -2, FBC

Ra = 389 KN

Rb = 161 KN

Maximum load per wheel = 389/2 = 194.5 kN

Maximum impact load on wheel = 194.5*25/100 = 48.625 kN (25% of maximum static load)

Lateral surge per wheel = (250+50)*10/100/4 = 30/4 = 7.5 kN (10% of (trolley wt.+ hoisting load))

Tractive force (acts along the direction of rail) = 9.725KN (5% of static wheel load)

Maximum vertical load on a wheel with maximum carrying and impact load = 194.5+48.65 = 243.125KN.

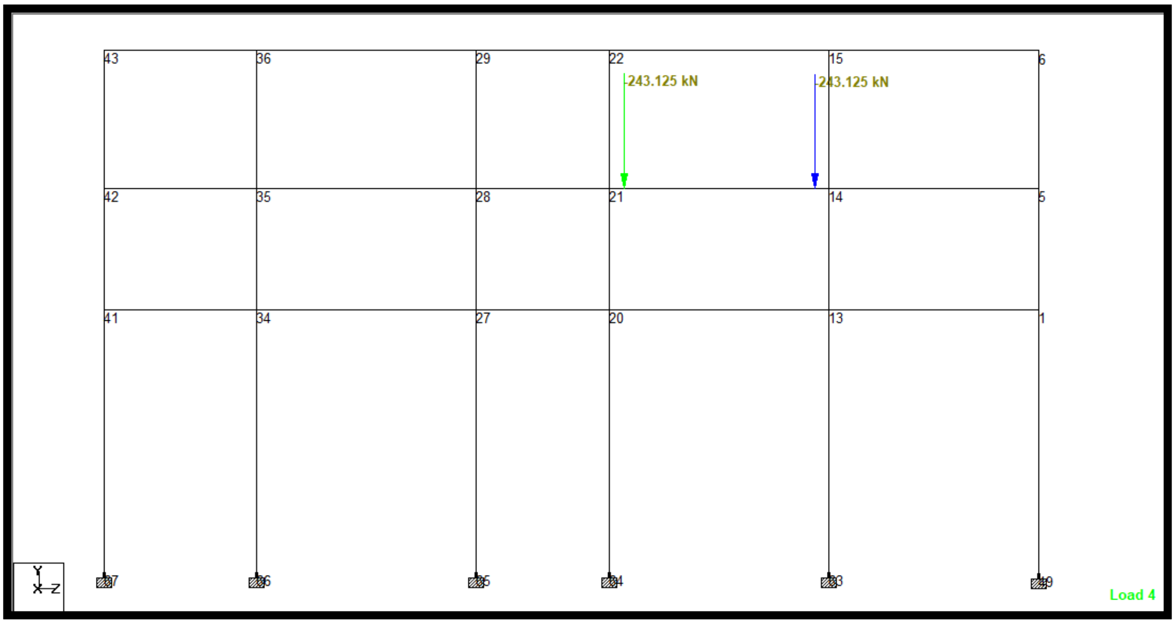


Figure-2. 10 Crane wheel load on beam (Crane load-1)

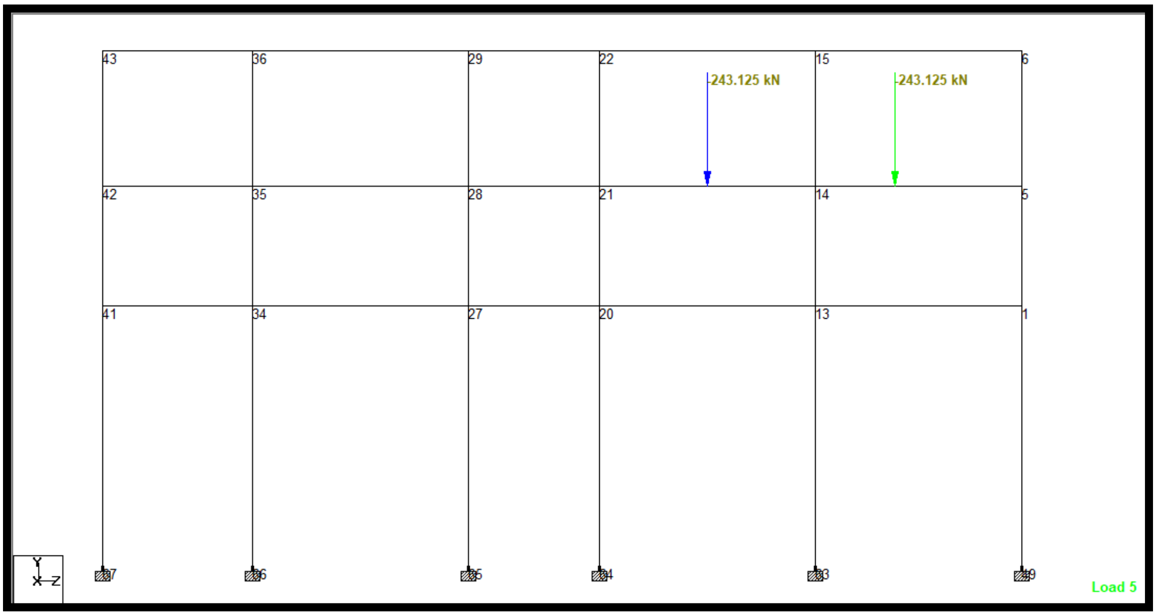


Figure-2. 11 Crane wheel load on beam (Crane load-2)

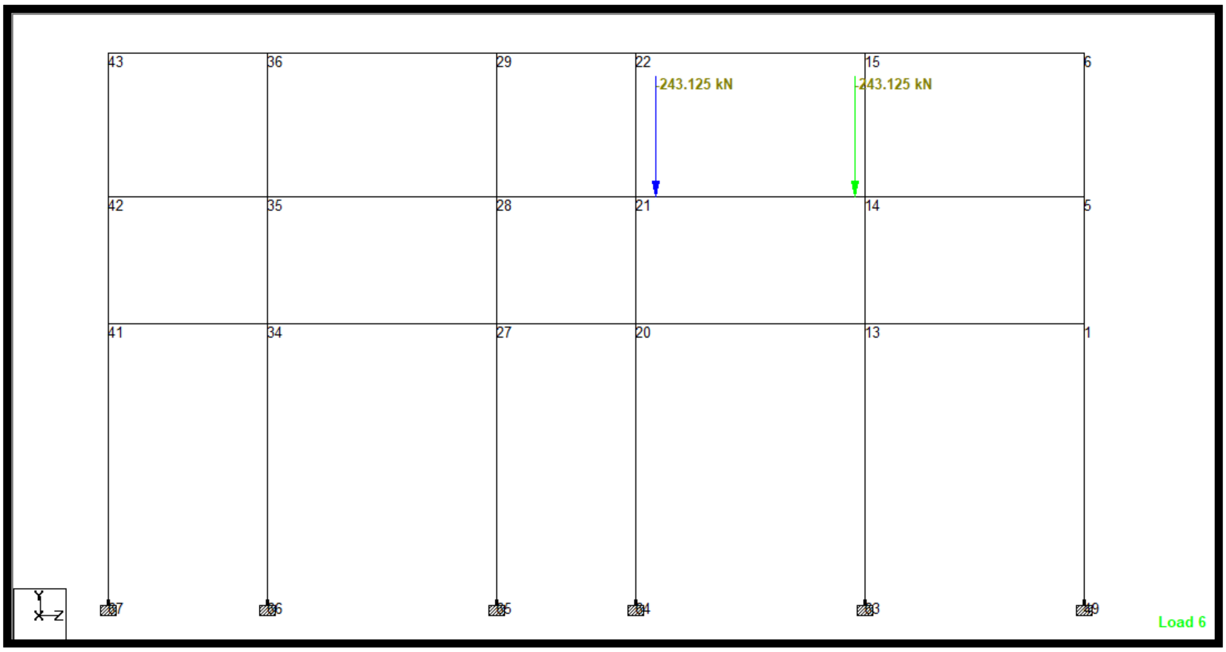


Figure-2. 12 Crane wheel load on beam (Crane load-3)

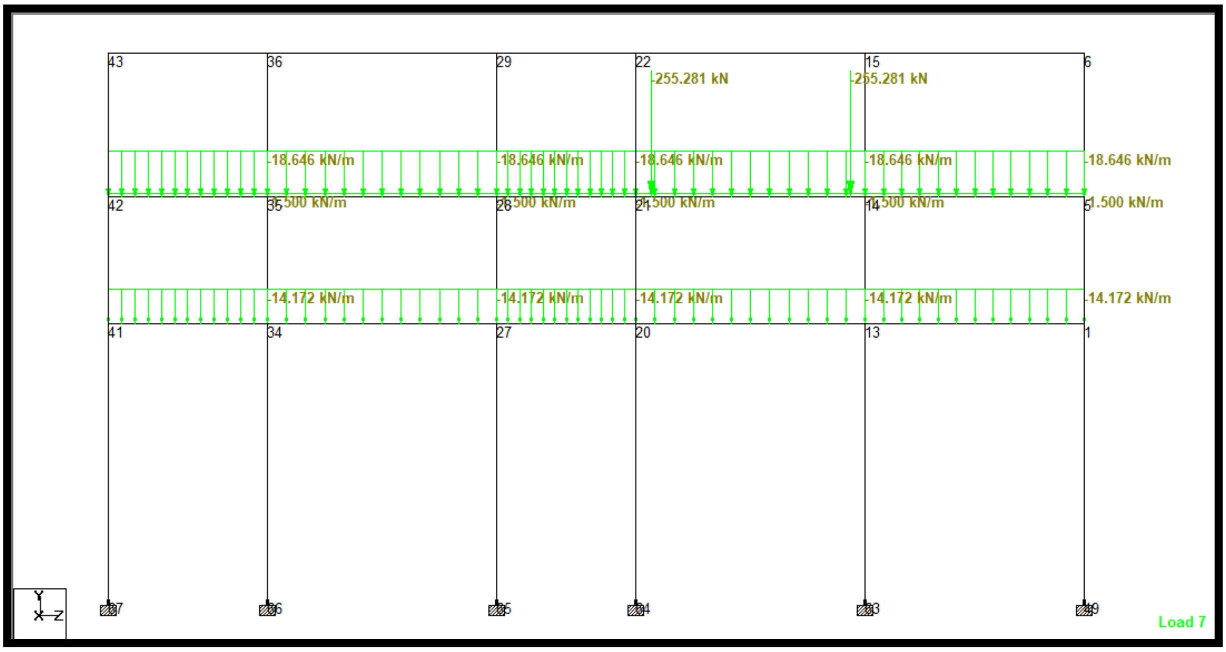


Figure-2. 13 Load acting on crane beam (1.5 DL+ 1.05 CL1)

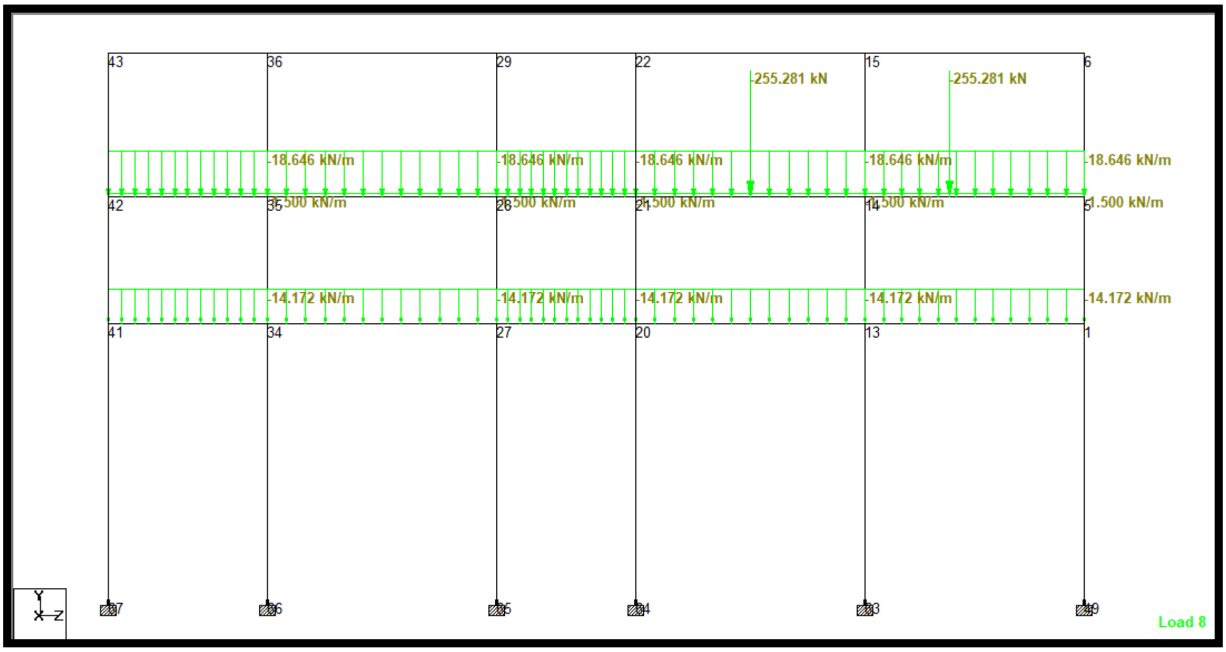


Figure-2. 14 Load acting on crane beam (1.5 DL+ 1.05 CL2)

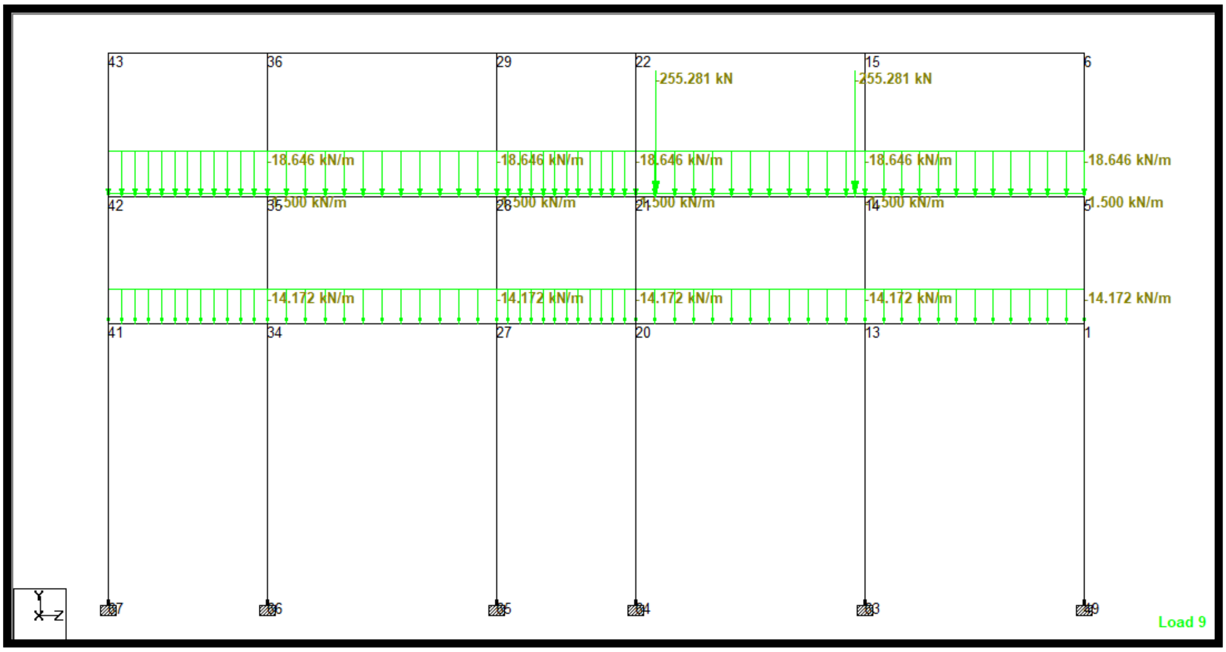


Figure-2. 15 Load acting on crane beam (1.5 DL+ 1.05 CL3)

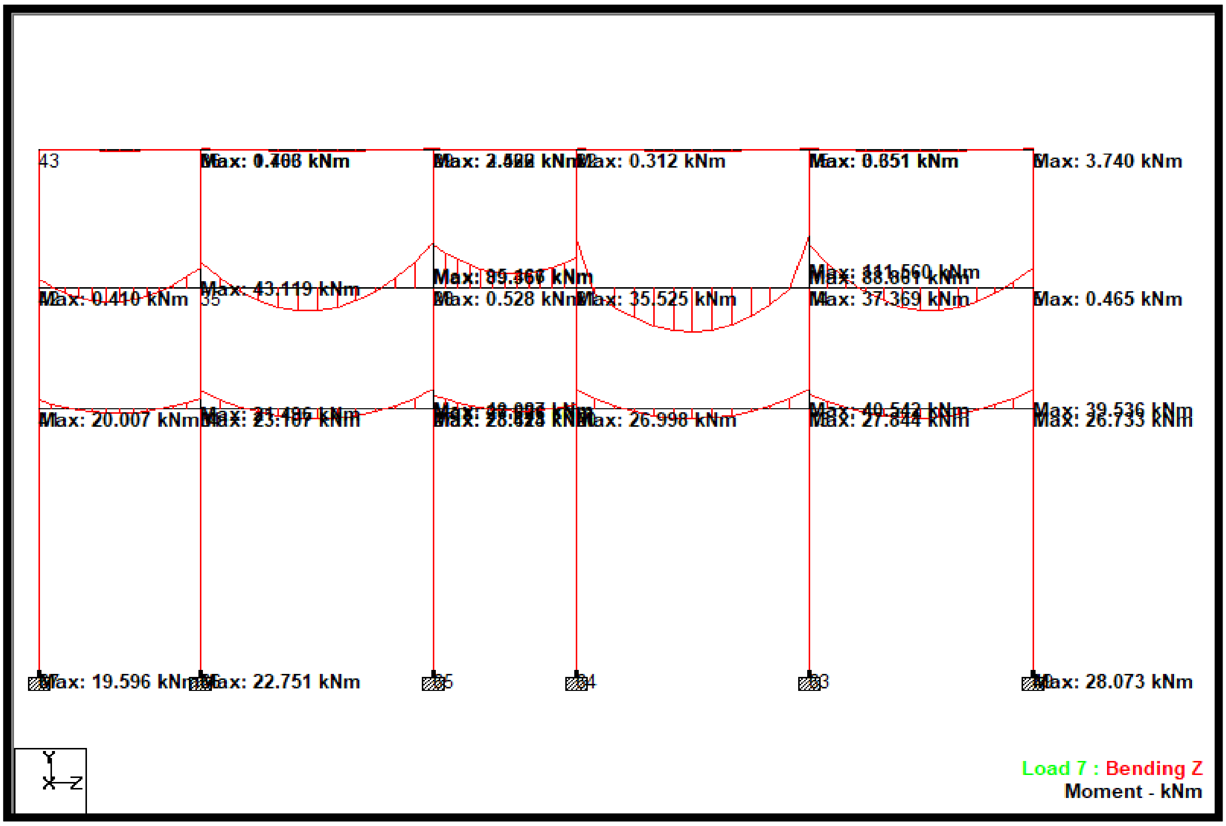


Figure-2. 16 Bending moment diagram (1.5 DL+ 1.05 CL1)

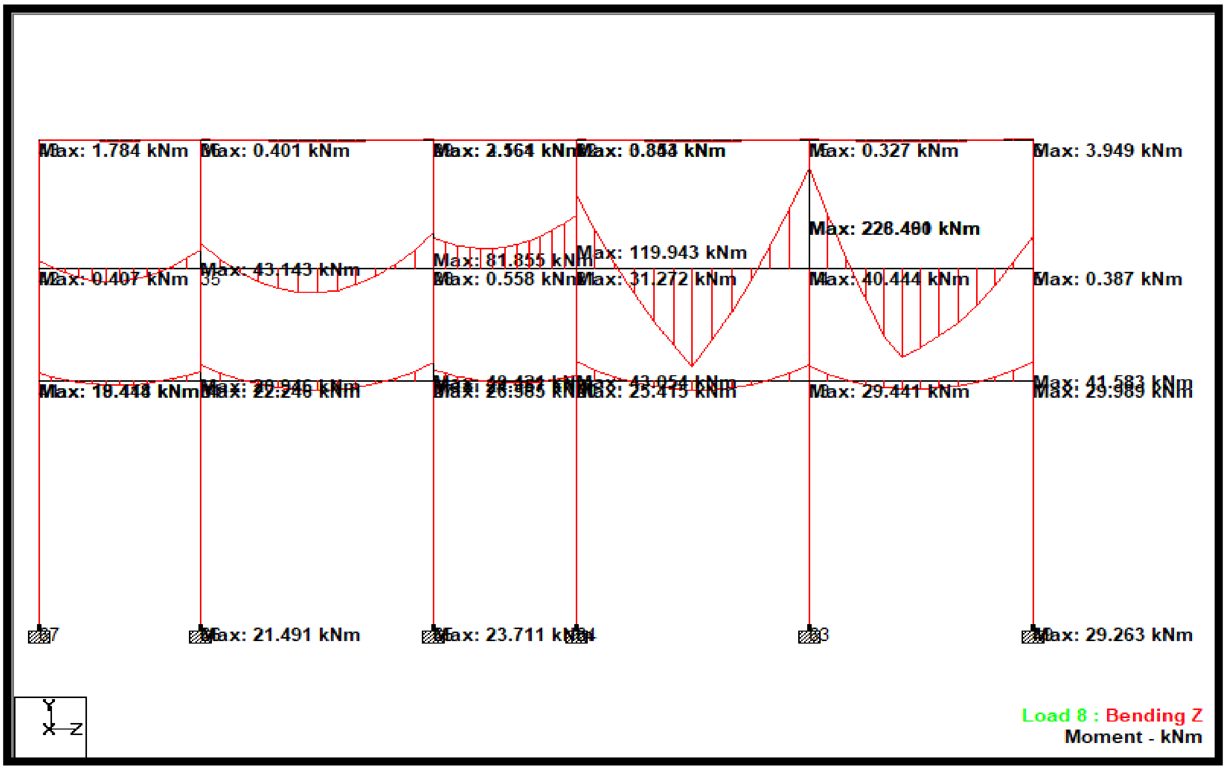


Figure-2. 17 Bending moment diagram (1.5 DL+ 1.05 CL2)

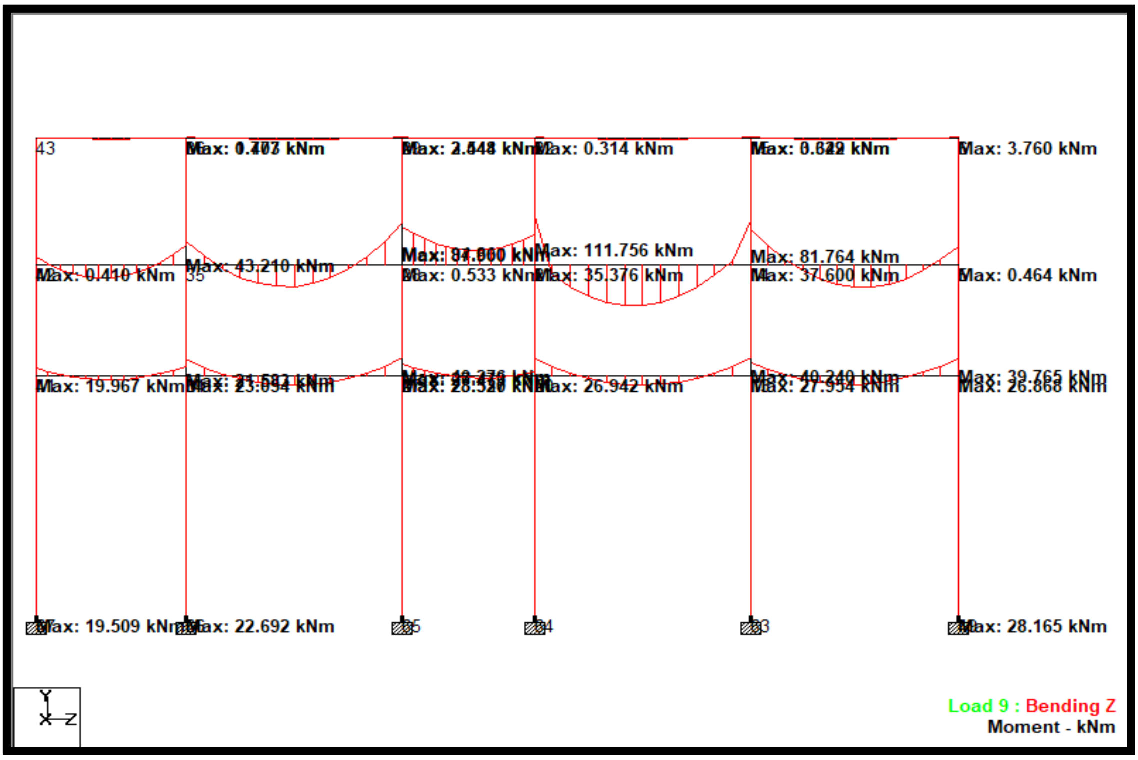


Figure-2. 18 Bending moment diagram (1.5 DL+ 1.05 CL3)

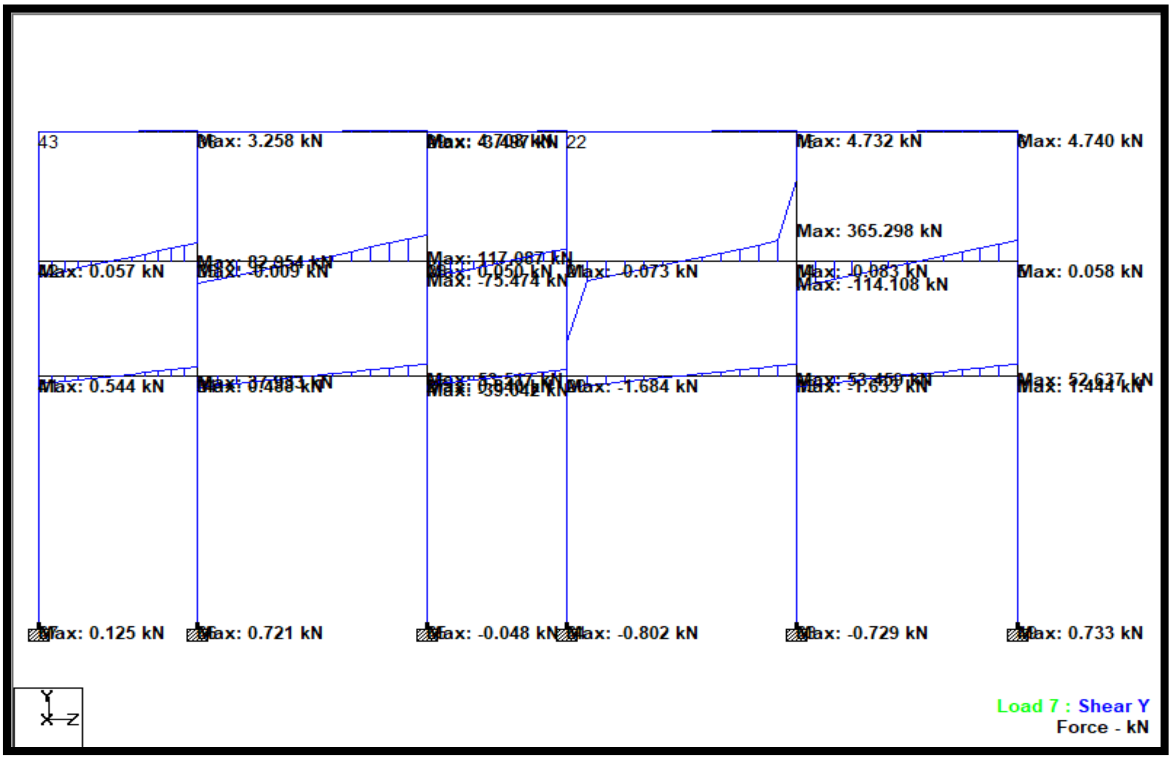


Figure-2. 19 Shear force diagram (1.5 DL+ 1.05 CL1

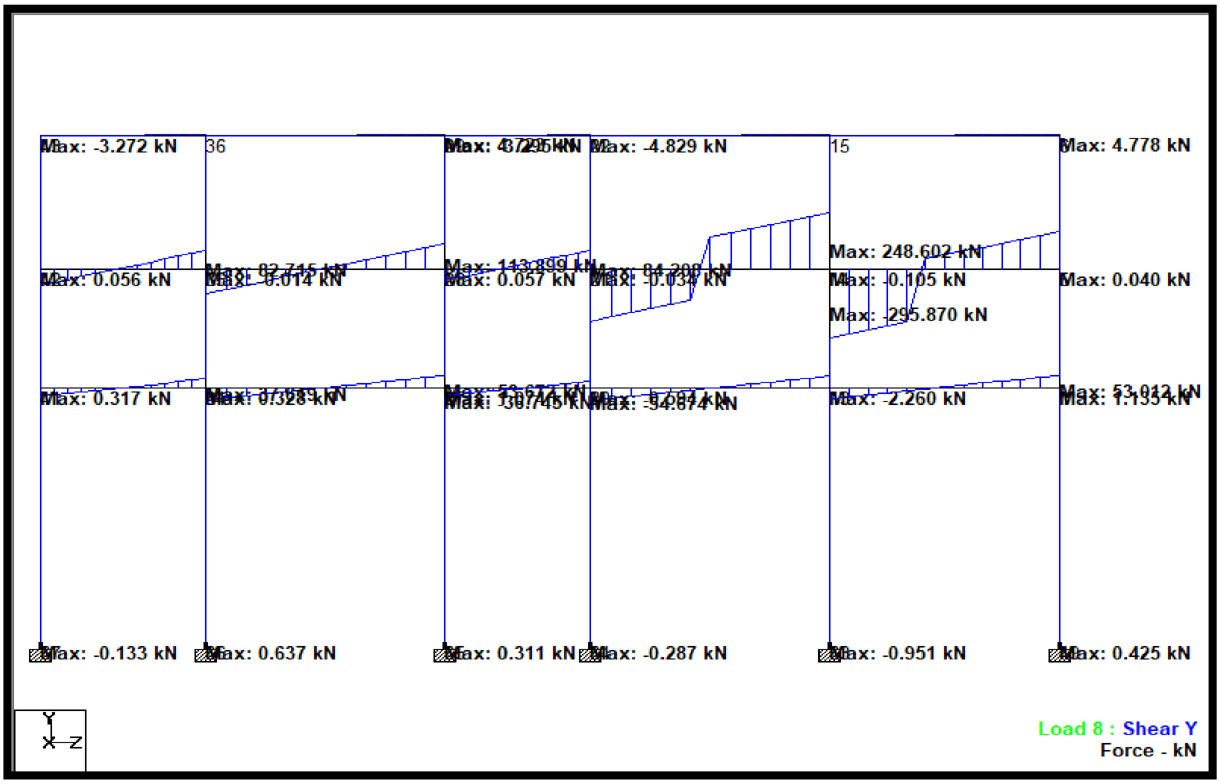


Figure-2. 20 Shear force diagram (1.5 DL+ 1.05 CL2)

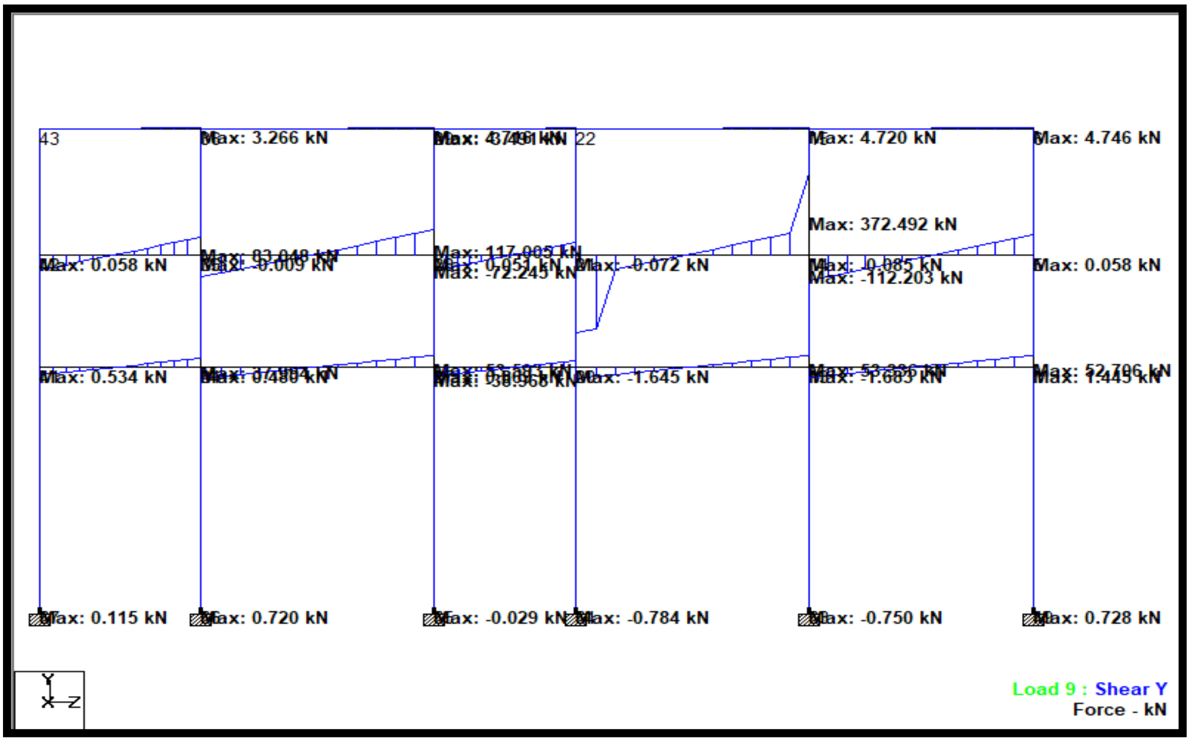


Figure-2. 21 Shear force diagram (1.5 DL+ 1.05 CL3)

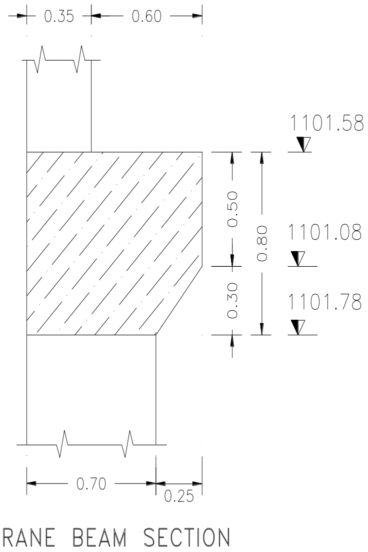


Figure-2. 22 Section of a crane beam

Check for reinforcement for bending moment:

Width of beam at top = 950 mm

Width of beam at bottom = 700 mm

Bottom width of the beam is taken as effective width of the beam for design of the section. However, minimum reinforcement of the reinforcement is calculated from the top width of the section.

