KERALA STATE ELECTRICITY BOARD Ltd

(Incorporated under the Companies Act, 1956)
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ABSTRACT

Cost effective implementation of Small Hydro Electric Projects – Hand book on "Guidelines for Cost effective implementation of Small Hydro Electric Projects March 2022"- Updating the Guidelines- Approved- Orders issued.

Coporate Office (SBU - G/C)

B.O. (FTD) No.263/2024 (DGC/AEEI/Cost Effecive Design2024)Thiruvananthapuram. Dated:27-05-2024

Read : 1. B.O. (FTD) No. 1076/2015 (DGC/AEEVI/GGCP/2014) dated 02.05.2015.

2. Office Order (CMD) No. 122/2023 (HRD.7/Ext, Trg.48/22-23) dated 25.01.2023.

3. Note No. DGC/AEE I/Cost Effective Design/2024 dated 21.05.2024 of the Director (Generation – Civil) to the Full Time Directors(Agenda No:-68-05/2024).

ORDER

The Kerala State Electricity Board has been in the field of Generation, Transmission and Distribution of electricity in the State of Kerala for nearly 6 decades. During this period 41 hydel projects were implemented in the State under the governance of erstwhile Travancore Cochin Royal regime, the Kerala State Electricity Department, KSEB and finally under the control of Kerala State Electricity Board Ltd. The implemented projects range from large hydel projects like the 780 MW Idukki Hydro Electric Project to Mini hydel projects like 1.25 MW Peechi Small Hydro Electric Project. The hydel projects of Kerala cover almost all types of hydel generation varying from large storage dams to small run off the river power houses. Almost all novel and modern techniques and functions have been experimented by KSEBL for hydel generation.

Implementation of large scale projects similar to Idukki or Sabarigiri has now become much difficult after enactment of Forest (Conservation) Act 1980 due to environmental constraints. KSEBL had constructed two diesel powered generating stations, the first at Brahmapuram, Kochi and the second at Nallalam, Kozhikode. It has been proven beyond question that the cost of generation from these two plants is nowhere near the cost of electricity produced from hydel schemes. The cost of generation or the levelized tariff for the power from the hydel stations is comparatively cheaper and this aspect gave more attraction to hydel schemes.

As of now, for achieving the goal of producing cheap electricity we have to harness the power potential of the 44 rivers of the state. For this, construction of small/mini/micro hydel schemes is considered as one of the best options in Kerala scenario. However, currently the cost of construction of hydel schemes that are planned or being implemented has increased considerably leading to a setback in the cost wise attraction of hydel projects. This situation has also led to a rethinking on implementing such expensive schemes with little outcome. Improper planning of scheme layout, non adoption of cost saving techniques vis-à-vis safety and non adoption of the aspect of ultimate development of a basin may be the reasons which can be attributed to the situation. An analysis of the shortcomings and drawbacks in implementation of hydel schemes in KSEBL has become inevitable to sort out the issues faced in hydel generation since it is high time to evolve a fruitful methodology for cost effective and innovative implementation of small hydel schemes.

KSEBL, during 1998-2002 had implemented four small schemes viz. Urumi I and II, Chembukadavu I & II, taking technical assistance from Hangshou International Center in Small Hydro Projects, (HIC IN SHP) China. By the adoption of several cost saving techniques these schemes could be implemented at low cost.

In the meeting convened by the Hon'ble Minister for Power, the Hon'ble Minister emphasised the development of small HEPs in a financially viable method and hence new technologies, innovative designs etc. have to be adopted to minimize the cost of the project and to change from the conventional designs now being adopted. He had also re-iterated that all efforts should be made to minimize the cost of the projects.

Subsequently vide B. O. read as 1 st above a committee was constituted for preparation of a manual /hand book on cost effective design of SHEPs with a direction that the manual/hand book shall contain planning and design practices detailing new technology and innovative design for general guidance during investigation and design. It shall serve as a base to work upon cost effective concept and as a check list to see whether all available options are duly considered in DPR.

The committee after detailed study, discussion and deliberations prepared a draft guideline for cost effective implementation of small HEPs. The draft was circulated among all Chief Engineers for comments. After obtaining comments/suggestions from respective Chief Engineers, the draft was modified and the final draft was prepared by the committee during March 2022. But the same is not implemented, till date.

As the present power scenario in the State badly requires capacity addition, we have to concentrate on early completion of ongoing schemes, take up new hydel projects, proceed with pumped storage schemes etc.

The main hurdle we are facing in taking up new small hydel schemes is the ceiling limit of cost/MW stipulated by the Hon'ble SERC, Kerala. As per the directions of the regulatory commission, for schemes up to 5MW the cost shall be 7.8 Cr/MW and for SHPs of capacity greater than 5MW, the limit is 9cr/MW. Unfortunately, in most of our SHPs, the total cost/MW is around 13 to 15Cr and while presenting the proposal of Capital Investment Plano of Generation SBU, Commission has directed to cut down the cost of SHPs by adopting cost effecting design methods, optimised storage, optimised generation, possibility of wind/solar projects in areas acquired for hydro projects and revised cost estimate for civil works and E&M works based on the latest SoR applicable in the state.

Moreover, a group of Civil & Electrical engineers had undergone a 2 weeks' training at IIT Roorkee during January-February 2023, on the subject of "Cost effective design of Small Hydro Power Projects" vide Office Order read as 2nd above.

At present the status of various SHPs on pipe line/PSPs are listed below:

Sl. No.	Name of Project	Capacity MW	Cost/ MW	Status
A.	**CAPEX**			
1	Chathankottunada Stage I SHEP	5	16.24	LA process to be initiated.
2	Pasukadavu	4	16.21	LA process to be initiated.
3	Valanthodu SHEP	7.50	12.20	LA process initiated.
4	Maripuzha SHEP	6	15.58	95% of private land acquisition completed against Rs. 6.55 Crores.
	Chembukadavu Stage III SHEP	7.50	17.71	LA process to be initiated.

5				
6	Peechad	3	17.30	LA sanction to be obtained from Government.
7	Western Kallar	5	13.40	LA process to be initiated.
8	Ladrum SHEP	3.50	18.91	LA procedures in progress.
9	Marmala SHEP	7	16.03	Notification as per LARR Act published on 29.08.2022. District Collector directed to remit Rs. 7.34 Cr towards the land value.
B.	**Pumped Storage Projects**	**MW**	**Mu**	**Status**
1	Manjapara	30	52.5	Requested the Government for In Principle approval for two pilot projects.
2	Mudirapuzha	100	208	
3	Marayoor	160	296	Proposed to implement through Tariff based bidding and requested the Government for In Principle approval.
4	Pallivasal	600	1248	
5	Upper Chaliyar	360	750	
6	Kakkayam	900	1260	requested the Government for In Principle approval for implementation on EPC Contract.
7	Idukki	700	1456	Identified potential PSP sites
8	Amrutha Pampa	300	520	
9	Poringal	100	198	
C.	**General**	**MW**	**Mu**	**Status**
1.	Idukki Extension Scheme	800	1301	1st stage environmental clearance obtained on 26.02.2022. EIA/EMP studies are progressing.
2.	Letchmi HEP	240	347	RFP for preparation of PFR/DPR was invited, tender opened on 30.04.2024 and under scrutiny.
3.	Keerithodu SHEP	12	27.65	Proposed to implement through Tariff based bidding and requested the Government for In Principle approval.

Since the exorbitant cost of execution is the main hurdle to move ahead with the projects, we are constrained to curtail the project cost by adopting cost effective technologies, by use of modern construction materials, etc. Hence it is high time to revise these DPR on the above basis so as to evolve a revised DPR with reduced cost/MW. The Director (Generation- Civil) has furnished the road map for attaining above as outlined below.

1. The "Guidelines for cost effective design of Projects" shall be updated and released officially. Necessary updations to this document shall be made from time to time on the basis of state of the art construction methods, cost effective techniques in planning and design, use of alternate materials which results in cost cutting. For this the draft guidelines in March 2022 shall be updated with the help of officers who had undergone training at

IIT, Roorkee on the subject. They shall conduct meetings and deliberations and submit the final version for approval within 30 days.

2. The next updated version of "Guidelines for Cost effective implementation of Small Hydro Electric Projects" could be send to accredited agencies like IIT Roorkee etc. for their vetting and suggestions if any or alternatively we may obtain concurrence Government agencies like Bureau of Indian Standards.

The matter was circulated among the Full Time Directors vide Note read as 3 rd above.

Having considered the matter in detail the Full Time Directors decided to accept the hand book/manual and to release the hand book on **"Guidelines for Cost effective implementation of Small Hydro Electric Projects"** (attached as Annexure) as May 2024 version for adoption in preparation of all future DPRs and revision of DPR of projects in pipeline.

The Full Time Directors also resolved to update the present version of hand book, by including latest cost effective technologies, for which a committee is constituted with the following engineers inclusive of engineers who had undergone a training on "Cost effective Implementation of SHPs" at IIT Roorkee.

1. Er. Vinod V., Project manager, Sengulam Augmentation Scheme – Chairman.
2. Er. Sunny C. D., Assistant Executive Engineer (Civil), O/o the Chief Engineer (Civil-Investigation & Construction Central) – Convenor.
3. Er. Anil B., Assistant Executive Engineer (Civil), Investigation Division, Munnar – Member.
4. Er. Shaji S., Assistant Executive Engineer (Civil), O/o the Chief Engineer (Civil Construction) South – Member.
5. Er. Anila, Assistant Executive Engineer (Civil), Design & Consultancy, North – Member.
6. Er. Dhanalakshmi K., Assistant Executive Engineer (Civil), Design & Consultancy, North – Member.
7. Er. Shihabmon C. S., Assistant Engineer (Ele.), Transformer maintenance Sub Division, Moolamattom – Member.
8. Er. Haridas Vijayan, Assistant Engineer (Ele.), Erection Sub Division II, Kallarkutty – Member.
9. Er. Yadupal P. S., Assistant Engineer (Ele.), Barapole Power House – Member.
10. Er. Sajith T. K., Assistant Engineer (Ele.), O/o the Chief Engineer (PED) – Member.

Full Time Directors also resolved that the Committee shall update/modify the hand book, by incorporating latest cost effective technologies based on the training received and their experience and submit the next edition within 30 days from the date of this Board Order.

Orders are issued accordingly.

By Order of the Full Time Directors

Signed by
Lekha G
Date: 27-05-2024 12:55:46

LEKHA G
COMPANY SECRETARY

/44285/2024

To:

1. The Chief Engineer (Civil - Investigation & Construction Central)
2. The Chief Engineer (Civil Construction) South
3. The Chief Engineer (Civil Construction) North
4. All Committee Members

Copy to:

The Chief Engineer (IT, CR&CAPS)/ Company Secretary/ Financial Adviser/ LA&DEO/ RCAO/RAO
The TA to the Chairman & Managing Director / Director (Generation-Civil)/ Director (Generation-Electrical, REES, SOURA, S & W)/ Director (Distribution, Safety, SCM & IT)/ Director (Transmission & SO &Planning)
The PA to the Director (Finance & HRM)
The Sr.CA to the Secretary (Administration)
Stock File/Library

Forwarded / By Order

Assistant Executive Engineer

Annexure to B. O. (FTD) No. 263/2024 (DGC/AEE I/Cost Effective Design/2024) Thiruvananthapuram dated 27.05.2024.

GUIDELINES FOR COST EFFECTIVE IMPLEMENTATION OF SMALL HYDRO ELECTRIC PROJECTS

MAY 2024

PREFACE

At present, use of standards, guidelines, manuals etc is voluntary for the design of components of hydroelectric projects. Most of the available standards and guidelines for the generation of hydropower projects are seen to be developed giving consideration only to large scale hydropower projects. Adoption of such standards renders the development of Small hydro projects uneconomical. Small scale hydropower projects have to be developed in a cost effective manner with quality and reliability. Therefore the KSEBL has decided to develop a set of standards that would help in cost effective design and implementation of small scale projects.

In this regard it may be noted that the AHEC and Indian Institute of Technology, Roorkee have developed a set of guidelines for planning, designing and implementing small hydro projects. The same can be applied to a greater extent in the case of small hydro projects.

However, it can be seen that the AHEC guidelines give emphasis on the Himalayan River basins. The terrain of Kerala is much different and hence it is felt that our case requires a different consideration. Accordingly, certain cases requiring some deviation from the AHEC guidelines alone are dealt in this handbook. Otherwise, in general, the AHEC guidelines (2013 or its subsequent revisions) may be adopted for planning and design of small hydro projects.

Chapter - 1. GUIDELINES FOR PLANNING AND LAYOUTS

1.1 SCOPE

These guidelines provide guidance on planning and layout for all types of small hydro power projects which utilise the falls, steep slopes of the natural streams as run off the river, existing dams, barrages, weirs etc as water diversion or storage structures. Planning and layout of a SHP on existing works is more complex than planning a new project on a natural stream as design and operational details, structural soundness of the existing structures etc. are important for the purpose of planning.

Investigations of Hydro Electric Projects are carried out in three stages. They are feasibility study, preliminary investigation and detailed investigation. The installed capacity of a hydroelectric project and expected energy depends on two factors. They are water availability expressed as power draft in m^3/sec and available net head expressed in metre. Purposes of conducting investigations in three stages are to select a best combination of water availability and head, for making the project most economical and eco-friendly. To achieve this goal, study of different alternatives, if any available, is a must. While planning small hydro electric projects, utmost care shall be taken to reduce length of water conductor system from weir to Forebay on a cost/energy basis unless there are no site constraints.

During detailed investigation for small hydroelectric projects, following activities shall be carried out in a systematic manner.

Chapter - 2. DETAILED INVESTIGATION

A detailed investigation survey consists of the following.

2.1 TOPOGRAPHICAL SURVEYS

Detailed topographical surveys shall be carried out along the routes selected during preliminary investigation survey. Topographical data for preparing contour, Longitudinal Section, Cross section etc of Weir site, reservoir area, power channel/tunnel route, Forebay site, Penstock route, Power house site, tail race channel route, Surplus channel route, any other component site if any shall be collected during survey. Besides these details regarding topographical features such as river, stream, road, bridges, building etc. shall be collected. Permanent bench marks shall be established at Weir site, Forebay site & Power house site. Alignment blocks shall be established at site and their locations of shall be shown in the contour drawings. The following drawings shall be prepared.

2.2 CONTOUR DRAWINGS

a) Weir site up to 100m of both the upstream & downstream of weir axis covering both the banks of the river to a width required for accommodating the weir, intake and allied structures giving sufficient margin. Reservoir area up to an elevation 5m above MWL of the reservoir. This drawing shall be prepared to a scale of 1:200.

b) Power channel/tunnel route from the proposed intake location to the Surge/Forebay location covering a width of minimum 30m on either side of the proposed alignment. For channel alignment through steep area the width to the uphill side may be suitably increased beyond the excavation limit for the channel. These drawings shall be prepared to a scale of 1:500. At Forebay site, required additional area to accommodate intake of Surplus channel shall also be included

c) From Surge/Forebay location to Power house site along Penstock route to a scale of 1:500. This drawing shall be prepared for a width covering the excavation limit for penstock track and to a minimum of 20m on either side of proposed alignment.

d) Power House site, a minimum of 50m length & width 80m and covering the excavation limit for PH shall be covered in the contour drawing. For tail race channel, contour shall be taken up to 20 m on either side of the alignment and river portion covering 100m u/s and 100 m d/s of tail race exit. This drawing shall be prepared to a scale of 1:200.

e) Along the Surplus channel route up to 20m on either side of the proposed alignment including the river portion for a width of 50m to u/s and 50 m to d/s of the exit drawn to a scale of 1:500.

f) Along the proposed road alignment to various project components such as Weir, Power House, Forebay/Surge, tunnel ADITs if any etc to a scale of 1:500. This drawing shall be prepared for 10m on either side of the proposed alignment covering the excavation limit.

The contour interval of the above mentioned drawings shall be preferably 1m.

2.3 L S DRAWINGS REQUIRED

a) LS of Weir site about 200 m d/s of Weir axis, and on u/s about 50m beyond the point where MWL of proposed Weir meets bed of river. This drawing shall be prepared to a scale of 1:200.

b) LS of Power channel/tunnel route including Forebay/Surge site to a scale of 1:500.

c) LS of Penstock route to a scale of 1:500.

d) LS of tail race channel including LS of river at tail race exit for a length of 100m to both u/s & d/s side drawn to a scale of 1:200.

e) LS of proposed access roads to various project components such as Weir, Power house, Forebay/Surge, tunnel ADITs if any etc to a scale of 1:500.

f) LS of Surplus channel route including LS of river at Surplus channel exit for a length of 100m to both u/s & d/s side drawn to a scale of 1:500.

g) LS of streams crossing Power channel route and Surplus channel route to a scale of 1:200. This shall be taken up to 30m u/s and 30m d/s of the proposed water conducting system alignment.

h) LS of Power house site to a scale of 1:200 at 10m intervals.

2.4 C S DRAWINGS REQUIRED

a) CS of river along Weir axis, 50m u/s of Weir axis and 50m d/s of Weir axis (at 10m intervals) to a scale of 1:200.

b) CS of Power channel route and Forebay/Surge at 10m intervals, and at points of drastic changes in topography to a scale of 1:200. This shall be taken up to the excavation limit and to a minimum 30m to uphill and 30m downhill of the proposed alignment.

c) CS of the tunnel route at 25m intervals to a scale of 1:200. This shall be taken up to 30m on either side of the proposed alignment.

d) CS of the streams crossing Power channel route and Surplus channel route to a scale of 1:200. This shall be taken at 5m intervals along its alignment.

e) CS of the Penstock route at 10 m intervals, and at the locations of Anchor blocks to a scale of 1:200. This shall be taken up to the excavation limit and to a minimum of 20m on either side of the alignment.

f) CS of Power House site at 10m intervals and at points of drastic change in topography of the area to a scale of 1:200.

g) CS of roads at 10m intervals and at points of drastic change in slope to a scale of 1:200.

2.5 HYDRO- METEORLOGICAL SURVEY

Data from all H & M Stations lying inside the catchment and adjacent to the catchment area of the scheme if available shall be collected and compiled properly for a continuous ten years period. Calculate an average annual rainfall of the catchment area by using "Theissen Polygon" method. If the required data are not available from the catchment area, the same may be collected from nearby similar catchments. Readings from H&M stations outside the catchment also have to be collected if the hydro-meteorology of these stations have specific influence on the catchment of the project.

Rainfall is a source of fresh water; its distribution shows random variation both in space and time. Project planning using mean values for rainfall is very unreliable. Since rainfall shows variation in intensity, amount and duration, it is not so simple to predict precisely the amount of rain to fall in the future. The planner needs to know the amount of rainfall, which can be depended upon with a certain degree of probability. This knowledge about dependable rainfall will ensure that the project is planned in such a way as to make optimum sizing of the machines. Dependable rainfall is defined as the rainfall, which can be expected in a set number of years out of a total number of years. The objective of this study is to estimate yearly dependable rainfall from yearly normal distributed rainfall data series.

Select a suitable weir gauge station with a continuous discharge data of minimum 10 years from its own catchment or from nearby similar catchments. If a weir gauge station is available in the same river, this can be utilised if characteristics of the catchment of weir gauge station and that of the scheme are almost similar. Rain shadow area, forest area, area with agricultural activities, average rain fall etc. shall be considered while selecting a model weir gauge station for studying power potential of the scheme. Discharge data of gauging stations which have huge difference in catchment area comparing to catchment of the project cannot be taken for arriving the potential of the project. Daily inflow at weir site of proposed scheme shall be worked out from daily inflow of selected model weir gauge station by directly proportioning in terms of catchment area. Proportioning also shall be done in terms of average annual rainfalls of both the catchments to have a more realistic water estimate.

Type of diversion structure, whether it is a gravity type weir or a trench type weir may be selected, and FSL of the canal/tunnel at intake may be fixed. Velocity of flow in the canal may be fixed from 2.20m/sec to 2.70m/sec. Fix a minimum tail water level at Power house site by considering the Normal river water level during monsoon months of river at Power house site. From the above data, carry out power potential studies, and calculate annual energy output for various combinations of machines for all the years of study. From these data obtain an optimum installed capacity by trial and error process based on certain dependability criteria. The power equation shall be **P= 8QH.** For energy estimate, 10% overloading shall not be considered. However for design of project components, 10% overload shall be considered.

