LOW HEAD HYDEL SCHEME ON CANAL FALLS

By

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1.0 Conceptual Design

Due to acute shortage of power attention of the Government as well as the private sector has focused on utilizing the falls on existing irrigation canals network spread all over Pakistan. This is the time when it should be declared by the Government that no new canal will be built without provision of Turbine Bays for installing Turbo Generators on the fall structures at any stage.

With the above stipulation in mind I am writing this paper to give a conceptual plan and design which I hope will be useful to the Engineering Community, specifically those working on the vast irrigation canals network. Of course the situation on the existing canal structures will require development strategy individually as per local conditions.

2.0 Hydraulic Parameters

Following hydraulic parameters have been assumed for design of the lined power canal, the spillway structure and turbine bays: Reference drawings 1 and 2 attached here.

i)	Full Supply Discharge of the lined canal	=	43.2 m^3/s
ii)	Full supply level upstream of fall	=	97.84 m.a.m.s.l.
iii)	Full Supply Level downstream of fall	=	88.0 m.a.m.s.l.
iv)	Available Gross Head (F.S.L u/s – F.S.L d/s)	=	9.84 m. (Say 10.0 m.)
v)	Minimum water level upstream in partial Operation (16.5 m^3/s flow)	=	96.99 m.a.s.m.l.
vi)	Depth of water in upstream lined canal against full supply of 43.2 m^3/s.	=	1.85 m.
vii)	Depth of water in upstream lined canal against half supply of 21.6 m^3/s.	=	1.2 m.
viii)	Depth of water against partial supply of 16.5m^3/s	=	1.0 m.
ix)	F.S Depth of flow in earthen tail race	=	2.5 m.
x)	Minimum level water level on downstream Structure with partial canal flow (16.5 m^3/s)	=	87.0 m.
xi)	Maximum head for uplift and exit gradient	=	97.84-87.0 = 10.84 m.
xii)	Lined canal section:		
	a) Bed width	=	15.0 m.
	b) Side slopes	=	1.5:1
	c) Velocity of flow in lined canal for full supply	=	1.31 m/sec
	d) F.S. depth for 43.2 m^3/s	=	1.85 m.
	e) Longitudinal slope of canal bed	=	0.00026

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f) N.S.L.[1] upstream of fall = 100.0

g) N.S.L. downstream of fall = R.L.[2] 90.0

h) Sub-soil WL = R.L. 85.0

3.0 HYDRAULIC DESIGN OF SPILLWAY AND TURBINE BAYS

While combining a hydel scheme with the outfall structure it is considered necessary that the spillway caters for full flow discharge and no bypass through turbines is taken into account. It is of-course correct that even on no load working, the turbines can pass some portion of full capacity discharge, but taking no risk it has been decided to consider that the turbine bays are completely closed and the hydel plants are shutdown.

With the above background the spillway is to be designed for 43.2 m^3/s for normal operation and complete energy dissipation in the cistern at the downstream end. Two turbine bays each with a capacity 21.6 m^3/s have been provided to install two Turbo-Generators. The turbine bays are placed in the middle while two spill bays each to cater for half the flow is placed on either side. This is done as the flow will be mostly passing the hydel plant bays in the middle which will ensure uniformity of flow in downstream channel. The spill bays will operate infrequently when the flow through each side will be released equally.

3.1 The maximum drop at the outfall in case of full flow would be from R.L. 97.84 to 88.0, which is about 9.84 meters. This is a high drop for a conventional glacis/cistern type of fall design on an alluvial soil and, therefore, following aspects needed special consideration.

i) In alluvial soils, in case of such a high drop exit gradients at the end of the structure will be excessive requiring either long upstream floor or deep end cut off, in shape of sheet piles.

ii) In case of deep end piles the exit gradient will reduce but the uplift on cistern floor will be very high, needing thick gravity floor.

iii) Uplift pressure created by seepage flow net all along the glacis and the lower cistern floor will be high needing thick gravity structure. Dissipation of surface flow energy will however not pose any difficulty as the intensity of flow is not much i.e. about 4.0 m^3/s per meter width.