Maximum bending moment, M_u = 228.49 kN.m

For Fe500 grade steel, effective depth required,

d = $\sqrt{\frac{M_u}{0.1336\, b\, \sigma_{ck}}}$ = 312.62 mm

Overall depth of the section provided = 800mm

Concrete clear cover = 60mm

Diameter of reinforcement = 20mm

Effective depth of the section = 800-60-20/2 = 730mm > 312.62mm (OK)

Area of steel required may be calculated from the equation given below

$M_u = 0.87 f_y A_t \left(d - \frac{f_y A_t}{\sigma_{ck} b}\right)$

Flexural reinforcement required to resist the bending moment = 741.032 mm^2

Minimum area of tension reinforcement $A_{min.} = \frac{0.85bd}{\sigma_y}$ = 0.85*950*730/500 = 1178.95 mm^2

Since, calculated area of steel is less than the minimum area of tension steel, amount of tension steel should be increased.

Check for shear force

Trial -1

Maximum shear force = V_u = 372.49 kN

Nominal shear stress (τ_v) $= \frac{V_u}{bd}$ = 372.49*1000/(700*730) = 0.729 N/mm^2

10 nos Φ20 mm at top and bottom are provided.

Area of steel provided = 3141mm^2

Percentage of tension reinforcement = 100* 3141 / (700*730) = 0.614 %

Design shear stress for 0.614% of steel (τ_c) = 0.526 N/mm^2

Maximum shear capacity of M25 section (τ_{cm}) = 3.1 N/mm^2

Since, τ_v is smaller than τ_{cm} and greater than τ_c beam section may be design with provision of shear strripus.

Note. If τ_v is greater than τ_{cm} than section need to be redesigned.

Excess shear (τ_{us}) = τ_v - τ_c = 0.729 - 0.526 = 0.203 N/mm^2

Excess shear force (V_{us}) = 0.203*700*730 = 103733N

Provide Φ 10 mm 2 legged stirrups

Area of Φ10 mm bar = 78.539mm^2

Area of 2 legs (A$_{sv}$) = 157.079 mm^2

Spacing of vertical stirrups (s_v) = $\frac{0.87\ \sigma_y\ A_{sv}\ d}{V_{us}}$ or $\frac{0.87\ \sigma_y\ A_{sv}}{\tau_{us}\ b}$

= 0.87*415*157.079*730 /103733

= 399 mm

Maximum spacing of vertical stirrups should not exceed minimum of 300mm or 0.75d.

Hence spacing of shear stirrups S_v = 300mm

Trial -2

8 nos Φ20 mm at top and bottom are provided

Area of steel provided = 2513 mm^2

Percentage of tension reinforcement = 100* 2513 / (700*730) = 0.4917 %

Design shear stress for 0.4917% of steel (τ_c) = 0.484 N/mm^2

Maximum shear capacity of M25 section (τ_{cm}) = 3.1 N/mm^2

Excess shear (τ_{us}) = τ_v - τ_c = 0.729 - 0.484 = 0.2442 N/mm^2

Excess shear force (V_{us}) = 0.2442*700*730 = 124786.2 N

Area of 2 legs (A$_{sv}$) = 157.079 mm^2

Spacing of vertical stirrups (s_v) = 0.87*415*157.079*730 /103733

= 331mm

Provide 8 nos Φ20mm at top and bottom of the beam within 700mm width of beam and 3 more Φ20 within bracket portion.

Note: Characteristics strength of stirrups and bent of reinforcement shall not be taken greater than 415N/mm^2.

Two different shapes of stirrups shall be provided. First stirrups is to resist the shear force and confine the tension reinforcement within the bottom width. However, to support and to confine the reinforcements in bracket portion additional Φ10 mm stirrups shall be provided at spacing of 300 mm. C/c distance between the two types of stirrups shall be 150mm.

Provide 2-legged Φ10mm @ 300mm c/c type-1

Provide 2-legged Φ10mm @ 300mm c/c type-2

Side face reinforcement

Side face reinforce shall be provided in the depth of the web is more than 750 mm and shall be 0.1% of the total web area and equally distributed in both faces.

Minimum area of side face reinforcement = 0.1*950*800/100 = 760mm^2

Check for deflection

L/d < = αβγδλ

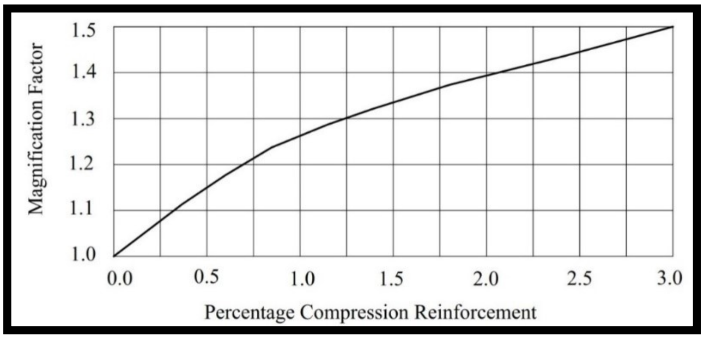
α = 26 for continuous beam

β = 1 for span less than 10m

Magnification factor (δ) for compression reinforcement

Note: figure has been taken form fig. 5 of IS: 456-2000

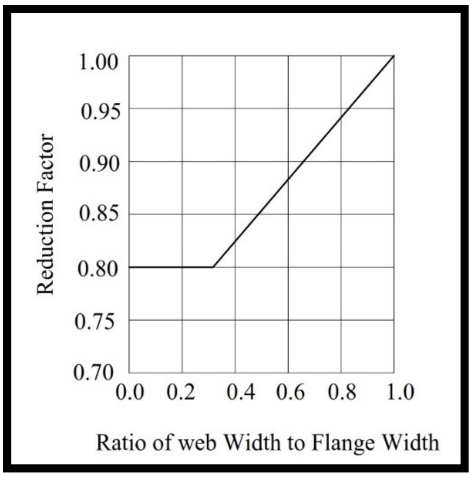
δ = 1.15 for 0.64 % of compression steel



Modification factor λ

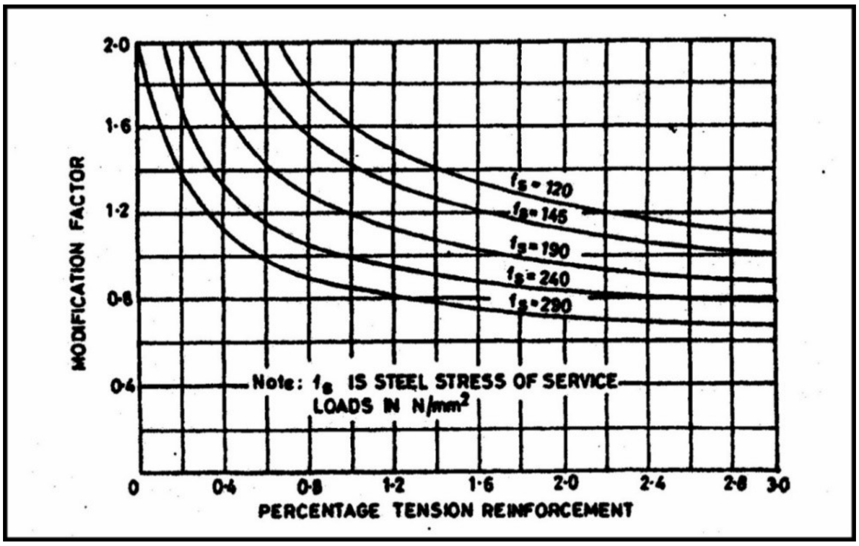
Note: figure has been taken form fig. 6 of IS: 456-2000

λ =1, for web width to flange width ratio 1



Modification factor γ

Note: figure has been taken form fig. 4 of IS: 456-2000



$$\sigma_s = 0.58\,\sigma_y \frac{\text{Area of cross-section of steel required}}{\text{Area of cross-section of steel provided}}$$

σ_s = 0.58*500* 741.032/3141 = 68.414N/mm^2

Percentage of tension reinforcement = 0.614 %

$\gamma = 2$

L/d = 4.6/ 0.73 = 6.301

α β γ δ λ = 26*1*2*1.15*1 = 59.8 <<<6.301 Hence, beam is safe in deflection.

Drawings:

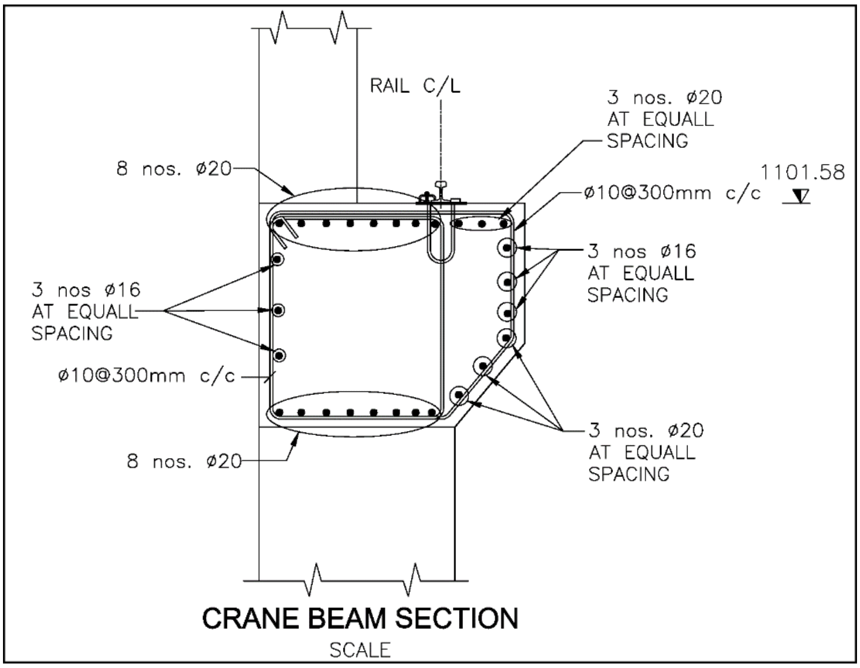


Figure-2. 23 Crane beam section

2.4 DESIGN OF CORBEL

Unit wt. of RCC concrete		25	KN/m^3
Unit wt. of brick masonry		19.5	KN/m^3
Unit wt. of crane rail		0.65	KN/m
Grade of reinforcement bar		500	N/mm^2
Grade of concrete		25	N/mm2
Maximum C/C span of column		4.6	m
Width of crane beam		0.95	m
Depth of crane beam		0.8	m
Span of EOT crane		10	m
Wheel distance of crane		4	m
Total load /wheel including impact	W1	243.125	KN
Beam wt.	W3	59.08125	KN

Load transferred to the corbel form crane beam/girder depends upon the position of crane beam/girder. Here, for the design of corbel not more than 75% of beam wt. is transferred on corbel

Rail wt.	W4	2.99	KN
Live load	W5	0	KN
Total vertical load. on corbel		305.20	KN
Factor of safety for crane and rail load		1.05	
Factor of safety for RCC beam		1.5	
Factor vertical load due to EOT crane and rail		258.42	KN
Factor vertical load of RCC beam		88.62	KN
Factored vertical load	**P_u**	**347.04**	**KN**

a) Check for bearing stress

Let us provide 200mmx180mm of base plate

Length of base plate	200	mm	
Width of base plate	180	mm	
Max. stress at base of plate	7.18	Mpa	
Permissible bearing stress on the concrete	11.25	Mpa	$0.45\ \sigma_{ck}$
Bearing area required	30848.23	mm^2	
Length of plate	200	mm	
Width of plate required	154.24	mm	

Provide 200mmx180mm of base plate

Since, provided plate size is greater than the required size structure is safe in bearing

b) Check for shear stress

Width of corbel	b	500	mm	
Maximum shear stress of M25 concrete	τ_{cmax}	3.1	N/mm^2	IS 456: 2000
Let, max. design shear strength of concrete	T_c	2.48	N/mm^2	80% of T_{cmax} has been considered
Calculated depth of corbel	d'	279.87	mm	
Provided overall depth of the corbel	D	800	mm	
Concrete clear cover	c_c '	50	mm	
Adopted	d	750	mm	
Dist. of load from the face of corbel	a	90	mm	Max. dist. Considered, from drawing
Span depth ratio	a/d	0.120		a/d < 0.6 & should not be greater than 1
Provide depth of front vertical face of corbel		500.00	mm	Min. depth of front face should be > 0.5 of total depth of corbel
Vertical depth of inclined face		300.00	mm	

c) Calculation of Lever arm

$\alpha =$	P_u /(0.86*σ_{ck}*b*d)	0.043
$\beta =$	a/d	0.120

$(z/d)^2 - (\alpha/(\alpha+\beta))*(z/d)+(\alpha/(\alpha+\beta))*\beta^2 = 0$

$-(\beta/(\alpha+\beta))$	-0.7360	
$(\alpha/(\alpha+\beta))*\beta^2$	0.0038	

Solving above equation

z/d	0.73080	0.0052
z	548.097	mm
$z = d-0.42x_m$		
$x_m = 2.38*(d-z)$	480.530	mm
x_m/d	0.6407	> 0.46 for Fe500, Compression rebar. is required.

d) Calculation of area of Tension steel

$F_t = a/z*p$		56.986	KN	must be > 0.5 Pu
Half of max. vertical load	0.5 Pu	173.521	KN	
Let horizontal resistance force	F_T	190.000	KN	

Minimum horizontal force resisted by main tension steel at corbel must be greater than or equal to half of vertical force.

Max. strain in tension steel	$\varepsilon_s = (d-x_m)/x_m*E_c$	0.001963	**$\varepsilon_{sy} > \varepsilon_s$, OK**	
	$\varepsilon_c = 0.0035$			
Young's modulus of elasticity	E_s	200000	N/mm^2	
Strain in reinforcement steel at yield point	ε_{sy}	0.002175		$0.87*f_y/E_s$
Strain in reinforcement steel at break point	ε_s	0.004175		$0.87*f_y/E_s+0.002$

<u>Table for points on design stress-strain curve for HSD grade bars</u> .

Stress level	415 grade		500 grade	
	Strain	Stress N/mm²	Strain	Stress N/mm²
0.80 σ_d	0.00144	288.7	0.00174	347.8
0.85 σ_d	0.00163	306.7	0.00195	369.6
0.90 σ_d	0.00192	324.8	0.00226	391.3
0.95 σ_d	0.00241	342.8	0.00277	413.0
0.975 σ_d	0.00276	351.8	0.00312	423.9
1.00 σ_d	0.00380	360.9	0.00417	434.8

Stress in tension reinforcement 370.65 N/mm^2 from above Table

Required area of tension steel 512.61 mm^2

Percentage tension steel 0.137 % <u>Not OK. P should be within 0.4% to 1.3% clause 7.7.2 of SP 34, 1987</u>

e) Calculation for Tension reinforcement

Dia. of main tension reinforcement φ 20 mm

Number of tension reinforcement n 6

Area of tension reinforcement provided A_t 1884.96 mm^2

% of tension reinforcement P 0.503 % OK. P is within the range of 0.4% to 1.3%.

f) Calculation of shear reinforcement

Min. area of shear reinforcement (0.5*A_t) A_{sv} 942.478 mm^2

<u>Provide 10 mm -4 legged in 3 rows in upper 2/3 of d</u>

Dia. Of shear rebar 10 mm

Type of rebar 4 legged

Number of rows in upper 2/3 d 3

Area of shear stirrups provided 942.478 mm^2 OK

Spacing of shear stirrups x 167 mm

g) Maximum shear capacity of section

For P % of tension reinforcement shear strength	τ_c	0.49	N/mm^2	IS: 456 :2000
Increased shear strength $\tau'_c = 2*\tau_c*(d/a)$		8.167	N/mm^2	
	τ'_c	3.1	N/mm^2	

Maximum value of τ'_c cannot be greater than 3.1N/mm^2 .

Total shear resistance

$V_u = V_c+V_v = \tau'_c*b*d+0.87*f_y*A_{sv}*d/x$	3003717.85	N	x = spacing of stirrups
	3003.72	KN	OK. Greater than Pu

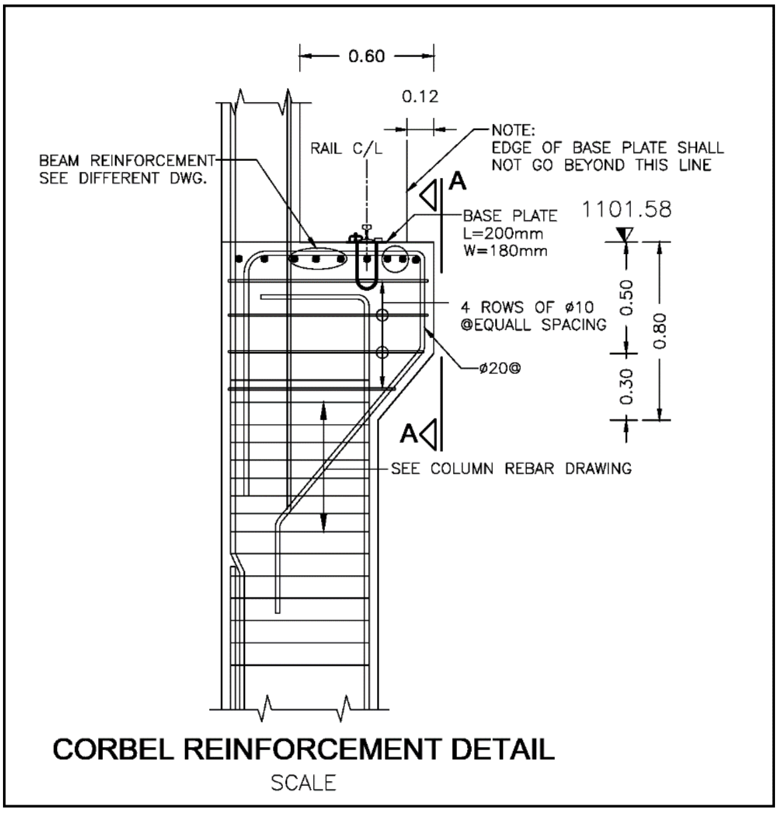


Figure-2. 24 Corbel reinforcement detail

2.5 DESIGN OF COLUMN

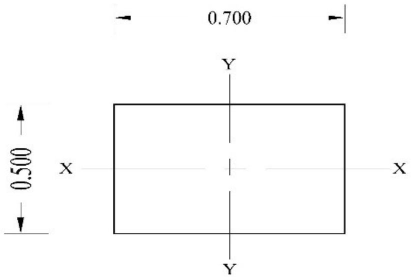


Fig. Crane Column Section

	371.439	KN
Crane load vertical	84.500	KN
Moment about x-x axis due to dead load	0	KN.m
Moment about x-x axis due to crane impact load	0	KN.m
Moment about y-y axis due to dead load & live load eccentricity	14.139	KN.m
Moment about y-y axis due to earthquake on dead load & live load	-279.981	KN.m
Moment about y-y axis due to crane load eccentricity	-25.350	KN.m
Moment about y-y axis due to earthquake on crane	-87.880	KN.m
FOS for dead load & live load	1.2	
FOS for crane load	1.05	
Factored Vertical load (P_u)	534.452	KN
Factored Moment about x-x axes (M_x)	0	KN.m
Factored Moment about y-y axes (M_y)	437.902	KN.m
Width of the column (B)	0.5	m
Depth of the column (D)	0.7	m
Concrete clear cover to vertical bar	0.04	m
Diameter of bar (ø)	20	mm
Numbers of bars provided equally in 4 sides	24	
Area of bars (A_s)	7539.822	mm^2
% of reinforcement (p)	2.154	%

Material properties

Grade of concrete			25	Mpa
Grade of steel			500	Mpa

1) Check for effective length

Unsupported length of the column		L	7.2	m
l_{ex}		1.2	8.64	m
ley		2	14.4	m

2) Slenderness ratio

lex/B	17.28	>12	Slender column
ley/D	20.57	>12	Slender column

The column is slender about both axes and additional monent is developed due to slenderness (p-Δ effect)

3) Additional moment due to slenderness

e_x & e_y may be calculated from table 1, page 106, SP 16, 1980

ex =	$B/2000*(l_{ex}/B)^2$	0.075	m
ey	$D/2000*(l_{ey}/D)^2$	0.148	m
Max'		39.897	KNm
May'		79.16	KNm

4) Calculation of reduction factor of additional moment

This additional moment is multiplied by **K** which reduces the amount of additional moment.
Max. value of **K** should not be greater than 1

K = (Puz-Pu)/(Puz-Pb) <= 1

$P_{uz} = 0.45*\sigma_{ck}*A_c+0.75*\sigma_y*A_{st}$ 6764.933 KN

This value can be taken form chart 63, page 148, SP 16, 1980

P_{bx}=

$P_{by}= (k_1+k_2*p/\sigma_{ck})*\sigma_{ck}*B*D$

d'			0.050	m
d'/B			0.1000	
d'/D			0.071	
K_{1x}			0.207	From Table 60, SP16 -1980
K_{2x}			0.425	From Table 60, SP16 -1980
K_{1y}			0.214	From Table 60, SP16 -1980
K_{2y}			0.4946	From Table 60, SP16 -1980
$P_{bx} = (k_{1x}+k_{2x}*p/\sigma_{ck})*\sigma_{ck}*B*D$			2131.69	KN
$P_{by} = (k_{1y}+k_{2y}*p/\sigma_{ck})*\sigma_{ck}*B*D$			3880.10	KN

Kx	1.38	1	Value of K ≤ 1
Ky	2.22	1	

The additional moment calculated above is multiplied with the k values

Max	39.90	KNm
May	79.16	KNm

5) Moment due to the the minimum eccentricity

$e_{min\ x}$	L/500+B/30	0.031	m
$e_{min\ y}$	L/500+D/30	0.038	m
M_{ex}		16.604	KNm
M_{ey}		20.167	KNm

Comparing this moment with the design moment

$M_{ex} > M_x$ therefore we take M_{ex} for design
$M_{ey} < M_y$ therefore we take M_y for design

M_{ux}'	16.60	KNm
M_{uy}'	437.90	KNm

6) Total moments

M_{ux}	56.50	KNm
M_{uy}	517.06	KNm

7) Uniaxial moment capacity of the section

$P_u/\sigma_{ck}*B*D$	0.061
$p\%/\sigma_{ck}$	0.086

for d'/B = 0.1, fe500 and reinforcement distributed equally in four side chart 48, SP 16-1980

$M_{uxl} /\sigma_{ck}*D*B^2$	0.155	
M_{uxl}	678.125	KNm

for d'/D = 0.071, fe500 and reinforcement distributed equally in four side chart 47, SP 16-1980

$M_{uyl} /\sigma_{ck}*D*B^2$	0.170	
M_{uyl}	1041.25	KNm

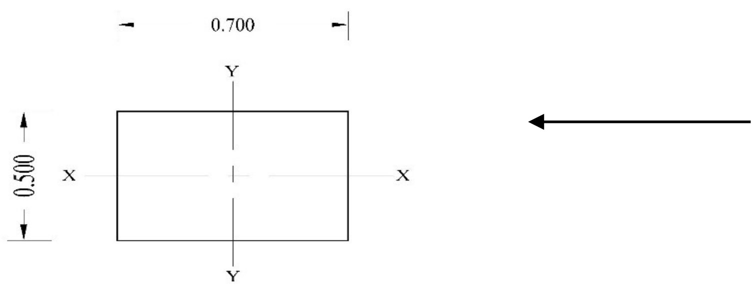
P_U/P_{uZ}	0.079
α_n	1.000

$(M_{ux}/M_{uxl})^{\alpha n}$	0.0833
$(M_{uy}/M_{uyl})^{\alpha n}$	0.4966

$(M_{ux}/M_{uxl})^{\alpha n}+(M_{uy}/M_{uyl})^{\alpha n}$	0.580	Calculated value < 1, OK. Design of Crane column is safe.

Shear capacity of column

a) Shear force along x- direction



Direction of shear force

Fig. Crane Column Section

Grade of steel	f_y	500	N/m^2
Characteristic strength of concrete	σ_{ck}	25	N/m^2
Depth of column/pedestal	D	700	mm
Width of column/pedestal	b	500	mm
Diameter of vertical bars	Ø	20	mm
Clear cover to vertical bars	C_c	40	mm
Effective depth	d	650	mm
Vertical load on the column/pedestal	P_u	371.439	KN
Max. shear/horizontal force	F_{vz}	149	KN
Max. shear stress	T_v	0.458	N/m^2
Nos. of bars at one face		7	
Area of steel at z- axis face		2199.11	mm^2
% of tension steel at z-axis face	p	0.68	%
Shear strength of concrete	τ_c	0.54	N/m^2

Increased shear strength of concrete as per section, 40.2.2 of IS:456-2000

$\delta=1+3*p_u(A_g*\sigma_c)$		1.127	
Increased shear strength of concrete	T'_c	0.609	N/m^2

Tv < T'c, hence OK

b) Design of Shear toward x- direction

Direction of shear force

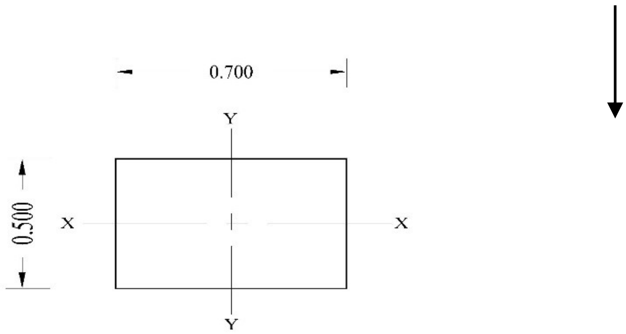


Fig. Crane Column Section

Depth of column	D	500	mm
Width of column	b	700	mm
Diameter of vertical bars	Ø	20	mm
Clear cover to vertical bars	C_c	40	mm
Effective depth	d	450	mm
Vertical load on the column/pedestal		371.439	
Max shear force at battery room floor	F_{vz}	85	KN
Max shear stress	T_v	0.270	N/mm^2
Nos of bars at one face		7	

Area of steel at z- axis face		2199.11	mm^2
% of tension steel at z-axis face	p	0.70	%
Shear strength of concrete	τ_c	0.554	N/m^2

Increased shear strength of concrete as per section, 40.2.2 of IS:456-2000

$\delta=1+3*P_u(A_g*\sigma)$	1.127	

Increased shear strength of concrete	T'_c	0.625	N/m^2
		Tv < T'c, hence OK	

Spacing of confinement stirrups-1

Size of column	
D	B
mm	mm
700	500

Area of cross section of bars forming link should be at least maximum of values given by equation (i) and (ii) as per 8.1 (c), (2) of IS: 1893-2016

$A_{sp} = 0.18*S*h*(A_g/A_c-1)*\ \sigma_{ck}/f_y$ ------------------------------(i)

$A_{sp} = 0.05*s_v*h*\ \sigma_{ck}\ /f_y$ ---(ii)

Where,

S = spacing of links
h = Longer dimension of the rectangular confining link/stirrup which should not exceed 300mm as per 7.4.2.(c) IS: 1893-2016
A_{sp} = cross section area of bar forming link
A_g = gross area of concrete
A_c = area of concrete core in rectangular link measured to its outer dimension

σ_{ck}	25	$N/\ mm^2$
f_y	415	$N/\ mm^2$

Clear cover to longitudinal bars	40	mm
Diameter of bars forming link	10	mm
Clear cover to stirrup	30	mm

A_g	350000	mm^2
A_c	260400	mm^2

h	640	mm	h should not be greater than 300.