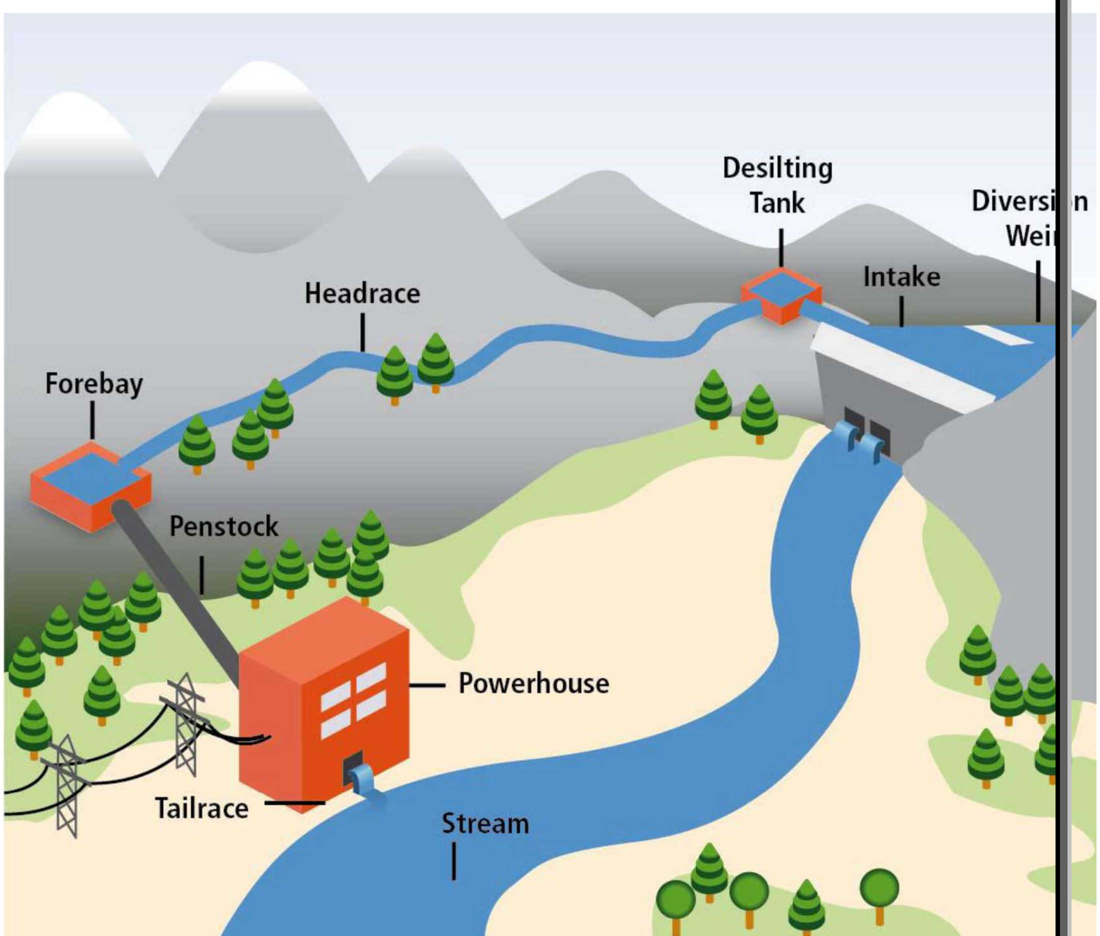
For computation of highest flood, generally Ryve's formula **$Q = CA^{2/3}$** is being used. Value of C is 10. This is the formula applicable for South Indian Rivers. A major part of South India is in rain shadow area and Kerala, though is a part of South India, is lying along Western Ghats. It has been observed that flood discharges measured in weir gauge stations are exceeding the value computed from Ryve's formula. But, there is an equation known as Dicken's formula **$Q = CA^{3/4}$,** where C is between 22.50 and 25, which is applicable for Central India and Western Ghats. Since Kerala comes under Western Ghats, Dicken's formula shall be used to work out highest flood. General terrain of Kerala consists of hilly area of Western Ghats, mid land and costal area. Most of the small schemes are situated in hilly areas, and its catchment areas are in the Western Ghats region. Catchment areas of most of the small schemes are very small, and hence chances of occurring rainfall of same intensity all over the catchment area are more. Since the topography of the above said catchment is very steep, flood discharge at the Weir sites will be more comparable to a scheme with very large catchment area, because in vary large catchments, chances of occurring rainfall of same intensity all over the catchment is very rare. So, maximum value of C in Dicken's formula shall be 25, which is applicable for Western Ghats region. Flood discharge corresponding to Max flood level at the site (based on local enquiry) can be calculated knowing river bed slope and cross sectional area, using Manning's equation. The value so obtained shall be compared with the value calculated using Dicken's formula to ascertain the reliability.

2.6 GEOLOGICAL STUDIES

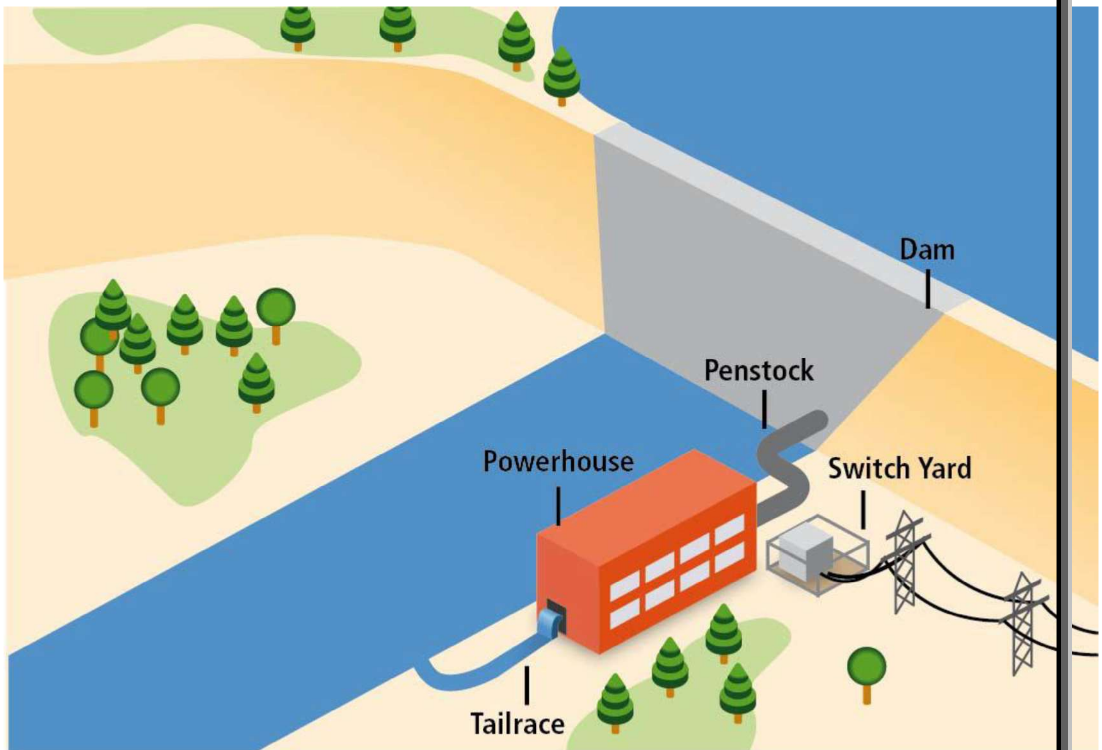
Necessary core-boring works shall be carried out at Weir site, Intake site, Forebay site, Anchor block sites along Penstock route, Power house site, Tail race site, major aqueduct site etc, to know depth at which rocks are available. List of Geotechnical and subsoil investigation to be carried out at specific location of the project are provided under clause 2.09 of this guidelines. These are to be generally followed. Investigation Wing should invite Geologists from Geological Survey of India after completion of bore hole drilling works for geological mapping of Project site. All the drawings, Geological Report and Hydrologic details shall be given to Design Wing for detailed design of all Project components. Design Wing should carry out detailed design of all the Project components, and handover the drawings to Investigation Wing for compilation of Detailed Project Report. Investigation Wing after getting design drawings shall prepare a detailed cost estimate based on the current CPWD rates and Data of KSEB and a detailed financial analysis to include in the DPR shall also be conducted.

2.7 SELECTION OF PROJECT COMPONENTS

Following are the general components of a small hydro electric project.



Typical Layout of Run off the River Scheme



Typical Layout of Dam toe Power Station

2.7.1. Small Runoff the River Scheme.

Diversion Weir (gravity type or trench type), Intake with plunge pool, de-silting tank or intake chamber with de-silting arrangements etc. are the components for a scheme with trench type weir. Where ever possible the diversion structure shall be trench type weir. This will avoid environmental impact due to creation of reservoir. Run-off-the river schemes generally do not envisage any storage of water. Power channel/tunnel, Forebay tank/Surge, Surplus channel for Forebay tank, Penstock, Power House, Tail race, switch yard and access roads are the other components.

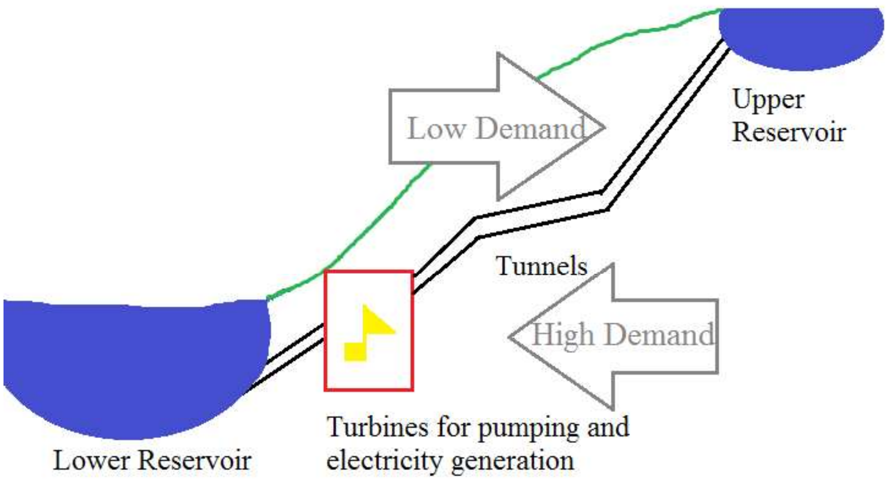
2.7.2. Small HE Scheme with Reservoir

A Diversion Weir, tunnel intake, tunnel, Surge tank, Penstock/pressure shaft, Power House, tail race, Switchyard and access roads are the components of such a scheme in general.

2.7.3. Dam toe Projects.

Penstock, Power House, Tail race, Switch yard and access roads are the main components of this type of projects.

2.7.4. Pumped-Storage Hydro Plants



Pumped storage hydropower is a modified form of conventional hydropower technology to store and manage electrical energy. Electric energy is converted to potential energy and stored in the form of water at an upper elevation. Pumping the water uphill for temporary storage "recharges the battery" and, during periods of high electricity demand, the stored water is released back through power tunnels to the turbines and converted back to electricity like a conventional hydropower station. The tail water then flows through a discharge tunnel into the lower reservoir. In a pumped storage power plant, instead of a conventional turbine reversible type turbines are installed; by this the same machine can function as a turbine and pump as per requirement by suitable switching mechanism. A PSP generally will have 2 reservoirs with large elevation difference. The power house is usually underground type. When demand for electricity is low, the turbines spin backward and pump the water back up into the upper reservoir to make it available to generate electricity when it's needed.

2.8 MAJOR COMPONENTS OF SHEP

2.8.1. Diversion Weir

A suitable structure is necessary for diverting the river water to the water conductor system of the project which is selected based on functional requirements, topographical and geological conditions of the site. Weir shall be along a profile, with a gentle longitudinal slope, preferably less than 1 in 20. Weir site not be located at sharp curves of the river course and just before or after water falls. If rock is available at shallow depth, and if there is no problem like submergence of forest area or other land of great importance, a conventional gravity type weir is most suitable. If rock is not available at shallow depth, a trench type Weir may be selected, which requires a de-silting chamber also. In case of gravity Weir, a guide wall between scour sluice and intake entry is very essential to reduce entry of silt and wooden trashes into the canal. This will also reduce the entry of flood discharge into canal during high floods. This excess water entering the canal may cause additional flow in the Surplus channel, which shall be prevented for safety of channel made on steep slopes. In the case of storage schemes, inlet is fixed above Dead storage level, and hence almost clear water in still condition will be entering through intake. Small schemes are constructed across small tributaries of rivers, and hence during flash flood time, lot of dried branches of trees dry leaves etc. will be coming along with the water. Though a trash rack with spacing recommended by suppliers of machineries are being placed in the Forebay tank, entry of huge quantity of trashes in to the Forebay tank causes frequent chocking of trash racks. This leads to reduction in water pressure inside Penstock forcing the operator to reduce the load on the machine. The immediate remedy is emptying the Forebay tank and removing trashes with rods. Since this process takes a lot of time, a lot of water is getting wasted. This is the situation in most of the running small run off the river schemes. The worst thing is that the chocking is happening mainly during the period of heavy rainfall, a time suitable for operating Power Station at its full load. During chocking of trash racks, the Penstock sucks water from Forebay tank causing entry of more wooden pieces and other trashes into the machine causing slippage to guide vanes and tripping of machines. This is a common issue observed in almost all the completed run off the river small schemes in Kerala. So, to reduce the entry of huge quantity of trashes in to the canal, introduction of a trash rack with large openings at the entry point to canal from the plunge pool is suggested. The clear spacing of trash bars may be 7.50 to 15.00cm. The workers engaged in operation and maintenance of Power Station shall clear the trashes at Weir and plunge pool daily, especially during days of downpour. Since this trash rack is exposed to open area, and accessible at shallow depth, cleaning can be carried out without affecting the generation. Cleaning of trash racks in Forebay tank is not possible without stopping the generation since it is lying very deep below water. If the above said additional trash rack is installed, the trash load in fore bay tank could be reduced by a considerable amount and the interval of chocking of trash rack at Forebay can be extended. If a cleaning mechanism as detailed under the head "Forebay tank" is also installed, this chocking can be prevented up to a large extent. All these will improve the efficiency of the Power Station resulting in higher generation. Thus the return from the Power Station can be improved to make it cost effective.

KSEB had implemented four small HE Schemes, namely Chembukkadavu I & II and Urumi I & II as pilot Projects with Chinese Technology. Since then, KSEB is implementing Small HE Schemes as per the technology adopted by the Chinese. In those Projects, trash racks are provided only in the Forebay tank. Those Projects are facing frequent chocking of Forebay tank trash racks affecting generation. Climatic conditions in China and India are entirely different. India is lying more near to the equator and hence a summer season with temperature rise up to 40^0C is occurring annually. Because of this, trees and other plantations are getting dried up heavily during summer, which is followed by a heavy monsoon, during which the generation activities of small schemes are taking place. This causes heavy flow of dried leafs, dried branches of trees etc along with river flow occurring during monsoon season. The situation is worst during the beginning of every monsoon season.

Discussions have been carried out with Service Engineers of Machine Suppliers, who are visiting the Projects all over India as well as abroad regarding the water conductor system of small Projects. They opined that in the Projects situated in North India, trash racks have been provided at Weir intake, at exit of plunge pool, in between canal length and at Forebay tank to remove trashes. Size of trash rack opening is higher at weir site and lower at forebay tank. Moreover, they explained that the Forebay tank trash rack is extending up to FSL of the tank. They cited some of the Projects executed by them with the above said construction features.

1). Chirchind SHEP (5 MW, H = 190m) in Himachal Pradesh.

2). Balsio SHEP (6 MW, H = 70m) in Himachal Pradesh

3). Rajwakkti SHEP (4 MW, H = 50m) in Utharkhand.

4). Rajaaldunadi SHEP (15MW, H = 140m) in Jammu & Kashmir.

Conventional trash rack arrangement is for drawing discharge from a Reservoir where relatively clean water is available above MDDL.

Trouble free operation of Power Station is very much essential to make it cost effective. Additional cost of trash rack seems to be very small compared to total cost of the Project. So, provide trash rack with a clear spacing of 6 cm in front of canal entry from plunge pool / de-silting chamber, and a trash rack with an opening recommended by the Suppliers of Machines at Forebay tank. Besides the above, trash rack in the Forebay tank may be extended up to FSL of the tank for permitting entry of water even after considerable chocking.

2.8.2. Power Canal/Tunnel

For cost effective implementation, the tendered cost of the Project must be low. If we include works of difficult nature in the schedule, the Contractor may quote higher percentage excess to overcome the difficulty. In Hydro Electric Projects, the canals are taken through hill slopes unlike in irrigation canal, in which case, it is generally aligned through plain areas. At present, in very steep areas, rectangular concrete channels are provided, and in gently sloping areas, trapezoidal canals are provided. But it has been observed from the presently executed Projects that construction of trapezoidal canal is a tedious work involving more labour and time.

Finishing works of excavation of trapezoidal canals to the required size can only be done manually. Laying necessary rubble pitching to the correct size along its sides is a labour-intensive work. Placing of thin concrete lining along the sides is also labourious works. Now days, labour intensive works are costly and time consuming. Excavation and concreting of rectangular canals can be carried out quickly with excavator and placing of concrete with chute. Since Power canals are taken along a hill slope, if any breaching occurs, the life of the inhabitants lying below the hill slope will be at risk. If any breaching occurs, it is not possible to close the intake gates of Weir immediately, since they are unmanned gates. In the estimate, the cost of rectangular concrete channel may be more than that of trapezoidal canal, but during tendering, the contractors are likely to quote high percentage excess due to the difficult nature of work. So, it is advisable to go for rectangular concrete canal than the trapezoidal lined canal for ultimate cost saving as well as for safety of the people living in the downhill side. As far as possible, an open contour canal shall be adopted for water conductor system. Tunnel shall be attempted only if the terrain is rocky and difficult for constructing canal, but suitable for driving a tunnel. If the design discharge is very low to the tune of $10m^3$/sec or less, laying MS pipes for water conductor system (LPP) with surge tank may be considered on cost comparison basis. MS pipes, Forebay tank and Surplus channel combination may also be considered on cost comparison basis, since due to provision of Surges tanks, the MS pipes will be subjected to higher pressure than open flow resulting in increased shell thickness.

A lot of natural streams will be crossing the Power channel. Hence necessary provisions of cross drainage works along with detailed design shall be included in the Report. A number of Panchayath and private roads will be crossing the Power channel. Canal bridges at these locations shall be made by making the canal as box culvert type structure or with a suitable alternate design. If the length of canal is more, and if available road crossings are less, all further developments in the uphill side of canal will be slowed down due to inaccessibility through roads. The canal practically cuts the region into two halves. This is one of the reasons for protest of land owners in giving their land during land acquisition process. Moreover, they are citing these reasons before the Courts to get enhanced compensation. So, at intermittent suitable points where there are chances of future road developments, canal bridges shall be proposed as box culvert type structure or with a suitable alternate design. The number of foot paths required across the canal for the passage of people shall be assessed and included with design drawings. Necessary cross drainage works across the canal to discharge the catch water discharges from uphill side shall also be included.

2.8.3. Fore Bay Tank/Surge Tank

In the case of Power channel, a Fore bay tank to retain water for 2 minutes working of all the machines shall be proposed with necessary Surplus channel arrangement. In the case of tunnel, Surge tank shall be provided. In the case of Fore bay tank, a trash rack with a bar spacing specified by the manufacturer of machines shall be fixed at the intake to Penstock. In case of tunnel, these trash racks are to be provided at tunnel intake in Weir/Reservoir.

Entry of trashes into Forebay tank shall be limited by placing additional trash rack at the beginning of transition from plunge pool as discussed earlier.

Besides the above, trash racks in the Forebay tank shall be equipped with a trash rack cleaning mechanism for cleaning the trash bars during the generation time itself. A screw down road fitted to a frame with combs is proposed. The height of combing frame may be 3 to 4 m below the FRL. From the operational point of view, these are to be divided into segments of around 1.50m width. Number shall be adjusted according to actual site conditions. Design of the same shall be carried out by considering the downward load as well as the uplift pressure exerted on the combing frame.

2.8.4. Penstock

Penstock is a most vital part of the water conductor system, and hence requires extreme care while designing. Any failure of Penstock may cause irreparable damages to the Power Station as well as people dwelling in the downhill side. Since Penstocks are to be erected along steep hill slopes, it is not advisable to bring it in larger lengths. There are limitations for machineries to operate along a steep hill slope for its erection. Maximum handling length is limited to 5m. In some of the Projects for eg, Vilangad SHEP, pressure relief valves are provided to reduce pressure rise up to 30% or 40% to reduce thickness of Penstock pipes. But during power station operation, it is observed that PRV is getting chocked due to accumulation of wooden pieces, leaves, trashes etc resulting in its dysfunction. Hence it is not advisable to go for small schemes with PRV from safety point of view.

2.8.5. Surplus Channel

Surplus channel is also a vital part in the operation of a run of the river scheme with Forebay tank. During tripping of machines, flow through Penstock will be stopped, and water will start accumulating in Forebay tank, because flow from canal will be still continuing due to gradient of the canal. If sufficiently large natural streams are available near Forebay tank, surplus channel may be discharged into it, but its effect on the stream shall be studied properly and additional protection works shall be carried out if necessary. If such natural streams are not available, an artificial channel shall be formed from Forebay tank to the river through hill slope, which will naturally exist with steep slope because of its location. Because of this steep nature, flow will be very turbulent, and hence likely to cause spill to adjoining land if open channels are provided. On the other hand, this water cannot be carried through pipes to the exit at river, because in such cases, there will be very high energy to this water at river exit like at the penstock exit, which may damage the entire region. So, the design of surplus channel shall be carried out in such a way that its energy shall be dissipated during its course into the river. In the case of projects with large head, best option is to provide a concrete box section of sufficiently large section to take the effect of turbulence, which will dissipate the energy. In the case of projects with low head, open channel may be adopted with large size to take the effect of turbulence.