iv) A long glacis structure with 1 in 2.5 to 3.0 slope based on weak alluvial soil will not be structurally safe due to weak foundation and with this high cross head (height of structure) chances of slippage are there. More-so in case of earthquake the structure will be subjected to further sliding forces and failure due to slippage may be accentuated. It is, therefore, decided to split the total fall in two steps and thus provide a longer base. First fall is thus designed from R.L. 97.84 to R.L. 94.0 i.e. a drop of 3.84 meters. This will work as a vertical drop fall and the second stage from R.L. 94.0 to R.L. 87.5 (6.5 meters drop) is designed as a conventional glacis fall, with a long and deep cistern at the end for complete energy dissipation.

v) The above arrangement i.e. the first fall bay is also incidentally required to create a surge pond at the Inlet of penstock for accommodatery the large bell mouth entry. Please see attached drawing 1 & 2.

vi) For increased stability of the structure additional rows of cross sheet piling has been provided under the first phase cistern, and toe of glacis.

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1. N.S.L. = (Natural Surface Level)
2. R. L. = (Reduced Level)

vii) It may be noted that this double fall arrangement will not be needed in case of drops less than 6.0 meter where the structure even on week alluvial soil can withstand the extra forces discussed above. Please see drawing-3.

3.2 It is decided to adjust the total waterway into four bays each 5.4 meters wide. The two side bays will act as spillway while the middle ones will have two smaller T. G. units[1] in place of one to get maximum efficiency even in partial flow. The second purpose is to generate at least 50% energy even in case of failure, repairs / refitting needed in one of the Turbo generators. The 5.4m width, it was studied, would accommodate a bulb type or vertical axis Kaplan turbine, considered most suitable and efficient for the capacity discharge of 21.0 m^3/s and a gross head of 10 – 11 meters or near about.

3.3 The turbine bays and the spillway is of uniform width from the crest of the fall (end of canal) to the tail exit. The spillway section will thus maintain a uniform flow all along. The first stage fall with its crest at bed level of the canal (95.99) and a vertical fall is envisaged forming a trajectory at full supply, falling within the enclosed well cistern, so as to almost completely destroy the energy released at this stage through impact. The second crest at start of glacis is fixed at R. L. 92.0 from where the second stage chute will operate and the lower cistern to be designed to completely destroy the energy generated, before the flow enters the earthen tailrace.

3.4 It may be observed that the turbine bay width of 5.4 meters cannot pass the design discharge of 21.0 m^3/s at the crest if the same crest level is provided as in case of spillway (i.e. keeping depth over crest same as the flow depth in canal). This is so as the crest of spill bay works as a free fall and the discharge over it, is determined on the basis of following equation ;

$$Q = CBH^{3/2}$$

Where C = 1.7 in Metric System

$$Q = 1.7 \times 5.4 \times 1.8^{3/2}$$

$$= 23 m^3/sec$$

In case of flow to the turbine bays the fall is completely drowned to get the full head for power generation and flow into the bay will depend on the approach velocity i.e canal flow velocity. Thus water way needed will be ;

$$\frac{Q}{V} = \frac{21.6}{} = 16.3 m^2/s$$

So Depth needed = $\frac{16.3}{5.4}$ = 3.1 meters

To obtain this depth the canal bed needs to be depressed by 1.26 m for approaching the turbine bays.

It was, therefore, found necessary to increase the flow depth in the canal at u / s while approaching the middle turbine bays. The increase in depth has to be created gradually by depressing the approach floor from R. L. 95.99 to R. L. 94.73. Please see drawing 1 & 2.

3.5 For sizing of Turbine bays and power house civil structure, the dimensions of Turbo-generators including loading weights etc can be easily obtained on INTERNET /

1. Turbo Generators.

WEBSITES from known international equipment manufacturers e.g. VOITH, MITSUBISHI, FUJI, BIWATER, SULZER etc.

The supplier will only need Gross-Generation head and design discharge available, which the Civil Engineer designer must have worked out based on hydrology of the selected site. The power generation of each unit and number of units to be installed is also assessed on economic consideration. Total generation capacity can be worked out as per following formulae;

P = 8.4 QH kilowatts.