Nos. of cross ties to provide		2	nos	
h		213.00	mm	<u>h does not exceed 300 hence OK.</u>
Area of stirrup	A_{sp}	78.54	mm^2	

$S = A_{sp}*\sigma_y/(0.18*h*\sigma_{ck}(A_g/A_c-1))$

Spacing of stirrups	s	98.83	mm
Clear height of column		4800	mm

Distance up to which special confinement should be max. of

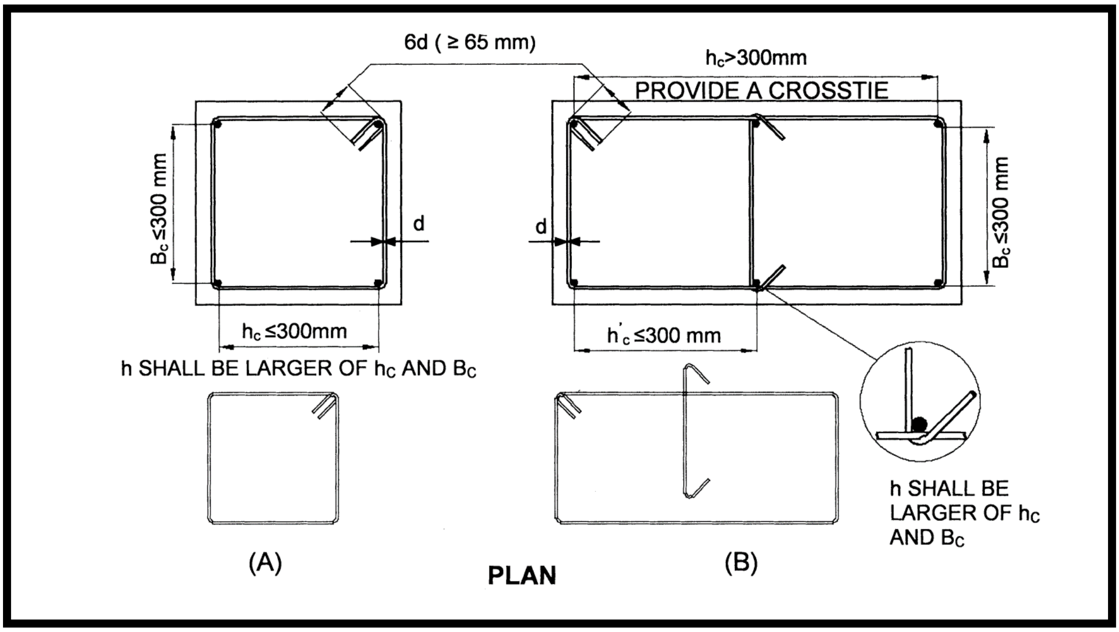
$l_o \geq L/6$	800	mm
$l_o \geq D$	700	mm
$l_o \geq 450$	450	mm
l_o	800	mm

l_o *is the distance from bottom face of the beam of or top face of beam/slab up to which confining reinforcement should be provided. Reference may be taken from section 8 & fig.12 of IS: 13920-2016.*

Provide 10mm stirrups @ 95 mm c/c up to 800 mm from the joint of beam column

 # If the calculated point of contra-flexure under the effect of gravity and earthquake is not within the middle half of the member clear height, special confinement reinforcement must be provided over the full height of the column. Reference may be taken from section 8.3 of IS: 13920-2016.

 # Special confinement reinforcement shall be provided over the full height of column which has significant variation in stiffness along its height. This variation in stiffness may result due to abrupt change in cross section size, or unintended restraint to the column provided by stair-slab, mezzanine floor, plinth or lintel beam framing in to the column and extending only for partial column height. Reference may be taken from section 8.4 of IS: 13920-2016.



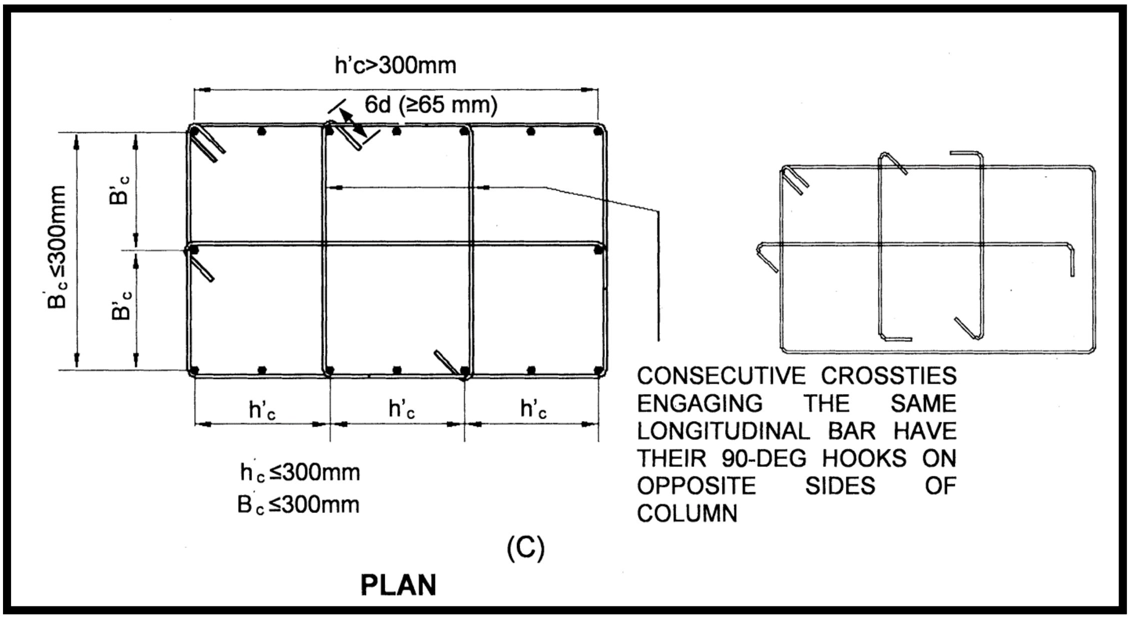


Figure-2. 25 Details of transverse reinforcement in column

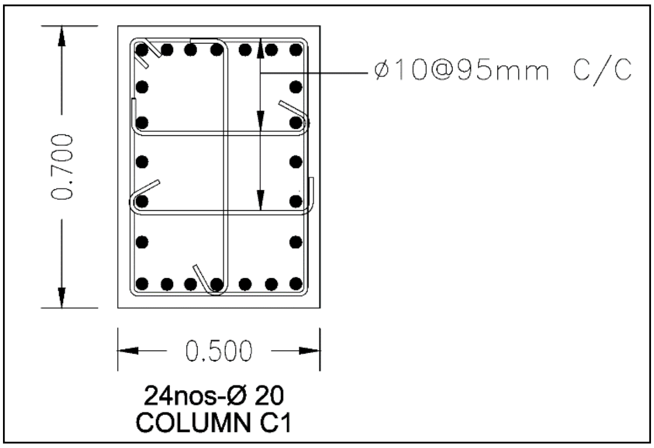


Figure-2. 26 column section with reinforcement detail

2.6 STRUCTURE ANALYSIS AND DESIGN REPORT OF POWERHOUSE SUPER-STRUCTURE AND CONTROL BUILDING

Unit weight of materials

Unit wt. of reinforced concrete : 25 KN/m^3

Unit wt. of brick masonry : 19.5 KN/m^3

Unit wt. of cement plaster : 20.4 KN/m^3

Unit wt. of terrazzo (40mm) : 0.24 KN/m^2

Bitumen felt (Water Proofing) : 0.04 KN/m^2

Wt. of CGI sheet : 0.3 KN/m^2 (0.4KN/m^2 has been taken including lapping and j-hooks and washers)

Properties of Material

Characteristics strength of concrete at 28 days (σck) = 25N/mm^2 (M25)

Grade of reinforcement steel (σy) = 500N/mm^2 (Fe500)

Elastic modulus of reinforcement (Es) = 205 KN/mm^2

Protective bar cover

The concrete cover to reinforcement bar shall be as given below

40mm for all columns

60mm for Crane beams

35mm for all other beams

25mm to 30mm for floor slab

Method of Analysis & Design

This example for the analysis and design of powerhouse super structures have been carried out using the computer software '*Staad. Pro', version 2006'*. The 'Staad. Pro 2006' software is a computer program for the analysis of and design of RCC and steel structure in 2d and 3d models. It provides the facility to design the RCC & Steel structures on the basis of codes/standards of different countries including Indian standard.

Three dimensional Frame model of Powerhouse Structure was created, physical properties, load values and design parameters were assigned to all members and subsequently analysis &design of members was performed. 'Fixed' type of support has been assigned at base of all column.

The Limit State Method based on the IS: 456-2000 has been adopted for design of all RCC elements of powerhouse.

The analysis results e.g. support reactions, bending moments, shear forces from critical load combinations have been abstracted from the output result of *Staad. Pro*. The area of reinforcement steel obtained at different points of structural members from the design result of *Staad. Pro* have been summarized below and have been utilized for the distribution of reinforcement bars in the structural members.

Analysis of the PH structure using Staad. pro

Powerhouse model

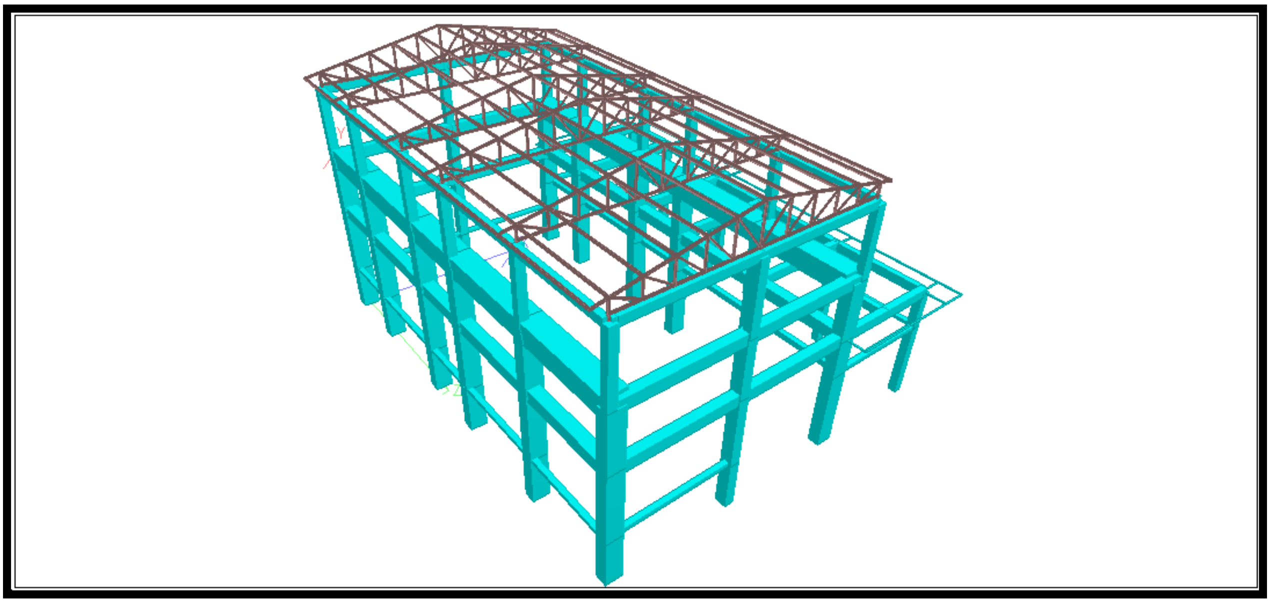


Figure-2. 27 Powerhouse Super Structure Model View-1

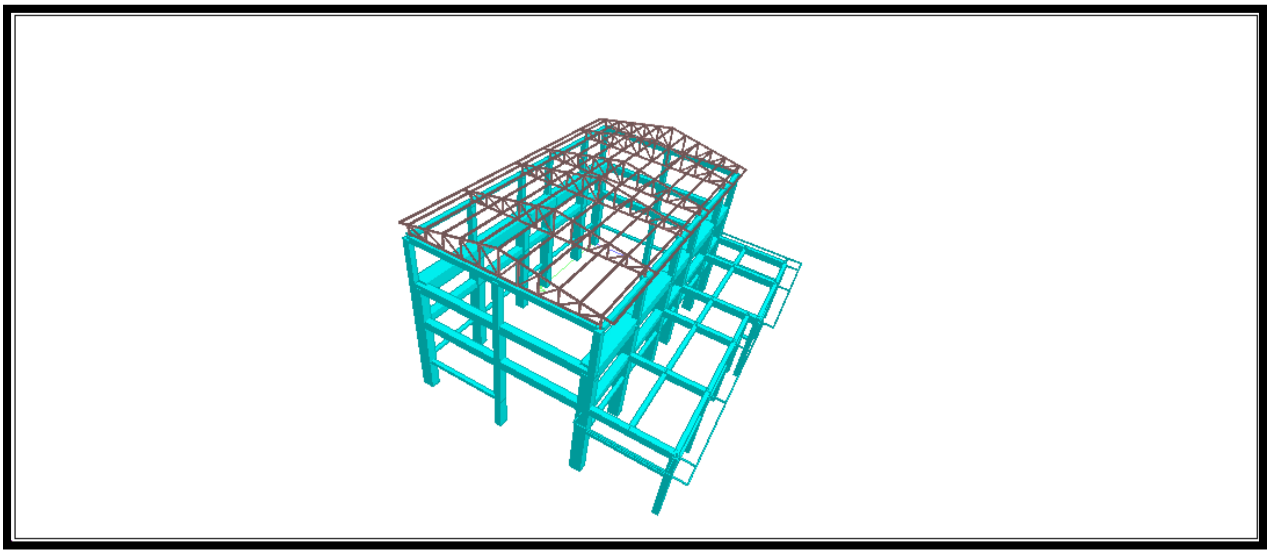


Figure-2. 28 Powerhouse Super Structure Model View-2

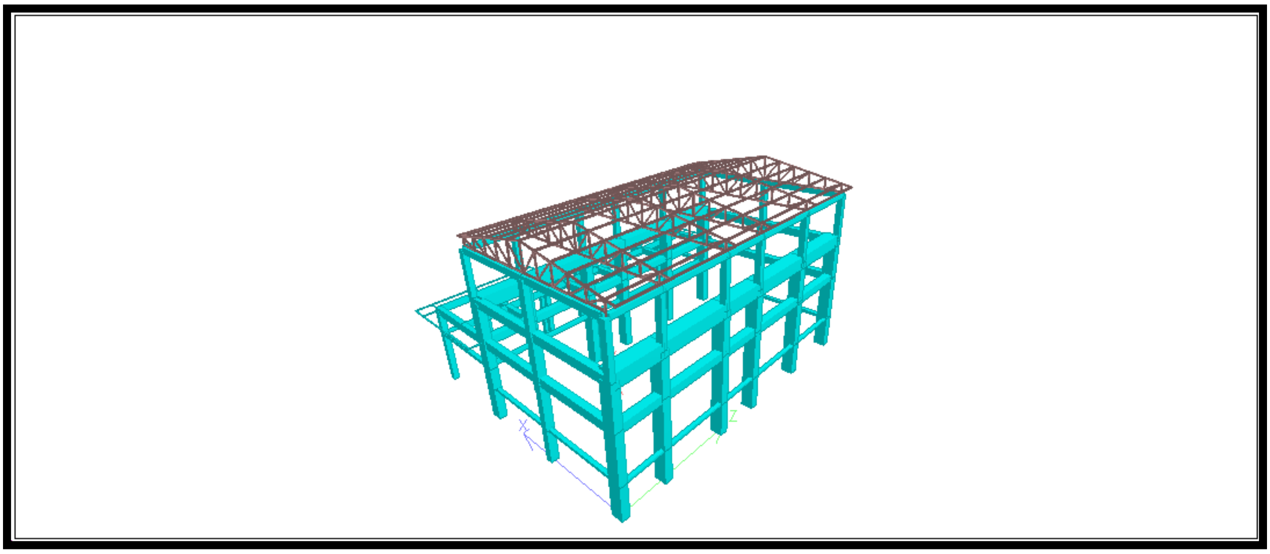


Figure-2. 29 Powerhouse Super Structure Model View-3

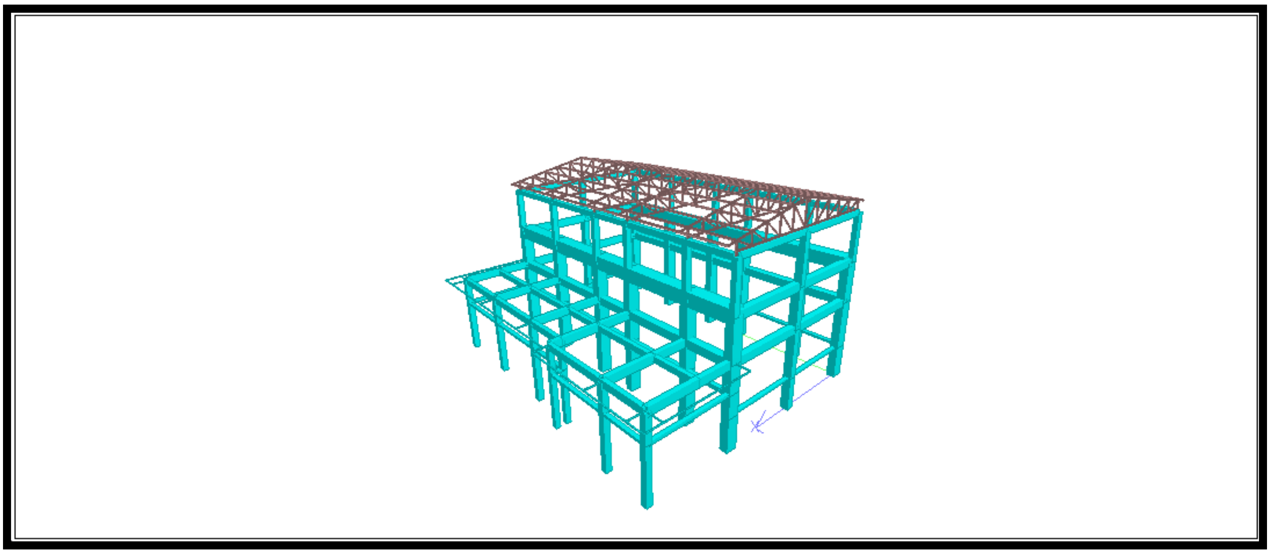


Figure-2. 30 Powerhouse Super Structure Model View-4

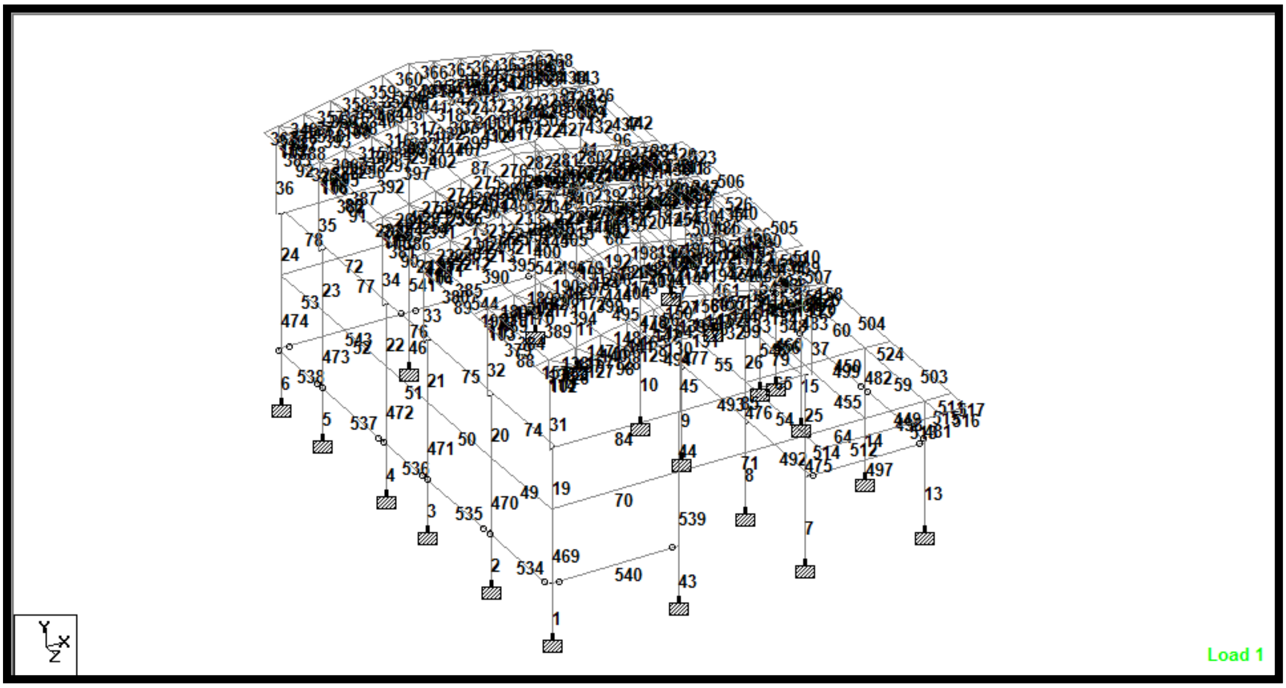


Figure-2. 31 Powerhouse Super Structure Model View-5, Member numbers

Load Details

Dead loads

Frame self-wt. and truss self wt.

-Calculated by FEM method

Floor Load

Floor Load - (Terrace of control room /hall)

a) Self wt. of 150mm thick slab

Ws = 0.15*25

Ws = 3.75KN/m^2

b) Load due to water proofing material

75mm thick Concrete (PCC or Wire mesh concrete)

= 0.075*25

= 1.875KN/m^2

Asphalt felt +Bitumen layer

= 1.25KN/m^2

Total floor load = 7.5KN/m^2

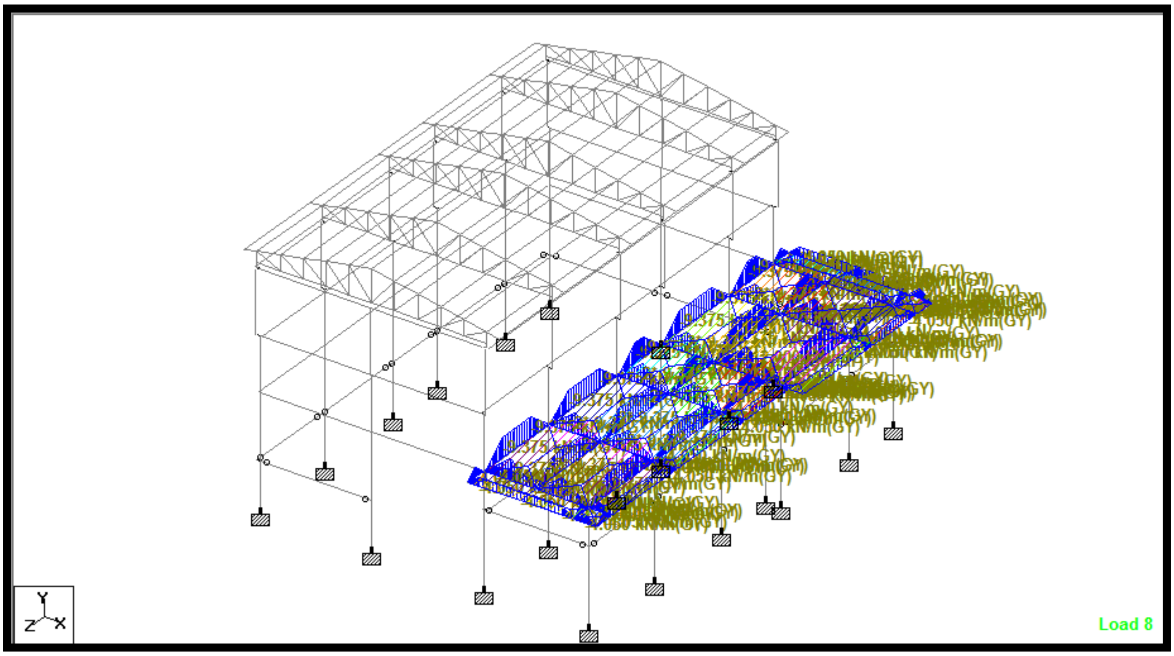


Figure-2. 32 Roof slab dead wt.

Wall load

Beams at EL.1098.88

a) Gird A (from grid 1 to grid 6)

Wall height = 1.9m

Wall thickNess = 230+12.5+12.55 = 255 mm

Ww = 0.255 x 1.9 x 19.5

= 9.448 KN/m

b) Gird D (from grid 1 to grid 6)

Wall height = 1.9m

Wall thickNess = 230+12.55+12.5 = 255 mm

Ww = 0.255 x 1.9 x 19.5

= 9.448 KN/m

c) Gird 1 (from grid A to grid D)

Wall height = 2.2m

Wall thickNess = 230+12.5+12.5 = 255 mm

Ww = 0.255 x 2.2 x 19.5

= 10.94 KN/m

d) Gird 6 (from grid A to grid D)

Wall height = 2.2m

Wall thickNess = 230+12.55+12.55 = 255 mm

Ww = 0.255 x 2.2 x 19.5

= 10.94 KN/m

Beam EL.1101.58

a) Gird A (from grid 1 to grid 6)

Wall height = 2.5m

Wall thickNess = 230+12.5+12.5 = 255 mm

Ww = 0.255 x 2.5 x 19.5

= 12.431 KN/m

b) Gird D (from grid 1 to grid 6)

Wall height = 2.5m

Wall thickNess = 230+12.5+12.5 = 255 mm

Ww = 0.255 x 2.5 x 19.5

= 12.431 KN/m

c) Gird 1 (from grid A to grid D)

Wall height = 2.5m

Wall thickNess = 230+12.5+12.5 = 255 mm

Ww = 0.255 x 2.5 x 19.5

= 12.431 KN/m

d) Gird 6 (from grid A to grid D)

Wall height = 2.5m

Wall thickNess = 230+12.5+12.5 = 255 mm

Ww = 0.255 x 2.5 x 19.5

= 12.431 KN/m

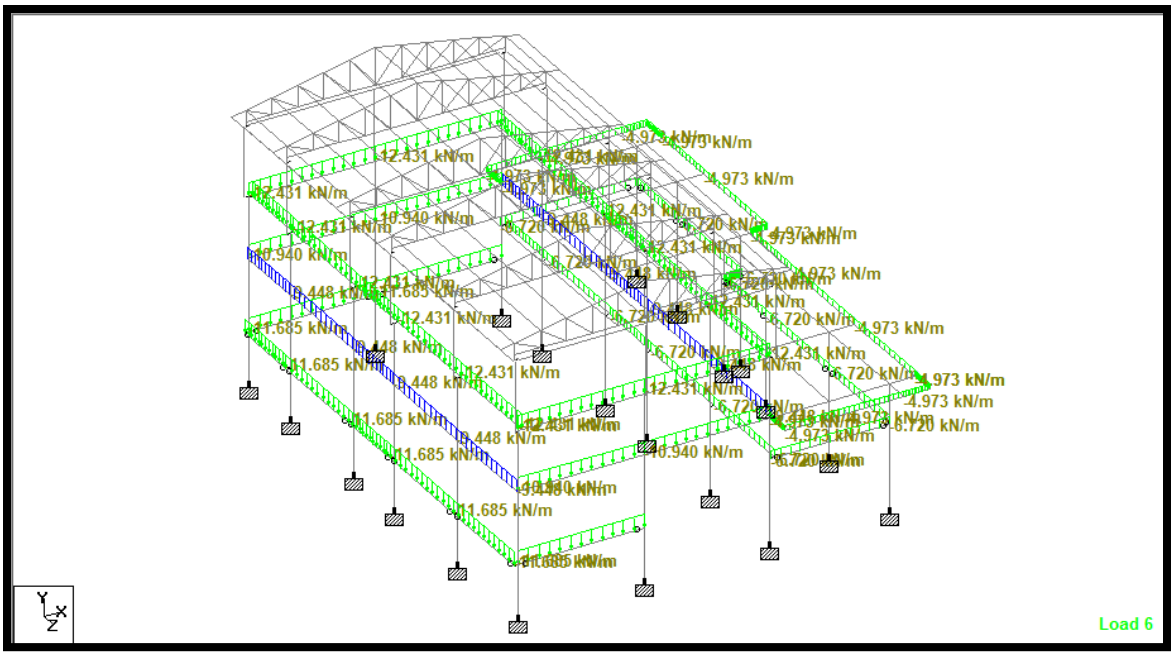


Figure-2. 33 Wall load

CGI sheet load

Load due to CGI sheet and purlin shall be taken form the design sheet of Roof truss

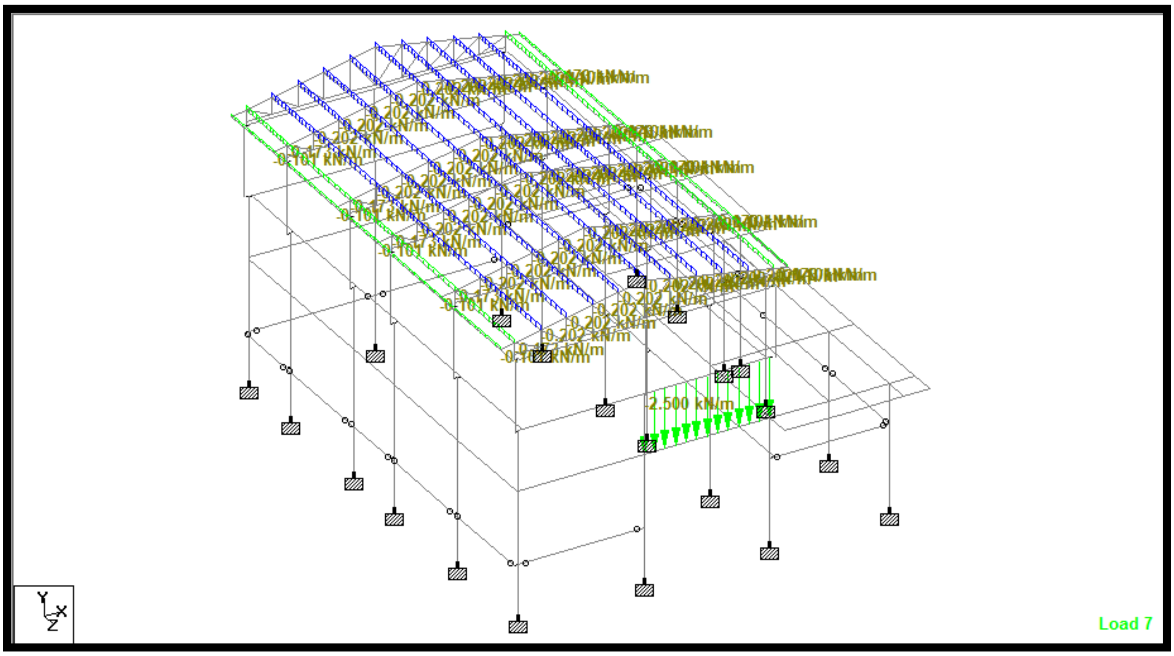


Figure-2. 34 CGI sheet load and load at shutter beam

Imposed load (Live load)

a) Floor at EL.498.10

Control Room = 2.5 KN/m^2

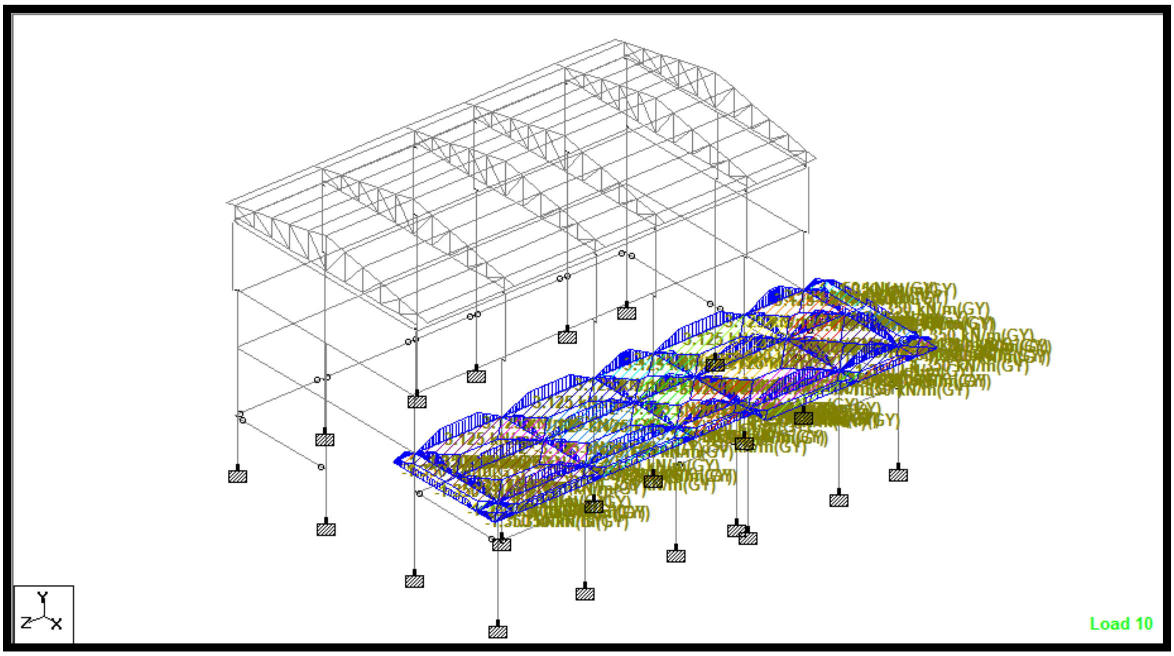


Figure-2. 35 Live load at control hall slab

EOT Crane Load

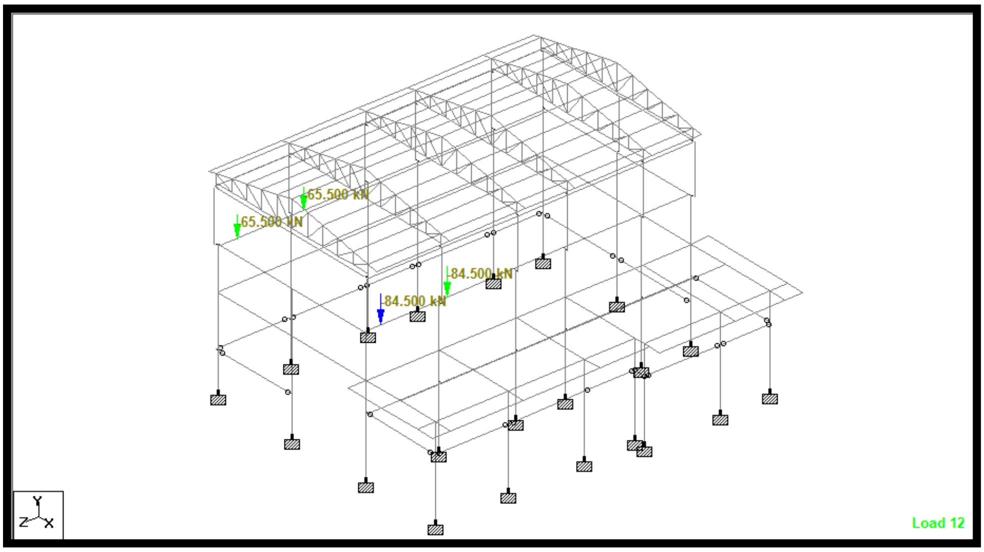


Figure-2. 36 EOT crane load self wt. only

Earthquake load

Calculation of earthquake loads using Seismic coefficient method:

The design horizontal seismic coefficient,

$\alpha_h = \frac{Z}{2}\frac{I}{R}\frac{S_a}{g}$

Zone factor (Z) = 0.36 (zone V)

Importance factor (I) = 1.5

Response reduction factor (R) = 5 (special moment resisting frame)

Rock and soil site factor = 3 (medium soil assumed)

Depth of foundation = 1.5m (assumed)

Load due to earthquake is auto calculated by FEM computer software

S_a/g = average response acceleration coefficient (depends upon time period of the PH building and type of the earth below foundation)

The approximate fundamental natural period of vibration T in seconds, of moment-resisting frame buildings without brick infill panels, may be estimated by the empirical expression:

$T = 0.075*H^{0.75}$

H = 12.52 m, from plinth level to top of truss (from drawing)

T = 0.499 s

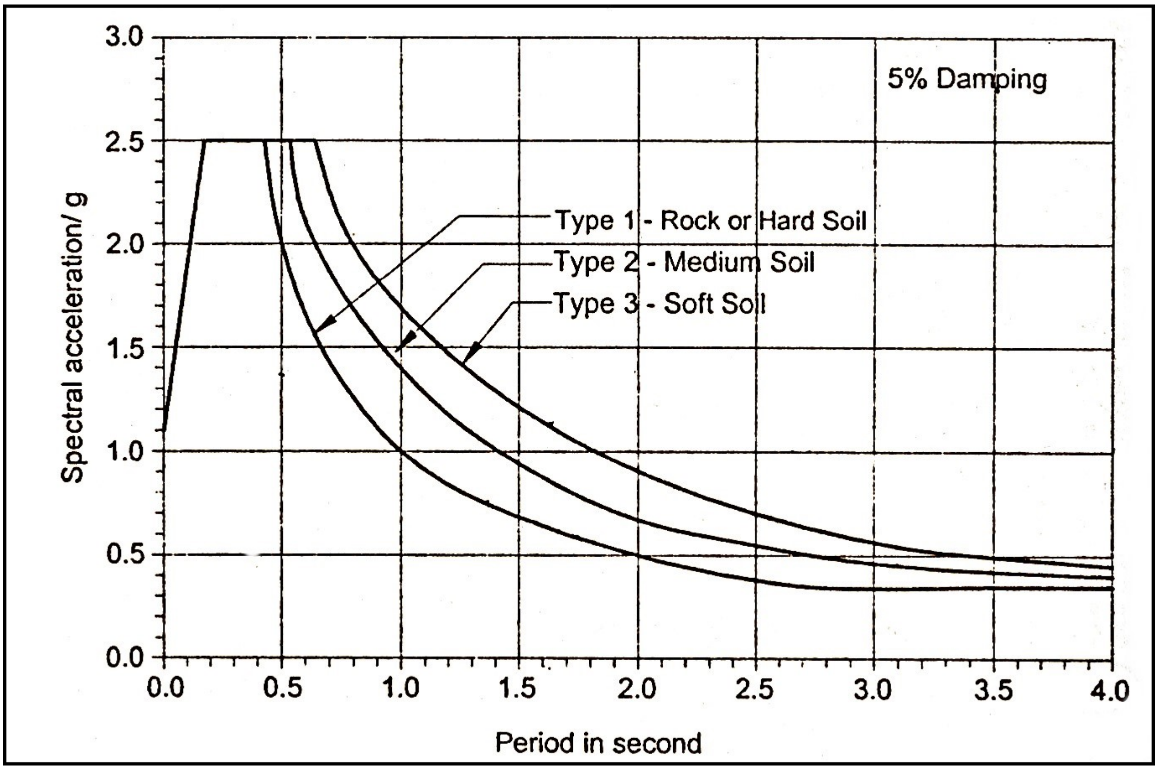


Figure-2. 37 Elastic response spectra IS: 1893-2002

Type of soil in foundation is assumed Type-3 (soft soil)

Damping = 5%

S_a/g = 2.5 for type 3 soil and 5% damping (from above figure)

Design horizontal seismic coefficient (αh)

α_h = 0.36*1.5*2.5/2//5 = 0.135 which is near to the value of horizontal seismic coefficient calculated by the computer software

The total design lateral force or design seismic base shear (VB) along any principal direction is determined by the following expression

$V_B = \alpha_h * W$

 # Load combination for Limit State of collapse

(i) Load combination-1

1.5 (DL + LL) + 1.05 (CL + CIL ± CSL_X ± CTL_Z)

For all crane supporting columns and crane beams

(ii) Load combination -2

a) **Case 1:** Dead load, live load, earthquake load and crane load act simultaneously when crane is in operation with maximum hoist load

1.2 (DL + LL) + 1.05 (CL + CIL ± CSL_X ± CTL_Z) ± 0.6 EQ_X

1.2 (DL + LL) + 1.05 (CL + CIL ± CSL_X ± CTL_Z) ± 0.6 EQ_Z

For all crane supporting columns and crane girder/beam except those of Erection/ Repair Bay

b) **Case 2:** Dead load, live load, earthquake load and crane load acts simultaneously when crane is in rest in Erection/Repair/Assembly Bay columns)

$1.2\ (DL + LL) \pm 1.2\ EQ_X + 1.05\ CL$
$1.2\ (DL + LL) \pm 1.2\ EQ_Z + 1.05\ CL$

For all crane supporting columns and crane beams/girder of Erection/Repair Bay

(iii) Load combination -3

$1.2\ (DL + LL) \pm 1.2\ EQ_X$
$1.2\ (DL + LL) \pm 1.2\ EQ_Z$
$1.5\ DL \pm 1.5EQ_X$
$1.5\ DL \pm 1.5\ EQ_Z$
$0.9DL \pm 1.5\ EQ_X$
$0.9DL \pm 1.5\ EQ_Z$

For all columns and beams of powerhouse

(iv) Load combination -4

1.2 DL + 1.2 EL
0.9 DL +1.2 EL

(v) Load combination -5

1.0 DL + 0.35LL + 0.35CL + 1.0 AL

Where,
DL: dead load

LL: live load

CL: maximum wheel load of crane when trolley is at the minimum distance from one side of wheel, at rest position.

EQ: earthquake load

EL: erection load

AL: accidental load

CIL: crane impact load in vertical direction

CSL: crane surge load

CTL: tractive force at rail

Note: x and z represents the respective direction of force

Input lines

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INPUT FILE: Str2.STD

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3. ENGINEER DATE 24-SEP-17
4. END JOB INFORMATION
5. INPUT WIDTH 79
6. UNIT METER KN
7. JOINT COORDINATES

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116. 85 63 43; 86 42 67; 87 67 48; 88 49 50; 89 50 51; 90 51 52; 91 52 53; 92 53 54

117. 93 55 56; 94 56 57; 95 57 58; 96 58 59; 97 59 60; 98 49 64; 99 64 55

118. 100 54 68; 101 68 60; 102 49 69; 103 50 70; 104 51 71; 105 52 72; 106 53 73

119. 107 54 74; 108 75 60; 109 76 59; 110 77 58; 111 78 57; 112 79 56; 113 80 55

120. 114 69 81; 115 70 82; 116 71 83; 117 72 84; 118 73 85; 119 74 86; 120 80 87

121. 121 79 88; 122 78 89; 123 77 90; 124 76 91; 125 75 92; 126 81 93; 127 93 94

122. 128 94 95; 129 95 96; 130 96 97; 131 97 98; 132 98 99; 133 99 100; 134 100 101

123. 135 101 87; 136 81 102; 137 93 103; 138 102 103; 139 97 104; 140 94 105

124. 141 95 106; 142 96 107; 143 98 108; 144 99 109; 145 100 110; 146 101 111

125. 147 103 105; 148 105 106; 149 106 107; 150 107 104; 151 87 112; 152 112 111

126. 153 111 110; 154 110 109; 155 109 108; 156 108 104; 157 102 113; 158 112 114

127. 159 112 101; 160 111 100; 161 110 99; 162 109 98; 163 108 97; 164 107 97

128. 165 106 96; 166 105 95; 167 103 94; 168 102 93; 169 82 115; 170 115 116

129. 171 116 117; 172 117 118; 173 119 120; 174 120 121; 175 121 122; 176 122 123

130. 177 123 88; 178 82 124; 179 115 125; 180 124 125; 181 119 126; 182 116 127

131. 183 117 128; 184 118 129; 185 120 130; 186 121 131; 187 122 132; 188 123 133

132. 189 125 127; 190 127 128; 191 128 129; 192 129 126; 193 88 134; 194 134 133

133. 195 133 132; 196 132 131; 197 131 130; 198 130 126; 199 124 135; 200 134 136

134. 201 134 123; 202 133 122; 203 132 121; 204 131 120; 205 130 119; 206 129 119

135. 207 128 118; 208 127 117; 209 125 116; 210 124 115; 211 83 137; 212 137 138

136. 213 138 139; 214 139 140; 215 141 142; 216 142 143; 217 143 144; 218 144 145

137. 219 145 89; 220 83 146; 221 137 147; 222 146 147; 223 141 148; 224 138 149

138. 225 139 150; 226 140 151; 227 142 152; 228 143 153; 229 144 154; 230 145 155

139. 231 147 149; 232 149 150; 233 150 151; 234 151 148; 235 89 156; 236 156 155

140. 237 155 154; 238 154 153; 239 153 152; 240 152 148; 241 146 157; 242 156 158

141. 243 156 145; 244 155 144; 245 154 143; 246 153 142; 247 152 141; 248 151 141

142. 249 150 140; 250 149 139; 251 147 138; 252 146 137; 253 84 159; 254 159 160

143. 255 160 161; 256 161 162; 257 163 164; 258 164 165; 259 165 166; 260 166 167

144. 261 167 90; 262 84 168; 263 159 169; 264 168 169; 265 163 170; 266 160 171

145. 267 161 172; 268 162 173; 269 164 174; 270 165 175; 271 166 176; 272 167 177

146. 273 169 171; 274 171 172; 275 172 173; 276 173 170; 277 90 178; 278 178 177

147. 279 177 176; 280 176 175; 281 175 174; 282 174 170; 283 168 179; 284 178 180

148. 285 178 167; 286 177 166; 287 176 165; 288 175 164; 289 174 163; 290 173 163

149. 291 172 162; 292 171 161; 293 169 160; 294 168 159; 295 85 181; 296 181 182

150. 297 182 183; 298 183 184; 299 185 186; 300 186 187; 301 187 188; 302 188 189

151. 303 189 91; 304 85 190; 305 181 191; 306 190 191; 307 185 192; 308 182 193

152. 309 183 194; 310 184 195; 311 186 196; 312 187 197; 313 188 198; 314 189 199
153. 315 191 193; 316 193 194; 317 194 195; 318 195 192; 319 91 200; 320 200 199
154. 321 199 198; 322 198 197; 323 197 196; 324 196 192; 325 190 201; 326 200 202
155. 327 200 189; 328 199 188; 329 198 187; 330 197 186; 331 196 185; 332 195 185
156. 333 194 184; 334 193 183; 335 191 182; 336 190 181; 337 86 203; 338 203 204
157. 339 204 205; 340 205 206; 341 207 208; 342 208 209; 343 209 210; 344 210 211
158. 345 211 92; 346 86 212; 347 203 213; 348 212 213; 349 207 214; 350 204 215
159. 351 205 216; 352 206 217; 353 208 218; 354 209 219; 355 210 220; 356 211 221
160. 357 213 215; 358 215 216; 359 216 217; 360 217 214; 361 92 222; 362 222 221
161. 363 221 220; 364 220 219; 365 219 218; 366 218 214; 367 212 223; 368 222 224
162. 369 222 211; 370 221 210; 371 220 209; 372 219 208; 373 218 207; 374 217 207
163. 375 216 206; 376 215 205; 377 213 204; 378 212 203; 379 113 135; 380 135 157
164. 381 157 179; 382 179 201; 383 201 223; 384 102 124; 385 124 146; 386 146 168
165. 387 168 190; 388 190 212; 389 103 125; 390 125 147; 391 147 169; 392 169 191
166. 393 191 213; 394 105 127; 395 127 149; 396 149 171; 397 171 193; 398 193 215
167. 399 106 128; 400 128 150; 401 150 172; 402 172 194; 403 194 216; 404 107 129
168. 405 129 151; 406 151 173; 407 173 195; 408 195 217; 409 104 126; 410 126 148
169. 411 148 170; 412 170 192; 413 192 214; 414 108 130; 415 130 152; 416 152 174
170. 417 174 196; 418 196 218; 419 109 131; 420 131 153; 421 153 175; 422 175 197
171. 423 197 219; 424 110 132; 425 132 154; 426 154 176; 427 176 198; 428 198 220
172. 429 111 133; 430 133 155; 431 155 177; 432 177 199; 433 199 221; 434 112 134
173. 435 134 156; 436 156 178; 437 178 200; 438 200 222; 439 114 136; 440 136 158
174. 441 158 180; 442 180 202; 443 202 224; 444 118 119; 445 140 141; 446 162 163
175. 447 184 185; 448 206 207; 449 225 26; 450 226 28; 451 227 30; 452 228 32
176. 455 225 226; 456 226 227; 457 227 228; 458 228 229; 459 229 230; 460 231 252
177. 461 233 253; 462 235 254; 463 32 232; 464 229 234; 465 230 236; 466 232 234
178. 467 234 236; 468 30 32; 469 2 270; 470 4 271; 471 6 272; 472 8 273; 473 10 274
179. 474 12 275; 475 243 14; 476 244 16; 477 245 18; 478 246 20; 479 247 22
180. 480 248 24; 481 249 26; 482 250 28; 483 251 30; 484 252 232; 485 253 234
181. 486 254 236; 492 243 244; 493 244 245; 494 245 246; 495 246 247; 496 247 248
182. 497 243 249; 498 249 250; 499 250 251; 500 252 253; 501 253 254; 502 248 254
183. 503 255 256; 504 256 257; 505 259 260; 506 260 261; 507 257 258; 508 236 261
184. 509 232 258; 510 258 259; 511 26 255; 512 262 264; 513 264 263; 514 14 262
185. 515 26 263; 516 263 265; 517 255 265; 518 266 267; 519 267 268; 520 268 269
186. 521 24 266; 522 236 268; 523 261 269; 524 28 256; 525 30 257; 526 234 260
187. 534 270 271; 535 271 272; 536 272 273; 537 273 274; 538 274 275; 539 276 62

188. 540 270 276; 541 277 66; 542 278 248; 543 275 277; 544 277 278; 546 279 280

189. 547 280 32; 548 251 280; 549 280 252

190. MEMBER OFFSET

191. 74 TO 78 START 0.125 0 0

192. 74 TO 78 END 0.125 0 0

193. 79 TO 83 START -0.125 0 0

194. 79 TO 83 END -0.125 0 0

195. 32 TO 35 START -0.175 0 0

196. 32 TO 35 END -0.175 0 0

197. 38 TO 41 START 0.175 0 0

198. 38 TO 41 END 0.175 0 0

199. 49 TO 53 START -0.05 0 0

200. 49 TO 53 END -0.05 0 0

201. 54 TO 58 START 0.05 0 0

202. 54 TO 58 END 0.05 0 0

203. 31 START -0.175 0 0.1

204. 31 END -0.175 0 0.1

205. 37 START 0.175 0 0.1

206. 37 END 0.175 0 0.1

207. 36 START -0.175 0 -0.1

208. 36 END -0.175 0 -0.1

209. 42 START 0.175 0 -0.1

210. 42 END 0.175 0 -0.1

211. 98 99 START 0 0 0.075

212. 98 99 END 0 0 0.075

213. 100 101 START 0 0 -0.075

214. 100 101 END 0 0 -0.075

215. 88 TO 92 START -0.235 0 0

216. 88 TO 92 END -0.235 0 0

217. 93 TO 97 START 0.235 0 0

218. 93 TO 97 END 0.235 0 0

219. 45 START 0 0 0.1

220. 45 END 0 0 0.1

221. 48 START 0 0 -0.1

222. 48 END 0 0 -0.1

223. 534 TO 538 START -0.185 0 0

224. 534 TO 538 END -0.185 0 0

225. 492 TO 496 START 0.185 0 0

226. 492 TO 496 END 0.185 0 0

227. 498 499 START 0.035 0 0

228. 498 END 0.035 0 0

229. 500 501 START 0.035 0 0

230. 500 501 END 0.035 0 0

231. 497 START 0 0 0.035

232. 497 END 0 0 0.035

233. 502 START 0 0 -0.035

234. 502 END 0 0 -0.035

235. DEFINE MATERIAL START

236. ISOTROPIC CONCRETE

237. E 2.17185E+007

238. POISSON 0.17

239. DENSITY 23.5616

240. ALPHA 1E-005

241. DAMP 0.05

242. ISOTROPIC STEEL

243. E 2.05E+008

244. POISSON 0.3

245. DENSITY 76.8195

246. ALPHA 1.2E-005

247. DAMP 0.03

248. END DEFINE MATERIAL

249. MEMBER PROPERTY AMERICAN

250. 1 TO 12 19 TO 30 469 TO 480 542 PRIS YD 0.7 ZD 0.5

251. 31 TO 42 PRIS YD 0.35 ZD 0.3

252. 43 44 46 47 539 541 PRIS YD 0.4 ZD 0.5

253. 13 TO 15 461 462 481 TO 483 485 486 PRIS YD 0.35 ZD 0.35

254. 74 TO 83 PRIS YD 0.8 ZD 0.9

255. 49 TO 58 PRIS YD 0.5 ZD 0.5

256. 70 TO 73 PRIS YD 0.5 ZD 0.4

257. 64 TO 66 449 TO 451 PRIS YD 0.45 ZD 0.3

258. 84 TO 87 PRIS YD 0.5 ZD 0.4

259. 88 TO 97 PRIS YD 0.3 ZD 0.23

260. 98 TO 101 PRIS YD 0.35 ZD 0.25

261. 59 60 466 TO 468 PRIS YD 0.4 ZD 0.25

262. MEMBER PROPERTY INDIAN

263. 160 TO 167 202 TO 209 244 TO 251 286 TO 293 328 TO 335 370 TO 376 -

264. 377 TABLE ST PIP603.0M

265. 137 139 TO 146 159 168 179 181 TO 188 201 210 221 223 TO 230 243 252 263 265 -

266. 266 TO 272 285 294 305 307 TO 314 327 336 347 349 TO 356 369 -

267. 378 TABLE ST PIP761.0M

268. 114 TO 136 138 147 TO 158 169 TO 178 180 189 TO 200 211 TO 220 222 -

269. 231 TO 242 253 TO 262 264 273 TO 284 295 TO 304 306 315 TO 326 337 TO 346 -

270. 348 357 TO 368 444 TO 448 TABLE ST PIP889.0M

271. 379 TO 443 TABLE ST PIP1016.0M

272. MEMBER PROPERTY INDIAN

273. 102 TO 113 PRIS YD 0.3 ZD 0.3

274. MEMBER PROPERTY INDIAN

275. 455 TO 459 PRIS YD 0.35 ZD 0.25

276. MEMBER PROPERTY INDIAN

277. 498 TO 501 534 TO 538 543 544 548 549 PRIS YD 0.15 ZD 0.23

278. MEMBER PROPERTY INDIAN

279. 503 TO 526 PRIS YD 0.05 ZD 0.05

280. MEMBER PROPERTY INDIAN

281. 67 TO 69 452 463 TO 465 PRIS YD 0.5 ZD 0.3

282. 45 48 PRIS YD 0.35 ZD 0.35

283. MEMBER PROPERTY INDIAN

284. 492 TO 496 PRIS YD 0.25 ZD 0.23

285. MEMBER PROPERTY INDIAN

286. 497 502 540 PRIS YD 0.2 ZD 0.23

287. MEMBER PROPERTY INDIAN

288. 460 484 546 547 PRIS YD 0.3 ZD 0.3

289. CONSTANTS

290. MATERIAL CONCRETE MEMB 1 TO 15 19 TO 60 64 TO 113 449 TO 452 455 TO 486 492 -

291. 493 TO 526 534 TO 544 546 TO 549

292. MATERIAL STEEL MEMB 114 TO 448

293. SUPPORTS

294. 1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 61 65 231 233 235 279 FIXED

295. MEMBER RELEASE

296. 498 TO 501 534 TO 538 540 START MX MY MZ

297. 498 500 501 534 TO 538 540 END MX MY MZ

298. 497 502 543 544 START MX MY MZ

299. 497 502 543 544 END MX MY MZ

300. 548 START MX MY MZ

301. 548 END MX MY MZ

302. 549 START MX MY MZ

303. 549 END MX MY MZ

304. DEFINE 1893 ACCIDENTAL LOAD

305. ZONE 0.36 RF 5 I 1.5 SS 3 ST 1 DM 0.05 DT 1.5

306. SELFWEIGHT

307. MEMBER WEIGHT

308. 49 TO 58 UNI -9.448

309. 70 TO 73 UNI -10.94

310. 74 TO 87 UNI -12.431

311. 389 TO 433 UNI -0.202

312. 384 TO 388 434 TO 438 UNI -0.173

313. 379 TO 383 439 TO 443 UNI -0.101

314. 74 TO 83 UNI -1.

315. 79 CON -84.5 1

316. 80 CON -84.5 0.6

317. 74 CON -65.5 1

318. 75 CON -65.5 0.6

319. 503 TO 507 510 512 TO 514 516 TO 521 523 UNI -4.973

320. 492 TO 502 548 549 UNI -6.72

321. 534 TO 538 540 543 544 UNI -11.685

322. 71 UNI -2.5

323. FLOOR WEIGHT

324. YRANGE 4 6 FLOAD -7.5 XRANGE 10 20 ZRANGE 0 0

325. YRANGE 4 6 FLOAD -0.625 XRANGE 10 20 ZRANGE 0 0

326. LOAD 1 LOADTYPE SEISMIC TITLE EQ+X

327. 1893 LOAD X 1

328. LOAD 2 LOADTYPE SEISMIC TITLE EQ-X

329. 1893 LOAD X -1.

330. LOAD 3 LOADTYPE SEISMIC TITLE EQ+Z

331. 1893 LOAD Z 1

332. LOAD 4 LOADTYPE SEISMIC TITLE EQ-Z

333. 1893 LOAD Z -1.

334. LOAD 5 LOADTYPE DEAD TITLE SELF WT.

335. SELFWEIGHT Y -1

336. LOAD 6 LOADTYPE DEAD TITLE BRICK WALL LOAD

337. MEMBER LOAD

338. 49 TO 58 UNI GY -9.448

339. 70 TO 73 UNI GY -10.94

340. 74 TO 87 UNI GY -12.431

341. 492 TO 502 548 549 UNI GY -6.72

342. 503 TO 507 510 512 TO 514 516 TO 521 523 UNI GY -4.973

343. 534 TO 538 540 543 544 UNI GY -11.685

344. LOAD 7 LOADTYPE DEAD TITLE CGI PURLIN & SHUTTER LOAD

345. MEMBER LOAD

346. 389 TO 433 UNI GY -0.202

347. 384 TO 388 434 TO 438 UNI GY -0.173

348. 379 TO 383 439 TO 443 UNI GY -0.101

349. 71 UNI GY -2.5

350. LOAD 8 LOADTYPE DEAD TITLE SLAB DEAD WT.

351. FLOOR LOAD

352. YRANGE 4 6 FLOAD -7.5 XRANGE 10 20 GY

353. LOAD 9 LOADTYPE DEAD TITLE CRANE RAIL LOAD

354. MEMBER LOAD

355. 74 TO 83 UNI GY -1.

356. LOAD 10 LOADTYPE LIVE TITLE LIVE LOAD

357. FLOOR LOAD

358. YRANGE 4 6 FLOAD -2.5 XRANGE 10 20 GY

359. LOAD 11 LOADTYPE LIVE TITLE REDUCED LIVE LOAD

360. FLOOR LOAD

361. YRANGE 4 6 FLOAD -0.625 XRANGE 10 20 GY

362. LOAD 12 LOADTYPE DEAD TITLE CRANE LOAD

363. MEMBER LOAD

364. 79 CON GY -84.5 1

365. 80 CON GY -84.5 0.6

366. 74 CON GY -65.5 1

367. 75 CON GY -65.5 0.6

368. LOAD COMB 13 1.5DL+1.5LL+1.05CL

369. 5 1.5 6 1.5 7 1.5 8 1.5 9 1.5 10 1.5 12 1.05

370. LOAD COMB 14 1.2(DL+RLL+EQ+X)+1.05CL

371. 1 1.2 5 1.2 6 1.2 7 1.2 8 1.2 9 1.2 11 1.2 12 1.05

372. LOAD COMB 15 1.2(DL+RLL+EQ-X)+1.05CL

373. 2 1.2 5 1.2 6 1.2 7 1.2 8 1.2 9 1.2 11 1.2 12 1.05

374. LOAD COMB 16 1.2(DL+RLL+EQ+Z)+1.05CL

375. 3 1.2 5 1.2 6 1.2 7 1.2 8 1.2 9 1.2 11 1.2 12 1.05

376. LOAD COMB 17 1.2(DL+RLL+EQ-Z)+1.05CL

377. 4 1.2 5 1.2 6 1.2 7 1.2 8 1.2 9 1.2 11 1.2 12 1.05

378. LOAD COMB 18 1.5DL+1.5EQ+X

379. 1 1.5 5 1.5 6 1.5 7 1.5 8 1.5 9 1.5

380. LOAD COMB 19 1.5DL+1.5EQ-X

381. 2 1.5 5 1.5 6 1.5 7 1.5 8 1.5 9 1.5

382. LOAD COMB 20 1.5DL+1.5EQ+Z

383. 3 1.5 5 1.5 6 1.5 7 1.5 8 1.5 9 1.5

384. LOAD COMB 21 1.5DL+1.5EQ-Z

385. 4 1.5 5 1.5 6 1.5 7 1.5 8 1.5 9 1.5

386. LOAD COMB 22 0.9DL+1.5EQ+X

387. 1 1.5 5 0.9 6 0.9 7 0.9 8 0.9 9 0.9

388. LOAD COMB 23 0.9DL+1.5EQ-X

389. 2 1.5 5 0.9 6 0.9 7 0.9 8 0.9 9 0.9

390. LOAD COMB 24 0.9DL+1.5EQ+Z

391. 3 1.5 5 0.9 6 0.9 7 0.9 8 0.9 9 0.9

392. LOAD COMB 25 0.9DL+1.5EQ-Z

393. 4 1.5 5 0.9 6 0.9 7 0.9 8 0.9 9 0.9

394. LOAD COMB 26 DL+LL (NO CRANE LOAD)

395. 5 1.0 6 1.0 7 1.0 8 1.0 9 1.0 10 1.0

396. LOAD COMB 27 DL+RLL

397. 5 1.0 6 1.0 7 1.0 8 1.0 9 1.0 11 1.0 12 1.0

398. PERFORM ANALYSIS

399. START CONCRETE DESIGN

400. CODE INDIAN

401. CLEAR 0.04 MEMB 1 TO 15 19 TO 48 74 TO 83 460 TO 462 469 TO 486 539 541 542

402. CLEAR 0.05 MEMB 64 TO 73 449 TO 452 463 TO 465

403. CLEAR 0.03 MEMB 49 TO 60 84 TO 101 466 TO 468

404. FC 25000 MEMB 1 TO 15 19 TO 60 64 TO 101 449 TO 452 455 TO 486 492 TO 502 -
405. 534 TO 544 546 TO 549
406. FYMAIN 500000 MEMB 1 TO 15 19 TO 60 64 TO 101 449 TO 452 455 TO 486 -
407. 492 TO 502 534 TO 540
408. DESIGN BEAM 49 TO 60 64 TO 91 93 TO 96 98 TO 101 449 TO 452 455 TO 459 463 -
409. 464 TO 468
410. DESIGN COLUMN 1 TO 15 19 TO 48 460 TO 462 469 TO 486 539 541 542 546 547
411. END CONCRETE DESIGN
412. FINISH