2.9 GEOTECHNICAL AND SUBSOIL INVESTIGATION

Geotechnical and Subsoil investigation are the backbone of all engineering projects, based on which designs are formulated. Utmost care shall therefore be taken to carryout such investigations with a view to obtain reliable and useful field data to utilise in design.

A list of important Geotechnical and subsoil investigations to be carried out for the successful implementation of a small hydro electric project are given below.

2.9.1. Geo-technical investigations

Bore Hole studies shall be carried out and report on this Geotechnical investigation shall be obtained from GIS, at the following locations.

2.9.1.1 At Weir site

1) One B H at deepest bed level of the river at weir axis, and one at (H+15m) d/s of weir axis, where H is the height of over flow section above deepest bed level.

2) One B H each along the weir axis at the meeting point of MWL at site with river banks.

3) In case of absence of sheet rock at river banks to abut the weir body, B H shall be made at both banks about 3H beyond HFL meeting point along the extended weir axis; where H is the maximum value of (MWL-TWLmax) or (FRL- River Bed level d/s)

- Note: - If good quality exposed sheet rocks are available on river bed, BH studies as explained above may be limited to minimum in consultation with GSI.
- If foundation grade rock is not expected at shallow depth, say 3to 4m below river bed a conventional gravity weir founded on rock may prove to be an uneconomical option. In such cases a weir on permeable foundation or trench weir are the alternate options. If similar situations are encountered, and weir on permeable foundation is selected as alternate solution, soil properties at location of weir/core wall are necessary. A list of soil properties to be taken on such situation is given under subsoil investigation.

2.9.1.2 Along the water conductor system

1) B H along tunnel route at every 300m including one at tunnel portal location. B H may also be taken at valley portions.

2) In case of open canals no B H studies are necessary. A Lists of subsoil investigation necessary in such cases are enlisted separately.

3) For major Cross Drainage structures; aqueducts etc B H studies may be carried out at the location.

2.9.1.3 At Surge/Forebay location:

At least one B H at centre of surge/Fore bay

2.9.1.4 Along Penstock route

Bore holes at location of each anchor blocks. If good quality exposed sheet rocks are available at such locations, B H study may be dispensed with.

2.9.1.5 At PH and Tailrace area

1) B H under each machine location.
2) B H at centre of tail race Pool

2.9.2. Subsoil investigations

2.9.2.1 Weir Site

In case of a weir on permeable foundation the following soil properties shall be ascertained at the weir site river bed.

- Specific gravity, porosity, voids ratio, coefficient of permeability and safe bearing capacity at founding level.

2.9.2.2 Along Water Conductor System - Open canal

After the hydraulic design of open canal water conductor system, the foundation level of canal structure shall be tentatively assessed and soil properties shall be ascertained.

- The number of test pits largely depends on how frequently the soil strata changes along canal route. However in general soil properties like cohesion C, angle of internal friction Ø, coefficient of permeability, porosity, specific gravity, and SBC (at founding level) shall be ascertained at 500m intervals.

2.9.2.3 At Surge/Forebay location

- Soil properties like C, Ø, Porosity, specific gravity, coefficient of permeability of the overburden at surge/forebay location.
- SBC shall be ascertained at founding level, if no rock is available for founding such structures.

2.9.2.4 Along Penstock route

- All the soil properties listed above shall be taken along penstock route at 2 locations, representing the entre penstock route.

2.9.2.5 At Power House site.

The procedure is to ascertain rock level at PH site, especially under the machine location and to log the details with the help of GSI. The type and nature of overburden at PH site are not given much importance. If the overburden properties are not understood properly, problems may popup during excavation of site. Hence soil properties as described elsewhere, nature and behavior of soil under water logged condition etc. at the PH site shall also be included in the study.

Chapter - 3. DESIGN

Hydro power, especially from small hydro power projects is considered as one of the best option in Kerala scenario owing to the fact that they are environment friendly, non polluting and need only short time for implementation.

3.1 GRAVITY WEIR ON ROCK

As small/mini/micro HE schemes envisages only small diversion structures, the scope of these guidelines is limited to such structures only. Hence these guidelines are applicable for gravity weirs of maximum 10 m height above deepest bed level. For structures of height more than 10 m, separate IS codes/other relevant guidelines shall be referred to.

The type of diversion structures covered under this are limited to Gravity weirs (founded on rock, and founded on permeable media) and trench weirs. Overflow portion termed as spill way and non-overflow portion are the major parts of a gravity wier. Other components associated with diversion structures are divide walls, core walls, intake structures, scour outlets etc.

3.1.1. Overflow Section

IS 13551-1992 cl.4.1 'General' specifies that on account of the geometry of spill way crest profile, tensile stresses are developed in the crest because of the loads acting over it. Reinforcement need to be provided to take care of these tensile stresses. The minimum thickness of structural concrete to be provided for spillway crest is 1.5 m measured normally.

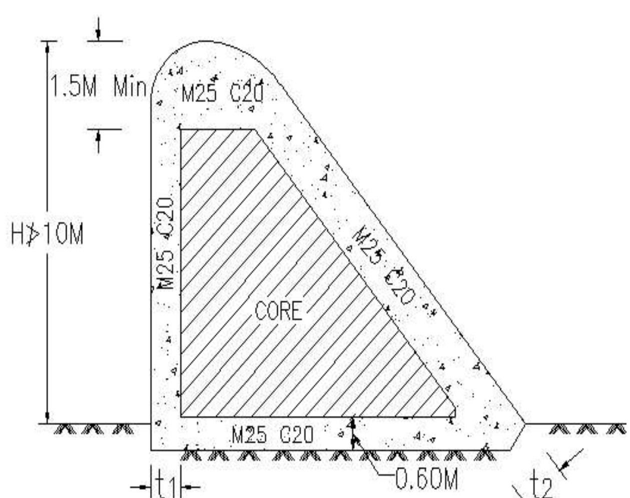


Fig (1)

The present practice is therefore to provide structural concrete of minimum 1.5 m over the entire outer surface of overflow section and to construct the inner core using lean mix concrete with large sized aggregate.

The downstream face slope of overflow section is preferably around 0.7 H to 1 V. If such slopes fails to yield satisfactory conditions for stability and stresses as laid down in IS 6512-1984, mass may preferably be added on upstream face. In such case the upstream profile near crest shall be elliptical with equation $(X_1^2/A^2) + (Y_1^2/B^2) = 1$,till it meets with the u/s face, as per guidelines specified in IS6934-1998.

For overflow section up to 10 m height and maximum head over crest of 3m, section shown in fig(1) is recommended. Upstream concrete lining thickness t_1 shall be H/10 where 'H' is the height above deepest bed level in metre subject to a minimum of 0.60m. Downstream concrete thickness t_2 shall be H/10, where H is the height above deepest bed level in metre subjected to a minimum of 0.90m. The base width shall be arrived at as per stability requirements/stress criteria specified in IS 6512-1984.

The central core shall be constructed in following ways:

a) If rubble is abundantly available, and also availability of skilled labour can be assured, central core could be constructed with random rubble masonry in cement mortar 1:6. In this case the overall unit weight of section shall be conservatively taken as that of RR masonry for stability analysis. To get proper connection with outer lining, RCC bands of 150mm thickness (reinforced with 12mm dia bars @ 300mm c/c both ways) shall be provided in the core at a vertical spacing not exceeding 2m.

b) Lean mix concrete M10C75 is an alternate method of construction of inner core.

c) At times mass concrete with plum may prove to be advantageous, considering savings in construction time. In such cases the concrete used shall be of pumpable grade like M15C20 and a plum content of maximum 50 % can be used.

3.1.2. Non Overflow Section

Non overflow sections of gravity weir can be constructed in similar way. Further cost saving could be attained by reducing the thickness of structural concrete; as no overtopping is expected. The thickness of structural concrete may be limited to a minimum of 0.6 m on all faces.

If a large quantity of tunnel muck is available at site, or substantial quantity of rubble is available during excavation, the possibility of concrete faced rock fill dam may be explored for the Non over flow portion on an experimental basis.

The upstream and downstream face slopes of concrete faced rockfill dam shall be 1.3 H to 1 V and the thickness of facing structural concrete may be provided proportional to the height of weir as described above.

3.1.3. Reinforcement in weir body

Gravity dams are designed to have predominantly compressive stresses throughout their body. However the crest profile fixed on basis of hydraulic considerations develops tension on the upstream face, and the crest has to be reinforced to prevent undesirable cracking.

For overflow section of maximum height less that 10 m, and when the head over crest is less than 3 m a reinforcement pattern shown in fig 2 is generally sufficient.

For non overflow sections, no reinforcements are needed. However piers on sides of opening/gates shall be of solid concrete M25 C20, with adequate reinforcement steel.

At locations on weir body where joints are to be provided, the concrete lining on outer faces shall be extended over the cross section for a minimum thickness of 600mm to accommodate water stoppers.

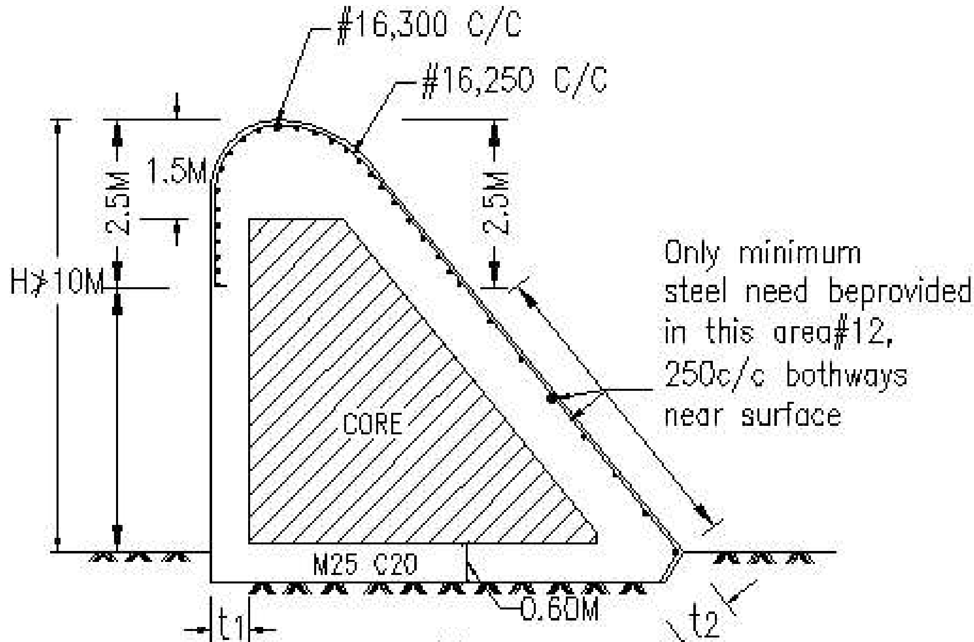


Fig (2)

3.1.4. Energy Dissipating Arrangements Below Spillway

No specific guidelines are presently available for providing energy dissipating arrangement for diversion structures of relatively small height as envisaged under this guidelines. Hence references are usually made to IS 11527-1985, IS 7365-1985, IS 4997-1968 ,USBR, CBIP etc. and energy dissipating arrangements are provided, which yield to structures as a miniature of major dams; leading to un-economy for small/mini hydroelectric schemes. Experience have shown that the diversion structures with simple energy dissipating arrangements constructed for the pilot projects under Chinese guidance viz Chembukadavu and Urumi are functioning satisfactorily.

The following arrangements below spillway are generally sufficient for small/mini HE schemes, which involves diversion structure of maximum height equal to or less that 10 m.

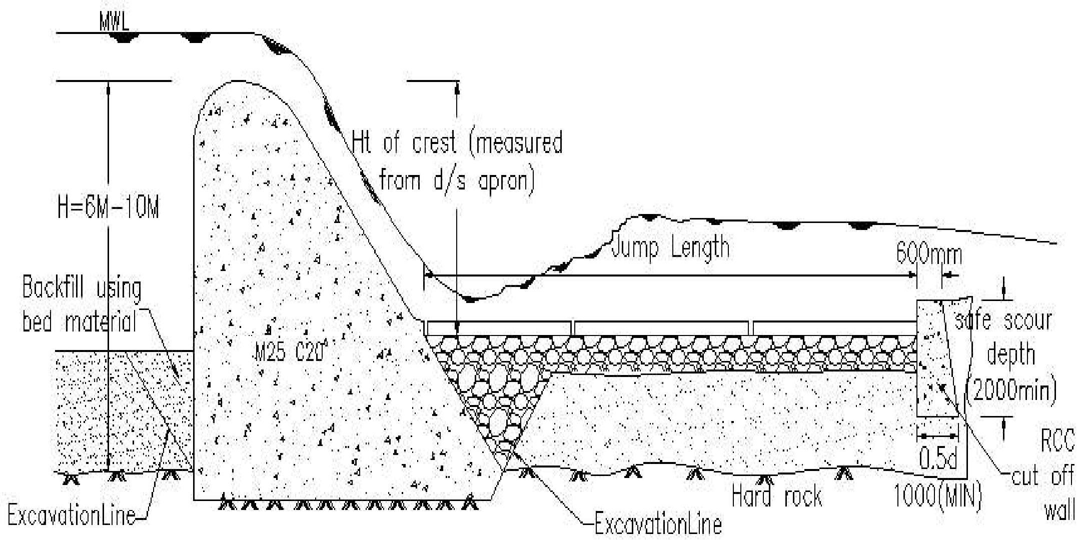
a) For gravity overflow section founded on bed rock; where the overburden is negligible (<1 m) a simple upturned bucket is enough. The bucket portion shall be reinforced as per guidelines in IS 7365-1985, IS 4997-1968.

However, since no standards are evolved yet, such simplifications are experimental only. Hence proper and regular monitoring of downstream portion shall be conducted and timely remedial measures shall be taken, in case damages are noticed.

b) For gravity weirs founded on rock, with relatively large overburden of the order of 3 – 4 m, which is a common case, the present practice is to provide energy dissipating arrangement, usually 600 mm thick RCC aprons (horizontal apron at bed level, sloping apron, or depressed apron as the case may be) for a length of 6 to 7 times difference between post jump and pre-jump heights.

A substitute arrangement to the above considering economy is shown in fig 3.

The type of downstream apron (horizontal, sloping, or depressed) may be finalised after calculating jump rating curve and tail water rating curve, in such a way that maximum energy dissipation is assured.



RECOMMENDED METHOD OF ENERGY DISSIPATING ARRANGEMENTS

Fig (3)

For different values of height of crest (measured from apron level), energy dissipation arrangements may be provided as below.

a) Ht = 10 to 6 m – 600 mm thick rubble masonry (RR in CM 1:6) overlaid with M25 C20, RCC of thickness 250 mm laid in open joint panels of max size

7.5mx7.5m. Steel may be kept minimum + drain holes using ϕ75mm PVC pipe @ 2m c/c.

b) For height Ht < 6 m – stone packing using machineries, using large stones available in river bed / obtained during blasting etc, weighing minimum 250 kg will be sufficient. Alternatively gabion structure 0.75m thick could be used.

- Large boulders (size more than 750 mm) present in river bed shall not be disturbed (if apron level matches with required bed level d/s as per hydraulic design) while constructing the downstream stone apron / gabions.

At the extreme end of d/s protective works, a RCC cut off wall may also be provided if site condition warrants so. The cut of wall shall be provided upto calculated safe scour depth. If the calculated safe scour depth falls beyond 2.0m below river bed, the foundation depth may be limited to 2.0m and boulder packing may be provided beyond the cut of wall for some distance on the river bed (3m). However a minimum of 2.0m deep foundation shall be provided below the river bed.

3.1.5. Guide Walls & Training Walls

The upstream divide wall (between intake and river proper) acts as a barrier preventing entry of torrential flow during high flood times directly to intake, preventing floating debris entering intake mouth. Hence upstream divide wall shall invariably be provided in small HE schemes. The length and orientation may be fixed to suite site conditions.

The downstream divide wall meant to separate scour outlet from spillway water need not be provided. The scour outlet can be kept open to the downstream apron directly.

If rock is available on both the banks, weir body could be abutted to the banks easily, and the river training works could be dispensed with or limited to minimum site requirements.

As far as possible gravity retaining walls using rubble masonry shall be adopted for river training walls. Horizontal RCC belts may be provided at regular intervals in case of large sections to perform the function of bond stones more effectively. Alternatively Gabion walls also could be used.

For training walls which has to perform partly as core walls also, the wall body should be impervious, starting from solid rock. In such cases RCC walls may be adopted.

In case the height of the retaining structure exceeds 6m or so, RCC cantilever / counter fort walls may be adopted, if impervious wall is required. If water tightness is not required Gabion walls can be constructed up to a height of 10m.

3.1.5.1 Depth of foundation of River training walls.

The general practice is to found the river training walls at safe scour depth, if no rock is available at shallow depth. When the safe scour depth calculated falls beyond 2.5m below bed level, the foundation depth could be limited to 2.5m below bed level and suitable scour protective measures like, boulder dumping/ stone packing for a distance of 2 to 3m on the river bed near the training wall is sufficient. However a minimum depth of 2m below the bed is recommended for foundation of training walls on soil bed.

3.2 WEIR ON PERMEABLE FOUNDATION

3.2.1. Gravity Weir

When the rock is not available on river bed at shallow depth to found the gravity weir, an alternate choice would be a weir with well-designed impervious aprons on upstream and downstream; founded on the river bed itself. This type of weir on permeable foundation is generally suitable when bed material is absent from substantial quantities of boulders. Large quantities of boulder on bed may adversely affect the water holding capacity leading to undesirably large water loss beneath the dam body.

In the case of small schemes that do not envisage any storage, minor water loss is not a serious problem. Also, the boulder layer can be suitably consolidated by providing concrete / clayey earth filling in the interstices and grouted suitably. Upstream cut off walls of sufficient depth can control the seepage to desirable limits. However apron length shall be designed properly to avoid piping.

The weir body design in the case of permeable foundation could be carried out according to guidelines in IS 6512 – 1984 and various cost saving measures described elsewhere in these guidelines could be adopted here also.

The upstream and downstream aprons are to be made impervious and hence shall be of reinforced cement concrete (Preferably M25C20 grade or above).

Hydraulic design of aprons may be carried out using Lane's creep theory or Bligh's theory.At the end of downstream apron, river bed protection may be carried out for suitable length using stone pitching / gabion walls according to site conditions.

3.2.2. TRENCH WEIR

A trench weir may become the most feasible option under the following conditions.

1) Requirement of FRL limitation at site
2) Absence of good quality rock at river bed / below the river bed for founding conventional gravity type weir.
3) Stream bed is bouldary making it unsuitable for constructing weir on permeable foundations with aprons.
4) Bed slope at weir location is steep (5 % or steeper), which is not suitable for constructing gravity weir / weir with aprons.
5) When the river is too wide at the location and also where discharge is large when compared to requirement for power generation.

The number of trenches across the river may be usually one with maximum width of trench as 2.5 m. When the hydraulic design requirement warrants width more than 2.5 m, multiple trenches are to be considered.

The discharge to be taken for hydraulic design of trench, intake well and de-silting chamber shall be inclusive of flushing discharge for removing shingles and silt, which can be taken as 25% of the design discharge of the scheme.

If sheet rock is available at the river bed in the weir site, the trench can be made on rock and a RCC lining may be provided such that the sufficient thickness shall be given to the lining at top of the trench to accommodate embedment for supporting trash bars.

River bed shall be cleared from large boulders / vegetation projecting into the waterway, for a length of 60 m or 3 times length of trench whichever is minimum, so as to ensure smooth flow near the weir location.

3.3 WATER CONDUCTOR SYSTEM

The most common water conductor systems being adopted in KSEB are tunnels (both pressure flow and open channel flow), and canals (rectangular, trapezoidal and box culverts).

Use of steel pipes (MS pipes), HDPE pipes, concrete pipes are also being tried now a days as water conductor system in hydro power projects by other implementing agencies and are gaining popularity.

Canals are extensively used by KSEB to convey water from weir location to forebay location especially in small HEPs and hence emphasis is given to this type of water conductor system while discussing cost effective measures.

Usage of trapezoidal open channels shall be discouraged as far as possible due to the following reasons:

- Usually trapezoidal canals are designed with a non structural lining using RCC on bottom and sides. Such linings are usually concrete slabs, pre-cast or cast in situ and require elaborate filter arrangements beneath it to protect them from seepage pressure.
- Experiences have shown that many difficulties are faced to provide filter media under the lining on sides, especially when the size of canal is large. This not only leads to imperfections in filter media but also affects the quality of lining concrete constructed over it.
- In the absence of usage of modern construction machineries for concreting, the lining concrete could not be constructed satisfactorily. Use of slip forms or highly sophisticated machineries is not advisable in hilly area owing to the high cost involvement and practical difficulties for transportation.