Q = Discharge in cumec

H_n = Net Generation Head (Gross Head – Losses at Entry & Exit and penstock friction losses)

In this example;

H_n = (10.0 – 0.4) = 9.6 m (Assumed losses 0.4m)

P = 8.4 x 21.6 x 9.6 = 1700 kw

Or 1750/1000 = 1.7 mw for each Turbine Generator

Total generation for 2 units = 3.4 MW

3.6 The operation of spillway and turbine bays is envisaged to take place as follows:
With the full operation of the canal, two hydel turbo-generators will become operational and total flow will pass through turbine bays. Any load rejection will initiate operation of the two spill bays, which will escape the full flow in case of total load rejection or closure of turbine bays. However the regulation of the two spill bays must always be done simultaneously to pass down half of flow through each to maintain uniformity of flow on the downstream end cistern and the tailrace canal.

4.0 STRUCTURAL DESIGN

4.1 Power house structure is basically designed as a gravity structure to counter the main forces of uplift on cistern floors (upper and lower cistern) and the glacis, caused due to ground water movement at the site from upper level to lower level. Ground water seepage, flow line network will be formed starting from u/s cutoff or pile at the start of the upstream pacca floor and will exit at the downstream of end piles. The pressure head will be the difference of upstream F.S.L and the downstream F.S.L.[1] or in worst case the downstream floor if there is no flow in the tailrace. FSL in the canal in our case would be RL 97.84. The lower water level creating the different head is the minimum water level in the tail race channel which is earthen section. The minimum level would thus be against partial flow of 16.5 cumec, i.e RL. 87.0. The gross differential head causing uplift on the structure floors will thus be 97.84 - 87.0 = 10.84 meter.

The balance uplift pressure at various points along the structure as well as the Exit-Gradient has been analysed by Mr. Khosla's on the basis of flow line network and he had also prepared diagrams for direct easy solution which can be referred.

In this example the power canal is lined and, therefore, very little seepage could be expected and can assume an extended pacca floor on the upstream approach to the fall. This leads to longer travel of ground water flow lines, reducing the uplift pressure on the downstream structure i.e glacis and cistern. The reduction will depend on extended length of upstream floor, as assumed it can be as high as 50% to 60%. The exit gradient

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1. F.S.L. = (Full Supply Level)

will also reduce proportionately. Another rational alternate would be to reduce the head across ‘H’ by 50% or 60% in view of the long lined bed and assess the uplift pressures and exit gradient based on the reduced head and normal upstream pacca floor length.

It has also to be observed that normal ground water level in the vicinity too would create uplift pressure, under the cistern and should be considered when there is no flow and the cistern level is lower than RL 85.0. i.e sub soil water level in the neighborhood.

4.2 The thickness of cistern floors and glacis has to provide total weight against residual uplift pressure at various points along the structure base, calculated on the basis of flow lines through the non-cohesive alluvium. In case of lower cistern weight of vertical vanes, wing walls will also add to the counter weight. Similarly power house super structure loading as well as the weight of machinery should be taken into account. The structure should therefore be designed in R.C.C. with the cistern bottom as a raft. It would be economical in cost by reduction in raft thickness and sizing of wing walls etc.

4.3 The exit gradient of seepage flow lines at the end of the structure can be reduced with the help of a deep steel sheet piles cut off, across the section. In this example it is taken 8 meters deep (from crest of toe wall) and has helped to provide a safety factor of 7 against floatation gradient, which is considered very adequate for the alluvium soil.

4.4 Rows of steel sheet piles have also been provided under the wing walls to reduce uplift pressure from the seepage from sides, as the ground water level at the point may be as high as R.L 85.0 while the water level in the lower cistern and part of glacis could be lower in some situations.

Incidentally the rows of the sheet piles on sides (under wing walls) and three rows across, i.e., under the end toe wall, at the junction of glacis and lower cistern, and upper two rows under upper cistern, would form a box to provide required foundation stability so much needed in case of the weak soil. Specifically the four rows of cross sheet piles will add to stability against sliding, even during an earthquake.