Output results

Seismic load

```
*******************************************************
  * TIME PERIOD FOR X 1893 LOADING =    0.49888 SEC       *
* SA/G PER 1893=    2.500, LOAD FACTOR= 1.000            *
*      FACTOR V AS PER 1893=    0.1316 X   5269.98        *
*******************************************************


*******************************************************
  * TIME PERIOD FOR X 1893 LOADING =    0.49888 SEC       *
* SA/G PER 1893=    2.500, LOAD FACTOR=-1.000            *
*      FACTOR V AS PER 1893=    0.1316 X   5269.98        *
*******************************************************
* TIME PERIOD FOR Z 1893 LOADING =    0.49888 SEC       *
* SA/G PER 1893=    2.500, LOAD FACTOR= 1.000            *
*      FACTOR V AS PER 1893=    0.1316 X   5269.98        *
*******************************************************
*******************************************************
  * TIME PERIOD FOR Z 1893 LOADING =    0.49888 SEC       *
* SA/G PER 1893=    2.500, LOAD FACTOR=-1.000            *
*      FACTOR V AS PER 1893=    0.1316 X   5269.98        *
*******************************************************
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Summary of area of reinforcement in beam

Output results only for a beam at EL 1198.88 at Grid A have been shown here. Based on the area of reinforcement provided by FEM, construction drawing may be prepared.

Similarly, area of reinforcement calculated by FEM software may be utilized for the distribution of reinforcement in remaining beams also.

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B E A M N O. 49 D E S I G N R E S U L T S

M25 Fe500 (Main) Fe415 (Sec.)

LENGTH: 4400.0 mm SIZE: 500.0 mm X 500.0 mm COVER: 30.0 mm

SUMMARY OF REINF. AREA (Sq.mm)

SECTION	0.0 mm	1100.0 mm	2200.0 mm	3300.0 mm	4400.0 mm
TOP	877.69	394.40	394.40	394.40	861.26
REINF.	(Sq. mm)	(Sq. mm)	(Sq. mm)	(Sq. mm)	(Sq. mm)
BOTTOM	599.80	407.65	392.70	392.70	498.61
REINF.	(Sq. mm)	(Sq. mm)	(Sq. mm)	(Sq. mm)	(Sq. mm)

SHEAR DESIGN RESULTS AT DISTANCE d (EFFECTIVE DEPTH) FROM FACE OF THE SUPPORT

SHEAR DESIGN RESULTS AT 710.0 mm AWAY FROM START SUPPORT

VY = 89.55 MX = 0.22 LD= 20

Provide 2 Legged 8í @ 180 mm c/c

SHEAR DESIGN RESULTS AT 710.0 mm AWAY FROM END SUPPORT

VY = -93.15 MX = 1.59 LD= 21

Provide 2 Legged 8í @ 180 mm c/c

===

B E A M N O. 50 D E S I G N R E S U L T S

M25 Fe500 (Main) Fe415 (Sec.)

LENGTH: 4600.0 mm SIZE: 500.0 mm X 500.0 mm COVER: 30.0 mm

SUMMARY OF REINF. AREA (Sq.mm)

SECTION	0.0 mm	1150.0 mm	2300.0 mm	3450.0 mm	4600.0 mm
TOP	770.24	395.25	395.25	395.25	748.10
REINF.	(Sq. mm)	(Sq. mm)	(Sq. mm)	(Sq. mm)	(Sq. mm)
BOTTOM	418.66	394.40	394.40	394.40	406.47

REINF. (Sq. mm) (Sq. mm) (Sq. mm) (Sq. mm) (Sq. mm)

SHEAR DESIGN RESULTS AT DISTANCE d (EFFECTIVE DEPTH) FROM FACE OF THE SUPPORT

SHEAR DESIGN RESULTS AT 710.0 mm AWAY FROM START SUPPORT

VY = 81.84 MX = 0.29 LD= 20

Provide 2 Legged 8í @ 180 mm c/c

SHEAR DESIGN RESULTS AT 710.0 mm AWAY FROM END SUPPORT

VY = -81.51 MX = -0.09 LD= 21

Provide 2 Legged 8í @ 180 mm c/c

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B E A M N O. 51 D E S I G N R E S U L T S

M25 Fe500 (Main) Fe415 (Sec.)

LENGTH: 3000.0 mm SIZE: 500.0 mm X 500.0 mm COVER: 30.0 mm

SUMMARY OF REINF. AREA (Sq.mm)

SECTION	0.0 mm	750.0 mm	1500.0 mm	2250.0 mm	3000.0 mm
TOP	847.47	395.25	395.25	395.25	850.33
REINF.	(Sq. mm)	(Sq. mm)	(Sq. mm)	(Sq. mm)	(Sq. mm)
BOTTOM	666.93	394.40	394.40	394.40	667.12
REINF.	(Sq. mm)	(Sq. mm)	(Sq. mm)	(Sq. mm)	(Sq. mm)

SHEAR DESIGN RESULTS AT DISTANCE d (EFFECTIVE DEPTH) FROM FACE OF THE SUPPORT

SHEAR DESIGN RESULTS AT 710.0 mm AWAY FROM START SUPPORT

VY = 110.58 MX = -0.16 LD= 20

Provide 2 Legged 8í @ 180 mm c/c

SHEAR DESIGN RESULTS AT 710.0 mm AWAY FROM END SUPPORT

VY = -110.70 MX = -0.25 LD= 21

Provide 2 Legged 8í @ 180 mm c/c

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B E A M N O. 52 D E S I G N R E S U L T S

M25 Fe500 (Main) Fe415 (Sec.)

LENGTH: 4600.0 mm SIZE: 500.0 mm X 500.0 mm COVER: 30.0 mm

SUMMARY OF REINF. AREA (Sq.mm)

SECTION	0.0 mm	1150.0 mm	2300.0 mm	3450.0 mm	4600.0 mm
TOP	739.54	395.25	395.25	395.25	735.77
REINF.	(Sq. mm)	(Sq. mm)	(Sq. mm)	(Sq. mm)	(Sq. mm)
BOTTOM	399.30	394.40	394.40	394.40	396.04
REINF.	(Sq. mm)	(Sq. mm)	(Sq. mm)	(Sq. mm)	(Sq. mm)

SHEAR DESIGN RESULTS AT DISTANCE d (EFFECTIVE DEPTH) FROM FACE OF THE SUPPORT

SHEAR DESIGN RESULTS AT 710.0 mm AWAY FROM START SUPPORT

VY = 80.27 MX = -0.40 LD= 20

Provide 2 Legged 8í @ 180 mm c/c

SHEAR DESIGN RESULTS AT 710.0 mm AWAY FROM END SUPPORT

VY = -80.14 MX = -0.59 LD= 21

Provide 2 Legged 8í @ 180 mm c/c

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B E A M N O. 53 D E S I G N R E S U L T S

M25 Fe500 (Main) Fe415 (Sec.)

LENGTH: 3000.0 mm SIZE: 500.0 mm X 500.0 mm COVER: 30.0 mm

SUMMARY OF REINF. AREA (Sq.mm)

SECTION	0.0 mm	750.0 mm	1500.0 mm	2250.0 mm	3000.0 mm
TOP	919.48	395.25	395.25	428.78	958.56
REINF.	(Sq. mm)	(Sq. mm)	(Sq. mm)	(Sq. mm)	(Sq. mm)
BOTTOM	692.75	395.25	395.25	467.65	798.11
REINF.	(Sq. mm)	(Sq. mm)	(Sq. mm)	(Sq. mm)	(Sq. mm)

SHEAR DESIGN RESULTS AT DISTANCE d (EFFECTIVE DEPTH) FROM FACE OF THE SUPPORT

SHEAR DESIGN RESULTS AT 710.0 mm AWAY FROM START SUPPORT

VY = 121.76 MX = -2.70 LD= 20

Provide 2 Legged 8í @ 180 mm c/c

SHEAR DESIGN RESULTS AT 710.0 mm AWAY FROM END SUPPORT

VY = -117.23 MX = -0.42 LD= 21

Provide 2 Legged 8í @ 180 mm c/c

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TL: tractive force

Beam Reinforcement Summary of Powerhouse

EL. 1198.88, Along grid A

Beam no.	Beam size		Area of Top reinforcement (mm^2)										Area of Bottom reinforcement (mm^2)										Grid
			Required			Provided							Required			Provided							
						End				mid						End				mid			
	B	D	End-1	Mid	End-2		nos	dia	Area of steel	nos	dia	Area of steel	End-1	Mid	End-2		nos	dia	Area of steel	nos	dia	Area of steel	A'
49	500	500	887.69	394.4	861.26	End-1	5	16	1005	3	16	603	599.80	392.70	498.61	End-1	4	16	804	4	16	804	6-5
						End-2	"	"	"							End-2	"	"	"				
50	500	500	770.24	395.25	748.1	End-1	5	16	1005	3	16	603	418.66	395.25	748.10	End-1	4	16	804	4	16	804	5-4
						End-2	"	"	"							End-2	"	"	"				
51	500	500	847.47	395.25	850.33	End-1	5	16	1005	3	16	603	666.93	394.40	667.12	End-1	4	16	804	4	16	804	4-3
						End-2	"	"	"							End-2	"	"	"				
52	500	500	739.54	395.25	735.77	End-1	5	16	1005	3	16	603	399.30	394.40	396.40	End-1	4	16	804	4	16	804	3-2
						End-2	"	"	"							End-2	"	"	"				
53	500	500	919.48	395.25	358.56	End-1	5	16	1005	3	16	603	392.75	395.25	798.11	End-1	4	16	804	4	16	804	2-1
						End-2	"	"	"							End-2	"	"	"				

Drawings

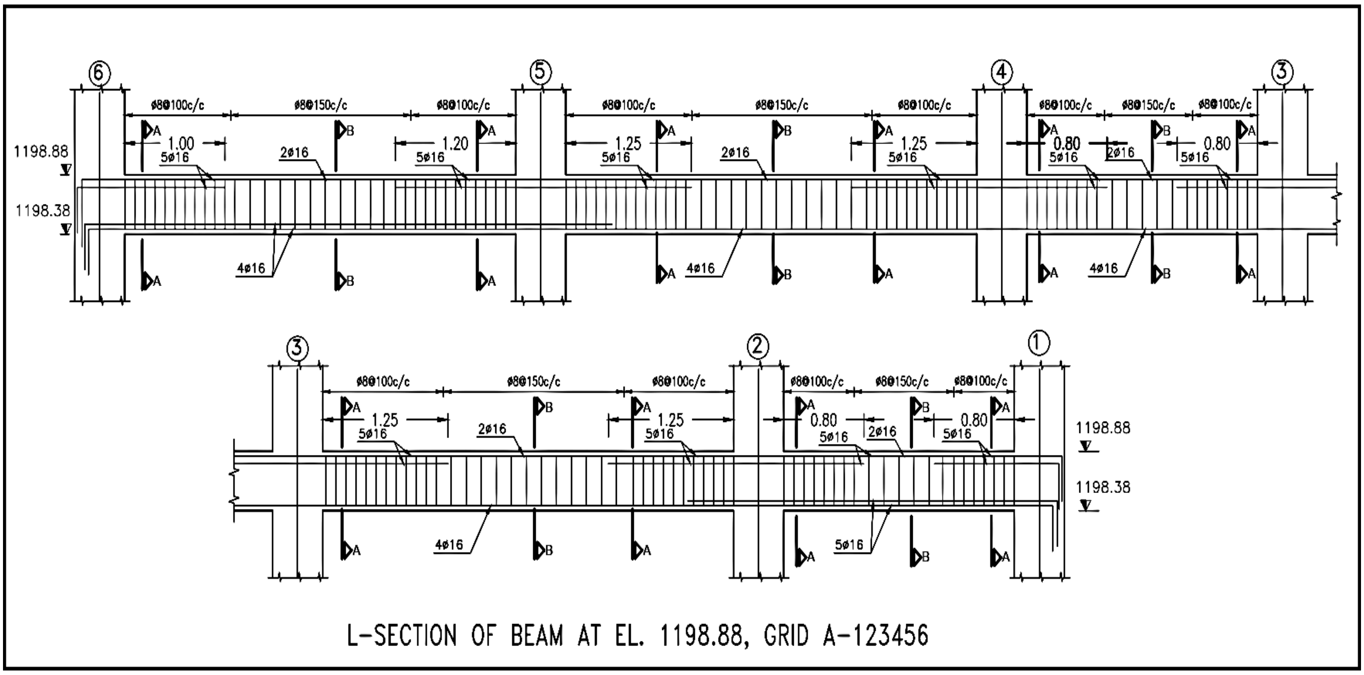


Figure-2. 38 Longitudinal section of beam at Grid A with reinforcement detail

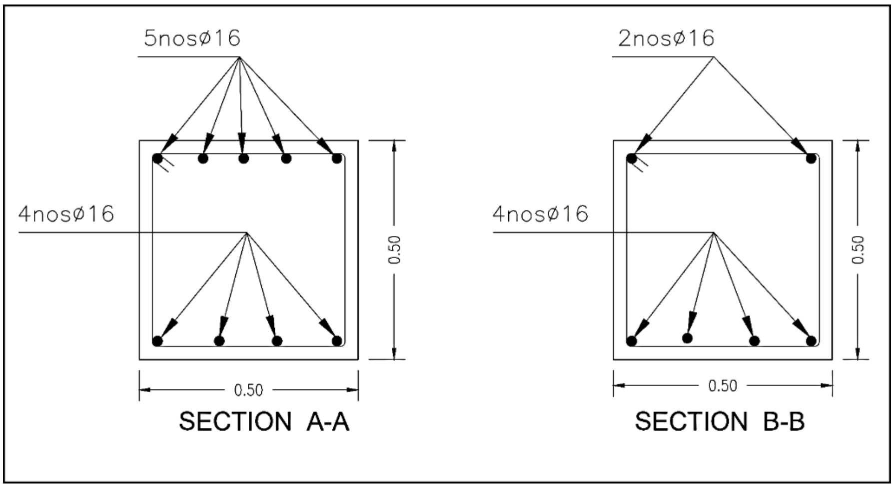


Figure-2. 39 Beam section at A-A & B-B

Area of reinforcement in Columns

For example output results, from the computer software, for a column at Grid A-5 have been shown here. The example of powerhouse analysis by using FEM model given in this section, does not consider the load maximum hoist load and the load due to impact of EOT crane i.e. crane is supposed to be in rest condition in Erection/Assembly bay. However, different consequences of all load combination should be checked.

Based on the area of reinforcement provided by FEM, construction drawing may be prepared.

Manual calculation for the design of crane supporting columns at dead load, earthquake load and crane load has been given in section 2.5 of Annex A.

==

C O L U M N N O.   1 D E S I G N R E S U L T S

M25 Fe500 (Main) Fe415 (Sec.)

LENGTH: 2100.0 mm CROSS SECTION: 500.0 mm X 700.0 mm COVER: 40.0 mm

** GUIDING LOAD CASE: 22 END JOINT: 1 SHORT COLUMN

REQD. STEEL AREA : 3848.31 Sq.mm.

REQD. CONCRETE AREA: 346151.69 Sq.mm.

MAIN REINFORCEMENT : Provide 8 - 25 dia. (1.12%, 3926.99 Sq.mm.)

(Equally distributed)

TIE REINFORCEMENT : Provide 8 mm dia. rectangular ties @ 300 mm c/c

SECTION CAPACITY BASED ON REINFORCEMENT REQUIRED (KNS-MET)

Puz : 5337.32 Muz1 : 520.65 Muy1 : 355.64

INTERACTION RATIO: 1.00 (as per Cl. 39.6, IS456:2000)

SECTION CAPACITY BASED ON REINFORCEMENT PROVIDED (KNS-MET)

WORST LOAD CASE: 22

END JOINT: 1 Puz : 5365.94 Muz : 549.81 Muy : 371.58 IR: 0.95

==