- Trapezoidal canals are more prone to weathering and subsequent damages. Any small subsidence of soil beneath it may cause failure of lining; requiring immediate maintenance works and may even cause catastrophes.

All these leads to high maintenance cost, and sometimes such maintenance works may warrant stoppage of generation leading to huge financial loss.

Construction cost wise water conductor system is a major component of SHE Scheme due to its length. Hence this component shall be selected judiciously and designed with maximum efficiency at minimum cost (considering maintenance aspects also).

The range of velocity of flow through power canal may be kept between 2.2 to 2.7m/s. A lower velocity may lead to higher cross sectional dimensions for canal, whereas a higher velocity may require a steeper longitudinal slope for canal resulting in large head loss which may become critical for low head schemes.

Generally for SHE Schemes with conventional type gravity weirs, with a regularly operated and well maintained scour outlet system, the provision of a de-silting chamber could be avoided. However for trench type weirs de-silting chamber is to be provided.

The water conductor system shall invariably contain a minimum of two surplus arrangements, one at beginning of canal itself, preferably immediately after the intake gate opening and the other at end very near to forebay or in the forebay itself.

The first one is to control the entry of unwanted discharge over the design discharge into the power canal during high flood times, since in most of our SHPs intake gates are unmanned and remain in fully opened position throughout.

The hydraulic components required for surplus arrangements such as surplus weir, collecting pool, downstream surplus channel etc. shall be designed for a discharge 'Qs' which is equal to full discharge through open intake gate during HFL – design discharge of the power channel.

The surplus arrangement at end of the power canal near forebay / in the forebay itself is meant for safely bypassing the discharge in power canal during a simultaneous sudden load rejection by all the turbines running at specified maximum overload.

The quantity of discharge considered in the above case may be slightly greater than the design discharge in power canal and may be roughly taken as 1.10 times the design discharge.

In addition to the two minimum surplus arrangements specified above, additional provisions may be made wherever possible along the canal route.

3.4 STRUCTURAL DESIGN OF RCC RECTANGULAR CANALS

a) Canal structure as a whole shall be safe against overturning

b) Canal structure as a whole shall be safe against sliding

c) Empty canal trough shall be safe against floatation, ie uplift.

d) Stresses on foundation shall be within permissible limits under severe loading condition.

e) Hill cutting slope on up hill shall be safe against slope failures.

3.4.1. Design concepts of canal trough

a) Side walls are to be analyzed and designed as RCC cantilever walls.

b) Bottom slab is to be designed as a slab supported on two side walls.

Ground Water level at location of canal is to be taken judiciously, as this is having much influence on stability analysis and structural design of canal structure.

Filter media is to be provided beneath the canal to reduce the effect due to uplift water pressure. The present practice is to provide elaborate filter arrangements at canal bottom and on u/s faces without giving due considerations to the permeability of soil through which water conductor system is constructed. Provision of filter media under a canal depends upon the nature and type of sub grade soil as mentioned below,

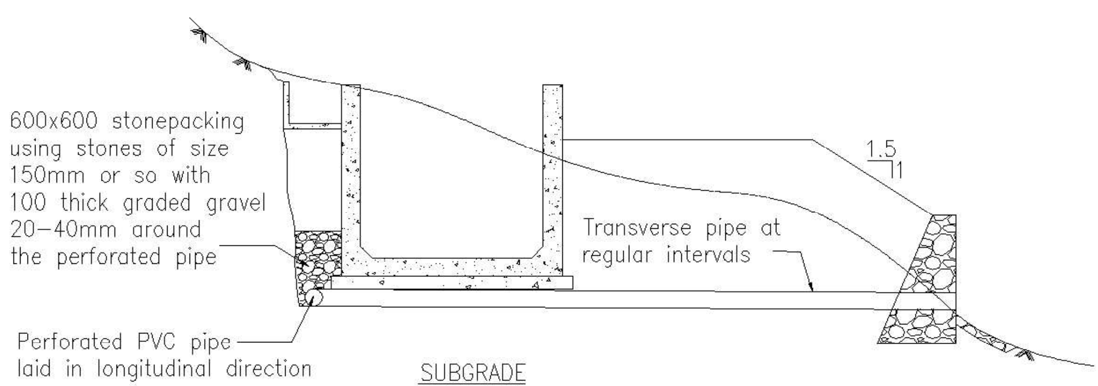
These provisions are applicable only when Ground Water level is below bottom slab of canal

1) For a free draining sub grade, ie soil comprising of gravel with sand having permeability 10^{-4} cm/s, no filter media is required. However to account for any unexpected water path/underground water flow etc, a filter of size 600x600 with perforated PVC pipes on uphill side as shown in fig(4) may be provided.

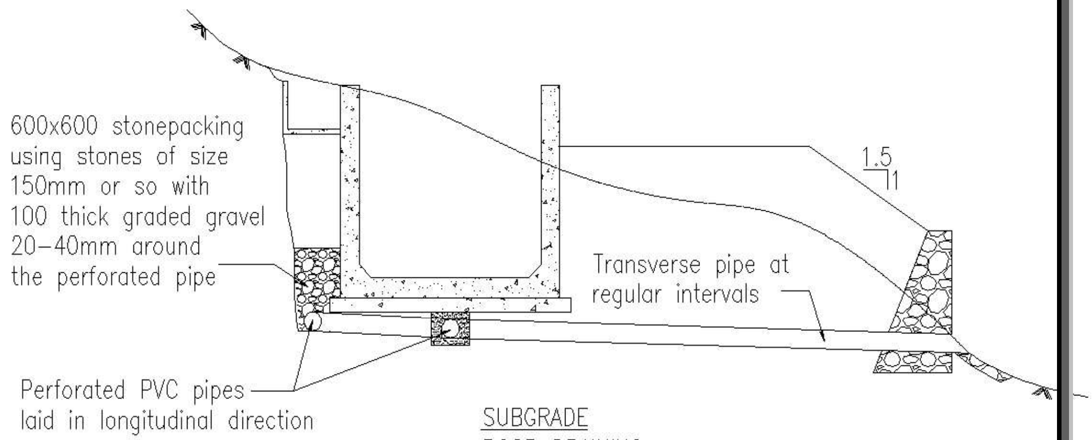
2) For poorly draining sub grade, ie soil comprising of very fine sand, silt and clay, having permeability between 10^{-4} and 10^{-6} cm/s, the canal shall be provided with a longitudinal filter on uphill side together with longitudinal filter only under the central part of canal bottom, with perforated PVC pipes inside connected to transverse drain as shown in fig (5) is sufficient.

3) For impervious type sub grade ie soil comprising of homogeneous clays with permeability less that 10^{-6} cm/s a well designed filter arrangement both under the canal as well as behind the uphill side wall are to be provided together with pipe networks for collecting and disposing off the seepage water is to be provided.

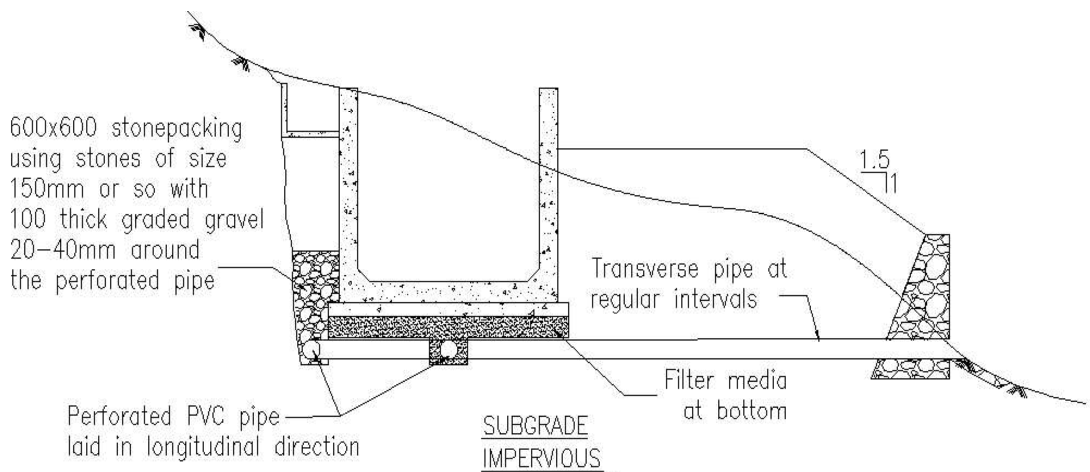
Notwithstanding any provision above said, the ground water table may be higher than the bottom slab level in some cases (such as power duct near the trench weir etc). In such case the effect of max possible water table is to be fully accounted for during stability analysis and structural design of the canal trough. Necessary flotation check is also to be carried out.



SUBGRADE
FREE DRAINING
Permeability $K>10^{-4}$ cm/s
Fig (4)



SUBGRADE
POOR DRAINING
Permeability K between $10^{-4} - 10^{-6}$ cm/s
Fig (5)



SUBGRADE
IMPERVIOUS
Permeability $K > 10^{-6}$ cm/s
Fig (6)

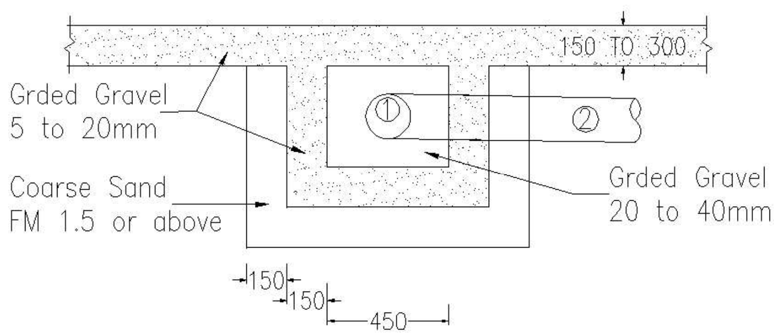


Fig (7)

Diameter & spacing of transverse PVC drain pipe in the figure is usually 150 mm at 50 m C/C along the length of canal. Sometimes, space constraints may warrant a larger spacing to be adopted. In such cases, the arrangement may require modification. The following table may be used for this purpose:

C/C spacing of transverse drains(m)	Diameter and no. of transverse pipes	Slope of transverse pipe	No. and dia of longitudinal drain pipes (Perforated PVC pipes laid at canal bottom)
50	1 no. 150 dia	1 in 200	1 no. 150 dia
100	1 no. 150 dia	1 in 200	2 no. 150 dia
150	1 no. 200 dia	1 in 200	2 no. 200 dia
200	1 no. 200 dia	1 in 200	2 no. 200 dia
250	2 no. 200 dia	1 in 200	3 no. 200 dia

Longitudinal pipe shall be of 150 mm dia PVC perforated pipe @ 100 holes per m length with a dia of 12 mm and in staggered pattern. The perforation shall preferably be factory made, as hole drilled at site is not so efficient due to imperfections.

Above table is applicable for a canal size of maximum 4 m width X 3 m depth. For larger dimensions the requirement may vary.

After providing filter arrangement and pipe network to dispose of effectively, no seepage water is expected to accumulate near the canal structure.

However in the analysis and design of canal the water level shall be conservatively taken at H/3 m above bottom on uphill side and zero at downhill side shall be taken for design, where H is the overall height of the side wall measured from bottom face of base slab.

Not withstanding anything above described, geological surprises like caves, under water passages, springs etc are not uncommon. It is difficult to suggest a generalized solution to such situations arising during execution stage. The solution shall be judiciously chosen as per site conditions and practical considerations.

3.4.1.1 Design Concept: Hydraulic part.

The cross sectional dimensions of Power canal, bed slope etc are to be designed on the basis of economic studies by optimizing cost of construction and cost of energy loss due to head loss in friction.

Sufficient free board shall be provided above the FSL to take care of surge effects in canal on account of load rejection/ demand in the Power station. Free board shall be determined from the criteria given below.

Free Board.

1) Free board shall be measured from the full supply level to the top of lining. Minimum free board for various canal discharges are given below.

Canal Discharges	Free Board	Remarks
More than $10m^3/s$	0.75m	25% extra free board shall be provided to avoid reduction in Power generation in subsequent years.
Between 3 to $10m^3/s$	0.60m	
Between 1 to $3m^3/s$	0.50m	
Less than $1m^3/s$	0.30m	

2) The maximum surge height in canal due to load rejection may be calculated from the empirical formula.

h_{max} for gradual load closure $= k + \sqrt{(k^2 + 2kh)}$

h_{max} for abrupt load closure $= k/2 + v\sqrt{(h/g)}$

Where $k = V^2/2g$, $h = \frac{\text{Area of Cross Section}}{\text{Top width}}$,

V = Mean velocity of flow.

A free board of 15% in excess of maximum surge height obtained as above shall be provided for canals.

3) The requirement of free board actually depends on the provisions made for surplus arrangements from the canal and the resulting back water curve during sudden full load rejection. Due consideration shall also be given while fixing free board to ensure that, a free board of 30 to 50cm should be

available from the back water curve and a gap of at least 15cm shall also be available between the bottom of cross drainage works crossing the canal and backwater profile during maximum load rejection.

3.4.1.2 Design Criteria : Structural part

Load conditions

- Canal empty – outside earth dry / partly submerged and saturated above.
- Canal full – outside earth dry/ partly submerged, saturated above and always present.

Where in the depth of submergence shall be taken as H/3 from bottom. Under special circumstances described elsewhere the actual maximum ground water table shall be taken.

Water pressure should include free board to accommodate worst condition, and to obtain a conservative design.

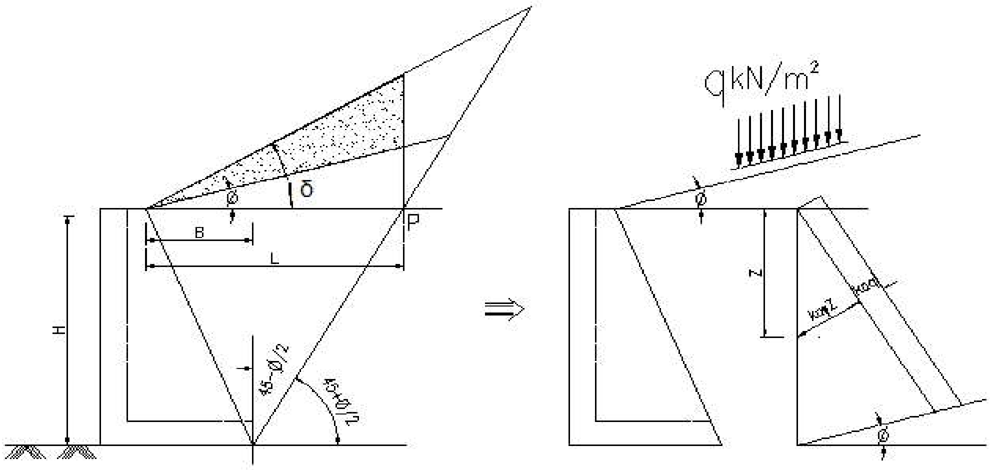
Earth pressure should be active pressure with surcharge, with co-efficient of active earth pressure given by the following equation:

Coefficient of active earth pressure

$$Ka = \cos\delta \times \frac{\cos\delta - \sqrt{(\cos 2\delta - \cos 2\varnothing)}}{\cos\delta + \sqrt{(\cos 2\delta - \cos 2\varnothing)}}$$

Where Ø - angle of repose of soil and δ - surcharge angle in degrees

In real situation, the surcharge angle δ may have values greater than repose angle , due to cohesive nature of soil / interlocking properties of lateritic soil etc. In such cases the above general equation for co-efficient of earth pressure Ka becomes obsolete.



$L = B + H\tan(45 - \phi/2)$

Approximate load intensity $q = \frac{\gamma L}{2}\left[\frac{\tan i - \tan\phi}{\cos\phi}\right]$

and pressure intensity can be evaluated by taking $K_a = \cos\phi$, where ϕ is the angle of internal friction

Fig (8)

A possible method to account for the weight of soil beyond angle of repose line is to consider an equivalent surcharge given by

$$q = \frac{\gamma L}{2}\left[\frac{\tan i - \tan Ø}{\cos Ø}\right]$$

Where 'γ' is specific weight of soil and 'L' is the horizontal distance beyond the wall as shown in fig(8) above.

The status of water retaining structure laid down in IS 3370 – 2009 Part 2 shall not be assigned to the power canal since it will lead to uneconomical sizes. The stress limitation in extreme fiber, based on crack stress criterion need not be adhered to. However use of dense concrete preferably M30 grade, adequate concrete cover, good detailing practices, provision for minimum steel as per IS 3370 – 2009 Part 2, good quality assurance measures in line with IS 456 and good construction practices particularly in relation to construction joint should be assured.

While following, working stress method of design for canal structure, the value of allowable tensile stress in steel reinforcement (flexural tension) may be taken as 150 N/mm^2.

Note: While evaluating forces/moments in downhill walls of RCC trench, when canal is running full up to top of wall the horizontal pressure from outside soil shall be taken as the active pressure of soil up to a vertical height between bottom slab and a point where a line drawn at 45+Ø/2 from the bottom most corner of the trough intersect with the finished downhill soil profile.

In case of open troughs a minimum horizontal distance of H/2 or 1.5m whichever is maximum shall be provided between the natural hill profile and lower downhill corner of the trough, where 'H' is the overall height of trough.

In order to reduce the reinforcement quantity and to keep the section under reinforced the thickness of RCC side wall at junction of bottom slab shall be between h/9 to h/10 excluding haunches, where 'h' is the total clear height of wall above bottom slab inclusive of free board.

In case of trough with very large bottom width, or for structures such as desilting chamber having large bottom width rectangular trough may sometimes prove to be uneconomical. In these circumstances the side walls may be designed as independent retaining walls (gravity walls, T walls, counterfort retaining walls etc) and base slabs as an independent slab, structurally not monolithic with side walls after giving due consideration for uplift acting on it.

3.4.1.3 Joints in Canal

The present practice is to provide expansion joints at a distance of 30 to 40 c/c along the length of canal. For RCC canals surrounded by soil on u/s and d/s portion, the spacing of expansion joint may be increased to 150m c/c as the trough is not free to expand/contract due to presence of soil outside. However joint shall invariably be provided at meeting points with aqueducts.

3.4.1.4 Use of Pipe Conduits for Water Conductor System

For micro scale hydroelectric schemes involving very low discharges of $2m^3/s$ or less, HDPE pipes may be used on a trial basis. The main advantages of using pipe conduit are that it requires only less land requirements compared to open canals with inspection roads. But jointing of HDPE pipes requires special machineries and skilled labourers making it costly, and hence may not prove to be economical for large discharges involving number of pipe conduits laid in parallel.

MS pipe conduits are extensively used in North India for WC system of HE schemes. It has the advantage of comparatively less land requirement, less earth cutting etc. By selecting suitable alignment, extensive cross drainage works can be minimized. Moreover the surplus arrangement can also be solved by adopting pipe system with surge tank. This method also has the advantage that leakage and theft of water are almost eliminated. This type of water conductor system envisages pressure flow inside it and shall be designed accordingly. Hence MS pipes with pressure flow could be tried on a trial basis in KSEBL also.

3.4.2. Guide lines for the Design of Tunnels

Planning and execution of a tunneling project requires the interdependent participation of the following disciplines, at a minimum.

- Geology.
- Geotechnical Engineering.
- Excavation technology and mechanical equipment.
- Structural design of tunnel support and lining.
- Contract principles and legal aspects.

The decision on the main design features should be the outcome of the co-operative integration of all the disciplines so that the project in all its details has been developed in unity and not as the consecutive addition of the separate work of each of the experts.

Basic documents required for the design of a tunnel:-

1) Geological report after extensive geological investigations such as geophysical surveys, test borings, test pits, shafts, drifts, bore logs etc. and mapping under the guidance of an engineering geologist before deciding the layout and alignment of tunnels (line, orientation and depth of tunnel). A geological profile along the selected tunnel alignment indicating the rock types and their condition (fissured, weathered etc), stratification, fold and fault zone, hydrological condition etc. should be prepared. Soil/rock strengths and primary stresses and standup time may be assessed by conducting ground probing and rock/soil mechanics.

2) Geotechnical report on site investigations, results of site and laboratory tests.

3.4.2.1 Subsurface Exploration (IS 4880 (part I) clause 2.3)

Core bore holes shall be driven along the alignment of tunnel in order to ascertain the subsurface details. The number of bore holes to be taken depends upon the length of tunnel, rock cover over tunnel grade, number of ADITs available and geological features. However a minimum number of 4 to 5 should be taken. These boreholes may be taken down 10 m below the invert or one driven diameter of tunnel whichever is less, below the tunnel sill, even in hard rock. Core samples of each bore shall be preserved and logged by an engineering geologist.

3.4.2.2 Laboratory test (IS4880 -part I – cl.3)

The core samples collected from the boreholes shall be classified and specimen from the tunnel grade, at least, tested to determine the following physical properties.

a) Specific gravity
b) Modulus of elasticity
c) Poisson's ratio
d) Tensile strength
e) Compressive strength
f) Triaxial shear strength
g) Hardness of rock
h) Swelling index in case of soft argillaceous rocks
i) Porosity, grain size for sand, stones and similar rocks.