4.5 Full load of the hydel power house building, to rest on R.C.C. wing walls and central vanes, has to be taken into account, as also the weight of turbines, generators, power house crane and other accessories for soil loading. Partial submergence of the structure as well as uplift pressures due to gradient of ground water movement has also to be considered for the design of base under worst cases of loading and sliding forces.

4.6 Horizontal seismic acceleration has to be adopted as per latest code of Pakistan.

4.7 An A-class loading service bridge has been provided at the upstream end of the outfall structure for ease of movement.

4.8 Steel gates at the upstream end are provided to control flow into each bay. These can be manually operated or better electrically powered and automatically operated.

Trash rack at upstream end of the turbine bays will keep the flow through turbines free of trash. This would be manually cleaned as not much trash is expected in the lined canal.

4.9 Stop log arrangement at the upstream and downstream ends of the turbine bay has to be installed for emergency closures, when the gates are stuck up or are to be repaired / painted.

4.10 When installation of Turbo-generators has to be taken up at a later stage and outfall structure including turbine bays have to be completed earlier vertical steel reinforcement of the walls and vanes may be projected 0.5 meter above the wing walls for 2nd stage construction and protected against rusting by enclosing the bars in 1:4:8 lean concrete.

It would however, be more practical if the power house building i.e the machine hall loading bay and control room are completed along with the structure, as shown in the attached figures. The total required area can be accommodated on wing walls and the bay walls.

4.11 In case the P.H machines have to be installed some time later the Turbine bays may be blocked by brick masonry walls on the upstream and downstream ends to enclose the area and leave it for the equipment supplier to do the installation work including gates stop locks, trash racks, penstock in the dry compartments at any later date and then dismantle the brick walls and commission the plant.

IMPORTANT

5.0 Following important considerations will have to be observed in design of Turbine bays :

i) The Bell mouth opening at the Intake should always be under water to avoid entry of air. For the purpose the upper lip must have about 0.8 meter water cover, even at lowest water level in the canal.

ii) Similarly the draft tube at exit must have not less than 0.8 m. cover (over upper lip) even with lowest water level in downstream channel.

iii) In case of Kaplan turbine including bulb type the suction head i.e. the difference between the Runner Centre line and the minimum downstream water level in the tail race has to comply with the following formula.

$$H_S = H_B\ (\sigma H + H_V + H_1)$$

Where

σ = Cavitations Factor. The value read from graphs represents data collected from existing plants. It would be better to contact the plant supplies and seek the correct values.

H_S = Desired Suction Head

H_B = Barometric pressure at Runner level

H = Net head of power generation. (Gross head – losses at entry exit of penstock)

H_V = Vapour pressure of water in meter (at the prevalent water temperature)

H_1 = height of runner blade leading edge above runner centre line in meter

= 0.15 D (for vertical shaft unit) where 'D' is Runner Diameter)

Or = 0.5 D (for horizontal shaft unit).

Values of σ, H_B, H_V & H_1 can be read from graphs given on next page. In case the value of H_S is positive the runner centre line can be placed above the minimum water level which would reduce excavation for laying the cistern foundation the draught tube and structure as a whole. However, if the value of H_S is minus, it has to be below minimum water level.