C O L U M N N O. 469 D E S I G N R E S U L T S

M25 Fe500 (Main) Fe415 (Sec.)

LENGTH: 3100.0 mm CROSS SECTION: 500.0 mm X 700.0 mm COVER: 40.0 mm

** GUIDING LOAD CASE: 22 END JOINT: 270 SHORT COLUMN

REQD. STEEL AREA : 1257.46 Sq.mm.

REQD. CONCRETE AREA: 157182.20 Sq.mm.

MAIN REINFORCEMENT : Provide 12 - 12 dia. (0.39%, 1357.17 Sq.mm.)

(Equally distributed)

TIE REINFORCEMENT : Provide 8 mm dia. rectangular ties @ 190 mm c/c

SECTION CAPACITY BASED ON REINFORCEMENT REQUIRED (KNS-MET)

Puz : 4394.90 Muz1 : 198.89 Muy1 : 138.42

INTERACTION RATIO: 1.00 (as per Cl. 39.6, IS456:2000)

SECTION CAPACITY BASED ON REINFORCEMENT PROVIDED (KNS-MET)

WORST LOAD CASE: 25

END JOINT: 2 Puz : 4431.17 Muz : 209.60 Muy : 145.44 IR: 0.94

===

C O L U M N N O. 19 D E S I G N R E S U L T S

M25 Fe500 (Main) Fe415 (Sec.)

LENGTH: 2550.0 mm CROSS SECTION: 500.0 mm X 700.0 mm COVER: 40.0 mm

** GUIDING LOAD CASE: 20 END JOINT: 37 SHORT COLUMN

REQD. STEEL AREA : 987.93 Sq.mm.

REQD. CONCRETE AREA: 123491.66 Sq.mm.

MAIN REINFORCEMENT : Provide 12 - 12 dia. (0.39%, 1357.17 Sq.mm.)

(Equally distributed)

TIE REINFORCEMENT : Provide 8 mm dia. rectangular ties @ 190 mm c/c

SECTION CAPACITY BASED ON REINFORCEMENT REQUIRED (KNS-MET)

Puz : 4296.86 Muz1 : 204.08 Muy1 : 142.58

INTERACTION RATIO: 1.00 (as per Cl. 39.6, IS456:2000)

SECTION CAPACITY BASED ON REINFORCEMENT PROVIDED (KNS-MET)

WORST LOAD CASE: 20

END JOINT: 37 Puz : 4431.17 Muz : 251.27 Muy : 174.23 IR: 0.81

===

C O L U M N N O. 31 D E S I G N R E S U L T S

M25 Fe500 (Main) Fe415 (Sec.)

LENGTH: 3000.0 mm CROSS SECTION: 300.0 mm X 350.0 mm COVER: 40.0 mm

** GUIDING LOAD CASE: 20 END JOINT: 37 SHORT COLUMN

REQD. STEEL AREA : 436.54 Sq.mm.

REQD. CONCRETE AREA: 54567.71 Sq.mm.

MAIN REINFORCEMENT : Provide 4 - 12 dia. (0.43%, 452.39 Sq.mm.)

(Equally distributed)

TIE REINFORCEMENT : Provide 8 mm dia. rectangular ties @ 190 mm c/c

SECTION CAPACITY BASED ON REINFORCEMENT REQUIRED (KNS-MET)

Puz : 1340.04 Muz1 : 32.97 Muy1 : 27.81

INTERACTION RATIO: 1.00 (as per Cl. 39.6, IS456:2000)

SECTION CAPACITY BASED ON REINFORCEMENT PROVIDED (KNS-MET)

WORST LOAD CASE: 20

END JOINT: 37 Puz : 1345.81 Muz : 33.62 Muy : 28.24 IR: 0.98

==

********************END OF COLUMN DESIGN RESULTS********************

2.8 DESIGN OF ISOLATED FOOTING

Approximate size of footing:

Unit wt. of soil	Υ	18.5	
Angle of repose of soil	φ	33	Degree
		0.575959	rad
Bearing capacity of soil		250	KN/m^2
Min. depth of foundation		1.174	m
Adopted depth of foundation		2.5	m

S.no.	Node no.	Grid		Support reaction			Crane load	Approx. size of foundation	Vertical load including soil wt.	factored load*1.1	Size of foundation required	Length of foundation adopted form detail	Width of foundation adopted form detail calculation	
				F_y	M_x	M_z								
				KN	KN.m	KN.m		m	KN	KN	m	L	B	
1	1	A-6	grid-A	316.29	-1.41	14.69	243.13	1.50	662.904	729.195	1.71	2.3	2.3	F4
2	3	A-5		362.30	-0.58	6.45	243.13	1.56	717.423	789.165	1.78	2.4	2.4	F3
3	5	A-4		305.78	0.04	4.82	243.13	1.48	650.457	715.503	1.69	2.3	2.3	F4
4	7	A-3		308.22	0.53	5.77	243.13	1.49	653.341	718.676	1.70	2.3	2.3	F4
5	9	A-2		317.50	0.95	10.73	243.13	1.50	664.336	730.769	1.71	2.3	2.3	F4
6	11	A-1		271.17	1.28	18.72	243.13	1.43	609.436	670.380	1.64	2.3	2.3	F4
7	13	D-6	grid-D	425.83	-4.52	18.33	243.13	1.64	792.709	871.980	1.87	2.5	2.5	F2
8	15	D-5		474.20	-1.23	-2.19	243.13	1.69	850.030	935.033	1.93	2.6	2.6	F1
9	17	D-4		396.93	1.02	9.63	243.13	1.60	758.464	834.310	1.83	2.5	2.5	F2
10	19	D-3		404.39	-1.97	8.73	243.13	1.61	767.305	844.036	1.84	2.5	2.5	F2
11	21	D-2		431.25	1.28	-6.08	243.13	1.64	799.137	879.050	1.88	2.5	2.5	F2
12	23	D-1		412.72	1.22	22.28	243.13	1.62	777.176	854.894	1.85	2.5	2.5	F2
13	61	B-6	grid-B	271.56	1.16	2.43		1.04	321.794	353.973	1.19	1.9	1.9	F5
14	65	B-1		295.72	-1.61	3.43		1.09	350.433	385.476	1.24	1.9	1.9	F5
15	25	E-6	grid-E	213.17	0.12	0.79		0.92	252.603	277.863	1.05	1.5	1.5	F6
16	27	E-5		255.51	0.27	12.18		1.01	302.784	333.062	1.15	1.5	1.5	F6
17	29	E-4		217.43	3.17	12.53		0.93	257.651	283.416	1.06	1.5	1.5	F6
18	279	E-3		162.52	0.81	4.46		0.81	192.590	211.849	0.92	1.8	1.5	F7
19	231	F-3	grid-E	87.99	-0.13	5.46		0.59	104.265	114.691	0.68			
20	233	F-2		230.78	-3.41	13.34		0.96	273.475	300.823	1.10	1.5	1.5	F6
21	235	F-1		192.51	-1.09	1.10		0.88	228.118	250.930	1.00	1.5	1.5	F6

Footing F1:

Grade of concrete	σ_{ck}	25	N/mm^2	
Grade of reinforcement	σ_y	500	N/mm^2	
Width of column	b	0.5		along y-y axis
Depth of column	D	0.7		along x-x axis
Length of foundation	L	2.6	m	along x-x axis
Width of foundation	B	2.6	m	along y-y axis
Area of foundation	A	6.76	m^2	
a) Calculation of Maximum support pressure				
Moment of inertia of footing about x-x axis	$I_{xx} = L*B^3/12 =$	3.81	m^4	
Moment of inertia of footing about y-y axis	$I_{yy} = b*l^3/12 =$	3.81	m^4	
Factor of safety		1.5		
Maximum vertical load		875.39	KN	
Vertical load	P_u	1313.08	KN	
Moment about x-x axis		15.438	KN.m	due to minimum eccentricity of column
Moment about y-y axis		18.751	KN.m	
Factored moment about x-x axis	M_{xx}	23.16	KN.m	
Factored moment about y-y axis	M_{yy}	28.13	KN.m	
Pressure at foundation base,	$P = P_u/A + (M_{xx}/I_{xx})*B + (M_{yy}/I_{yy})*L =$	229.3	KN/m^2	
		197.6	KN/m^2	
		159.2	KN/m^2	
		190.8	KN/m^2	
Maximum base pressure		229.3	KN/m^2	< 250 kN/m^2 OK
Maximum bending moment about x-x axis		328.581	KN.m	per 'm' along y-y
Maximum bending moment about y-y axis		268.975	KN.m	per 'm' along x-x
		`		
Minimum depth of footing required for x-x axis		194.52	mm	
Minimum depth of footing required for x-x axis		194.52	mm	
Adopted thickNess of foundation	d	500	mm	
Concrete clear cover	cc	40	mm	
Overall depth of foundation	D	548	mm	

b) Calculation of tension reinforcement

for moment about y-y axis			for moment about x-x axis		
a	3.346154		a	3.3461538	
b	-217500		b	-217500	
A_t	63738.87	mm^2	A_t	63738.87	mm^2
A_t	1261.13	mm^2	A_t	1261.13	mm^2

Taking the maximum value of area of tension reinforcement in both direction			
Diameter of bars	Φ	16	mm
Numbers of bars calculated	n	6.272	nos
Spacing of bars calculated	s	415	mm c/c
Spacing of bars provided in both direction		200	mm c/c

Provide Φ16mm @ 200 c/c in both direction

Number of rebar along x direction provided		13	nos
Number of rebar along y direction provided		13	nos

c) Check for one way shear

Critical section is at 'd' distance away from the face of column

i) x-x axis

Area of tension reinforcement	A_t	2613.805	mm^2	
Minimum area of tension reinforcement in x-x	A_0	2210	mm^2	
	`	**OK**		
% area of tension steel	P	0.201	%	
Maximum shear force	V_u	327.84	KN	
Shear stress	τ_v	0.252	N/mm^2	
Design shear strength for P% of steel	τ_c	0.325	N/mm^2	for M25 concrete
		OK		
Area of tension reinforcement	At	2613.805	mm^2	
Minimum area of tension reinforcement in x-x	A0	2210	mm^2	
		OK		
% area of tension steel	P	0.201	%	
Maximum shear force	V_u	268.23	KN	
Shear stress	τ_v	0.252	N/mm^3	
	τ_c	0.325	N/mm^2	for M25 concrete
		OK		

d) Check for two way shear

Critical section is at '0.5*d' distance away from the face of column

Length for critical section in two way shear	$b_0 = 2*(D+d)+2*(b+d)$	4.4	m
Shear force	$V_u = \sigma (L*B-(D+d)*(b+d))$	1274.665	KN
Nominal shear stress	$\tau_v = V_u/(b_0*d)$	0.5794	KN
Shear strength of M25 concrete	$\tau'_c = K_s \tau_c$		
	$\tau_c = 0.25\ \sigma_{ck}^{0.5}$		
	$K_s = (0.5+\beta_c)$		

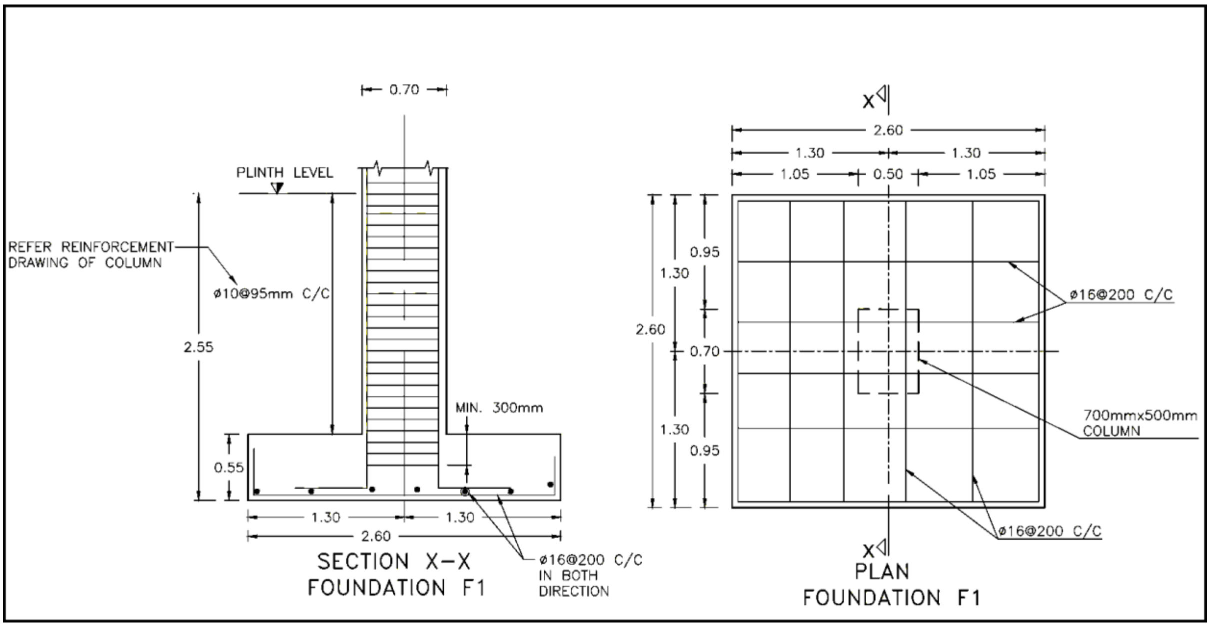
β_c = length of shorter side of column / length of longer side of column			
β_c	0.7143		
K_s	1.2143	ks ≤ 1	
	1		
τ'_c	1.25	N/mm^2	
	OK		

e) Transfer of load at base of foundation

Nominal bearing stress at concrete column concrete	$\sigma_{br} = P_u/A_c =$	3.75	N/mm^2
Allowable bearing stress	$0.45^* \sigma_{ck} =$	11.25	N/mm^2
		OK	

Since, allowable bearing stress of concrete footing is greater than σ_{br} column load can be transferred by bearing alone, no dowels are required.

Drawings



Note: Footing may be tapered at the top.

Figure-2. 40 Reinforcement detail of isolated footing

2.9 DESIGN OF INLET VALVE PEDESTAL

Minimum reinforcement required in pedestal		0.15 % (of gross cross-section area)	
a) Design of Shear toward z- direction			
Grade of steel ,	f_y :	500	N/mm^2
Characteristic strength of concrete,	σ_{ck} :	25	N/mm^2
Depth of column/pedestal,	D :	850	mm
Width of column/pedestal,	B :	800	mm