3.4.2.3 In-situ rock tests

When a cavity is formed in rock mass, the in-situ stresses are altered for some distance around the opening. Hence the following are required.

1) In-situ rock characteristics like shear strength, compressive strength and modulus of elasticity by Flat jack test to obtain the values before and after excavation.
2) Deformation of rock around opening.

3) Topographical survey details such as contour, LS, cross sections showing surface drainage/streams, buildings/permanent structures.

4) Plans for driving procedures for different ground conditions has to be detailed on excavation methodology.

5) Design documents for different types of excavation methods and tunnel supports, water proofing, drainage arrangements eg. Excavation advance, face support types, number of anchors, shotcrete strength, closure length, etc.

6) Program for in-situ monitoring of the tunnel by field measurement. During and after excavation, reports on the field measurements and interpretation of the results gives the response of the ground and the structural safety of the tunnel.

7) Documentation of the problems encountered during the excavation and measures applied eg. Strengthening of the ground or changing the anticipated type of support based on the actual monitored results etc.

3.5 GENERAL PLANNING AND LAYOUT OF TUNNEL

Hydraulic tunnels are classified into

a) Pressure tunnels
b) Free flowing tunnels
c) Free flowing cum pressure tunnels.

Pressure tunnels are further classified on the basis of head as

1) Low pressure tunnels with head less than 10 m
2) Medium pressure tunnels with head (10-100m)
3) High pressure tunnels with head more than 100 m

3.5.1. Alignment Selection

The layout and location of tunnel should be in sound rock with favorable stratification as far possible, should ensure adequate top and lateral cover and should be the shortest and straight route, and fault zones avoided as far as possible. Portal sites at points where there is little overburden or where ground is steeply sloping and with favorable geology. If open cut is unavoidable, it should be within 20-25m.

3.5.1.1 Gradient

- Free flowing tunnels, gradient must be enough to give the required discharge without causing excessive velocities calculated using the manning's equation.
- Pressure tunnel – In no case the friction head loss and entrance loss result in the unsealing of tunnel at exit end. Tunnel must remain under positive pressure in its entire length at all discharges. Gradient has to be as low as possible so as to decrease the hydrostatic load and construction cost. Normally a positive gradient 1 in 300 to 1 in 500 in the direction of power house is adopted.

3.5.1.2 Spacing between adjacent tunnels

Stress distribution around an opening is not appreciably influenced if the point of consideration is away from the opening boundary by at least 2 times the driven maximum dimension. However it will be better to keep a wall to wall clearance of 5 – 7 driven diameter as a safe measure.

3.5.1.3 Curves or bends in tunnel

Curves or bends in tunnel alignment are to be avoided as far as possible. However, where curves are unavoidable, in order to avoid undesirable flow conditions and excessive losses, the radius of bend should be preferably not less than 5 times driven diameter. In certain cases for enabling the easy movement of mechanical excavators, pipe roofing/fore poling machines and long gantries, the radius of the bend has to be increased to 10 times driven diameter.

3.5.2. Geometric Design (IS 4880 – part II)

- For hydraulic consideration, circular shape is ideal especially when the internal pressure is high. If rock tends to creep or squeeze, a circular cross section will be self stabilizing. But difficult to excavate as narrow base width causes inconvenience in driving and concreting.
- D-shaped – suitable for tunnels in good quality, intact sedimentary rocks, massive igneous rock and hard compacted metamorphic rocks. Most suitable where external pressure due to rock and water are not excessive. This section

has a greater and flatter width at invert and provides greater construction ease. For free flowing tunnels in good rock, a partly lined D- shaped section may be adopted.

- Horse-shoe and modified horse-shoe common section for free flow and low pressure tunnels in moderately good rock. This section provides the advantages of a flatter and wider base, without affecting hydraulic efficiency and easy to change to circular where rock quality is poor. When circular finished cross section is needed on hydraulic or structural considerations due to poor geology and a wider and flatter base required for constructional ease, an excavated modified horse shoe is the best answer as it can be lined circular at minimum extra cost.
- Egg-shaped and Egglipse sections. Where rock is stratified, soft and very closely laminated (Sand stones, slates, micaceouschists) where external pressures and tensile forces are very high. Due to the practical difficulty while driving, not generally adopted.

3.5.3. Hydraulic design of tunnel

3.5.3.1 Area of cross section

Cross section area enough to carry the maximum flow on the available head and large enough not to put a free flow tunnel under pressure and not to cause excessive head loss.

In designing the profile of pressure tunnel, pressure on tunnel should be kept as low as possible and the length of high pressure tunnel as short as possible, subject to the roof of tunnel for the entire length remaining below the hydraulic gradient by at least 3m so as to avoid creation of vacuum, turbulence, cavitation and probable collapse of lining.

If tunnel profile includes sections having counter slope, the intermediate 'saddle' should be provided with dewatering valves and galleries while 'summit' may require the installation of an air outlet valve and shaft.

3.5.3.2 Permissible velocity

Velocity allowable in a tunnel depends upon the purpose, its surface and the sediment load on flowing water. Recommended average permissible velocity in concrete lined tunnel is 4.5 m/s, this may be reduced to 2.5 m/s if water carries significant abrasive sediment load. IS 4880 allows maximum of 6 m/s for concrete lined tunnels. Increase in velocity will sharply increase the head loss and in turn reduces the net head available and power output. Concrete tunnels which have been designed for velocities of 5.5 - 6 m/s are protected by carefully placed concrete lining, highly resistant to wear. For very large tunnels with very high head, adoption of values close to upper limit of 6 m/s can be done. H.Press suggest the following limits for hydro power tunnels.

SI No	Surface	Velocity m/s	Remarks
1	Very rough rock surface	1.0 – 2.0	Lower value to be adopted in case of significant quantities of sediment load.
2	Trimmed rock surface	1.5 – 3.0	
3	Concrete surface	2.0 – 4.0	
4	Steel lining	2.5 – 7.0	

During surge oscillations, velocities in tunnel will be more and also to be borne in mind is that very high velocities close to the upper limit in pressure tunnels can cause vibrations in pipe lines and its controls and even impair turbine regulation. The above limits do not apply to diversion and spillway tunnels, in which velocity can be higher.

3.5.3.3 Diameter of Tunnel

Based on the permissible velocity, diameter of tunnel can be obtained

$$Q = \pi D^2 V/4$$

Economic diameter shall be worked out at which increase in cost balances power generation. Moreover practical considerations also to be accounted while fixing the driven diameter of tunnel. Minimum drive diameter shall be 3.30m in hard intact rock and 3.50m in jointed rock to enable supported & / mechanized tunnelling and to ensure better pull.

3.5.3.4 Air Locking in Hydraulic Tunnel

To prevent air entry in tunnel following precautions to be taken while designing and construction,

1) Intakes should be properly designed so that vortices that threaten to supply air to the tunnel should be avoided. In shallow tunnels, vortices should be suppressed by baffles, hoods or other devices. (IS 9761)
2) Throughout the length of tunnel / water conductor system, velocity should remain more or less constant or increase towards outlet end.
3) Partial gate openings that result in hydraulic jumps must be avoided
4) Natural traps or pockets along the crown should be avoided. Tunnel when empty should be filled slowly.
5) Thorough surge analysis should be carried to see that at no point on tunnel negative pressures are developed.
6) Where some air entry is inevitable as in secondary feeder shafts supplying a main tunnel, a de-aeration chamber with enlarged area should be provided.

3.5.3.5 Transitions

Transitions are required at (1) Entrance (2) Contractions and Expansions and (3) Exits to minimize head loss and to avoid cavitation, transitions should be designed in accordance with standard criteria (IS 4880 part III)

Entrance Transition: - To obtain best hydraulic efficiency shape of inlet entrance should simulate that of a jet discharging into air and should guide and support the jet with minimum interference until it is contracted to the conduit dimensions. If entrance curve is too sharp or too short, sub atmospheric pressure may develop leading to cavitation. Hence a bell mouth entrance that conforms to a free jet profile may be adopted.

For circular opening,

$$\frac{X^2}{(0.5D)^2} + \frac{y^2}{(0.15D)^2} = 1$$

Square or rectangular opening

$$\frac{X^2}{D^2} + \frac{y^2}{(0.331D)^2} = 1$$

Rectangular opening with bottom suppressed

$$\frac{X^2}{D^2} + \frac{y^2}{(0.67D)^2} = 1$$

3.5.3.6 **Contraction and Expansions:**

When there is a convergence in a vertical plane or a divergence in horizontal plane or both, length of transition will be determined by angle of divergence. It is better to keep the invert profile running through. Contraction and expansion transitions to and from gate control sections in a pressure conduit should be gradual.

For contractions, maximum convergent angle α, such that tan α = 1/u, Where α is angle of the conduit wall with respect to centerline or half cone apex angle

Parameter $u = V/\sqrt{gD}$ Where V and D are the average of velocities and diameters at the beginning and end of transition.
For Expansion, maximum value of tan α = 1/2u → Expansion should be more gradual than contraction. it is preferable to limit the wall angle 'α' to 10o, as the head loss increase rapidly after the angle α exceeds 10^o

3.5.3.7 **Exit:**

When a circular tunnel flowing partly full empties into a flat bottom channel, transition should be made by gradually decreasing the circular quadrant from full radius at the upstream end of transition to zero. Length of transition is related to exit velocity. For velocities up to 6 m/s , L =2VD/3.

3.5.4. Pressure flow losses

3.5.4.1 **Friction loss.**

For tunnels flowing full,

$h_L = V^2n^2L / R^{4/3}$ (Manning's formula) , For concrete lined tunnels, n = 0.012 – 0.018. The value of 'n' commonly adopted for well finished concrete lined tunnels is 0.012 – 0.013.

Concrete lined	Values of 'n'
very smooth	0.011-0.013
Trowel/float finish	0.015-0.018
Formed, No finish	0.018-0.02
Gunited finish	0.018-0.022

Unlined tunnel	Values of 'n'
Surface trimmed and invert concreted	0.020-0.030
Surface trimmed	0.025-0.035
Very rough rock surface	0.04-0.06

Darcy – weis bach formula

For circular section $h_L = fLV^2/(2gD)$,

For non circular section $h_L = fLV^2/(8gR)$, 'f' is the friction factor.

Due to the fluctuation in load demand, turbulent flow can be assumed in tunnel for which Re 3000 – 10000, and $1/f^{1/2} = 2 \log 10\ (1/2E) + 1.74$

where E = Ks/D and for Re>10000, refer IS 2951 for formula for f.

For flow through horse – shoe sections, better to workout friction loss from Manning's formula

Partially lined reaches and the rest unlined

$$N = \left[\frac{nr \left\{ Pr + Pc\ (nc/nr) \right\}^{3/2}}{(Pr+Pc)} \right]^{2/3}$$

nr - n in rock

nc - n in concrete

Pr - length of perimeter in rock & Pc - length of perimeter in concrete.

3.5.4.2 **Trashrack loss (IS 11388 : 2012)**

$$h_t = kt \cdot V^2/2g \quad \text{or} \quad h_t = k\ (t/b)^{4/3} \cdot V^2/2g \cdot \sin \alpha$$

Partial clogging of 25 – 50 % shall be accounted. For rivers carrying heavy sediment load , 50 % clogging can be taken.

3.5.4.3 Entrance loss

$he = ke \cdot V^2/2g$

ke=loss coefficient for various types of entrance as per cl. 4.3 of IS 4880 (part-III)

For circular bell mouth ke = 0.05

For fully rounded entrance ke = 0.10

For square bell mouth entrance ke = 0.16

3.5.4.4 Head loss in gradual Expansion

Transitions shall be gradual expansion or gradual contraction to reduce the hydraulic losses.

$Hex = kex(V1-V2)^2/2g$; kex values as per IS : 2951(part II)-1965

Cone angle (2α)	2^o	5^o	10^o	12^o	15^o	20^o	25^o
kex	0.03	0.04	0.08	0.10	0.16	0.31	0.40

Source : WRDTC , uty of Roorkee

For sudden enlargement :-

For cone angle in the range of 7.5^o to 35^o, actual formula for

$K = 3.50 \left[\tan(\alpha/2)\right]^{1.22}$

Where as for cone angles in the range of 40^o to 60^o, K=1.

3.5.4.5 Head loss in gradual contraction

Head loss is comparatively less.

$Hc = Kc\,(V_2^2/2g - V_1^2/2g)$ (IS 4880 (part III)

Kc - loss coefficient for contraction

Where flare angle of the conduit wall 'α' is limited to 10^o, Kc can be assumed as 0.10

For abrupt right angle contraction, Kc shall be taken as 0.50.

3.5.4.6 Bend loss (IS: 2951 (part II) -1965)

$h_b = K_b . V^2/2g$

K_b = bend loss coefficient which depends on R_b/D

$$= 2\Delta \quad \pi^2 \quad \ln (R_b/D) + \Delta$$

Where Δ – deflection angle

R_b - radius of curvature

For R_b/D ratio between 4 and 6, K_b is in the range of 0.07 to 0.09 for deflection angles in the range 35^o to 80^o.

3.5.4.7 Gate loss

No gate loss need be assumed of the velocity of flow is less than 1 m/s or of the gate is located at the entrance. Where a gate is mounted inside a tunnel, so that the floor, sides and the roof, both upstream and downstream, are continuous with the gate openings, only the loss due to the slot shall be considered, with Kg not more than 0.10

For small opening, Kb = 1.0 and

For wide open gates, Kb = 0.19

For partly open gates, Kb depend on top contraction,

Gate full open Kb = 1.0

Gate 3/4 open Kb = 1.15

Gate 1/2 open Kb = 5.60

Gate 1/4 open Kb =24.0

Where gate is mounted at either u/s or d/s of a thin head wall such that the sides and bottom are suppressed and the top is contracted, Kb shall be taken from Table 1 (IS 4880 – part III)

	Average Kb
Gate in thin wall – unsuppressed	1.50
Gate in thin wall – bottom and sides suppressed	1.00
Gate in thin wall – corners rounded	1.50

3.5.4.8 **Exit loss :-**

Where release from a pressure tunnel discharges freely or is submerged or supported on d/s floor, $K_{exit} = 1.0$, $h_{exit} = K_{exit} . V^2/2g$

Where diverging tube is provided at the end of a tunnel, recovery of portion of velocity 0head will be obtained and if the end of gradual expansion is submerged, K_{exit} shall be reduced from 0.1 by the degree of head recovery.

Once hydraulic analysis is complete for the entire water conductor system, for the actual net head, rework the power potential study for the actual machine parameters and ensure that the expected generation is possible. Or else modify the system especially finished diameter of tunnel for the expected power generation.

3.5.5. Different approaches based on ground conditions and Tunnelling methods

The response of the ground to excavation of an opening can vary widely. Based on the type of ground in which tunnelling takes place, four principal type of tunnelling can be employed.

a) 1. For cut and cover tunnelling where tunnel is passing at shallow depths, the ground acts passively as a dead load on tunnel structure.

b) In soft ground, immediate support must be provided by a stiff lining (tunnel supports like lattice girder and shotcrete with wire mesh or in shield driven tunnels with tubbings for ring support and pressurized slurry for face support). In such support system, ground also participates actively by providing resistance to outward deformation of the lining.

c) In medium hard rock or in more cohesive soil, the ground may be strong enough to allow a certain open section at the tunnel face. Here, a certain amound of stress release may be valid before the supporting elements and lining begin their action effectively. In this situation only a fraction of the primary stress of the ground act on the lining.

d) When tunnelling in hard rock, the ground alone may preserve the stability of the opening so that only a thin lining, if any, will be necessary for surface protection. For hydro tunnels, especially pressure flow tunnels, concrete lining is preferred even in rock which will ensure better hydraulic efficiency. The design model accounting the role of rock around the tunnel will be the optimum.

Especially in ground conditions that change along the tunnel axis, the ground may be strengthened by injections (grouting), anchoring, pipe roofing, fore poling, draining, freezing etc. Studies on the previous tunnels reveal that (Erdmann 1983) in medium stiff ground, nearly 80% of the deformations have already taken place before the lining is stiff enough to participate. Where full primary stresses are assumed to act on a lined opening, displacement may be only 0.4 times that of an unsupported tunnel. Even in the unrealistic case when full primary stress acts simultaneously on the ground opening and lining, only 55% of the stress is taken by lining. For very soft ground, requiring immediate support, as in the case of shallow tunnels ($h<3D$),where h is depth of tunnel bore crown from ground surface, almost 100% of the primary stresses are acting on the lining.

The main purposes of structural analysis are to provide the design engineer with better understanding of the ground-structure interaction induced by the tunneling process. Knowledge of what kinds of principal risks are involved and where they are located

1) A tool for interpreting the site observations and in-situ measurements.

In-situ monitoring is important and should be an integral part of the design procedure especially in cases where stability of the tunnel face is a point of concern. Deformations and displacements generally can be measured with much more accuracy than stress. The geometry of the deformations and their development over time are most significant for the exact interpretation of actual events.

3.5.6. Guidelines for the structural detailing of the lining

3.5.6.1 Minimum Excavation line (A-line)

A line within which no unexcavated material of any kind and no supports other than permanent structural steel supports shall be permitted to remain. Where due to the nature of strata, steel supports are essential, the minimum excavation line may be at least 75 mm behind the outer flange of the support to accommodate permanent lagging or primary concrete.

3.5.6.2 Payline (B – line)

An assumed line beyond A –line denoting mean line to which payment of excavation and concrete lining is made, whether the actual excavation falls inside or outside it. The distance between A and B lines shall be decided by contracting Authority depending upon the nature of rock.

3.5.6.3 Primary Lining

A concrete lining laid immediately after excavation and installation of steel supports. This may cover full section excavated or part, depending on conditions of strata.

3.5.6.4 Final lining or Secondary lining

Concrete between primary lining and the finished line of the tunnel. The provision of reinforcement in tunnel lining complicates the construction sequence besides requiring a higher thickness for the lining, to avoid concrete placing issues. The portions of a tunnel which should be reinforced and the amount of reinforcement required depends on the physical features of the tunnel, geological factors and internal water pressure.

Pressure tunnel with high hydrostatic loads shall have concrete lining reinforced, to with stand bursting, where inadequate rock cover and unstable ground conditions prevail. Generally if a pressure tunnel has cover less than the internal pressure head(H), then it should be reinforced and if the cover is less than

0.5H or cavitation is expected due to high velocity of water or erosion due to suspended load , is expected , provision of steel liner shall be considered.

If reinforced concrete lining is adopted, the stress in reinforcement shall be checked to avoid excessive crack width in the concrete as these may lead to seepage from the tunnel to the strata around, endangering its stability.

3.5.6.5 Cover

Cover of a tunnel in any direction is the distance from the tunnel soffit (crown of driven section) to the rock surface/ground in that direction. However if sizable thickness of overburden exists over a rock cover of 3D, its equivalent weight may also be considered to find out the cover over soffit of the tunnel. For tunnels at mountain slopes, lateral cover may be governing. In such cases effective lateral cover shall be found out according to provisions given in IS 4880 (part IV).

1) The thickness of the secondary lining of cast-in-place concrete may have a lower limit of 25-30 cm to avoid concrete placing problems and 30 cm is recommended for watertight concrete. For preliminary designs, lining thickness 6cm per 'm' of finished diameter may be assumed for tunnels in reasonably stable rock and 12cm/m finished diameter in case of soils, can be taken subject to the minimum value specified above.

2) In cases where Reinforcement is not required from the structural point of view , it may be desirable for crack control, but reinforcement cause concrete placing problems. Hence a closely placed steel mesh reinforcement 1.5 cm2/m at the outer surface or if required 3 cm^2/m at the inner surface also, may be a better option.

3) Recommended minimum cover of reinforcement.

6 – 8 cm at the outer surface, if lining is directly in contact with ground and ground water. 5 – 8 cm at the inner tunnel surface. 5 cm for the tunnel invert where water is aggressive.

Where structural steel supports are used, they shall be considered as reinforcement, only if it is possible to make them effective. A minimum cover of 18cm shall be provided over the inner flange of steel ribs. In soft strata tunnels, it may become necessary to embed steel supports partly or fully in primary concrete immediately after erection.

4) If segmented tunnel ring is the outer primary lining, specifications 1, 2 and 3 are not valid, but special attention to avoid damage during transport and erection.

5) Sealing against water may be necessary when

- aggressive action of water threatens to damage steel.
- water pressure level is more than 15 m above crown.
- possibility of freezing of ingressing water close to the portal.

6) In achieving water tightness of concrete, special specifications of concrete mixture, avoidance of shrinkage stress and temperature gradients during setting are more important than theoretical computation of crack widths.

7) Temperature tension stresses may be somewhat controlled by working joints (as close as 5 m at the portals) and by providing additional surface reinforcement in exposed concrete face.

8) An initial lining of shotcrete may be considered to participate in providing stability of tunnel by avoiding shotcrete shadows behind steel arch rib supports and reinforcements.

3.6 DESIGN OF STRUCTURAL SUPPORTING SYSTEMS

3.6.1. Shallow or Deep tunnel

If the depth of tunnel bore overt from GL (h) is more than 3 Driven (Bore) Diameter of tunnel, then it is a deep tunnel, otherwise shallow tunnel.