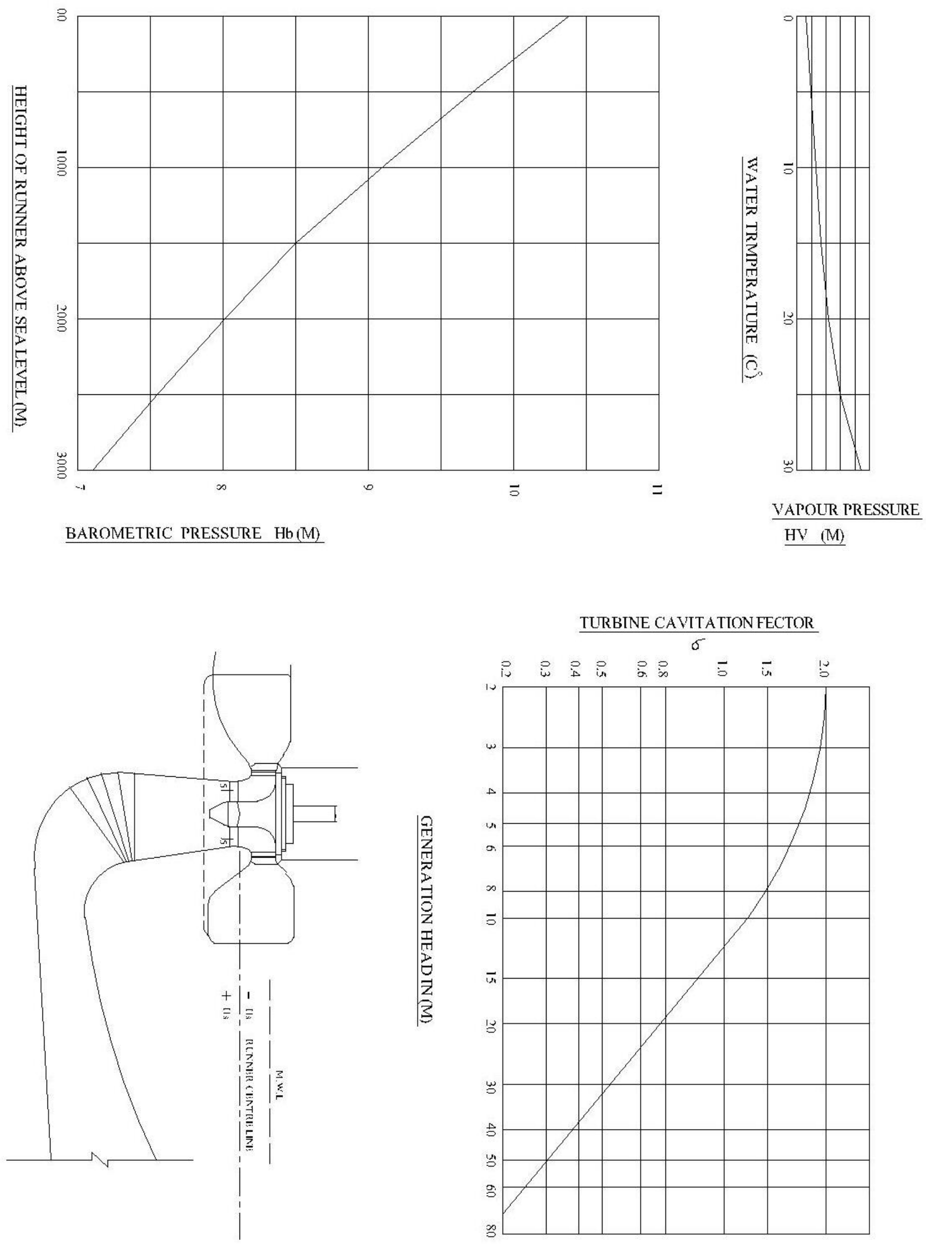
The settings higher than above value will cause pitting of blades due to cavitation and produce also loud thudding noise impairing smooth working and efficiency of turbines. The blades will thus need early replacement.
Calculated H_S value on the proposed plant will be;