Min. longitudinal reinforcement required,	A_{min} :	1020 mm^2	
Diameter of vertical bars,	Ø :	16 mm	
Clear cover to vertical bars,	C_c :	40 mm	
Effective depth ,	D :	802 mm	
Vertical load on the column/pedestal,	P_u :	10 kN	(due to wt. of pipe, water & valve)
Let max. shear/horizontal force on pedestal,	F_x :	250 kN	(during sudden closure of valve)
Max. shear stress ,	T_v :	0.390 N/mm^2	
Nos. of bars at one face,		10	(tension rebar at one face)
Area of steel at z- axis face,		2010.62 mm^2	
% of tension steel at z-axis face ,	P :	0.31 %	(% of tension rebar at one face)
Shear strength of concrete,	τ_c :	0.3912 N/mm^2	

Increased shear strength of concrete As per section 40.2.2 of IS:456-2000;

$\delta=1+3*p_u(A_g*\sigma_{ck})$ = 1.002

Increased shear strength of concrete, T'_c : 0.392 N/mm^2 (OK)

b) Check for pressure at base of steel base plate

Max. allowable stress on M25 concrete =	$0.45*\sigma_{ck}$ =	11.25 N/mm^2
Dist. of horizontal force line form base plate,	d =	0.49 m
Maximum moment due to horizontal force,	$M_u = F_x*d$ =	122.5 kN.m
Eccentricity,	$e = M_u/P_u$ =	12.25 m
Length of base plate,	l =	0.56 m
Width of base plate,	b =	0.5 m
Total area of base plate,	A =	0.28 m^2
Maximum pressure at base	$\sigma_{base} = P_u/A+6*e/l$ =	0.167 N/mm^2

Maximum design stress on concrete is less than permissible stress on concrete. Hence, OK.

Hence, M25 concrete is safe below steel base plate

Since, shorter portion of the Inlet Valve support takes vertical load and very small amount of horizontal force, there is no need to check for shear capacity and only minimum reinforcement may be provided as shown in the drawing.

Drawings:

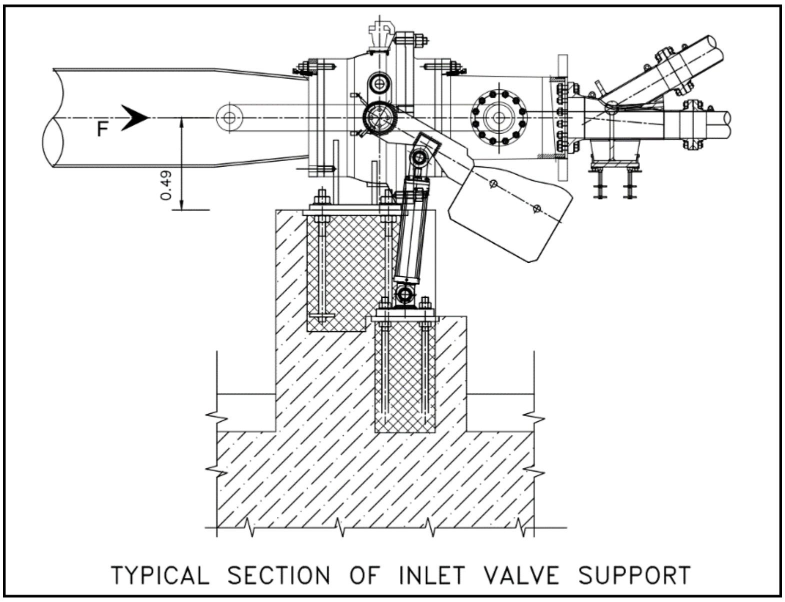


Figure-2. 41 Typical section of inlet valve support

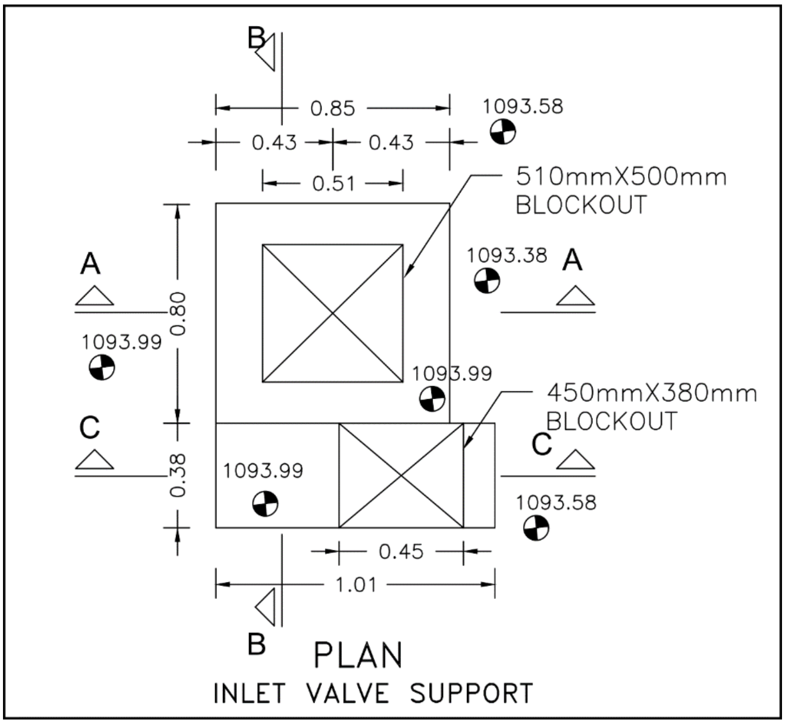


Figure-2. 42 Plan view of inlet valve support

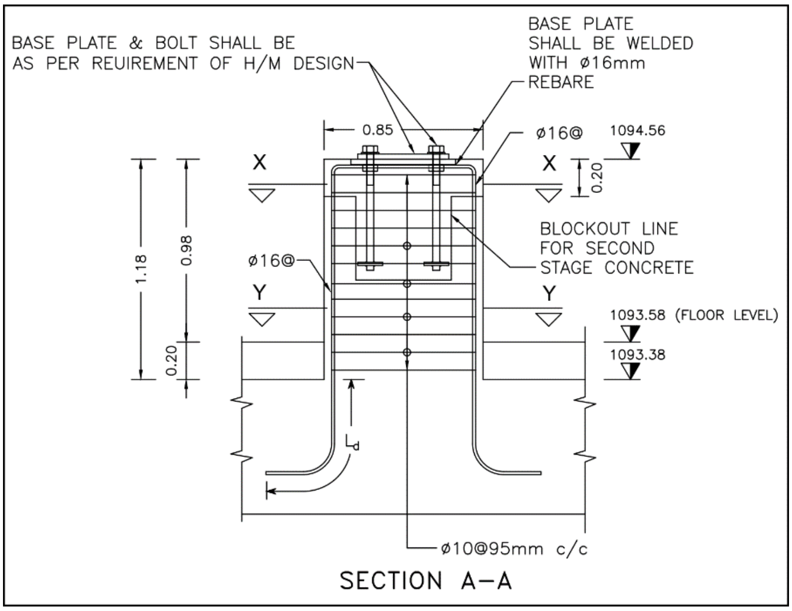


Figure-2. 43 Section A-A of inlet valve support

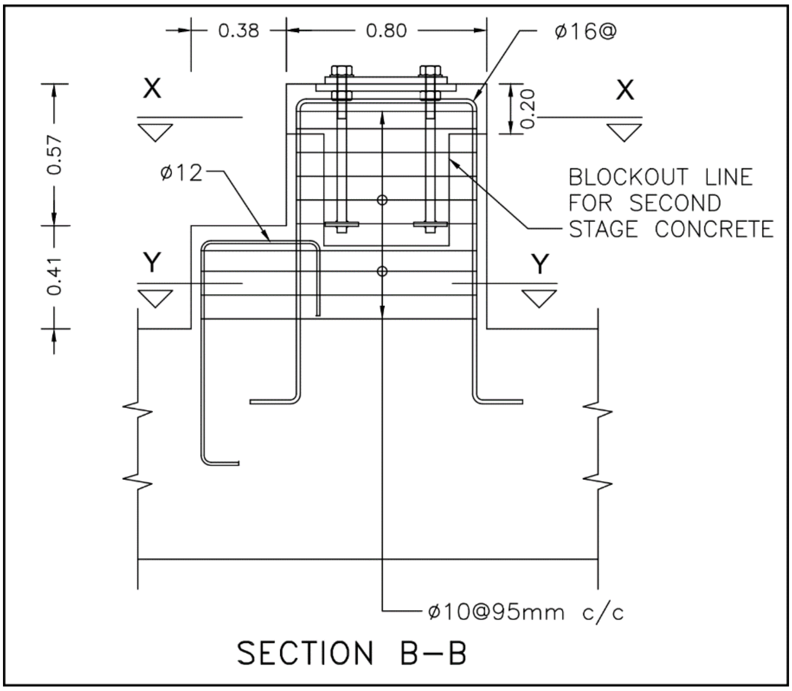


Figure-2. 44 Section B-B of inlet valve support

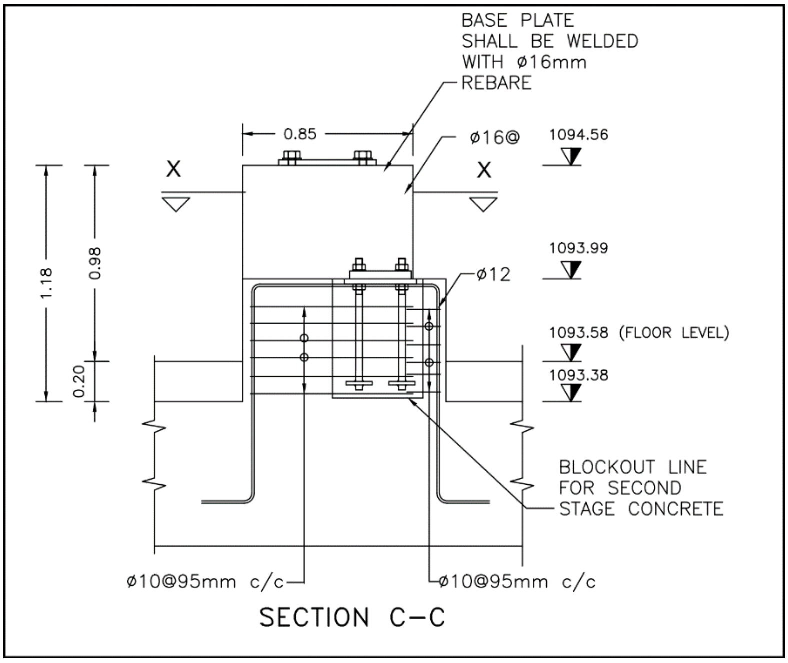


Figure-2. 45 Section C-C of inlet valve support

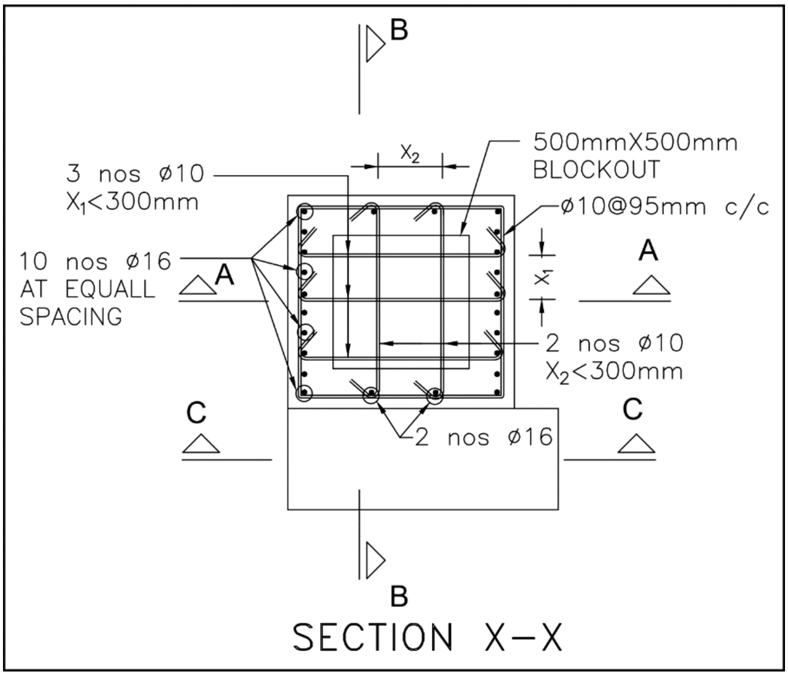


Figure-2. 46 Section X-X of inlet valve support

2.10 PLINTH SLAB OF MACHINE HALL

Thickness of the plinth slab should not be less than 30cm in Repair Bay.

Minimum thickness of the plinth slab of Machine Hall for surface powerhouse is governed by

a) The maximum shear force at different location due to concentrated static load of machinery/ equipment.
b) Plinth slab may encounter impact load of the equipment and tools during construction, installation and repair period which should be taken into account for design of plinth slab.
c) Depth of the second stage concrete for E/M and H/M equipment also should be kept in consideration to fix the thickness of plinth slab.

d) For the design of plinth slab in erection bay load due to moving vehicle with maximum wt. of machinery should be considered.

Most of the powerhouse are situated near by the river bank. Hence, plinth slab and plinth beam should be constructed monolithically and the reinforcement of the slab should be provided across the plinth beam as far as practicable. It prevents the movement of moisture and the water during rise of water table.

Thickness of the slab = 300mm

Minimum amount of reinforcement in slab = 0.15%

Area of reinforcement in one meter = 300*1000*0.15/100= 450mm^2

Provide φ12mm c/c 200mm in both direction.

2.11 DESIGN OF PLINTH BEAM

Along grid 6-6 from grid A to D, Machine hall:

Factored moment at plinth level of crane column about Y-Y axis ,	M_u:	505 kN.m
Grade of concrete,	σ_{ck} :	25 N/mm^2
Grade of reinforcement,	σ_y :	500 N/mm^2
Width of the section,	b :	450 mm
Clear concrete cover,	Cc :	50 mm
Diameter of reinforcement,	Φ :	20 mm

a) Section size and reinforcement calculation

Effective depth of the section may be calculated using the expression;

$M_u = 0.36\sigma_{ck}\, b\, x_m(d-0.42\, x_m)$

Where,

$x_m = 0.46d$ for Fe500 grade steel

Calculated depth of the section,	d:	549.9 mm
Adopt overall depth of the section,	D :	700 mm
Adopt eff. depth ,	d:	640 mm

Moment of resistance w.r.t steel is given by expression;

$$Mu = 0.87 f_y A_{st}\left(d - \frac{f_y A_{st}}{\sigma_{ck} b}\right)$$

Calculated area of steel, A_{st} : 2127 mm^2

Provide 5nos. φ25mm at top

Side face reinforcement = 0.1% of 700*450 = 448 mm^2

Provide 1no. φ16mm at both side face

a) Check for Shear

Provide 2-legged φ8mm stirrups @ 120mm c/c at end section and
Provide 2-legged φ8mm stirrups @ 150mm c/c at mid-section

Drawings:

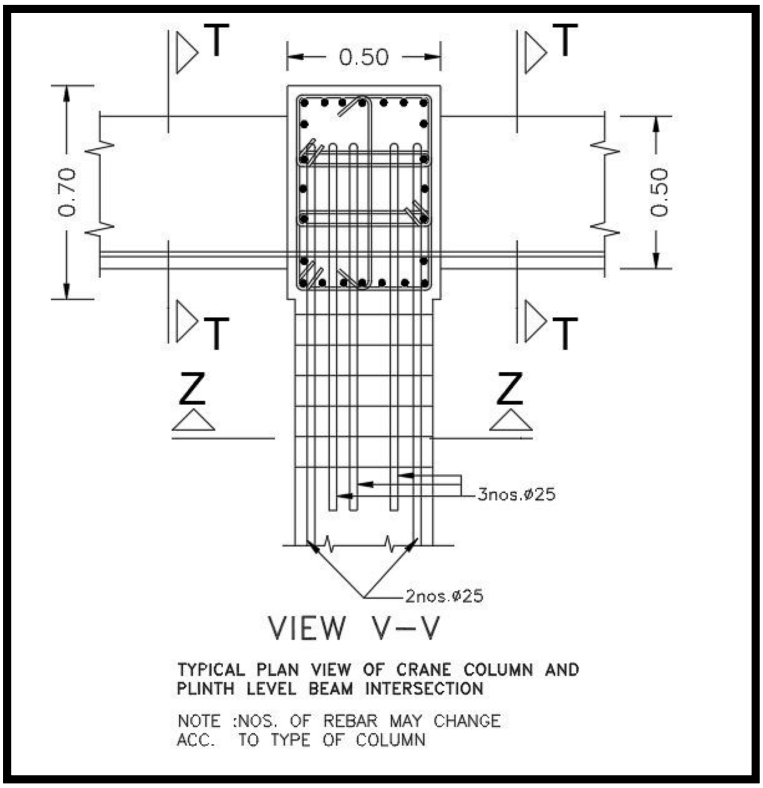


Figure-2. 47 Typical plan view of crane column and plinth level beam intersection

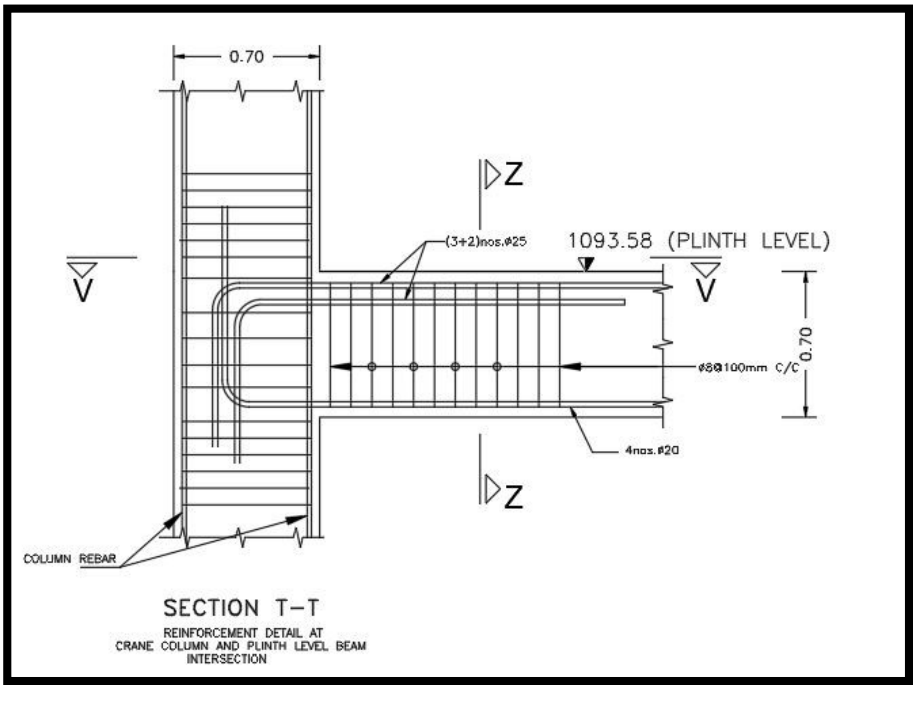


Figure-2. 48 Section T-T of crane column and plinth level beam intersection

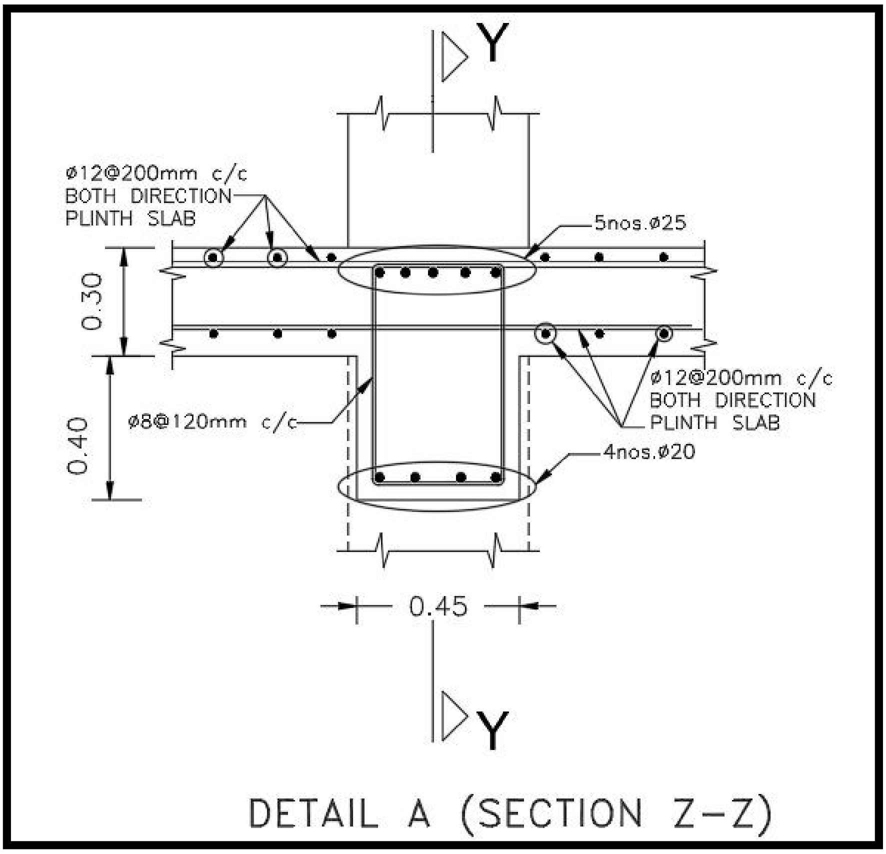


Figure-2. 49 Detail A at section Z-Z of crane column and plinth level beam intersection

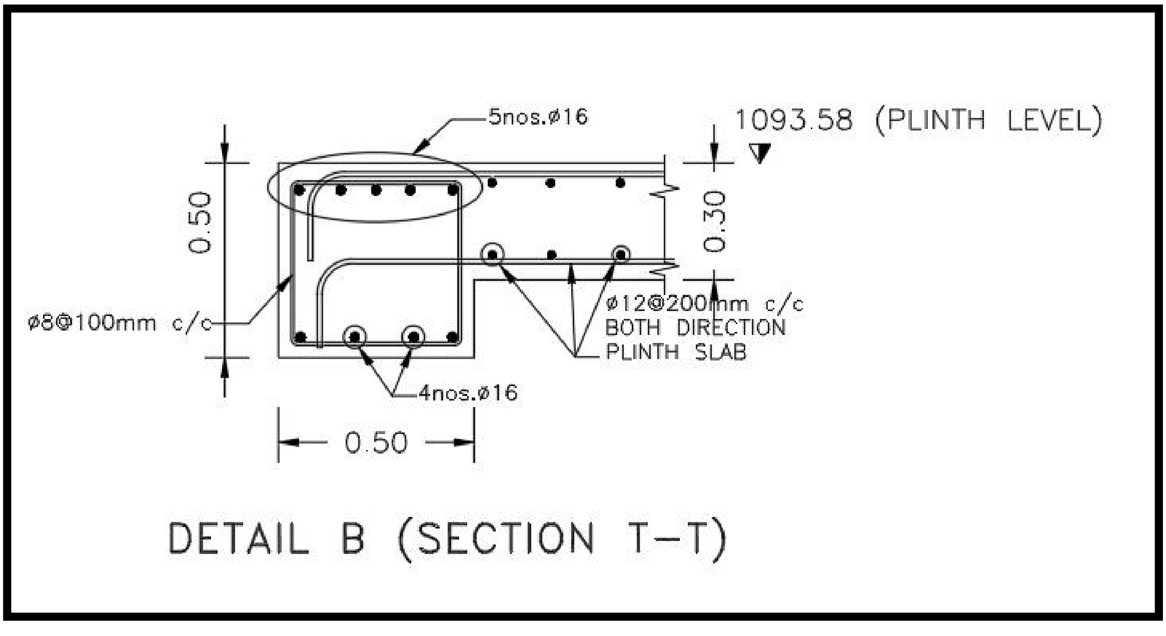


Figure-2. 50 Detail B at section T-T of crane column and plinth level beam intersection

2.12 EXAMPLE OF DYNAMIC ANALYSIS OF BLOCK TYPE OF MACHINE FOUNDATION BY USING MSD MODEL

Acceleration due to gravity	g	9.81	m/s		
Unit wt. of concrete	Υ_c	24	KN/m^3		
Shear modulus of soil	G	50	kg/cm^2		
		4905000	N/m^2		
Poisson's ratio of soil	ν	0.25			
Damping coefficient	ζ	0.15			
Turbine and Generator wt.	M_1	11000	kg		
RPM of turbine and generator	RPM	1000	RPM		
Amplitude of externally applied force along z & x direction	P_z & P_x	5000	N	provided by Machine Manufacturer	
Amplitude of externally applied moment about y-y	M_Ψ	500	N.m	provided by Machine Manufacturer	
Amplitude of externally applied moment about z-z	M_ϕ	500	N.m	provided by Machine Manufacturer	
Eccentricity of unbalanced mass	e_x	1	mm	provided by Machine Manufacturer	
Unbalanced eccentric mass rotating about y axis	M_e	50	kg	provided by Machine Manufacturer	
Trial dimension of foundation block					
Length	l	3	m		
Width	b	2.93	m		
Height	h	2.1	m		
Wt. of the foundation	$M_{foundation}$	45159.633	kg	443.016	KN
Total wt. of the foundation + machine	M	56159.633	kg	550.926	KN
Operating frequency of machine system	ω	104.72	rad/s		
1) Vertical Mode of Vibration					
Equivalent circular radius of rectangular foundation	r_z	1.673	m		
Soil spring constant	K_z	43757977.5	N/m		
Natural frequency of the system	ω_{nz}	27.9136	rad/s		

Frequency ratio	$\beta_z = \omega/\omega_n$	3.752			
A) Constant force type excitation					
a) At operating frequency					
Amplitude of vertical vibration at operating frequency	A_{zo}	0.00871	mm		
		Az < 0.2mm O.K.			
Check the value of Az form Richart Chart also.					
b) At resonance					
Amplitude of vertical vibration at resonance	A_{zr}	0.38524	mm		
		Az > 0.2mm Not OK			
Check the value of Az form Richart Chart also.					
B) Rotating mass type of excitation					
a) At operating frequency					
Amplitude of vertical vibration at operating frequency	A_{zo}	0.00095	mm		
		Az < 0.2mm O.K.			
Check the value of Az form Richart Chart also.					
b) At resonance					
Amplitude of vertical vibration at resonance	A_{zr}	0.00300	mm		
		Az < 0.2mm O.K.			
Check the value of Az form Richart Chart also.					
2) Sliding mode of vibration					
Equivalent circular radius of rectangular foundation	r_x	1.673	m		
Soil spring constant	K_x	39382179.8	N/m		
Natural frequency of the system	$\omega_{n\,x}$	26.4812	rad/s		
Frequency ratio	$\beta_x = \omega/\omega_n$	3.954			

A) Constant force type excitation					
a) At operating frequency					
Amplitude of sliding displacement at operating frequency	$A_{x\,o}$	0.00968	mm		
		Az < 0.2mm O.K.			
Check the value of Ax form Richart Chart also.					
b) At resonance					
Amplitude of sliding displacement at resonance	$A_{x\,r}$	0.42805	mm		
		Az > 0.2mm Not OK			
Check the value of Ax form Richart Chart also.					
B) Rotating mass type of excitation					
a) At operating frequency					
Amplitude of vertical vibration at operating frequency	$A_{x\,o}$	0.00089	mm		
		Az < 0.2mm O.K.			
Check the value of Ax form Richart Chart also.					
b) At resonance					
Amplitude of vertical vibration at resonance	$A_{x\,r}$	0.00300	mm		
		Az < 0.2mm O.K.			
Check the value of Ax form Richart Chart also.					