For shallow tunnels, external load of the full overburden shall be considered acting on the tunnel roof where as for deep tunnels, rock load for a height of HP (m) above the crown need to be taken. HP for different rock conditions are given in Appendix B, of IS 4880 (part IV or V), has been arrived on the basis of observation and behavior of support where the load was derived mainly on loosening type of rock ,as recommended by Terzaghi.

3.6.2. Design of Supports

There are three types supports viz. Steel Ribs, Rock bolts and Shotcrete

3.6.2.1 Steel Ribs

Load is transmitted to the ribs at the Blocking points fibre stress fb in the rib = T/A + M/ƶ where A is net area of the rib, ƶ section modulus. Actual fibre stress should be less than permissible stress in steel.

3.6.2.2 Lagging

May be either of steel, precast concrete or timber. Members which span the space between ribs. Lagging need to be designed for the load of rock of the small arch (equilateral triangular) between the ribs in longitudinal direction of tunnel. Load on lagggng may be assumed to be triangular.

3.6.2.3 Shotcrete:-

Shotcrete arch designed for the primary stress acting on the lining for the arch load. Mix of shotcrete shall be designed for the early stregth and allowable deformaation criteria.

Lining shall be designed for the normal thrust, shear and bending moment values calculated at each section using the tabulated values given IS4880 part IV,V etc for the different loading and ground conditions.

3.7 FOREBAY

Main functions of forebay in a water conductor system are:

- Distribute evenly over a proper transition, the water conveyed by the power canal among the penstocks
- Regulate the flow into penstock
- To ensure disposal of excess water
- Act as a settling tank facilitating disposal of silt
- Reduce drop of water level in case of sudden load increase
- Act as a tank for accommodating upsurge during load rejection
- Facilitate installation of trash rack arrangement in front in penstock intake etc.

For small HE schemes, usually the storage capacity between FSL and MDDL is calculated as the quality of inflow of water for 2 to 3 minutes. How ever water contained in a portion of water conductor system ie canal can also be counted as a part of forebay while calculating the storage capacity.

When flow velocity is of the order of 2.5 m/s through the canal, the volume of water contained in 50 m length of canal just upstream of forebay inlet could be considered as a part of forebay.

The forebay proper shall however be provided with sufficient area to accommodate not only the trash rack assembly designed according to guide lines specified in IS 9761 -1995 but also shall have sufficient space outside the trash assembly through out. A minimum distance of 2.5m is preferable from the forebay wall to the nearest portion of trash assembly.

Experience has shown that, for small HE schemes, trash accumulation in forebay is a major problem, requiring stoppage of generation for trash removal. This phenomenon unfortunately occurs during peak rainy season resulting in generation loss. To reduce the frequency of trash removal by stoppage of generation, a trash removal system shall be invariably provided inside the forebay itself. In addition to the well designed trash rack assembly with trash removal mechanism a trash rack assembly with large openings, say 60 mm wide x 400 mm high in the power canal will reduce the trash load on forebay to a very great extent.

The main purpose of this trash rack is to remove large trashes from entering through intake opening. The location shall be preferably in the plunge pool in front of intake, from where trash could be easily removed manually or mechanically. Installation of additional trash rack anywhere along the power channel shall be discouraged, since any trash accumulation unattended may result in upsurge, leading to canal overtopping on upstream reaches.

3.7.1. Centre line of intake

To prevent vortices the centre line of intake should be so located as to ensure sufficient submergence requirements.

The minimum depth of submergence above C/L of intake specified in different codes/reference materials, differ significantly, the following formulae given in IS9761-1995 can be adopted to evaluate the submergence requirements.

- For large size intakes at Power plants (ie $F_r = v/\sqrt{gD} \leq 1/3$) a submergence depth h=1Dto1.5D is recommended.
- For medium and small size installations (ie $F_r \geq 1/3$), submergence requirements may be calculated using the formula $h/d = 0.50 + 2F_r$,

Where F_r is Froude Number,

V is Velocity of flow at vena contracta = $Q/(b_e x D)$

Q - Design discharge, be – Width of gate opening,

D – Depth of gate opening (equal to penstock diameter) in appropriate units

Note: The usual practice is to provide sufficient submergence depth below MDDL in forebay.

This procedure results in deeper positioning of intake opening, deeper forebay bed level and large trash rack area requirements affecting the cost of construction/maintenance.

As the water level in forebay normally fluctuates between FSL and MDDL, the submergence depth could be taken from an intermediate level between FSL and MDDL.

When a water level control system capable of monitoring real time water level in forebay tank and transmit to the turbine governor which could accordingly adjust the load and keep the forebay water level within the specified range, the submergence depth could be safely measured upto = MDDL + ½ (FSL – MDDL), provided that the control system as above mentioned or any other equivalent method is capable of controlling the load to keep the forebay water level as above, according to varying canal flow.

3.8 PENSTOCK

The velocity of flow through penstock shall be optimal (viz a viz size of penstock and head loss). A velocity range of 5 to 6 m/s could be permitted, if head losses are within acceptable limits so that size of penstock and associated components like ring girders, expansion joints, width of penstock track etc could be reduced.

Wherever possible buried penstock shall be provided so that provision of expansion joints, rocker supports etc could be avoided.

A minimum pressure rise of 25 % due to water hammer and a maximum of 40 % shall be taken during design. The fact that maximum water hammer pressure shall be limited to 40 % shall be included in tender specifications so that machine manufacturers will be able to provide precautionary measures in E&M equipment so as to limit the water hammer pressure to 40 % in the penstock. One expansion joint shall be provided between two anchor-blocks, in case of open penstocks it should be positioned just down stream of uphill anchor block, preferably midway between the first span constituted by the anchor block and rocker support or saddle support as the case may be.

Penstocks shall be as far as possible aligned along the ridge line for better economy.

Anchor blocks shall be preferably founded on hard stratum ie rock. In the absence of hard rocks, anchor blocks could be located on overburden also, provided the stresses on founding level are within permissible limits, sufficient depth of foundation is to be provided so that a line drawn at 30^0 from base of foundation will not cut the down hill slope, the structure shall be stable against over turning and sliding at severe load conditions and sufficient erosion protection measures are to be taken around the anchor block.

3.9 POWER HOUSE, MACHINE FOUNDATION, TAILRACE POOL, TAILRACE CHANNEL AND ALLIED WORKS

Structures of power house building below yard level shall be constructed with RCC. Super structure above yard level may be of masonry work (laterite/brick/cement blocks etc) up to about 3 m above yard level and balance portion may be constructed with Galvalume sheets on steel frames to reduce construction cost and to save construction time. Necessary openings for lighting/ventilation could be provided in the lower part constructed with masonry. Roofing may be done with space frames to reduce cost/construction time.

When the machine setting as per standard guidelines results in a condition where the machine centre line, blades, guide vanes, spiral casing are well above the maximum possible tail water level, provision for DRAFT TUBE GATE is not necessary. However a walkway may be provided in from of power house above tail pool for inspection.

Chapter - 4. ELECTRO MECHANICAL EQUIPMENT

4.1 TURBINE SELECTION

Selecting the type, kind, (within a particular type) configuration (horizontal or vertical), size, and number of turbine units that best suit a project is a warily process. This involves technical, environmental, financial and other considerations. The most inexpensive turbine may not be the best solution to the available head and discharge. For small hydro up to 5 MW unit size, selection on the basis of typical turbine data furnished by manufacturers can be looked into. For units above 5 MW size information exchange with turbine manufacturers is recommended for turbine at project stage. The selection procedure is prepared for selection of turbine based on the techno economic consideration to permit rapid selection of proper turbine unit, estimation of its major dimensions and prediction of its performance. The number of units is to be carefully decided considering the variation in output in various months and the shape of the load curve where the power is to be fed.

The selection of a suitable turbine is to be made considering net head available to the turbine at a particular site. The rate of flow determines the capacity of the turbine. The term specific speed is generally used in classifying types of turbines. The manufacturer to be made responsible for the mechanical design and hydraulic efficiency of the turbine. A turbine, that result in the most economical combination of turbine, related water passages, and structures is to be selected. Competitive bidding for the least expensive turbine that will meet the specification is required. To develop a given power at a specified head for the lowest possible first cost, the turbine and generator unit should have the highest speed practicable. However, the speed may be limited by mechanical design, cavitation tendency, vibration, and drop in peak efficiency or loss of overall efficiency because, the best efficiency ranges of the power efficiency curve is narrowed. The greater speed also reduces the head range under which the turbine will operate satisfactorily.

The Turbines shall be designed, manufactured, tested, installed and commissioned in accordance with the latest revision of applicable IS/IEC or equivalent standards. The turbine shall be designed to withstand runaway speed for 15 minutes without causing any residual detrimental effect on future operation of the machine. However the critical speed of the machine shall be around 25% higher than maximum runaway speed. Provision for removal of runner from bottom for maintenance shall be made, wherever feasible.

- IS 12800 - 1993 (Part 1) Guidelines for selection of turbines.
- IEC 60034-1 :1983 Turbines and Generator (Rotating Electrical Machines)
- IEC 61366-1 :1998 Turbines and Generator (Rotating Electrical Machines)
- IEC 61116-1992 Turbines and Generator (Rotating Electrical Machines)
- IS 4722-2001 Turbines and Generator (Rotating Electrical Machines)
- IEC 60545 Guide for commissioning, operation and maintenance of hydraulic turbines.
- IEC 60193 and 60193A International code for model acceptance tests of hydraulic turbines.
- IEC 60609 Cavitation pitting evaluation in hydraulic turbines.
- IEC 60041 International code for field acceptance test of hydraulic turbines.
- IEC 61366-2 Guidelines for technical specification for Francis turbines.

4.2 MODEL TEST REPORT FOR TURBINES

If found necessary, before the manufacture of prototype turbine is taken up, homologous scale model of the prototype turbine shall be made if not already available and tested to demonstrate that the prototype turbine will meet the guaranteed performance in respect of efficiency, output, smooth operation, pressure pulsations and other guarantees as stipulated in the technical specifications.

KSEBL shall have the option to get the model test performed by the contractor at an extra cost after the award of the contract. In that event, the manufacture of any part of the prototype turbine shall be started only after the efficiency and other guarantees and requirements of the turbine are established and fulfilled on the basis of model tests. In case the contractor has already performed model test on homologous models, the purchaser may, at his discretion, permit the contractor to proceed with the manufacture after approval by the purchaser of the model test report.

The performance of the model test either afresh or that had been done earlier shall be as per IEC 60193 and 60193A in all respects. Hydraulic performance tests shall be made with a number of guide vane openings to determine the machine characteristics including regimes of safe operation, zones of cavitation and vibration etc. The phenomenon of cavitation and vibration, particularly at lesser guide vane openings, shall be specially investigated. Usually the reaction turbines are supposed to operate above 50% load to avoid cavitation due to less opening of guide vanes. These tests shall include determination of capacity, cavitation limit, hydraulic thrust, runaway speed, wicket gate torque relationship, etc. and such other details as covered in IEC 60193 and 60193A. Prototype efficiencies shall be derived from model tests by the step-up formula as applicable for the type of turbine contained in IEC 60193. Model tests shall simulate all possible normal operating conditions of the prototype for entire range of fore-bay/reservoir and tail-race levels.

The tenderer shall clearly mention the time within which the model tests including manufacture of a new model, if required, will be complete. The delivery schedule given by the tenderer shall be reckoned from the date of approval of model tests or model test report or from the time of permission to proceed with the prototype manufacture. If the model test report is already available, this shall be submitted within one month after the award of contract, if required by KSEBL.

4.3 RUNNER DIAMETER AND DIMENSIONS OF TURBINE

The diameter of runner at the outlet or throat diameter is taken as characteristic dimension of the particular design of turbine. Other dimensions are taken as multiples of this characteristic dimension. For Francis turbines the discharge diameter is calculated using the formula

$$D = \frac{4.48\ (Q)\ 1/3}{n^{\frac{1}{3}}}$$

Where, Q is the full load discharge in m^3/sec and n is the speed in rpm. Other salient dimensions can be assessed from the discharge diameter with the help of multiplying factors shown on the drawing of such turbine. (Refer Publication No. 305 of CBIP).If turbine output/ dimensions are large as may happen for example at low heads, vertical shaft arrangement may be considered. The runner diameter is calculated using above formula and dimensions of turbine are determined as per standard practice. Reference in this regard may also be made to IS 12800(Part 3).

Axial flow turbines of small kW output may be quite large in physical dimensions at low heads of the order of 2 to 3 m. However at higher heads and low output sizes will be quite small. For low heads vertical shaft arrangements are commonly used whereas for small and large heads s- type arrangement is commonly used. In axial flow (Kaplan and Propeller) turbines the runner diameter forms the characteristic dimension to which all other main turbine dimensions can be referred to such as draft tube, speed ring, scroll case etc. Kaplan turbines of any particular head show a good correlation of the form C= D/pt where D is runner diameter, Pt is turbine rated output and C is a constant depending on head. (Refer Publication No. 305 of CBIP Chapter 9)

Pelton turbines (Impulse turbines) have many differences in hydraulic and construction aspects from reaction turbines and do not present a simplified method for preliminary estimates of salient dimensions. Pelton turbines can have many variants with number of jets, number of buckets, wheel diameter etc. The following factors are useful for estimating dimensions.

a) Pelton turbines can have a single jet or more jets; upto 6 jets have been used

b) Horizontal axis turbines can conveniently have only one or two jets. More jets will usually be with vertical axis arrangements.

c) For small turbines one or two jet design is used. A 2 jet machine gives double the output of one jet machine with same runner diameter and speed.

d) Specific speed of turbine is computed in usual way for output and speed of entire turbine considering all jets. However in design or calculation of dimension specific speed of jet is also used.

In the case of Pelton turbines, the most practical method to get preliminary estimates of speed, No. of jets and runner diameter is to utilize corresponding figures of turbine having nearly similar output and head. (Refer Publication No. 305 of CBIP subhead 9.7.9 of Chapter 9 for more detailed information)

Reaction turbines of Francis and Kaplan/Propeller type are prone to cavitation effects. This results from sub-atmospheric pressures at places on runner and runner chamber. To minimize this problem the turbine runner is set at depths below the minimum tail water level to obtain a countering pressure. The appropriate value of the depth of setting for runner of different specific speed is computed using a characteristic "cavitation constant" for the particular speed as

$$Z = (H_a - H_v) - \sigma H$$

Where, Z is the depth of center line of runner w.r.t minimum level of tail water

H_a is atmospheric pressure in metre water column at plant elevation

H_v is vapour pressure in metres at plant location temperature

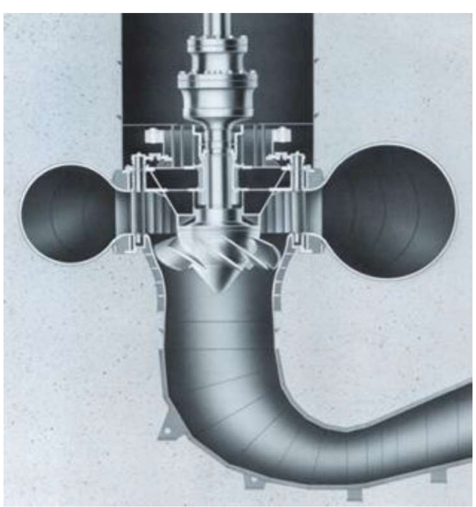
σ is plant sigma or cavitation coefficient for the turbine specific speed

H is Head on turbine in metres.

The value of σ may be found from the expression $\sigma = (\eta_s)^{1.64} / 50327$ where η_s is the specific speed. The value of σ can also be taken from the curves relating to η_s and σ in fig 9.3 in Publication No. 305 of CBIP subhead 9.7.9 of Chapter 9 for more detailed information. The value of σ for Francis turbines are lower than those for propeller or Kaplan turbine and consequently the setting level for propeller /Kaplan is lower than for Francis turbines. Many low specific speed Francis turbines will yield setting levels above minimum tail water level and same may be the case with Kaplan/Propeller turbines of very low heads. Pelton turbines are set above the maximum tail water level.

DERIAZ TURBINES

The Deriaz turbine was developed by Paul Deriaz in the 1900s. The positive aspect of the turbine is that it can have fixed or adjustable blades. When they are adjustable, it enables the turbine to work with high efficiency in various loads and



heads. Therefore, it is suitable for a power station with wide variation of head and discharge. The other positive aspect is its higher efficiency at part-load operation when compared to Kaplan turbine. Moreover, the Deriaz turbine has lower specific and runaway speed, lower hydraulic thrust and higher cavitation coefficient than the Kaplan wheel. The Deriaz turbine has reduced discharge at over speed. It can be used for reversible pump-turbine service for heads above 90m. The hub contains the blade servomotor and operating linkages used for adjusting position of the runner blade.

4.4 MAIN INLET VALVE

The Main Inlet Valve shall be of Spherical or Butterfly type depending on the available head. The valves shall have service seal on downstream side and maintenance seal on upstream side. Penstock protection valve designed for penstock rupture condition shall be provided as a second line of defense. Suitable Air release valves shall be provided at appropriate location.

Sufficient opening and closing time shall be provided for the Main Inlet Valve. In SHEP where penstock is not present, proper isolating valves or vertical gates shall be provided for second line protection and for undertaking maintenance of MIV safely. Automatic counter weight closing mechanism shall be provided for the Main Inlet Valve as a failsafe arrangement for overcoming oil flow failure.

The Main Inlet Valves shall be designed, manufactured, tested, installed and commissioned in accordance with the latest revision of applicable IS/IEC or equivalent standards.

- IS 7332 Turbine Inlet Spherical Valves for Hydro-power Stations and Systems.
- IS 7326-2 - Penstock and Turbine inlet Butterfly valves for hydro power stations and systems.
- ASME Pressure Vessel Code

4.5 GOVERNING SYSTEM

Microprocessor based digital governing system shall be used for regulating flow of water to turbines for control of active power, thereby providing speed/frequency control and load control. Microprocessor based governor control system are capable of carrying out the following control functions in addition to speed control during idle run. i) operating in isolated grid ii) interconnected operation and iii) islanding operation.

• Control the power output depending on variation in grid frequency i.e. load frequency control

• Joint power control in case multiple numbers of generating units are there in a power station

• Power control as per water levels in Fore-bay and/or Tail-race, in case of high level variation in the upstream and downstream side of machines

• Automatic Starting / Stopping by single command

• Fast response to transient conditions

• Control from remote place Supervisory Control and Data Acquisition (SCADA)

Modern control schemes also utilise personal computers (PCs) in conjunction with PLC control systems. The PCs are utilized with man-machine interface (MMI) software for control display graphics, historical data and trend displays, computerized maintenance management systems (CMMS), and remote communication and control. In addition, the PLC programming software is usually resident on the PC, eliminating the need for a separate programming terminal implement or changes the PLC software coding. A PC also can be used for graphical displays of plant data, greatly enhancing operational control. Standard Microsoft-based graphical display software packages are available for installation on a standard PC. The software package can be utilized on the PC to create specific powerhouse graphical displays based upon real-time PLC inputs. These displays typically include control displays with select-before-execute logical, informational displays for plant RTD temperatures, or historical trending plots of headwater, tail water, and flow data. Modems with both dial-out and dial-in capabilities can be located either in the PC, the PLC, or both to provide off-site access to plant information. These modems may also be utilised to control the plant operation from a remote location. Programmable Logic Controller (PLC) type plant controllers with a manually operated back up system combined with PC based SCADA system are used as Governors and for Plant control and data acquisition. This makes the system costly but reliability is stated to be good and can be used for small hydro generation control. It is considered that dedicated digital control systems which is digital P.C. based can perform all functions of governing, unit control and protection as well as for data storage and can be more economical, dependable and are also available indigenously.

Turbine Control Actuator system compares the desired turbine actuator position command with the actual actuator position. In most of the hydroelectric units it requires positioning of wicket gates in reaction turbines, spear in Pelton turbines and turbine blades in Kaplan turbines. In load actuators shunt load bank is adjusted. Pressure oil system with oil servomotor is most commonly used actuator.

Separate oil pressure systems shall be used for control of turbine and control of MIV. Piston type accumulator with Nitrogen bottle shall be used for pressure above 60 kg/cm^2. The oil volume below its machine shutdown level shall be sufficient to perform 3 full operations of the servomotor viz. Close-Open-Close with all oil pumps out of operation.

4.5.1. Governing System used in India

Basically there is no difference in governors used for large generating units and small units except in size, operating pressure and control features as per requirement of individual project. Also for smaller units, hydro-mechanical part of governor is built on the sump of oil pressure plant for compactness. Higher operating pressure is used to reduce sizes of control elements and pipelines. Nitrogen cylinders are used in place of pressure air to avoid use of high-pressure air compressors. Oil pipelines of sizes up to 50 mm are used in stainless steel with ermeto (dismantlable) couplings to reduce welding and maintain cleanliness.

Following types of governing system are used:

Micro Hydel (upto 100 kW) - Digital speed control system with load actuator is used.