$$H_S = H_B - (1 \times 10 + 0.4 + 0.3) = 10.3 - 10.7$$
$$= -0.4$$

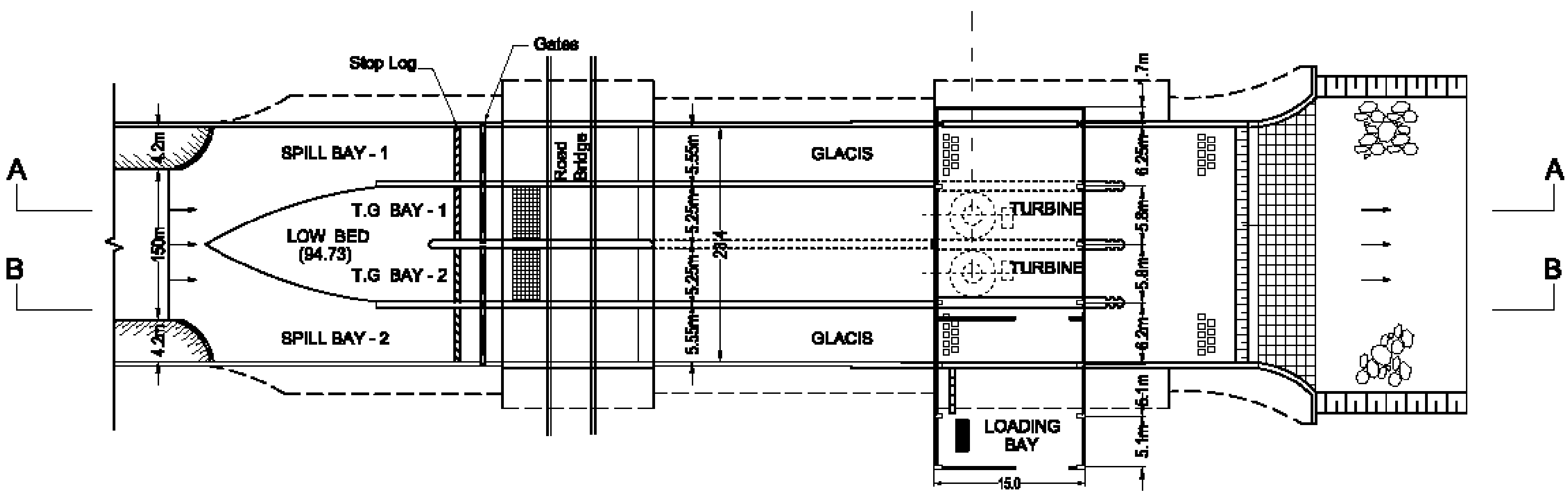
As $\sigma = 1.0$ from the graph

Thus the runner center line has to be 0.4m below downstream water level.

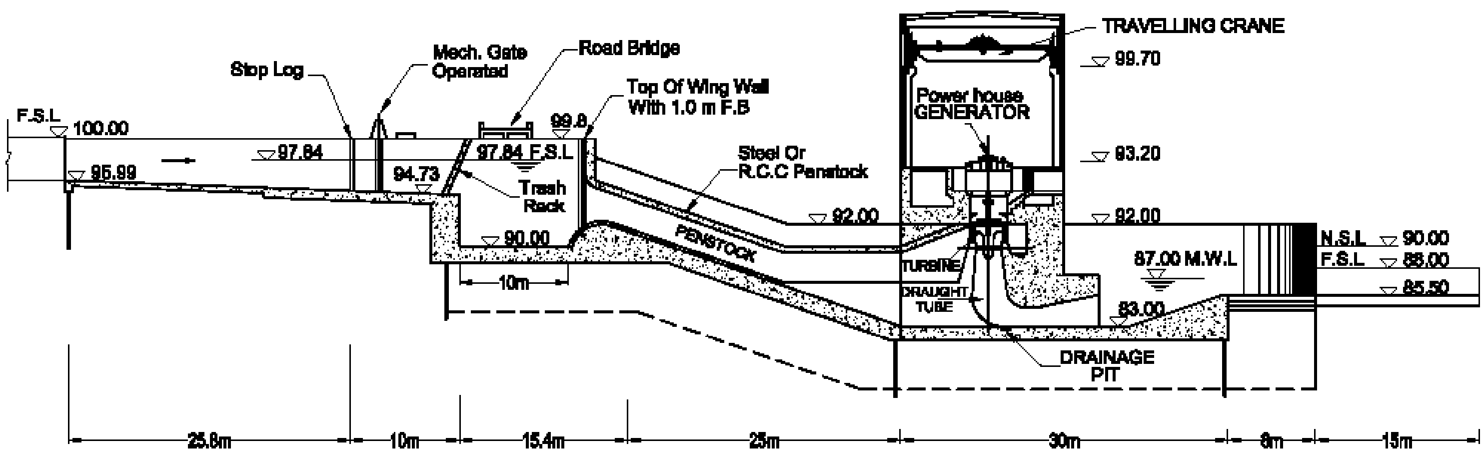
iv) The bed level of downstream cistern will have to be designed on the bases of providing upper conjugate depth (d_2) needed for formation of hydraulic jump with full flow in case of the spillway bay. On the other hand the Turbine setting has to meet the two parameters 5(ii) & (iii). Naturally the lower of all these levels in case of minimum water in the tail race, will have to be selected so as to provide a uniform cistern bed level in its entire length and width.