3) Rocking mode of vibration					
Equivalent circular radius of rectangular foundation	r_{Ψ}	1.682	m		
Soil spring constant	K_{Ψ}	83011110.1	N/m		
Mass moment of inertia of the system	$M_{m\Psi}$	75384.348	kg.m^2		
Natural frequency of the system	$\omega_{n\Psi}$	33.18	rad/s		
Frequency ratio	$\beta = \omega/\omega_n$	3.156			
A) Constant force type excitation					

a) At operating frequency					
Amplitude of rotational displacement at operating frequency	$A_{\Psi o}$	0.00000067	rad	In standard practice z = 0.5h	
		0.00140			
		Az < 0.2mm O.K.			
Check the value of Az form Richart Chart als.					
b) At resonance					
Amplitude of rotational displacement at resonance	$A_{\Psi r}$	0.00002	rad		
		0.04265	mm		
		Az < 0.2mm O.K.			
Check the value of Az form Richart Chart als.					
B) Rotating mass type of excitation					
a) At operating frequency					
Amplitude of vertical vibration at operating frequency	$A_{\Psi o}$	0.00000077	rad		
		0.00162	mm		
		Az < 0.2mm O.K.			
Check the value of Az form Richart Chart als.					
b) At resonance					
Amplitude of vertical vibration at resonance	$A_{\Psi r}$	0.00000235	mm		
		0.004931	mm		
		Az < 0.2mm O.K.			
Check the value of Az form Richart Chart als.					
4) Torsional/Yawing mode of vibration about z-z					
Equivalent circular radius of rectangular foundation	r_0	1.692	m		
Soil spring constant	K_ϕ	126767662	N/m		
Mass moment of inertia of the system	M_ϕ	66177.303	$kg.m^2$		
Natural frequency of the system	$\omega_{n\phi}$	43.77	rad/s		

Frequency ratio				$\beta_\phi = \omega/\omega_{n\phi}$	2.393			
A) Constant force type excitation								
a) At operating frequency								
Amplitude of rotational displacement at operating frequency				$A_{\phi\, o}$	0.00000083	rad		
					0.00124	mm		
					Az < 0.2mm O.K.			
Check the value of Az form Richart Chart als.								
b) At resonance								
Amplitude of rotational displacement at resonance				$A_{\phi\, r}$	0.00001	rad		
					0.0199	mm		
					Az < 0.2mm O.K.			
Check the value of Az form Richart Chart als.								

We can see displacement amplitude of the system in vertical mode of vibration and sliding mode of vibration in resonance condition is not within the permissible limit though the displacement amplitudes are in permissible limit in operating frequency. This implies that the system may go in resonance condition with the vibration of the machine during the starting of closing of machine. However, for important machine risk cannot be taken hence design may be revised to get the all displacement amplitudes within permissible limit in all conditions of motion.

Drawings:

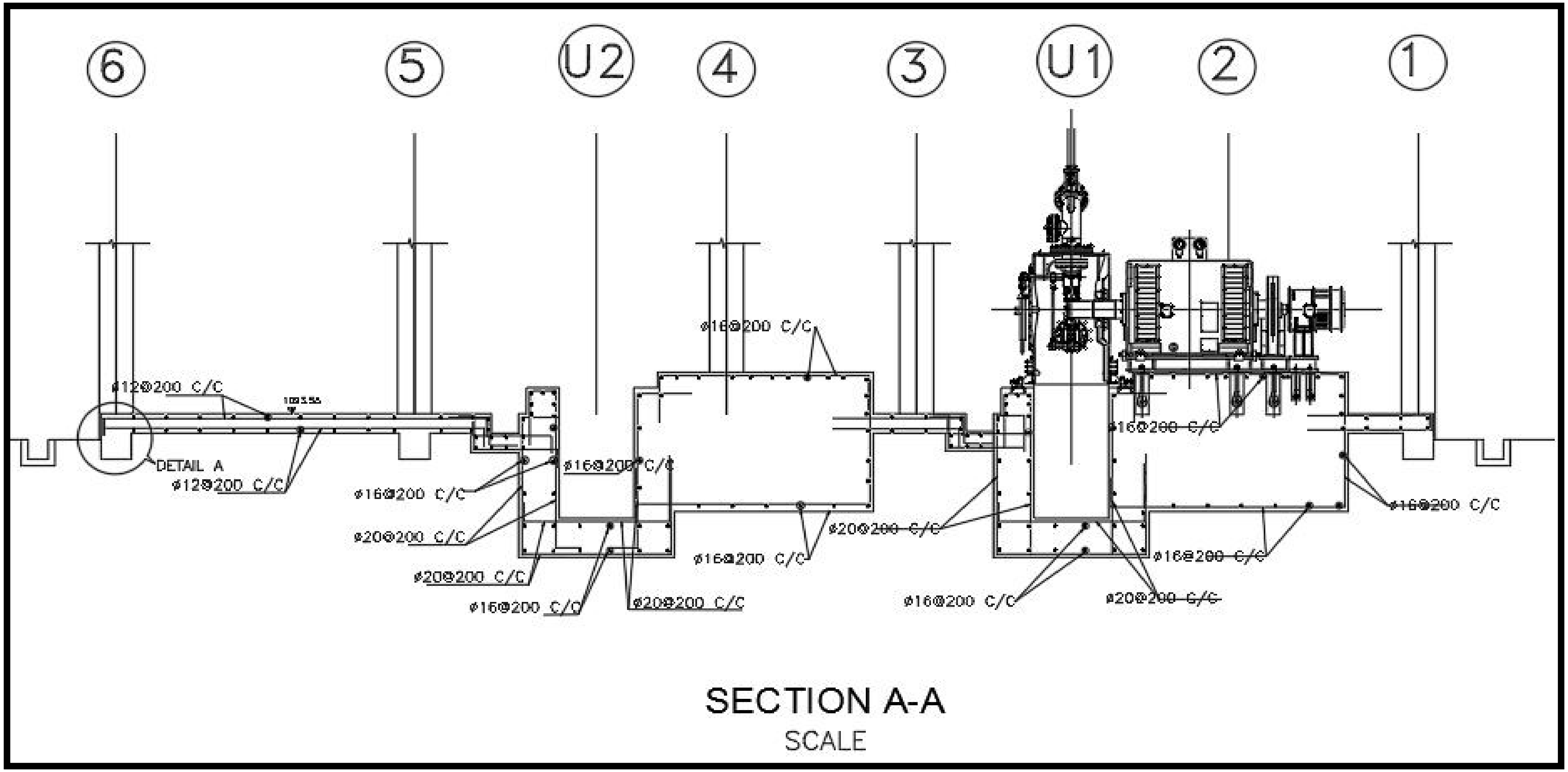


Figure-2. 51 Longitudinal section of block type machine foundation

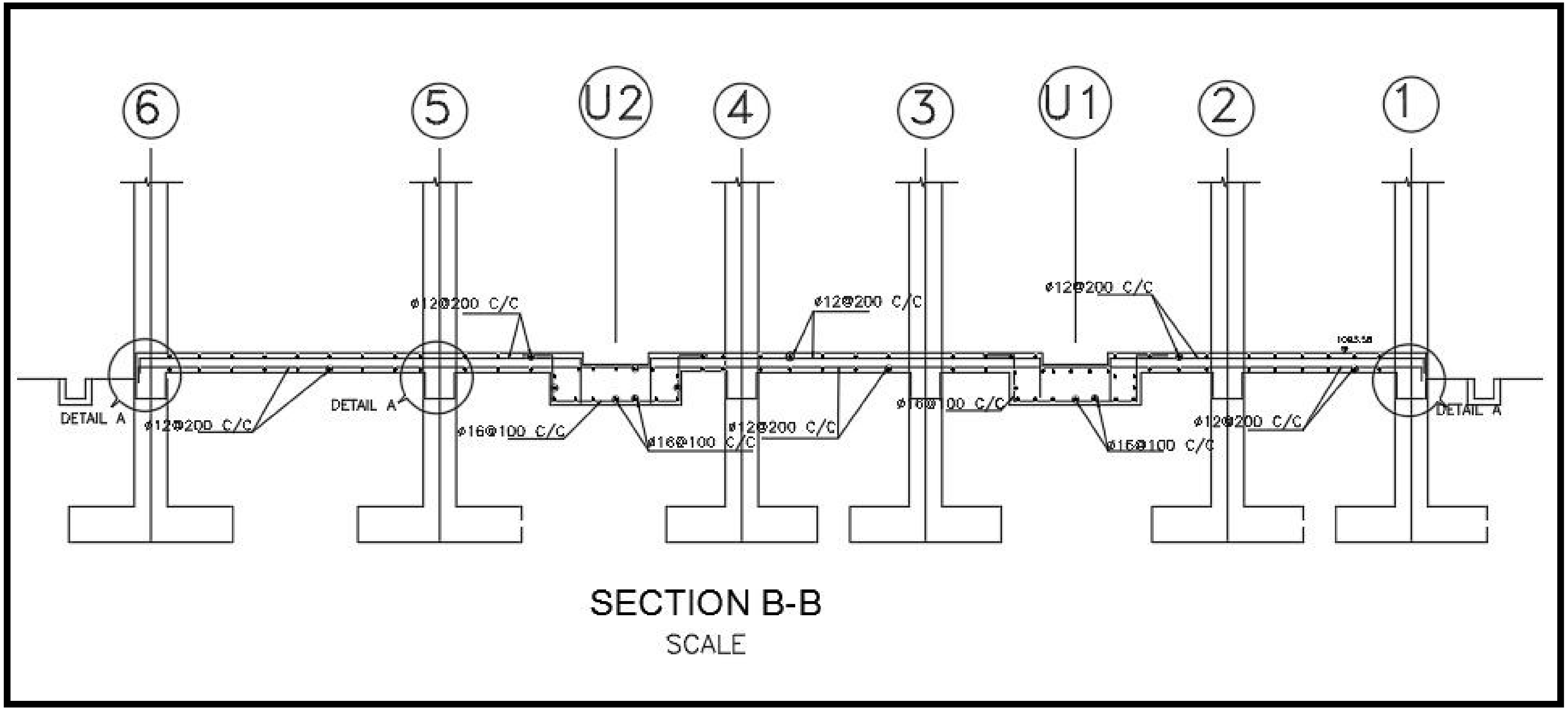


Figure-2. 52 Longitudinal section of foundation at control room section

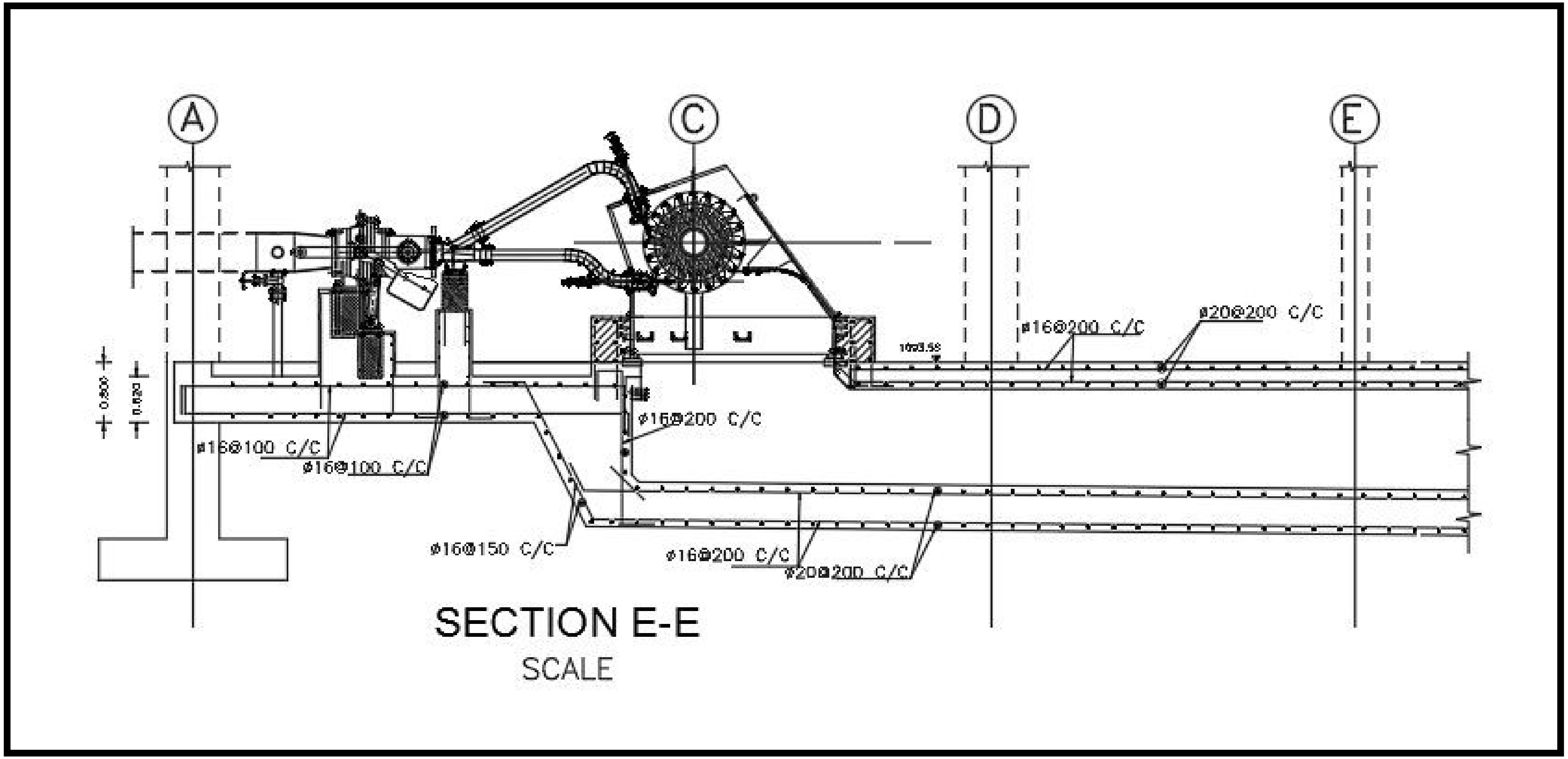
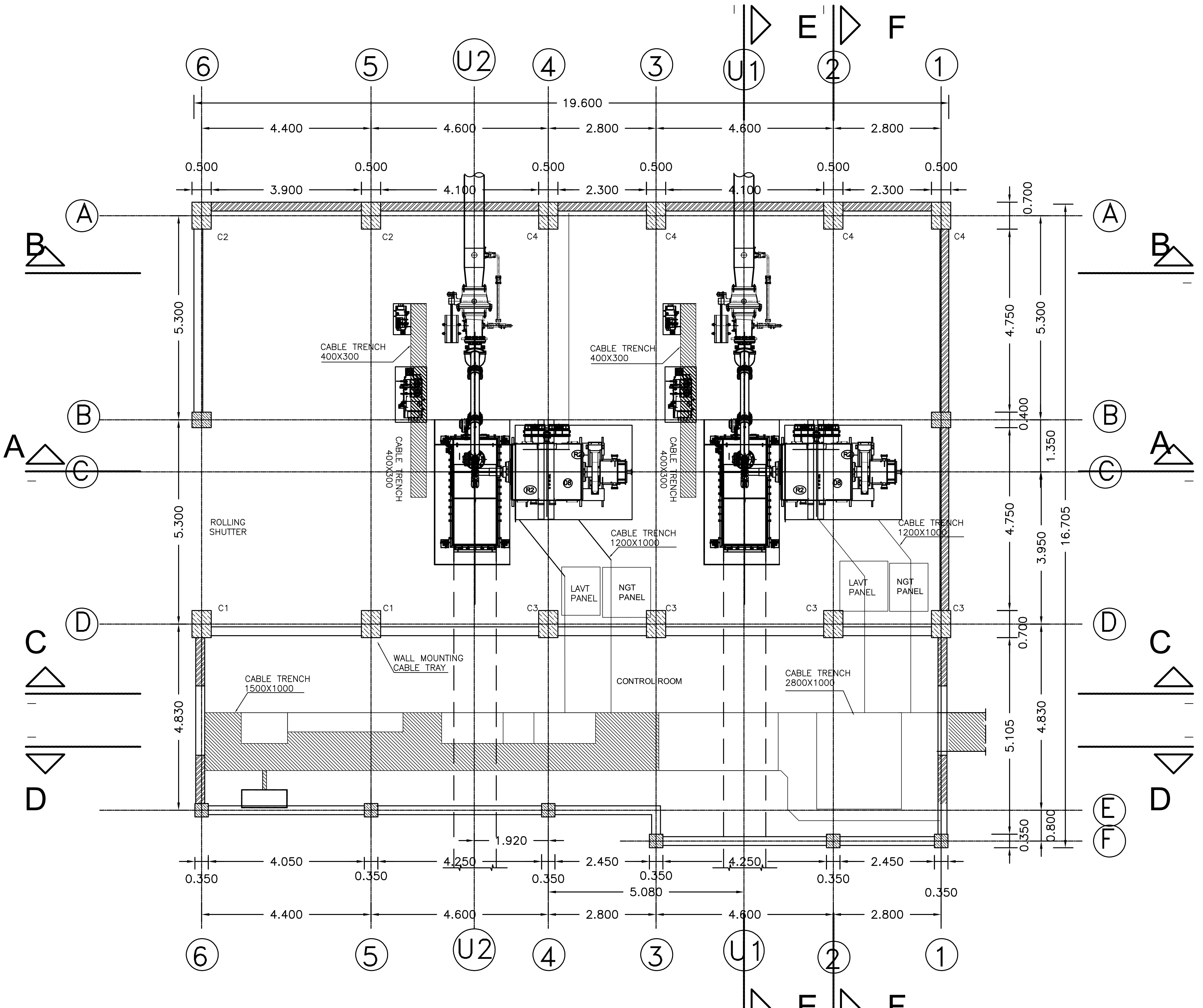


Figure-2. 53 Transverse section of foundation at runner section along with tailrace

ANNEX 2

SAMPLE DRAWINGS OF POWERHOUSE

SURFACE TYPE



PLAN

SCALE 1:100

NOTES:

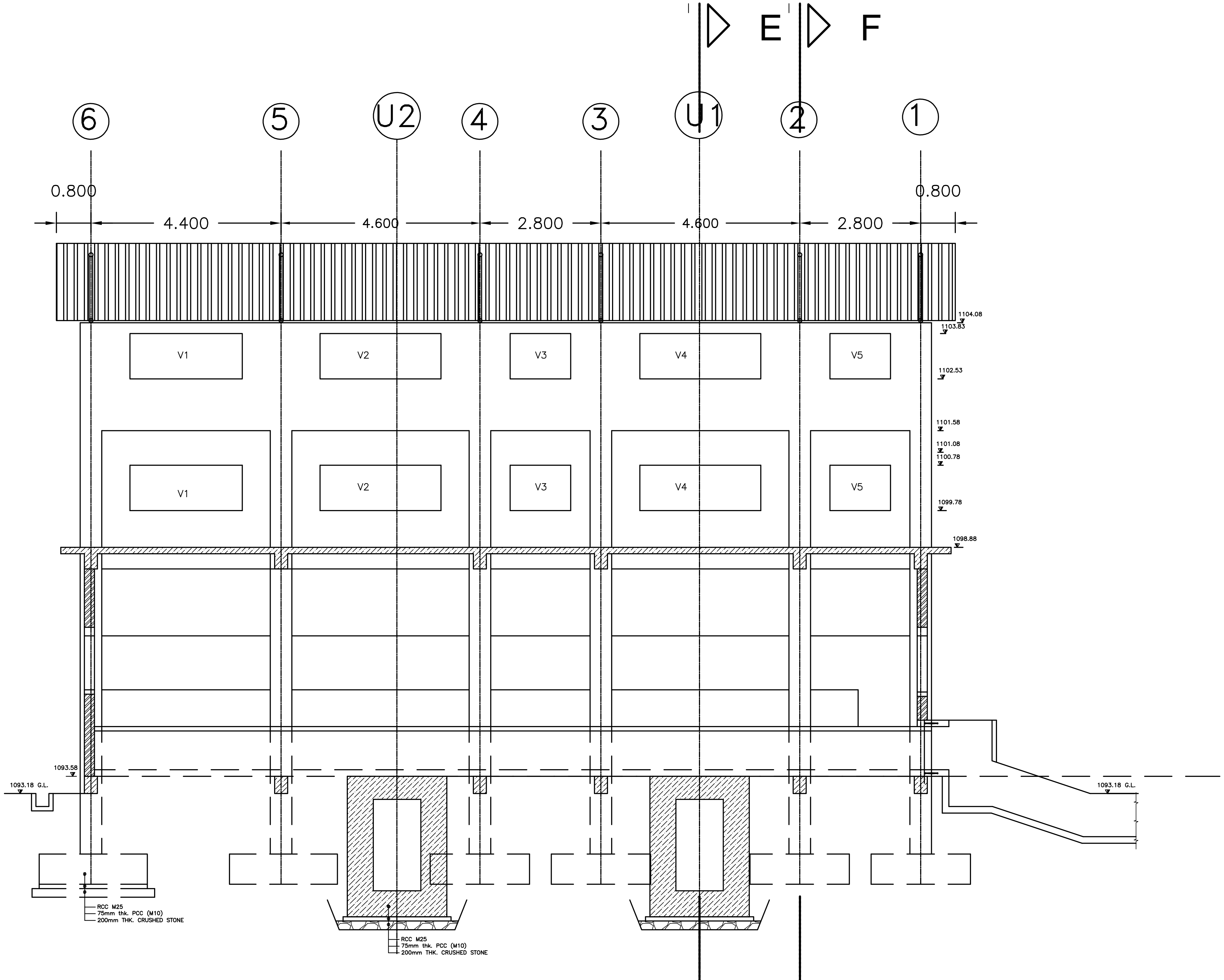
1. ALL DIMENSIONS ARE IN METER UNLESS SPECIFIED
2. SPACING OF THE REBAR IN mm
3. ALL ELEVATIONS ARE IN MASL.
4. GRADE OF CONCRETE FOR THIS STRUCTURE IS M25
5. GRADE OF ALL REINFORCEMENT BARS IS fe500
6. MIN. CONCRETE CLEAR COVER
   - -FOR COLUMN 40mm
   - -FOR FOUNDATION 50mm
7. DEVELOPMENT LENGTH OF THE REBAR SHALL NOT BE LESS THAN 60 TIMES THE DIAMETER OF REBAR.
8. LENGTH OF LAP AND SPLICES SHALL NOT BE LESS THAN DEVELOPMENT LENGTH OF REBAR.

SOURCE: UPPER CHHANDI KHOLA SHP

(Designed By: INSIGHT ENGINEERING CONSULT Pvt. Ltd.)

POWERHOUSE DRAWINGS

POWERHOUSE PLAN



SECTION C-C

SCALE 1:100

NOTES:

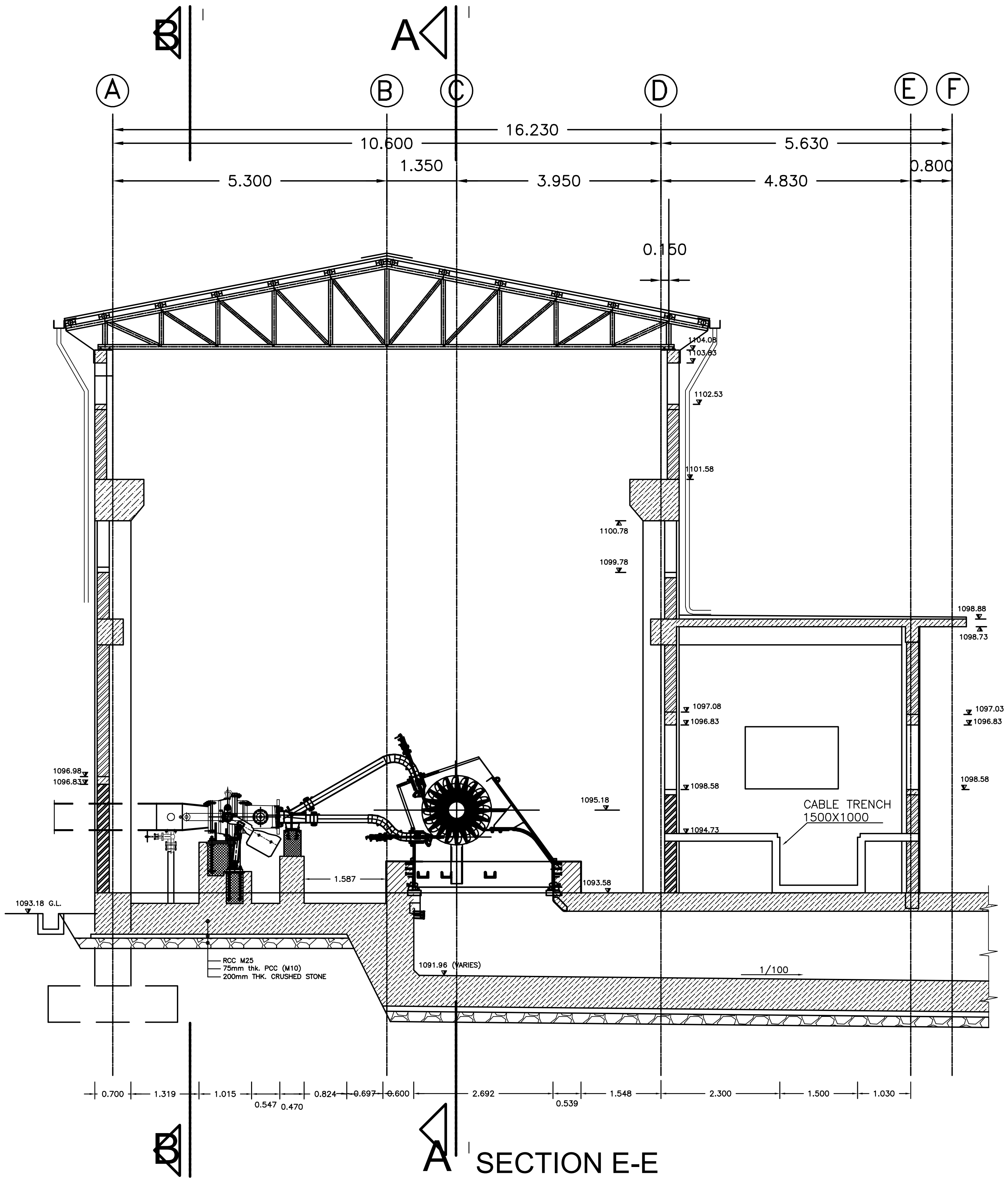
1. ALL DIMENSIONS ARE IN METER UNLESS SPECIFIED
2. SPACING OF THE REBAR IN mm
3. ALL ELEVATIONS ARE IN MASL.
4. GRADE OF CONCRETE FOR THIS STRUCTURE IS M25
5. GRADE OF ALL REINFORCEMENT BARS IS fe500
6. MIN. CONCRETE CLEAR COVER
   - -FOR COLUMN 40mm
   - -FOR FOUNDATION 50mm
7. DEVELOPMENT LENGTH OF THE REBAR SHALL NOT BE LESS THAN 60 TIMES THE DIAMETER OF REBAR.
8. LENGTH OF LAP AND SPLICES SHALL NOT BE LESS THAN DEVELOPMENT LENGTH OF REBAR.

SOURCE: UPPER CHHANDI KHOLA SHP

(Designed By: INSIGHT ENGINEERING CONSULT Pvt. Ltd.)

POWERHOUSE DRAWINGS

POWERHOUSE SECTION



SECTION E-E

SCALE 1:100

NOTES:

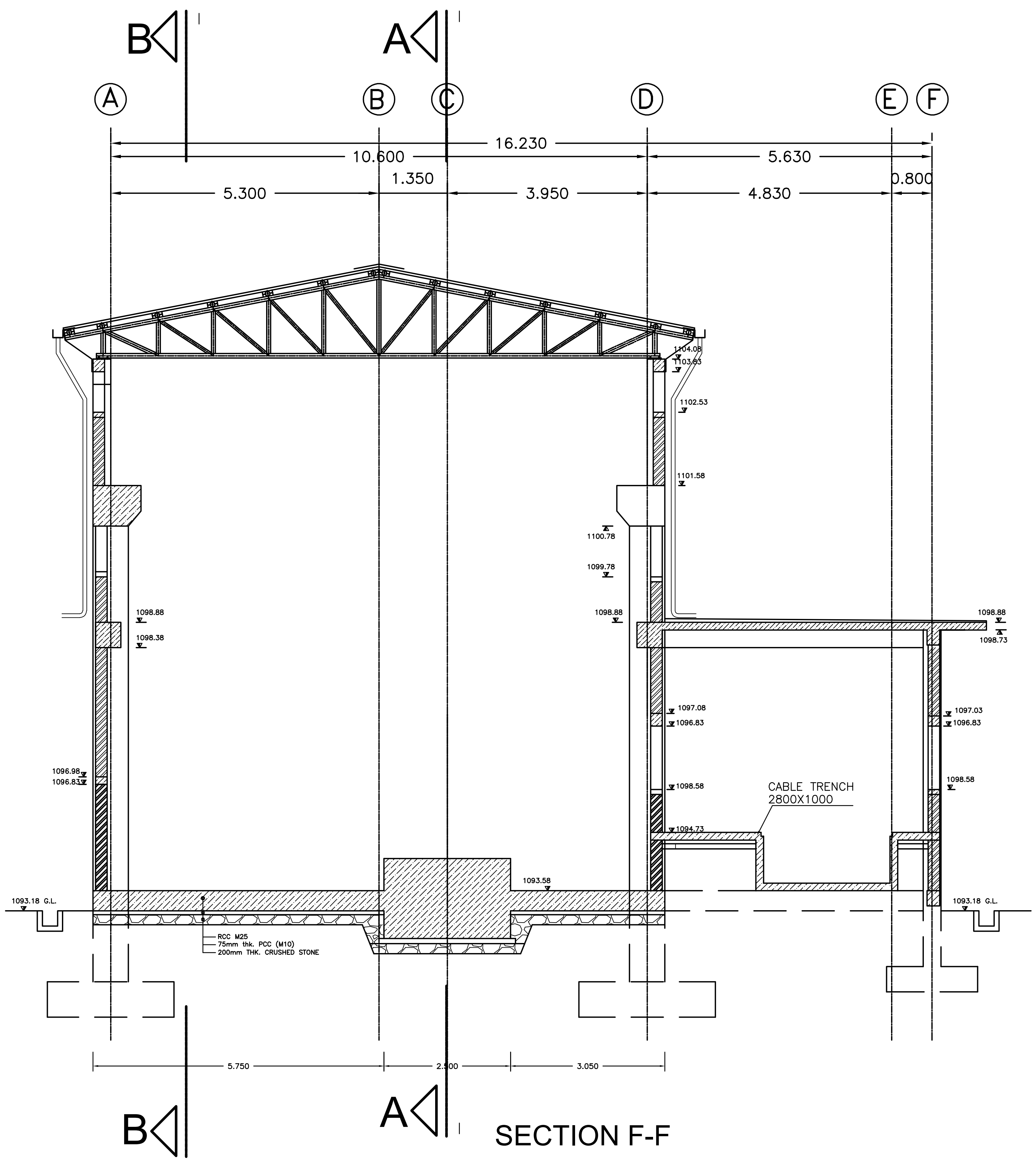
1. ALL DIMENSIONS ARE IN METER UNLESS SPECIFIED
2. SPACING OF THE REBAR IN mm
3. ALL ELEVATIONS ARE IN MASL.
4. GRADE OF CONCRETE FOR THIS STRUCTURE IS M25
5. GRADE OF ALL REINFORCEMENT BARS IS fe500
6. MIN. CONCRETE CLEAR COVER
   - -FOR COLUMN 40mm
   - -FOR FOUNDATION 50mm
7. DEVELOPMENT LENGTH OF THE REBAR SHALL NOT BE LESS THAN 60 TIMES THE DIAMETER OF REBAR.
8. LENGTH OF LAP AND SPLICES SHALL NOT BE LESS THAN DEVELOPMENT LENGTH OF REBAR.

SOURCE: UPPER CHHANDI KHOLA SHP

(Designed By: INSIGHT ENGINEERING CONSULT Pvt. Ltd.)

POWERHOUSE DRAWINGS

POWERHOUSE SECTION



SECTION F-F

SCALE 1:100

NOTES:

1. ALL DIMENSIONS ARE IN METER UNLESS SPECIFIED
2. SPACING OF THE REBAR IN mm
3. ALL ELEVATIONS ARE IN MASL.
4. GRADE OF CONCRETE FOR THIS STRUCTURE IS M25
5. GRADE OF ALL REINFORCEMENT BARS IS fe500
6. MIN. CONCRETE CLEAR COVER
   - -FOR COLUMN 40mm
   - -FOR FOUNDATION 50mm
7. DEVELOPMENT LENGTH OF THE REBAR SHALL NOT BE LESS THAN 60 TIMES THE DIAMETER OF REBAR.
8. LENGTH OF LAP AND SPLICES SHALL NOT BE LESS THAN DEVELOPMENT LENGTH OF REBAR.

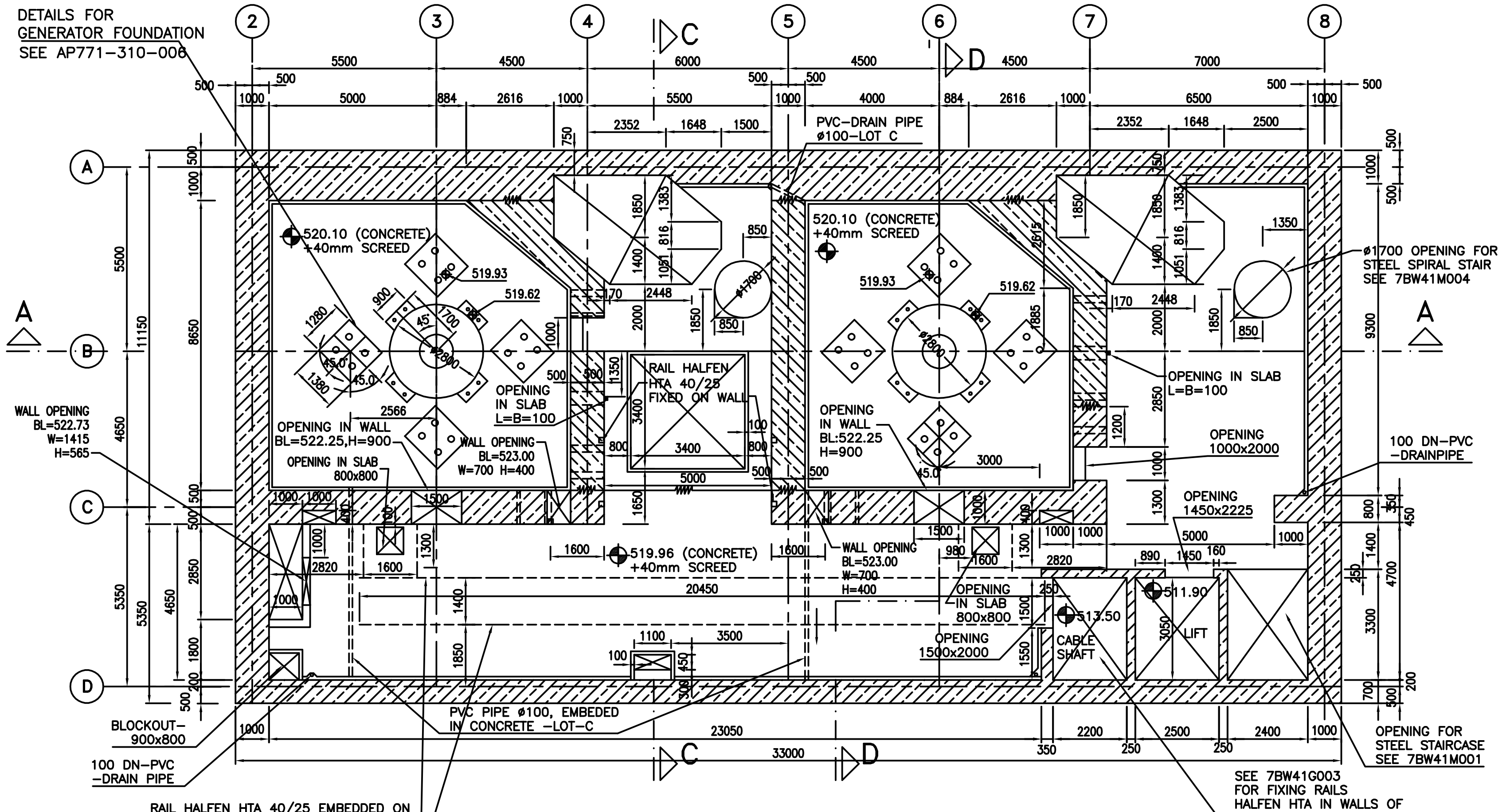
SOURCE: UPPER CHHANDI KHOLA SHP

(Designed By: INSIGHT ENGINEERING CONSULT Pvt. Ltd.)

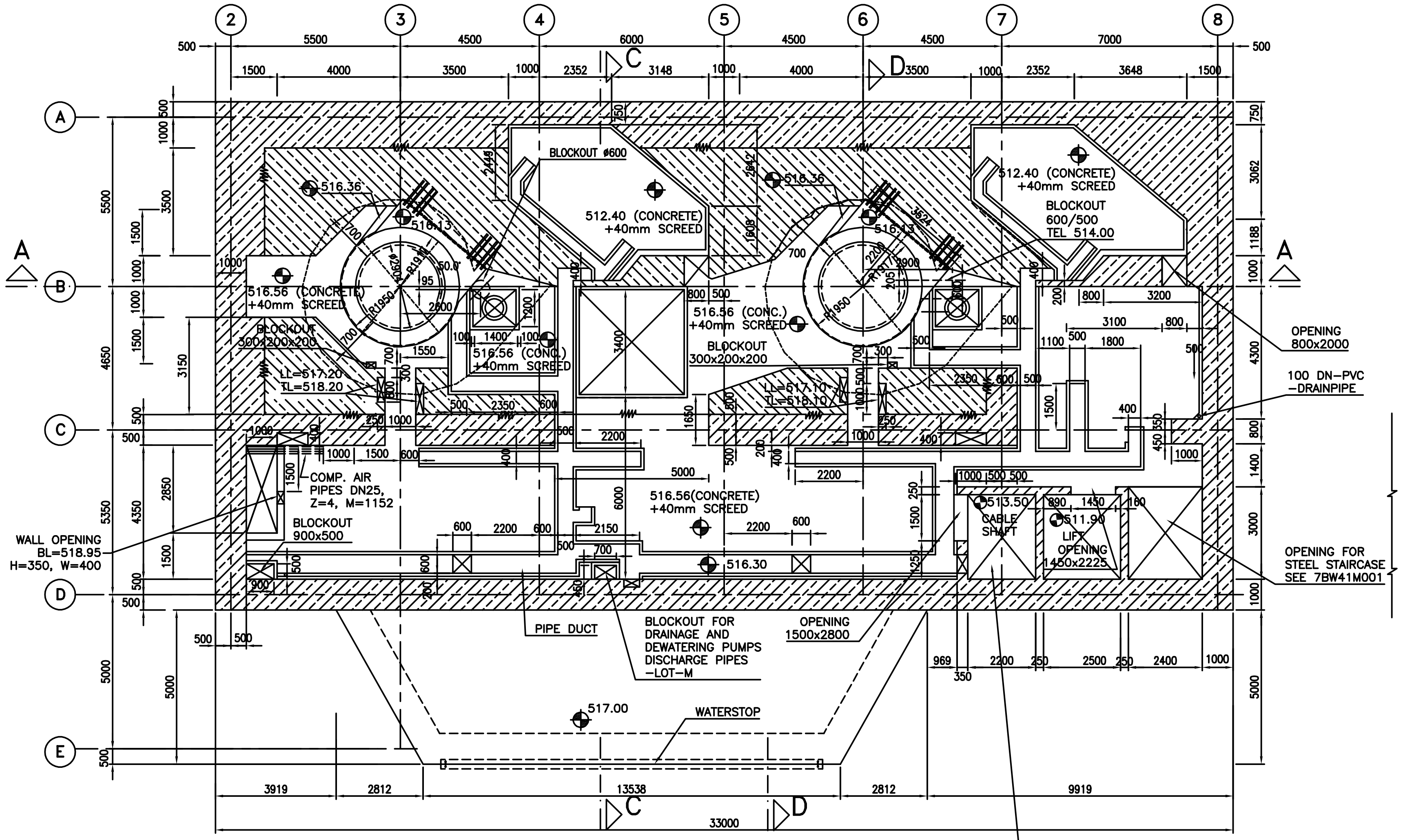
POWERHOUSE DRAWINGS

POWERHOUSE SECTION

SEMI SURFACE TYPE



GENERATOR FLOOR PLAN AT EL. 520.14
SCALE A



TURBINE FLOOR PLAN AT EL. 517.00
SCALE A

LEGEND:

- FIRST STAGE CONCRETE
- SECOND STAGE CONCRETE
- INTERFACE BETWEEN FIRST STAGE & SECOND STAGE CONCRETE
- FIXING RAILS HALFEN HTA 40/25 ON CEILING OF FL.SLAB EL. 520.00

1. FORMWORK TYPE FOR EXT. SURFACES OF EXT. WALLS-F1 ACC. TO SPECIFICATION 11.2.7.2

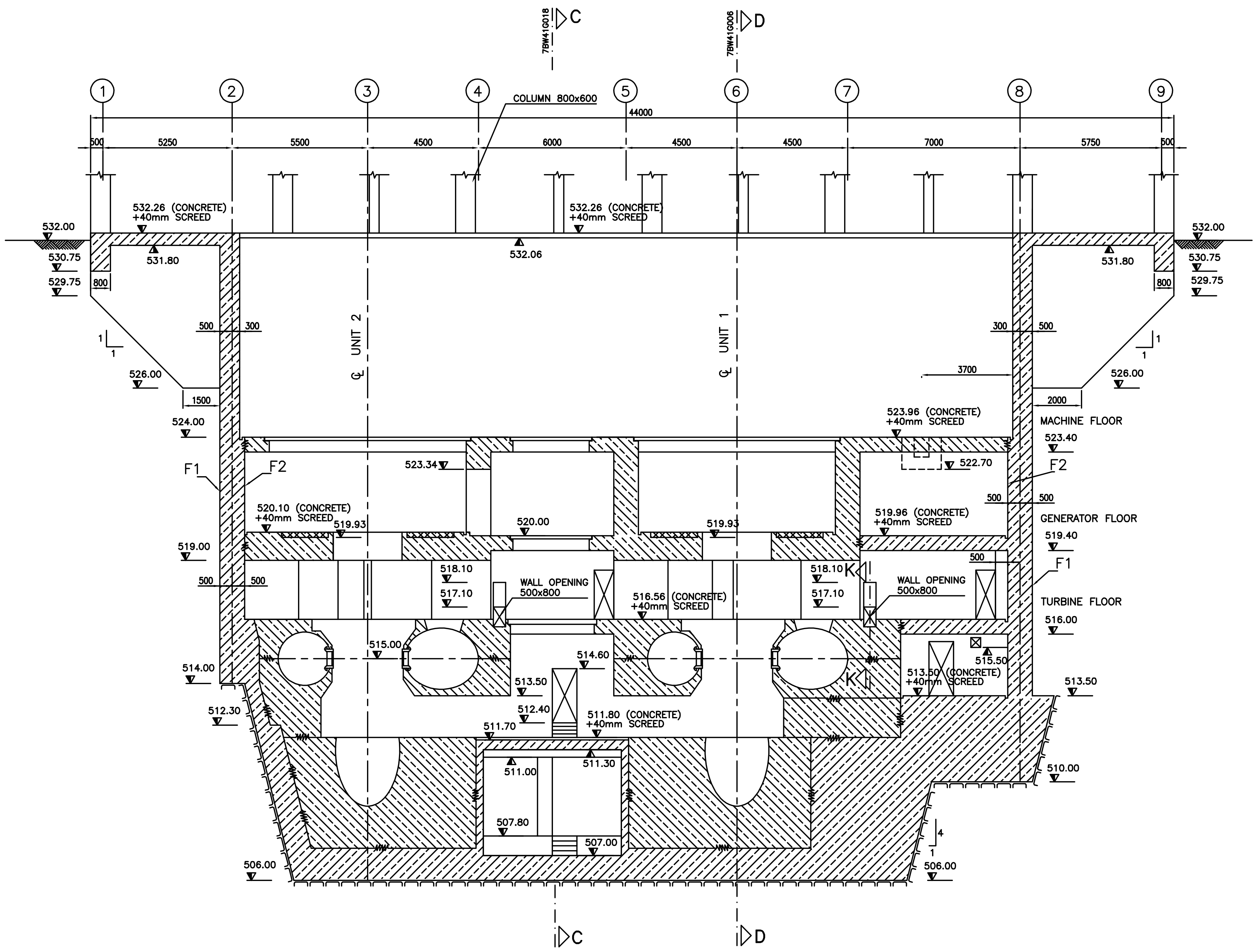
2. FORMWORK TYPE FOR INTERNAL SURFACES OF EXT. WALL AND INTERMEDIATE WALLS-F2 ACC. TO SPECIFICATION 11.2.7.2

0 2 4 6 8 10m
SCALE A
All dimensions are in mm

SOURCE: MIDDLE MARSYANGDI HYDROELECTRIC PROJECT
NEPAL ELECTRICITY AUTHORITY (NEA)

POWERHOUSE AREA

TURBINE FLOOR AND GENERATOR FLOOR PLANS



LONGITUDINAL SECTION A–A

SCALE A

LEGEND:

- FIRST STAGE CONCRETE
- SECOND STAGE CONCRETE
- NON SHRINK GROUT ACC. TO GEN TECH.SPECF. 11.2.6.6.6
- INTERFACE BETWEEN FIRST STAGE AND SEC. STAGE CONCRETE

0 2 4 6 8 10m

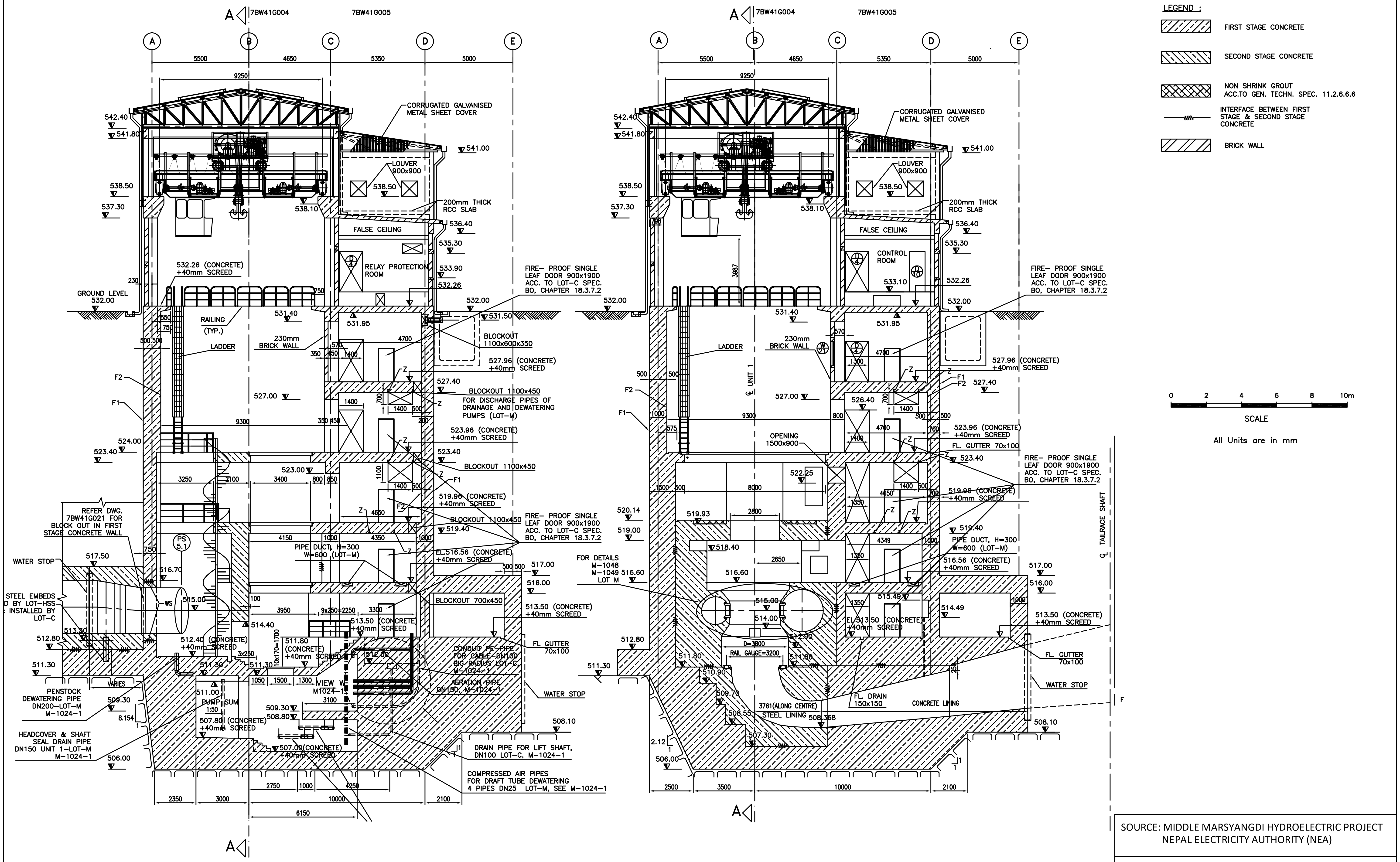
SCALE A

All dimensions are in mm

SOURCE: MIDDLE MARSYANGDI HYDROELECTRIC PROJECT
NEPAL ELECTRICITY AUTHORITY (NEA)

POWERHOUSE AREA

SUBSTRUCTURE LONGITUDINAL SECTION A–A



SECTION C–C

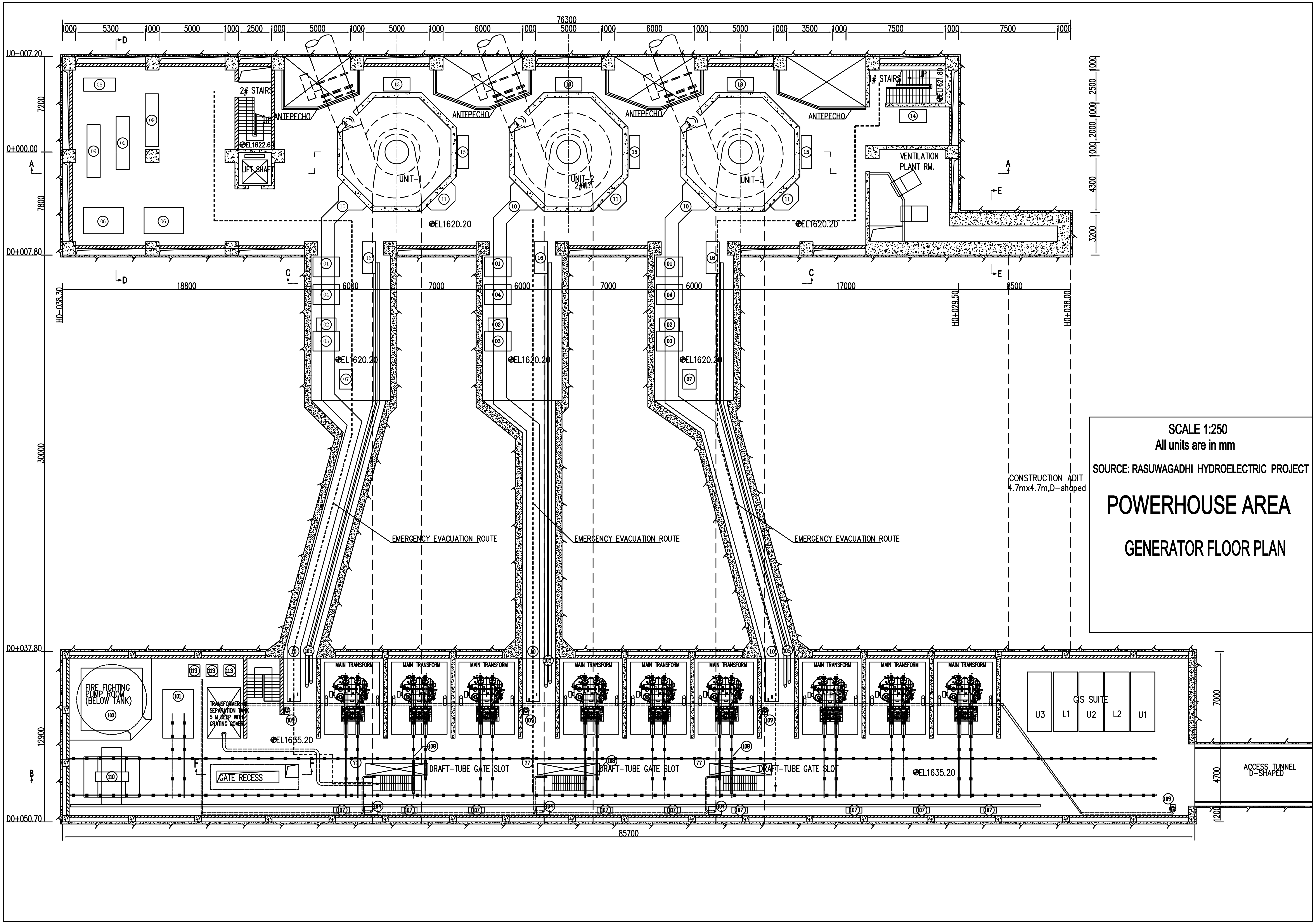
SECTION D–D

SOURCE: MIDDLE MARSYANGDI HYDROELECTRIC PROJECT
NEPAL ELECTRICITY AUTHORITY (NEA)

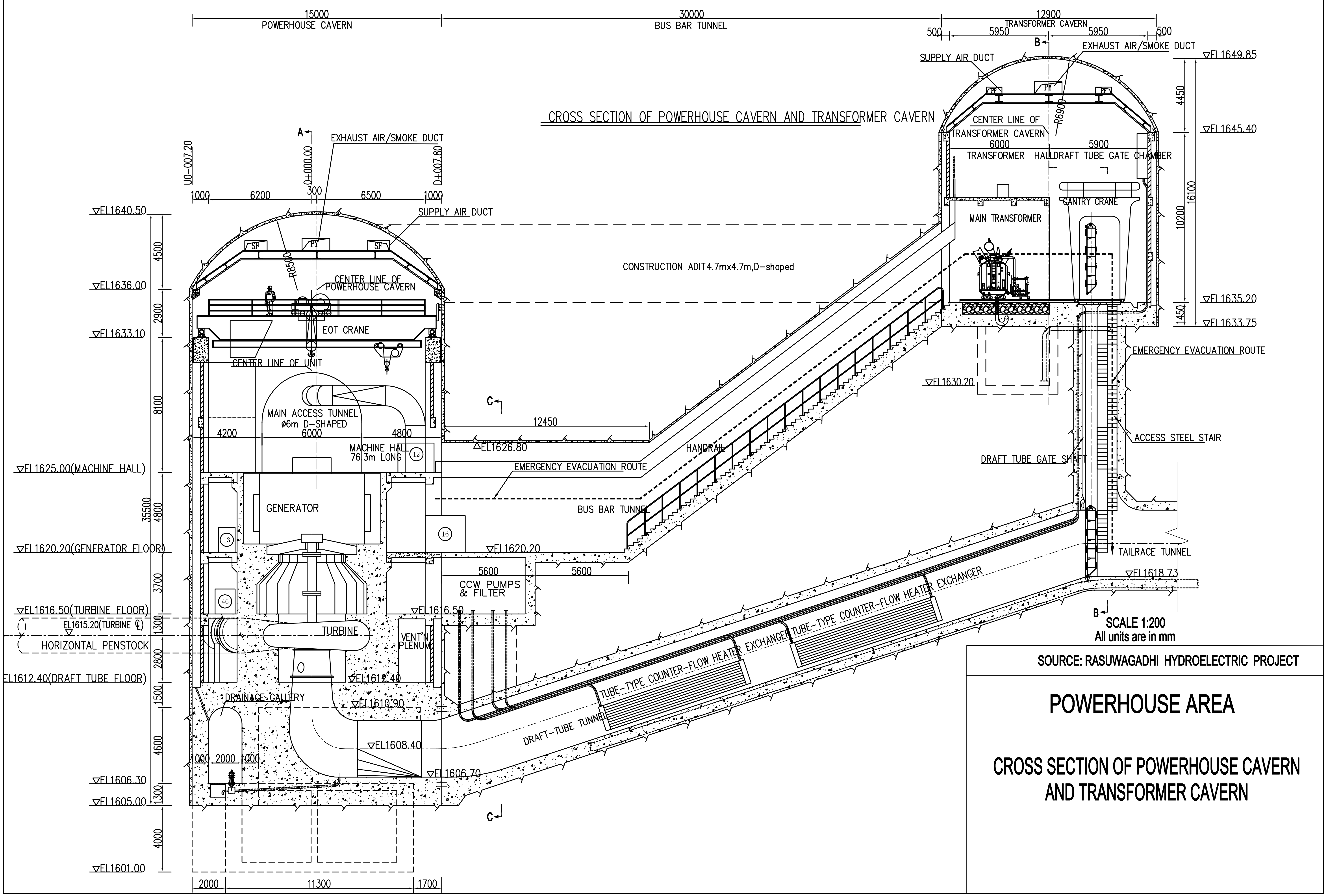
POWERHOUSE AREA

SUBSTRUCTURE CROSS SECTIONS C–C AND D–D

UNDERGROUND TYPE



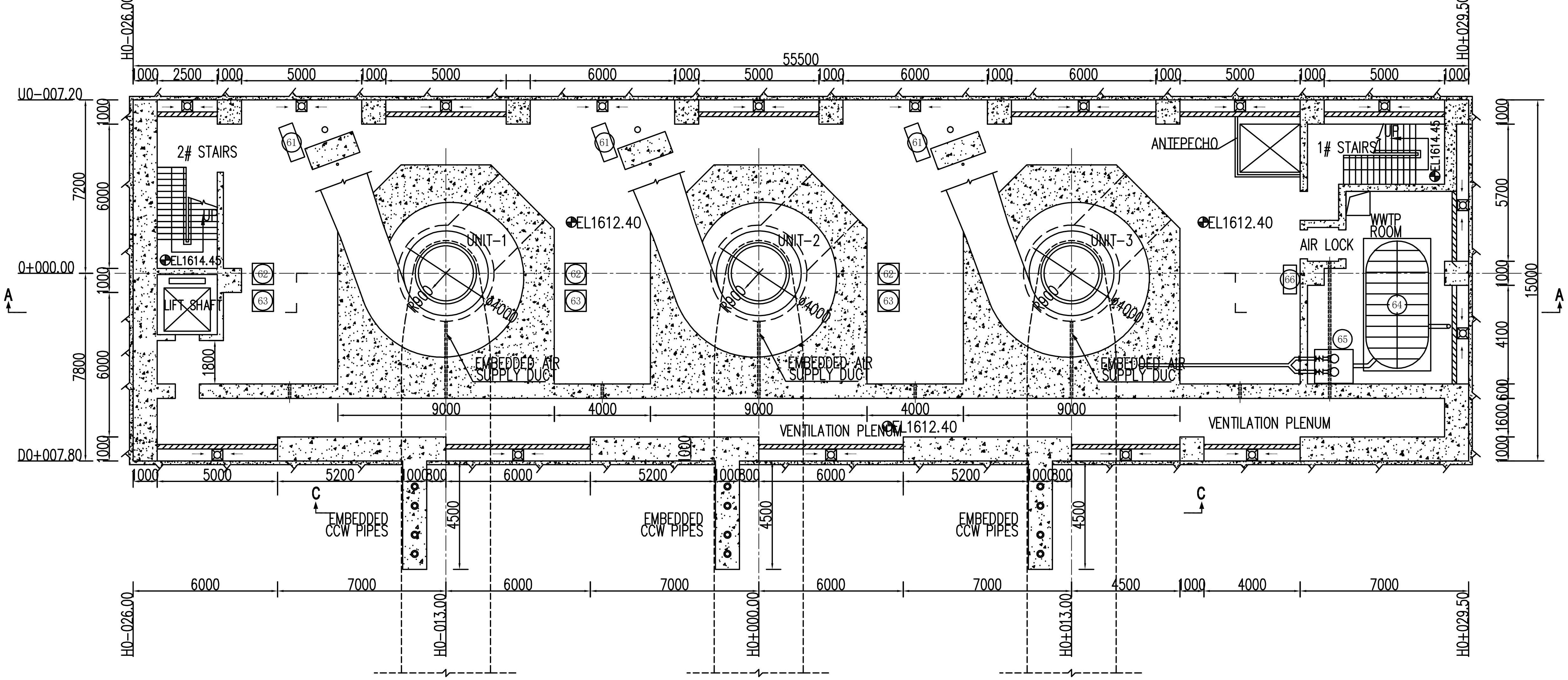
SCALE 1:250
All units are in mm
SOURCE: RASUWAGADHI HYDROELECTRIC PROJECT
POWERHOUSE AREA
GENERATOR FLOOR PLAN
UNIT-1
UNIT-2
UNIT-3
ANTEPECHO
2# STAIRS
LIFT SHAFT
VENTILATION PLANT RM.
EMERGENCY EVACUATION ROUTE
CONSTRUCTION ADIT 4.7mx4.7m,D-shaped
MAIN TRANSFORM
FIRE FIGHTING PUMP ROOM (BELOW TANK)
TRANSFORMER SEPARATION TANK 5 M DEEP WITH GRATING COVER
GATE RECESS
DRAFT-TUBE GATE SLOT
GIS SUITE
U3
L1
U2
L2
U1
ACCESS TUNNEL D-SHAPED
EL1620.20
EL1622.60
EL1621.80
EL1635.20
76300
85700



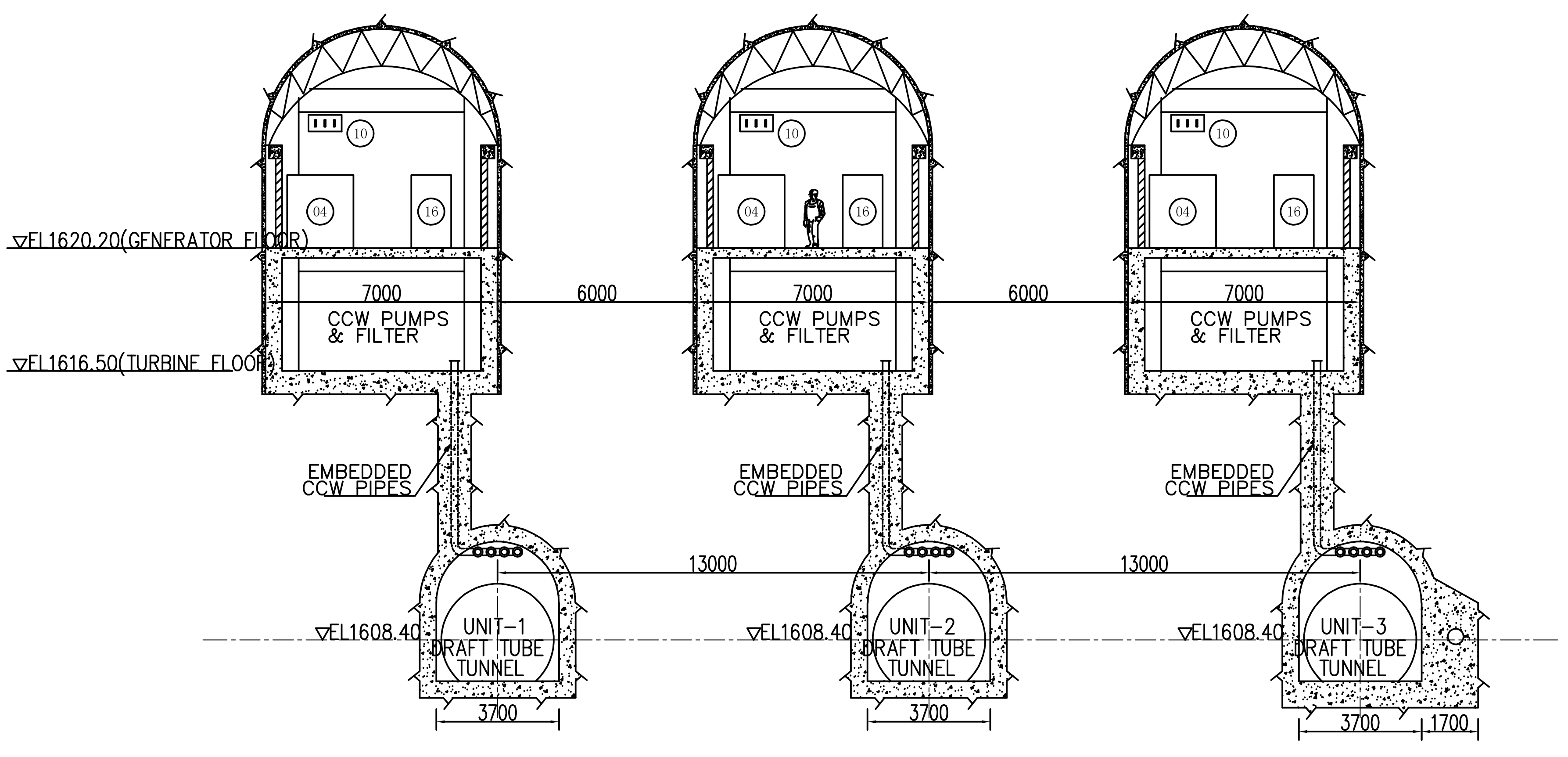
SOURCE: RASUWAGADHI HYDROELECTRIC PROJECT

POWERHOUSE AREA

CROSS SECTION OF POWERHOUSE CAVERN AND TRANSFORMER CAVERN



DRAFT TUBE FLOOR PLAN



SECTION C-C

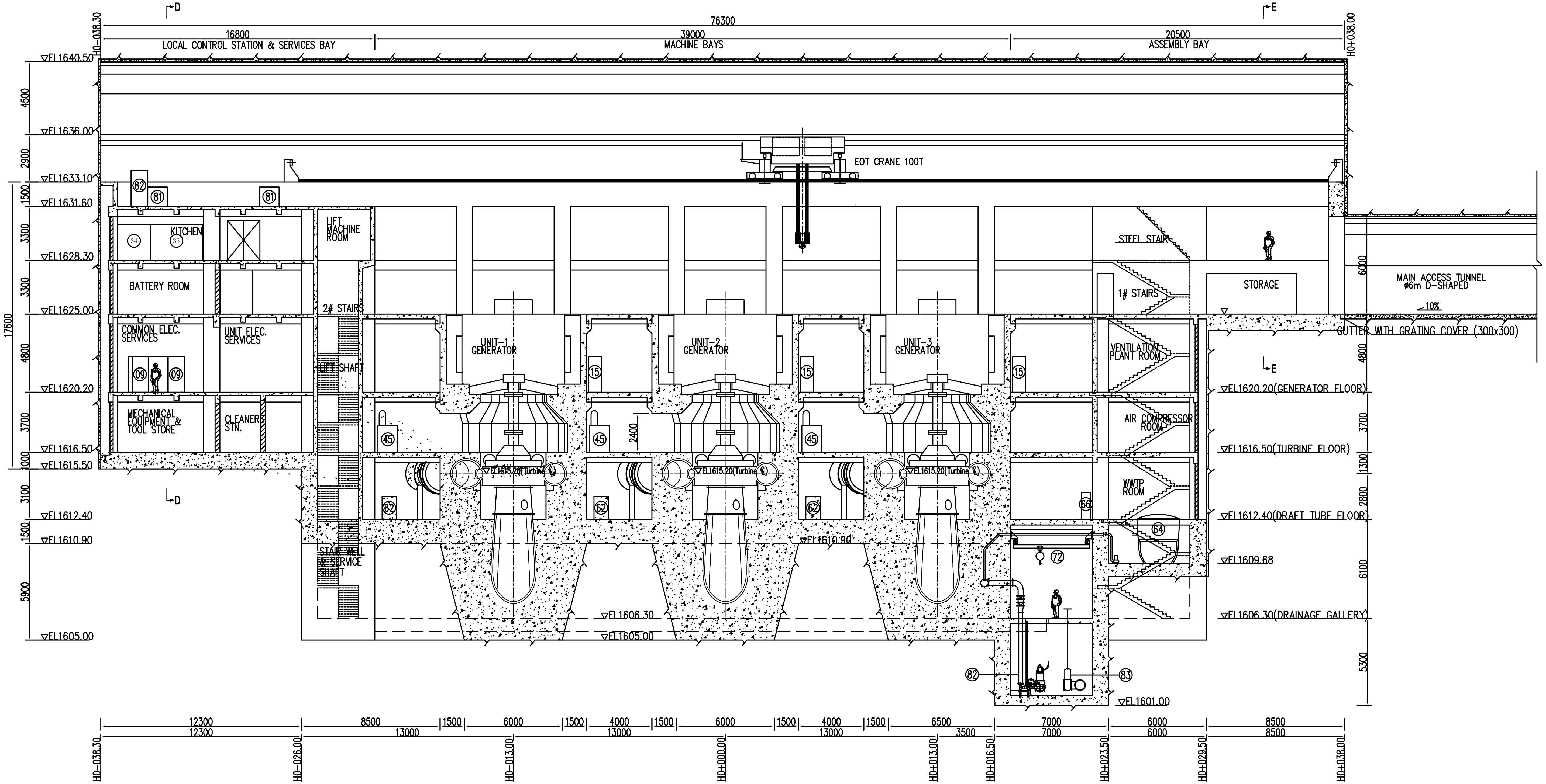
SCALE 1:200

All units are in mm

SOURCE: RASUWAGADHI HYDROELECTRIC PROJECT

POWERHOUSE AREA

DRAFT TUBE FLOOR PLAN AND SECTION



LONGITUDINAL SECTION OF POWERHOUSE CARVEN (SECTION A–A)

SCALE 1:250
All units are in mm

SOURCE: RASUWAGADHI HYDROELECTRIC PROJECT

POWERHOUSE AREA

LONGITUDINAL SECTION OF POWERHOUSE CAVERN

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