Small Hydros (Upto 3 MW) - Flow control governing system with hydraulic actuator and digital PID speed and power control system. Mechanical motor type actuator have also been, used up to 1000 kW unit size with microprocessor based level control PI Controller.

Small Hydro (Above 3 MW) - Flow control PID governor with hydraulic actuator.

The Governor shall be capable of programming to operate under both Free Governor Mode of Operation (FGMO) and Restricted Governor Mode of Operation (RGMO). Under RGMO there should not be any reduction in generation in case of improvement in grid frequency up to a specified level. The present specified level under CERC Regulation 5.2. (f) is 50.2Hz whereas for any fall in grid frequency, generation from the unit should increase by 5 % limited to 105 % of the Maximum Current Rating (MCR) of the machine subject to machine capability.

Ripple filter of ± 0.03 Hz shall be provided to prevent governor hunting due to small variations in frequency. Under RGMO, the droop setting shall be between 3% and 6%. Grid frequency input shall be insisted for smooth synchronization. Auto synchronization may be considered for small hydro stations.

The Governors shall be designed, manufactured, tested, installed and commissioned in accordance with the latest revision of applicable IS/IEC or equivalent standards.

- IEC 308 International code for testing of speed governing system.
- IEEE 125 - 1988 or equivalent IEEE recommended standard for governor
- IEEE 472 - 1974 or equivalent Testing of electronic circuits of governor
- ASME Performance Test Code 29 Acceptance test of governor

4.6 PRESSURE/SPEED RISE

The pressure rise and speed rise of turbine shall be within the range specified by relevant Indian standards. For a unit which is one of the several units on a common header system, the permissible percentage of speed rise shall be computed on the basis of one unit operating alone.

The turbine shall be designed to withstand runaway speed for 15 minutes without causing any detrimental effect on future operation of the machine. However, critical speed of the machine shall be around 25% higher than maximum runaway speed.

The turbine and the generator (moving mass) shall be capable to withstand runaway speed for the specified time without any mechanical damage to the individual equipment (bearing, rotor, gearbox, if present, etc.).

4.7 PRESSURE RELIEF VALVE (REACTION TURBINES)

PRV shall be provided as per design requirement and turbine type to maintain the pressure rise, speed rise and water hammer effect within the specified limit at all heads and load conditions. In Pelton turbines, at the time of tripping deflectors deviate the jet away from the buckets and hence sudden closing of jet is not essential. However in reaction turbines sudden load rejection and closing of guide valve causes the pressure to rise in the spiral casing and penstock. Pressure Relief Valve (PRV) is used to reduce the pressure within safe limits rapidly. Hydraulic pressure operation of the PRV is to be insisted for reliable operation.

4.8 PRESSURE OIL SYSTEM FOR VALVE AND GOVERNOR

High pressure oil system shall be provided for each turbine for the operation of wicket gates/nozzle/deflector servomotors through governors and for the control of Main Inlet Valve. Piston type accumulator with Nitrogen bottles shall be used for pressures higher than 60 kg/cm^2. Separate oil pressure systems shall be used for the control of turbine and the control of MIV. The sizes of various components of oil sump tank and pressure receiver shall be calculated as per relevant IS/IEEE standards. The oil volume below its machine shutdown level shall be sufficient to perform three (3) full operations of the servomotor viz. Close-Open-Close with oil pumps being out of operation. Main and standby pumps shall be provided to maintain oil pressure at the time of bulk requirement or at the time of failure of main pump. Since pumps are of positive displacement pumps suitable protections shall be provided viz high pressure release valve, oil level gauge, pressure gauge, switch and alarm system.

4.9 POWER HOUSE LAYOUT

The layout and dimensions of power house are determined by the type of turbine, hydraulic passages for leading in and leading out of water, number of units etc. The dimensions are to be fixed after finalizing the arrangement of turbine and generator with due consideration for space and clearance requirements. Turbines can be of vertical or horizontal mounted. Vertical mounting allows a smaller plan area and permits a deeper setting of turbine with respect to tail water. Generator costs for vertical units are higher than for horizontal units because of the need for a larger thrust bearing. However the saving on construction costs for medium and large units generally offset this equipment cost increase. Horizontal units are more economical for small higher speed applications, where standard horizontal generators are available. The required civil features are different for horizontal units than for vertical units. Horizontally mounted turbines require more floor area than vertically mounted units. General excavation for construction of PH and powerhouse height is less for horizontal unit than for a vertical unit.

4.10 GENERATORS

Generators of hydroelectric units are mostly of synchronous type, which runs at a constant speed and draws its excitation from a power source external or independent of the load or connected transmission network. It has an exciter that enables the synchronous generator to produce its own "reactive" power and to also regulate its voltage. Synchronous generators can operate in parallel with the utility or in"standalone" or "island" mode. Synchronous generators of small hydroelectric units are also of salient pole type since speeds higher than 1500rpm have not been used. For large vertical hydroelectric generators, where speeds may go down to very low values for low heads, generators of even more than 100 pole construction have been used. In case of small hydro units, use of speed increasing gear box is now normally adopted for low head low speed turbines. The main parameters that govern the design of synchronous generator are rated output (kVA), Frequency (50 Hz), No. of phases (3), range of voltage between phases of rated output ($\pm$ 5%), range of frequency variation ($\pm$ 3%), short circuit ratio of > 0.8, Inertia constant of > 1.0. The power factor, speed, rated terminal voltage and range of variation, stator winding connection etc. are to be provided for each particular case. (Refer Publication No. 305 of CBIP subhead 9.11 of Chapter 9 for more detailed information).

The scope shall include design, manufacture, test at works, supply, delivery at site, supervision of erection, testing at site and commissioning of AC Generators complete with excitation system, voltage regulating equipment, neutral grounding and generator terminal equipment including CT's, PT's, Surge protection equipment, etc. and auxiliaries such as CO_2 generator fire fighting equipment (if required), lubrication system (if required), oil, water and air piping with valves and fittings, instrumentation, controls and safety devices (as required), spares for 5 years operation of the plant, special tools and testing devices as required. The scope of supply shall include all parts, accessories, and spares etc, which are essential for construction, operation and maintenance of the complete generator even though these are not individually or specifically stated or enumerated. Corresponding components of all the generators and associated equipment and the spares shall be of the same material, dimensions and finish and shall be interchangeable. The generator manufacturer shall co-ordinate with the turbine supplier so that the turbine to be coupled to the generator is matched in respect of speed, runaway speed, moment of inertia, overload capacities, coupling and other relevant requirements. In vertical machines, provision shall be insisted for easy dismantling of rotor poles without need for lifting of the entire rotor.

The Generators shall be designed, manufactured, tested, installed and commissioned in accordance with the latest revision of applicable IS/IEC or equivalent standards

Relevant Codes and Standards:

- IEEE Test Code 115 Test Code of Synchronous Generator
- ANSI Standard C.501 Synchronous Generator
- IEC 60034 Rotating Electrical Machines
- IEC 60034-2 Calculation of Efficiency
- ANSI Standard B49-1 Generator Shaft Coupling
- IS 5422 Turbine Type Generator
- IS 7132 Guide for Testing Synchronous Machines
- IEC 60034-4 Synchronous Machines
- IS 4728 Terminal Marking for Rotating Electrical Machines.
- IEC-85-1987 - Classification of materials for the insulation of electrical machines

4.11 EXCITATION SYSTEM

Presently the following types of excitation system are used with synchronous AC generators:

1) Static Excitation system
2) Brushless Excitation system

4.11.1. Static Excitation System

In this system, the excitation power is taken from the generator output through an excitation transformer. This is rectified through a stationary Thyristor bridge system. The voltage regulation signals are also applied here. The excitation equipment comprises of excitation transformer, Thyristor Bridge and AVR system is housed in a separate cubicle. The automatic voltage regulator senses the deviation in generator terminal voltage and signals advancing/retarding of firing pulses of the Thyristor and in turn of the excitation current of the generator. The rectified excitation current is applied to generator field through slip ring.

4.11.2. Brushless Excitation System

In this system, the generator is provided with a separate 3 phase AC exciter of a construction having rotating armature and stationary field poles. The AC output of exciter is fed to a diode bridge system mounted on a disc or cylinder on the generator shaft adjacent to the armature rotor of the AC exciter. The AC output of the exciter is thereby rectified on the rotor shaft of the generator and supplied to the generator field directly without slip ring and brushes. The automatic voltage regulator in the case of brushless excitation system is a separate piece of equipment through which the current supplied to the stationary poles of the AC exciter can be controlled and in turn the output voltage of the generator.

Both types of excitation system provide generators of compact construction and fast response. Brushless excitation system seems to be gaining preference in small machines and large machines to avoid slip ring problems.

Two AVR's (1+1) for 100% redundancy shall be insisted along with at least one Manual Control Regulator (MCR) for the Excitation system

Relevant Codes and Standards:

- IEEE standard 421 or equivalent standards
- NEMA TR 27 – Dry type transformer
- IEC 726 - Specification for dry type power transformer
- IS 11171 - Dry type power transformer IEEE Test Code 115

4.12 ANCILLARY AND AUXILIARY EQUIPMENT

Many items are to be selected and provided in the power station to make a complete functioning system. Some of these are ancillary to the turbines, generators and valves and are given as part of these such as Governor, pressure oil system, excitation equipment etc. Other items like LT switch gears, HT switchgears, protection, controls need to be designed properly. Careful and proper design and correct installation of the supporting systems play a very important role in good operation of the power station. The basic designs of the electrical system are consolidated in the single line diagram. Layout for various mechanical systems like for water supply and drainage, fire protection, compressed air etc. are to be prepared and incorporated in main layouts. Power station auxiliary electrical supply, DC supply etc have a vital role in the reliable working of a power station.

The main ancillary equipment like Governor, pressure oil system for governor and valve, bearing lubrication pumps, compressors, Excitation/AVR cubicle, Local control board/boards have to be located on power house floor in position of functional convenience. The number and dimensions of the items may vary with the different manufacturers. Normally functional specifications are to be given by the purchaser as detailed in CBIP Publication 175- Small Hydro station standardization.

Mechanical auxiliary systems for different types of small/medium size hydro power stations comprise mainly of Overhead travelling crane, Dewatering and drainage system, cooling water system with water pipelines and valves, high pressure compressed air system with air pipelines and valves, water level sensing and transmitting device for forebay and tail race, centrifugal type governor/ lubricating oil purifier unit, fire protection system for generators, main transformers and other equipment of power house, Ventilation and Air conditioning.

- I S 325 - Three phase induction motors
- I S 9046 - AC Contactors
- I S 13947 - Low voltage switchgear and control gear
- I S 13118 - Circuit breakers
- I S 4503 - Heat exchangers
- IS 7613 - Air filters
- IS 8148 - Packaged air conditioners
- IS 1391 - Room air conditioners
- IS 11465 - Reciprocating air compressors up to 25 kW
- IS 10962 - Reciprocating air compressors above 60 kW
- IS 5456 - Testing of air compressors

4.13 INSTRUMENTATION CONTROL AND PROTECTION

The generator supplier is normally entrusted with the supply of unit control board with all necessary instrumentation, control and protection items mounted thereon or in generator.

This includes all necessary CTs and PTs also. Indications, controls related to turbines are also mounted thereon. The equipment is required to form complete and coordinated set of instruments, gauges, controls and safety devices for control of the unit during running and emergency. The suggested controls, instruments and safety devices are listed in schedules in CBIP Publication No. 175. This equipment is for a conventional scheme of instrumentation. At present many suppliers have started providing microprocessor based controls and indications including with PLC/SCADA systems.

Relevant Codes and Standards:

- IEC 62270 - Hydroelectric power plant automation - Guide for computer based control
- IEC 61158 - Digital data communications for measurement and control - Field bus for use in industrial control systems
- IEEE 1003.1 1990 - Portable Operating system Interface (POSIX)
- IEEE 1003.3 1991 - Test methods for measuring conformance to POSIX
- IEEE 1010-2006 - IEEE Guide for Control of Hydroelectric Power Plants
- (Reaffirmed 1992)
- IEEE 1046-1991 - IEE Guide for Distributed Digital Control and Monitoring for
- (Reaffirmed 1996) Power Plants (ANSI)
- IEEE 1249-1996 - Guide for Computer-Based Control for Hydroelectric Power Plants
- IEEE Std C37.1-1994 IEEE Standard Definition, Specification, and Analysis of Systems Used for Supervisory Control, Data Acquisition, and Automation Control (ANSI)

The codes/standards referred shall govern the specifications and mean latest revisions, amendments, changes adopted and published by the relevant agencies.

4.14 COOLING WATER

The cooling water requirement for the station shall be met by designing an adequate cooling water system by drawing water from tail water pit or draft tube or by providing penstock tapping. However as far as possible, penstock tapping for cooling water requirement shall be avoided and shall be employed as a last resort in unavoidable site constraints and when the pen stock pressure is less than 5 kg/cm^2.

4.15 Drainage system and Dewatering system

A separate drainage sump shall be provided for collection of leakage & seepage water. Flow to this sump from various locations of the PH is usually by gravity. The water from this sump shall be discharged above the maximum tailrace water level. The dewatering and drainage sumps shall be interconnected through a gate valve and non-return valve to allow rising water in the drainage sump to be drained into dewatering sump on failure of drainage pumps. Automatic control of the pumps shall be arranged through level controllers. Provision for manual operation shall also be made on the control panel. Control of pumps shall be built in Unit Control panels.

For dewatering the underwater parts, there shall be a sump, whose bottom elevation will be sufficiently lower than the lowest point of the draft tube where the drain box is fitted so as to permit flow of water by gravity to the sump by opening a long spindle type gate valve provided at the sump. Dewatering system shall consist of adequate number of pumps of suitable capacity, level controllers, pipes and valves. The pump shall be capable of deterring the turbine in 4-5 hours. The pump shall discharge into the tail race above the maximum tail water level.

The control panels for drainage and dewatering pumps shall be located at a floor higher than that of turbine floor.

4.16 POWER STATION ELECTRICAL LAYOUT (SINGLE LINE DIAGRAM - SLD)

The SLD is an important design document as it defines the concept of functioning of the power station, its monitoring, control and protection. This is to be developed at the project report stage itself and refined and finalized considering the specifications at the implementation stage. In the case of SHPs the important points to be considered in electrical layout include whether transformation is required and if so whether paralleling of units is to be done at generator voltage and transformation after that or a unit step up is to be used. The manner of connection to the grid will have to be settled and the possible ways to get outside power supply is to be looked into. Protection, Relaying, indications, instrumentation, synchronizing arrangement is to be properly set out. Auxiliary power supply scheme for the station has to be worked out.

4.17 OTHER ELECTRICAL/ MECHANICAL EQUIPMENT

These include instrumentation, control and protection equipment for generating units, LT switchgear, DC equipment, HT switchgear and many mechanical service items such as pumps , cranes etc. Selection of main items such as transformer's rating and type, main switchgear, and control arrangement has to be done at preliminary stage. Whereas for other items the same may be done at design stage. Electrical systems for power house include Auxiliary transformers, Station battery and battery charger, LT switchgear (AC and DC), Power and control cables, Lighting system, Cabling, earthing and lightning protection, Communication system, Transformer oil purifier, Personal computer system, D.G set.

4.17.1. Step-up Transformer

The rating of the step-up transformer should be fixed as the higher standard rating. It shall be designed and constructed as per IS 2026(latest revision). It shall be designed for humid and tropical weather conditions. It shall be capable of delivering rated output continuously without crossing specified temperature limits for voltage variations to be indicated in technical particulars. Rated capacity shall be guaranteed with natural cooling as far as possible. It shall withstand stresses due to short circuit. The mineral oil used shall conform to IS 335 (latest revision). It shall be core type having non-aging, low loss, cold rolled, grain oriented silicon laminations. Normally generator transformer is designed with LV (generator side) in Delta and High Voltage side in star. The impulse voltage is attenuated and its wave front is reduced in steepness so that the winding will be in a protected position and the surges are restricted to less than 1.5 times line voltage with a duration of few micro seconds. Due to star delta formation the 3rd harmonics could be minimized in delta side. The winding temperature and oil temperature feedback shall be made available at Operators control room through use of suitable transducers.

All the type and routine test shall be as per IS 2026 (latest revision). The impedance and losses shall be limited generally to the values listed in Clause 9.15.1 of Chapter 9 of CBIP Publication 305.Due consideration is to be given to the voltage variation range, taps and use of OLTC.

4.17.2. 415 V L.T Switchgear Control and Relay Boards

In small power stations when 415 V switch gear has to be utilized for generators, the panels for accommodating all controls, instruments, alarms indications etc is used and formed as main Control board. These boards shall be of indoor type suitable for hot, humid and tropical atmosphere. The cubicles shall be dust tight, vermin proof as per IS 54 and IS 2147 and shall be self standing. The construction shall be compartmentalized having doors with isolating switch handle of inter-locking type. All the components shall be mounted on sheet steel and wired up to terminal block. Height of cubicle shall not be more than 1800 mm and easy extension on either side shall be possible. Sheet thickness shall be 14 SWG. All the equipment and their components shall be suitable for 415 V $\pm$ 10% voltage, 3 phase, 4- wire 50 Hz grounded system. The fault level shall be worked out on the basis of total MVA of step-up transformer and its reactance and synchronous generators MVA and their transient reactance's. It shall be not less than 30 MVA. A.C control voltage shall be single phase 240V $\pm$ 10%.

4.17.3. Bus bar

Bus bar shall be suitable for short circuit and continuous current and maximum temperature rise shall be 35^oC above 50^oC ambient. Bus-bars shall be at the top of the cubicle in separate compartments, vertical bus-bars shall be isolated from central compartments by metallic barriers or insulating sleeves. Bus support shall be arc resistant, no-tracking, low absorptions, moulded insulators, high impact strength and long creepage surface. It shall withstand short circuit stresses. Supporting calculations for bus-bar size calculations is to be provided.

- IS 8084 - Interconnecting bus bars
- IS 5082 – Aluminium / Aluminium alloy bars for electrical purposes
- IEEE Publication 298

4.17.4. Individual module

Individual module shall be draw out type comprising circuit breaker, isolating switch fuse, contactors, relays, lamp push buttons, wiring terminal blocks as per approved drawings. Lamp push buttons, relays shall be accessible from front outside.

4.17.5. Circuit Breaker

Circuit breaker shall be vacuum / SF6 type 3 poles, indoor, metal clad, draw out type, mounted on welded sheet steel, fault level 30 MVA or more depending on installed capacity. It shall be complete with transfer trucks aligning primary and secondary disconnecting device. Main and arcing contacts shall be of forged copper with brazed silver tungsten alloy. Provision for emergency trip, mechanical ON –OFF indicators, operation counter, mechanical charge- discharge indicator, manual closing device, safety shutters for female primary contacts, racking switch with 3 contacts for test and 3 for service position, operation in local and remote mode etc. shall be made. It shall be motor operated and shall have spring charging mechanism, trip free with anti- pumping arrangement auxiliary relays etc. it shall operate at 70% rated control voltage, 4 NO and4 NC auxiliary contact shall be provided. It shall have thermal overload and instantaneous magnetic release arrangement.

The circuit breaker can be classified on the basis of rated voltage. Circuit breakers below rated voltage of 1000V are called low voltage breakers and above 1000V are called high voltage circuit breakers. The classification of breakers based on medium of Arc extinction is as follows.

1) Air blast Circuit Breaker
2) Oil Circuit Breaker
3) Minimum Oil Circuit Breaker
4) Sulphur Hexafluoride Circuit Breaker (Single pressure or Double Pressure)
5) Vacuum Circuit Breaker

4.17.6. Isolating Switch

It shall be provided with triple pole/ double/ single pole air break making capacity equal to current rating of fuse and with removable type neutral link. External handle with position indicator and door interlocking shall be provided.

4.17.7. Fuses

These shall be HRC link type, minimum rupturing capacity of 30 MVA or more as per Installed capacity at 415 V, complete with fuse base, visible indication for blowing, possible to change with circuit alive, etc. AC rewireable fuses are not acceptable.

4.17.8. AC Motor Starters with Thermal Overload Relays, Single Phase Preventer

It shall be triple pole solenoid operated, air-break type, suitable for direct on-line start of required kW squirrel cage induction motor, Class-Ill category AC 3* IS:2959 duty. Its contactor should not drop out up to 75% rated voltage, Control circuit shall be protected by HRC fuse and shall have provision of 3 elements ambient temperature compensated bimetal thermal over load relay. It shall be manual reset type with knob at the front. The T.O.L, relay shall be connected directly or through C.T., and shall have auxiliary contacts for interlocking and Indication. Single phase preventer shall operate on negative phase sequence current. It shall operate at any load, and its resetting shall be possible by knob on front door.

4.17.9. Indoor Switchgear 3.3 kV, 6.6kV or 11 kV

In case panel type indoor switchgear of these voltages is adopted these can also be utilized as main control boards. The requirements would broadly be as described for 415 V panels above.