(Graph)

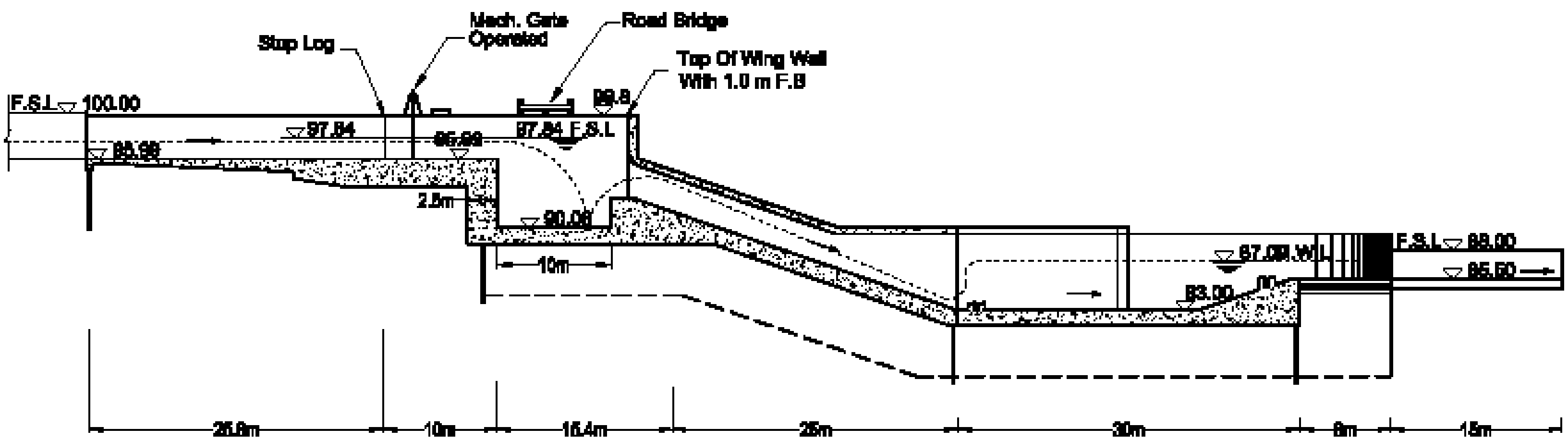


PLAN OF LOW - HEAD HYDEL POWER STATION



SECTION A-A - THROUGH TURBINE BAY

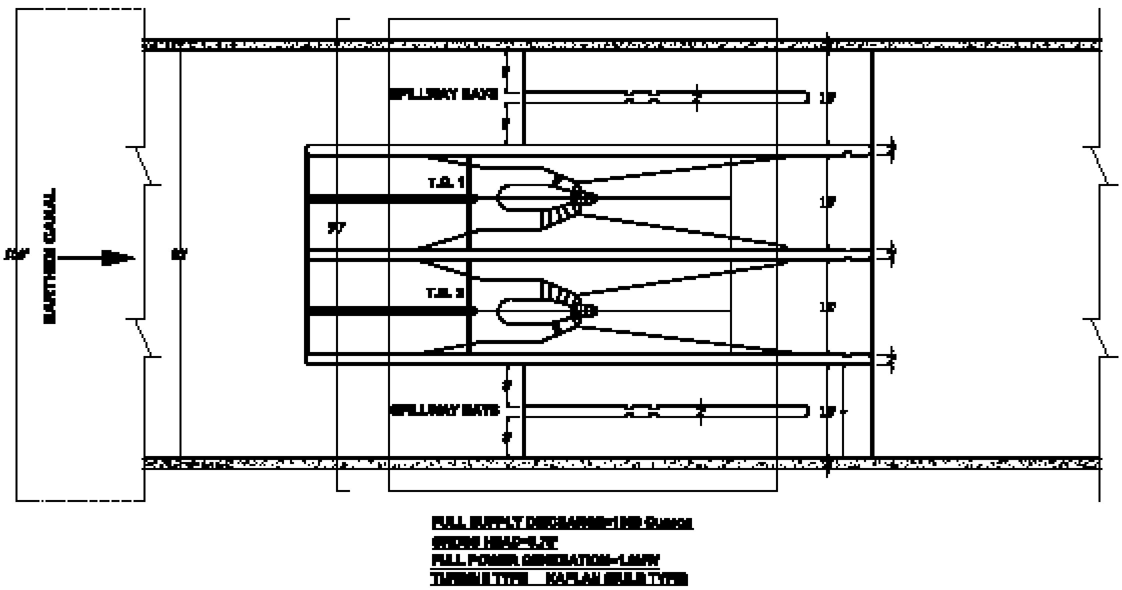
DRAWING NO. 01



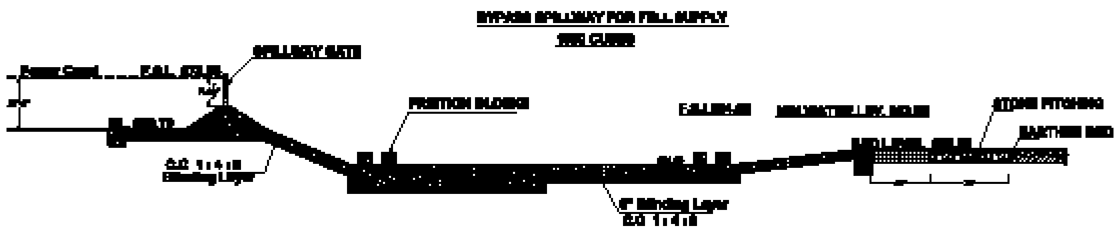
SECTION B-B - THROUGH SPILLBAY

DRAWING NO. 02

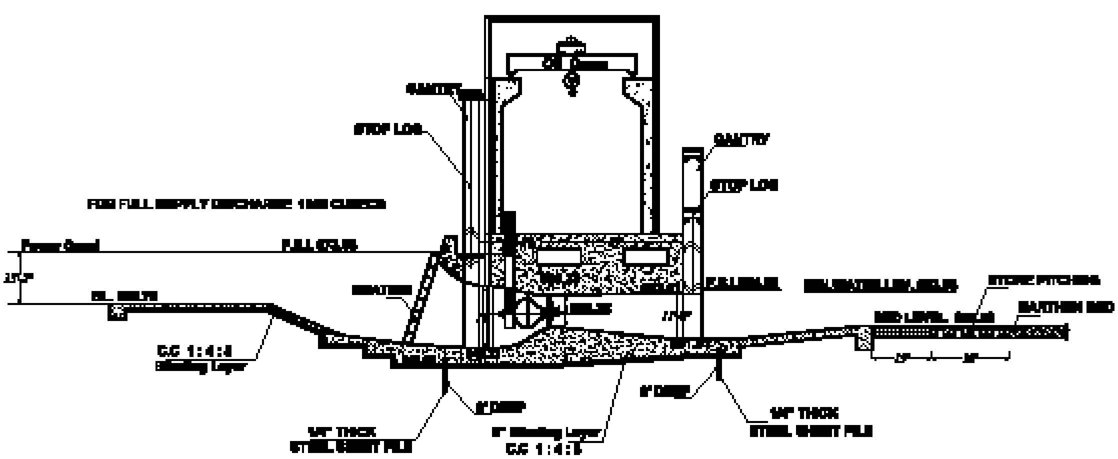
DIMENSIONS IN F.P.S



POWER HOUSE PLAN



SPILLWAY SECTION



POWER HOUSE SECTION

(Drawing No. 3)