4.17.10. General Design Criteria for Control and Relay Protection Scheme

Various controls, protections required for generator, turbine, gates, valves, are indicated in their respective specifications in CBIP Publication 175. The Generator Protection shall necessarily include Stator earth fault protection 95% (59N), 100% stator earth fault protection (64G)

Negative phase sequence protection (46), Rotor earth fault protection (64 F), Loss of field protection (40), Generator over voltage protection, Impedance backup protection (21G)

Generator differential protection (87G), Reverse power flow protection etc. Other protections shall include Generator Transformer differential protection (87T), Transformer oil temperature rise protection (49Wo), Transformer winding temperature. rise protection (49w), Transformer oil surge protection (63S),Alarm for abnormal oil level in transformer conservator, Breaker failure protection (50BF),V/Hz relay 59VHz ,Buchholz relay protection (63),Transformer O/C relay on HV side (51 N),Transformer REF relay on HV side (87 TN), For Unit Auxiliary Transformer (UAT), Over current protection (50/51) and Sustained earth fault protection (LV side) (64) shall be provided . For Excitation Transformer Over current protection (50/51) shall be provided.

Outgoing and tie feeders shall be provided with 3 inverse time Over Current (51) and one inverse time earth fault relay for bus fault and back-up protection. All motors shall be protected against single phasing, O.C., etc. Control, protections for gates, etc., shall also be covered. Auto synchronizer, check synchronizing relay shall be considered in appropriate cases. Indications, annunciation, alarm due to fault in any equipment, such as various motor/transformer, gate operation, etc., shall be indicated on these panels. Isolations of these equipment, emergency tripping, etc., shall be possible from panels. However, tenderer may be asked to indicate additional protection if required to safeguard the equipment and also shall indicate the protections which could be deleted or are unimportant. However the actual relay protection scheme shall be finalized with the supplier during detailed engineering. Protection scheme shall be complete in all respects (including primary and auxiliary relays, timers contactors, etc.) to suit the requirements of protection, monitoring, alarm tripping for various equipment having R.T.D. or DTTD. Provision for continuous monitoring of Rotor insulation value shall be provided for either through Numerical Rotor Earth Fault (REF) relay or by alternate means. In case remote control operation is opted, then proposals for same may be asked separately.

- IS 8686 - Numeric / Static protective relays
- IS 3231 - Electrical relays for power system protection
- IS 1248 & IS 2419 - Indicating instruments
- IS 6236 - Direct recording electrical measuring instruments
- IS 722 (Part I to IX) - AC electricity meters
- IS 6875 - Control switches (LV switching devices for control and auxiliary circuits)
- IS 2705 - Current transformers
- IS 3156 - Voltage transformers
- IS 5578 - Guide for marking of insulated conductors
- IS 11353 - Guide for marking and identification of conductors and apparatus terminals
- IS 1554 - PVC insulated cables up to and including 1000 volts
- IS 3842 (Part I to IX) - Application guide for electrical relays for AC systems
- IS 9224 (Part II) - Low voltage fuses
- IS 13947 - Low voltage switchgear and control gear
- IS 6005 - Code of practice for phosphating of iron and steel
- IS 5 - Colours for ready mixed paints and enamels.
- IS 2147 - Degrees of protection provided by enclosures for LV Switch gear and control gear.

4.17.11. Protective Relays, Meters Auxiliary Relays CT, P T

These shall be of standard make only and got approved. These shall be draw out type, flush, semi-flush, mounted and shall operate at 70% to 110% rated voltage. Auxiliary relays may be plug in type also. All relays shall conform to IS : 3231 (latest revision). Auxiliary relay and timing relays for each breaker shall be indicated. These shall operate in less than 15 milli-seconds. Relays for automatic change-over scheme if any shall be indicated. All relays and their contacts shall be rated for 5 ampere C.T. secondary and 110 V P. T. secondary. Relay contact shall be capable of breaking/making maximum current of its control circuit. All relays shall have two pairs of independent contacts. Indicating meters shall be moving iron type with square, 90^{o}C scale (110 x 10 mm), accuracy class 1.5%, full scale 120% rated current flush mounting. Its zero adjuster shall be accessible from front. Integrating meters shall have current and pressure coil test blocks. The entire AC/DC ammeter, volt meter shall conform to accuracy class —1.5. Frequency meter shall be digital type and of accuracy class —1. Instrument should not damage due to passing of fault current through primary winding of their respective C. T. Integrating meter shall be provided with reverse stop.

4.17.11.1 Current Transformers (CT)

These shall be epoxy cast, dry type unit conforming to IS: 2705 latest revision. 415 V.C.T. shall be indoor type and 11 kV or 33 kV may be either indoor or outdoor type as per the scheme. C.T. shall withstand the thermal and magnetic stresses due to short-circuit. For big generators C.T shall be supplied by generator manufacture and shall be installed in the neutral grounding and line terminal cubicles. These shall be suitable for metering and protection. The accuracy class of Current transformers for protection shall be as per the Relay manufacturer specification and shall be finalized during detailed engineering. The accuracy class of Current Transformers for Metering shall be 0.2S class. The burden of CT shall be so decided that it is higher than the connected VA of the protective equipment with suitable provision for future addition of load.

4.17.11.2 Potential Transformer (PT)

It shall be single phase epoxy cast, dry type unit conforming to IS: 3156 latest revision. It shall be protected on primary and secondary side by current limiting fuses. The secondary voltage shall be generally 110 V unless specified. The accuracy class of Potential transformers for protection shall be 3P. The accuracy class of Potential Transformers for Metering shall be 0.2 class. The burden of PT shall be so decided that it is higher than the connected VA of the protective equipment with suitable provision for future addition of load.

4.17.11.3 Braking System

When the machines are stopped it may take more than half an hour for the machine to come to a stop unless a braking force is applied. During the final moments before the rotor finally comes to a stop the bearing thrust face will be crawling and there is every possibility for the erosion of the white metal of the bearing pads. Hence generators are provided with a braking system like frictional brakes usually of piston and cylinder type. The brake tracks are made in segments for ease of manufacture and also to allow circumferential expansion, since with prolonged braking the temperature of the track may rise to high levels. With high speed generators and small hydro generators with relatively small diameter, it is difficult to dissipate heat energy in the restricted area of brake track without distortion of the track. In such cases brake track is provided with steel cylinder attached to the outside of the rotor or on the rotor. A number of caliper brakes are fitted in which friction torque is applied on both side of the cylinder thus producing heat on either side of cylinder and avoids distortion.

Dynamic braking is applied in case of pumped storage units where frequent starting and stopping will be necessitated in a day. In this case after the generator has tripped, the three terminal are short circuited and the rotor winding is excited from a separate DC supply upto 75% of rated current on the stator winding and then frictional brakes are applied when speed is 25% so that the stopping time is minimized.

4.17.12. Vibration Monitoring System

The vibrations in a generator is mainly due to mechanical out of balance of rotor and is reduced to an acceptable level by static and dynamic balancing of the rotor. Another major cause of vibration is the failure of insulation between two adjacent turns of a rotor coil thus causing the coil to generate less mmf and flux. If a number of turns or the whole pole is shorted, the resulting vibration for a few seconds can seriously damage the bearing and its supports. A suitable vibration monitoring system consisting of detectors, proximeter and control unit can give early indications of the failures to the machines on account of loss of balancing.

4.17.13. Miscellaneous

Control panel shall have space heaters rated for 240 V, control wiring by flexible heat resistant, PVC insulated, stranded copper conductor 2.5 mm^2. Multi way terminal blocks with 20% spare terminals, power terminals with tinned copper crimping lugs, ground bus through the panel for specified short-circuit current shall be provided. General arrangement drawings, final wiring diagram with cable/terminal numbers, leaflets of various accessories, test certificates of major equipment, short-circuit and temperature rise calculation of bus-bars, list of special tools and tackles, list of spare parts of all major equipment for 5 years operation is to be insisted invariably.

4.17.14. Routine and Type Tests

These shall be as per latest revision of relevant I.S. including short-circuit, temperature rise and high potential test.

4.18 DC SUPPLY EQUIPMENT

4.18.1. DC Distribution Boards

These shall be designed for 110 V or 30 V D.C. batteries as applicable. Each D.C. circuit shall be protected by fuse and shall have suitable isolating switch indications, annunciation, etc. It shall conform to relevant I.S.

4.18.2. Battery and Battery Chargers

4.18.2.1 110 V DC, 200 AH capacity lead acid battery

No. of cells	:	55
Voltage of each cell	:	2V
Capacity	:	200 AH at 10 hours rate of discharge to 1.85 V per cell at 27^{o}C

The battery set will be equipped with: 1 set inter row/inter tier connectors for the above battery, 1 lot of sufficient quantity of sulphuric acid will be supplied with the battery set. One set battery stand for double row/double tier shall be supplied with the battery. All the standard accessories like hydro meter, cell testing voltmeter, thermometer, spanners, syringe, etc., one number each shall be supplied with the battery set. For hydropower stations Plante type battery system shall be insisted for reliable and safe operation. The capacity of the battery system including charging system for power house and switchyard shall be so designed that there is redundancy for both the areas.

4.18.2.2 24 V battery with Charger

One set 24 V 15 AH battery with charging equipment shall consist of:

12 numbers cell each of 2 V 15 AH capacity complete with inter cell connectors and lead acid indicating floats. The batteries shall be supplied in dry uncharged condition. The cell in general shall conform to IS: 1651-1979 latest revision.

4.18.2.3 Accessories to be supplied with the Battery

Wooden stand to accommodate the above cells in single row/double tier arrangement. The wooden stand shall be painted with three coats of anti-acid paint. 1 No. syringe type hydro meter, 1 No. thermometer with specific gravity correction scale, 1 No. rubber syringe, 1 No. acid resisting funnel shall be supplied with the battery.

The charging equipment consists of float charger and boost charger with the necessary components housed in a common cubicle made up of suitable angle iron structure and sheet steel of 2 mm thick for front panel and 1.6 mm thick for the other panels. The float and boost charger shall operate on 3-phase, 4-wire 415 V AC 50 Hz.

The A.H. capacity and voltage of battery may vary as per the proposed scheme. The tenderer shall indicate it for scheme proposed by him.

4.19 H.T. BREAKERS (33 kV OR 11 kV OR 6.6 kV OR 3.3 kV)

The H.T. breakers as per scheme can be either Kiosk type or outdoor switch yard type. These may be SF6 or vacuum breaker. The fault level for breakers up to 11 kV may be taken as 250 MVA and for 33 kV it shall be 750 MVA. The breakers shall be conforming to relevant I. S. specification. It shall have ammeter, voltmeter, IDMT relay; earth fault relay, alarm, annunciation, etc. These may be included in control relay panel for complete P.H.

4.20 ISOLATING SWITCHES, LIGHTNING ARRESTERS

Isolating switches of double break type, horizontal air break switches for 33 kV or 11 kV side of power transformer. It shall have arcing horns, line type lightning arresters on incoming 33 kV or 11 kV line. Standard voltage rating for 11 kV L.A. should be 9 kV, current rating 5 kA, maximum 100% spark, 1.2/50 spark over voltage 32.5 kVP. For 33 kV arrestor it shall be 30 kV (rms). 5 kA or 10 kA, 108 kVP respectively. However the lightning arresters for Generators shall be suitable non effective earthing say for eg.LA rating shall be 12 kV for 11 kV.

- IS 1180 - Outdoor type three phase distribution transformers
- IS 2026 - Power transformers
- IS 3043 - Code of practice for earthing
- IS 9046 - AC contactors
- IS 13118 - Circuit Breakers
- IEC 60947 - Low Voltage Switchgear & Control gear
- IEC 62271 - High Voltage AC Circuit breakers
- IEC 60044 - Instrument Transformers
- IEC 60076 - Dry Type Transformers
- IEC 62060 - Secondary cells and batteries – Monitoring of lead acid stationary batteries – User guide
- IEC 60896-21 - Stationary lead-acid batteries –Valve regulated types –Methods of test
- IEEE 484-1996 - Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications.
- IEEE 450-2002 - Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications.
- IEEE 485-1997 - Recommended Practice for Sizing Lead Acid Batteries
- IEEE 1184-1994 - Guide for the Selection and Sizing of Batteries for Un-Interruptible Power systems
- IEEE 1375-1998 - Guide for Protection of Stationary Battery Systems
- IEEE 1491-2005 - Guide for Selection and Use of Battery Monitoring Equipment in Stationary applications.

4.21 POWER AND CONTROL CABLES

The FRLS (Fire Retardant Low Smoke) type cables shall be preferred. Power cables which are buried in ground should be armoured. The armouring should be covered with water-proof jute or PVC, etc., to prevent corrosion. As far as possible, cable route should be accessible throughout their length. Cables should be either buried or carried in pucca trenches depending upon the site condition. Cables trenches, if provided, should have suitable slopes, to ensure automatic draining of rain water. Where necessary, a sump may be provided to collect water. When more than one power cables are laid in trench, they should be separated by providing suitable cable clamps. If cable are buried, separate route may be followed to facilitate repair of faulty cable. In selecting the size of the cable for any particular service, the short-circuit rating of the cable should be considered in addition to its normal current carrying capacity, taking into account the derating factors.

Control cables may be single core or multi core PVC insulated and PVC sheathed, 2.5 sq mm copper conductor. As far as possible control cables should have a different route from power cables, In case they are laid in the trenches along with power cables, they should be separated. The control cables, wherever laid directly in the ground, should be armoured. In case suitably protected trench/ trays are provided for then unarmoured cables can be accepted.

Cable end markers and code numbers/alphabets should be provided at both ends for easy detection of the faulty cable and replacements, etc.

The size of each of the cable is to be finalized during detailed engineering.

4.22 EARTHING SYSTEM

Earth mat shall be designed with mild steel flats/bars. Earthing System shall conform to IS:3043-1966 latest edition and Indian Electricity Rules 1956 along with latest amendments. Voltage between any two earthed points not to exceed 32 V. Earthing shall be done by 25 mm x 6 mm M.S. flat up to 6 MVA capacity and by 50 mm x 6 mm M.S. flat for 10 MVA capacity.

Size of earthing rod shall be 22 mm dia 3 m long, buried in ground at a depth of 0.76 m. Number of electrodes should be such so as to limit the current carried by each rod up to 500 amp. Number of electrodes shall vary from 10 to 15 depending upon soil resistivity. The value of resistance of the earth shall be so maintained so as to make operation of the protective device effective. Soil treatment with salt, charcoal, etc., shall be done to bring down soil resistivity to 60 ohm-m. Earthing electrode shall be uniformly distributed and located adjacent to fencing. Spacing should be more than depth of rod. Top end to be connected with MS flat of 25 x 6 or 50 x 6 as the case may be. The earth mat shall cover all equipment including auxiliary transformers.

4.22.1. Equipment to be Earthed

a) Neutral point of generators, transformers, neutral conductor of 3-phase — four wire system etc.

b) Equipment framework, other metal parts and all non-current carrying metal parts associated with HV/EHV installation.

c) Boundary fence steel structure, etc.

Two earthing connections to two separate electrodes for all the equipment shall be made. Earth connections for lightning arresters shall be made directly to the electrode or at the junction of the earth mat.

- IS 3043 - Code of Practice for Earthing
- IEC 62305 - Protection against Lightning
- IEC 61140 - Protection against Electric shock
- IEEE 80 - Guide for Safety AC Substation Grounding

4.23 ILLUMINATION AND VENTILATION

Illumination at all the important locations such as Powerhouse, Switchyard, Bypass Gate Area, D.T. Gate, etc. shall be carried out as per relevant I.S. specifications and accordingly calculations shall be asked for the same. It shall include emergency lighting also.

All the fittings, luminaries, conduits, wires fixtures, etc., shall be of standard make good quality. In the general layout of whole scheme, locations of various important luminaries may be indicated. Illumination scheme can have following different types of lamps.

(i)Twin tube light fittings.

(ii) Halogen/sodium vapour lamp.

Emergency light: wattage, number, location shall be indicated.

As part of Energy conservation, possibility of use of LED & other energy efficient lighting, use of energy efficient motors, solar energy shall also be explored and used wherever feasible

- IS 4013 - Dust-tight Light Fittings
- IS 1944 - General Lighting
- IS 9583 - Emergency Lighting System
- IS 1913 - General and Safety Requirements for Luminaries

Ventilation: It shall be conforming to relevant I.S. specification and shall include exhaust fans, ceiling fans etc.

Air conditioning of critical areas shall be included in the scope of works by adopting most energy efficient techniques.

4.24 CRANE FACILITIES

Large substations sometimes require the facilities of repair bay along with a crane of adequate capacity for handling the heaviest equipment, which is usually the transformer. In hydropower station powerhouse crane is generally used for this purpose. Repair/Service bay of powerhouse is used for repair of transformer.

Provision of a rail track should be made for movement of transformer from switchyard to the repair bay. Points for jacking, winching should be provided at the transformer foundations and 90^o turn on the rail track for changing the direction of the wheels.

The possibility of using A frame cranes, Goliath crane etc shall also be explored as part of cost reduction before deciding on the type of crane for the power house.

4.25 FIRE PROTECTION SYSTEM

If any oil filled transformers are used in the power plant, provisions should be made to contain any oil leakage or spillage resulting from a ruptured tank or a broken drain valve. Physical separation in the use of fire wall/barriers is also provided in power plants. Specifications for fire protection of power transformers may be provided in accordance with CBI&P manual on Transformer in Section 'O'

The arrangements of fire protection in Power house and switchyard may be divided under the following three groups:

(a) Fire Protection scheme for Generators

(b) Fire Protection for generator transformers located in outdoor switchyard.

(c) Fire Protection of the area and equipment in power house not covered nder above two groups.

The details of the equipment and method of firefighting scheme for above referred equipment / area shall be designed, manufactured, installed and commissioned generally as per the scheme.

The Fire protection scheme shall follow the IS code 10386 Part 5 & 7 for hydroelectric stations

4.26 POWER EVACUATION SYSTEM

The most feasible proposal for power evacuation from the proposed generating station is to be firmed up before tendering of the E&M activities. The arrangement for evacuation of power depends on the number of generating units, capacity of units, voltage of generation, voltage of transmission security of power supply and the cost of the evacuation system. The evacuation voltage level is to be finalized considering the proximity and voltage levels at the receiving substation, the line route, forest clearance aspects etc. The evacuation system can be unit system or Non unit system. In unit system each generator is provided with its step up transformer and generator circuit breaker. The generators of the powerhouse are paralleled at the transmission voltage. This system has the highest reliability and consequently the system is costlier also. In non-unit system, all the generators in the powerhouse are paralleled at generation voltage. The generation bus is connected to the transmission bus through one or more step up transformers, which is to be decided judiciously.

4.27 SWITCH YARD LAYOUT

Switchyard design criteria include equipment layout with safety clearances, short let force calculation etc. Adequate land required for power evacuation and "right of way" as per standards to be assessed considering possible future requirement also.

The Equipment shall be designed, manufactured, tested, installed and commissioned in accordance with the latest revision of applicable IS/IEC or equivalent standards.

- IS 8686 - Static protective relays
- IS 3231 - Electrical relays for power system protection
- IS 1248 & IS 2419 - Indicating instruments
- IS 6236 - Direct recording electrical measuring instruments
- IS 722 (Part I to IX) - AC electricity meters
- IS 6875 - Control switches (LV switching devices for control and auxiliary circuits)
- IS 2705 - Current transformers
- IS 3156 - Voltage transformers
- IS 5578 - Guide for marking of insulated conductors
- IS 11353 - Guide for marking and identification of conductors and apparatus terminals
- IS 3842 (Part I to IX) - Application guide for electrical relays for AC systems
- IS 9224 (Part II) - Low voltage fuses
- IS 13947 - Low voltage switchgear and control gear
- IS 6005 - Code of practice for phosphating of iron and steel
- IS 5 - Colours for ready mixed paints and enamels
- IS 2147 - Degrees of protection provided by enclosures for LV Switch gear and control gear.

4.28 Safety Aspects

Safety aspects are to be given prime importance in the execution of the project and the operation and maintenance of the station. Fire exit, emergency exit, ladder, handrails etc. shall be provided for at all required places as per prevailing regulations

4.22.2. ERECTION, TESTING AND COMMISSIONING

The Equipment shall be designed, manufactured, tested, installed and commissioned in accordance with the latest revision of applicable IS/IEC or equivalent standards.

- IEC test Code 41 - International Code for Field Acceptance Tests on Hydraulic Turbines
- IEC Publication No. 308 - International Code of Tests of Speed Governing System for Hydraulic Turbines
- IEC Test code 545 - Commissioning Guide for Hydraulic Turbines
- IEEE 472 (1974) - Testing of Electronic Circuits of Governor
- ASME performance test code 29 for governor acceptance test
- IS 5456 - Testing of air compressors

Reference documents (E&M part)

1) Standards/Manuals/Guidelines For Small Hydro Development (version 2) published by the Ministry of New and Renewable Energy Govt. of India and Alternate Hydro Energy Center Indian Institute of Technology Roorkee.

2) Publication No. 305- Manual on Development of Small Hydroelectric Projects published by The Central Board of Irrigation and Power

3) Relevant IS, IEC codes stated in the above reference documents

4) CEA(Technical Standards for Construction of Electrical Plants and Electric Lines) Regulations 2010

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