Main Features of Civil Structure in Upper Kotmale Hydropower Project

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Abstract: An optimisation study was conducted on three (3) alternatives after the completion of the feasibility study on Caledonia and Talawakelle diversions. Out of these, 'Talawakelle Diversion - 150MW' was selected giving priority for the economic aspects and the system requirement. An appropriate project layout was formulated for Talawakelle Diversion alternative to utilise maximum water resources economically in the Upper Kotmale Hydropower Project area.

Main intake dam for the power generation was planned at Talawakelle across Kotmale Oya with six (6) tributary diversions by proposing measures to maintain waterfalls affected by the diversions. In the year 2005 the government decided to implement the diversion of Kotmale Oya in the upstream of St. Clair Waterfall excluding the six tributary diversions. Implementation of Upper Kotmale Hydropower Project was commenced based on the revised scope of Talawakelle diversion across Kotmale Oya with the original design for the waterways and Powerhouse Complex for 150MW hydropower plant.

The major civil structures such as 35m high concrete gravity dam, 13.9km length underground pressure tunnel, underground power house with access tunnel and cable tunnel, surge tank, outlet and other structures necessary for the operation of hydropower plant were completed as planned for the generation of electricity with an installed capacity of 150MW.

Keywords: Dam, head pond, headrace tunnel, surge tank, powerhouse, tailrace tunnel

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1. Introduction

The Upper Kotmale Hydropower (UKHP) plant was commissioned in July 2012 with an installed capacity of 150MW to meet the high growth rate of demand for electricity which is crucial for the economic development of the country.

Initially, it was planned to implement the UKHP with six (6) tributary diversions on Devon Oya, St. Andrews Ela, Pundal Oya, Pundal Fall Oya (Dunsinane Oya), Ramboda Oya and Puna Oya. In the year 2005, the government first decided to implement the diversion of Kotmale Oya in the upstream of St. Clair Waterfall keeping the original design for the waterways and underground powerhouse.

The construction of Lot 2 - Main Civil Works was commenced in January 2007 and main structures were completed on January 17, 2012 for the commissioning of wet tests of electrical equipment.

2. Major Civil Structures

For the implementation of UKHP as run-of-river plant, the following major civil structures were constructed.

- Dam and intake facility
- Head pond
- Headrace tunnel
- Surge tank
- Penstock
- Powerhouse complex
- Tailrace tunnel and outlet structure.

2.1 Dam and Intake Facility:

The dam with intake facility is located across Kotmale Oya at distance 1.25km downstream from the Talawakelle railway bridge. The dam can be accessible from both A7 and B412 national highways.

The UKHP diversion facilities consist of a 35m high concrete gravity dam having 180m crest length with appurtenant

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structures such as intake and inlet tunnel portal. As the dam height is greater than 15m, it was designed in accordance with the criteria of Japan National Committee on Large Dams. The other appurtenant reinforced structures were designed in accordance with JSCE allowable stress method.

Figure 1 shows the typical overflow section of the UKHP dam.

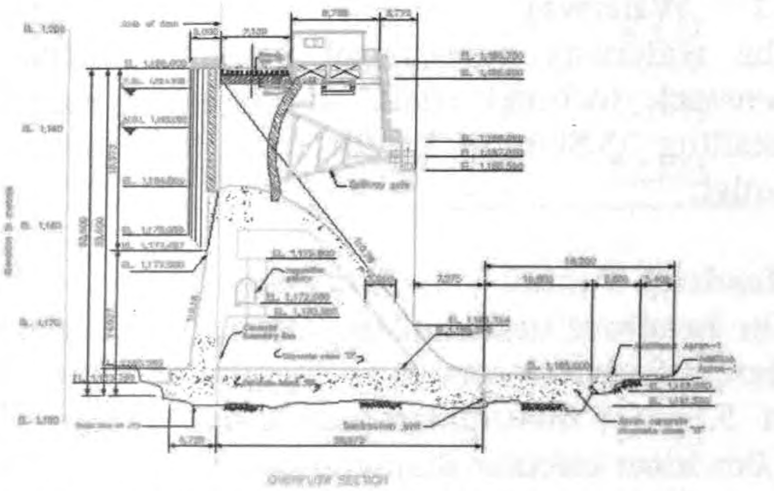


Figure 1 - Typical Dam Overflow Section

The intake channel was designed to have inflow velocity less than 0.24m/s at minimum operation level, in order to prevent inflow of large size sediment more than 0.3mm into the inlet tunnel. The most suitable shape for the inlet tunnel was determined by the hydraulic model test to avoid any vortex at the intake. The details of intake and inlet tunnel are shown in Figure 2.

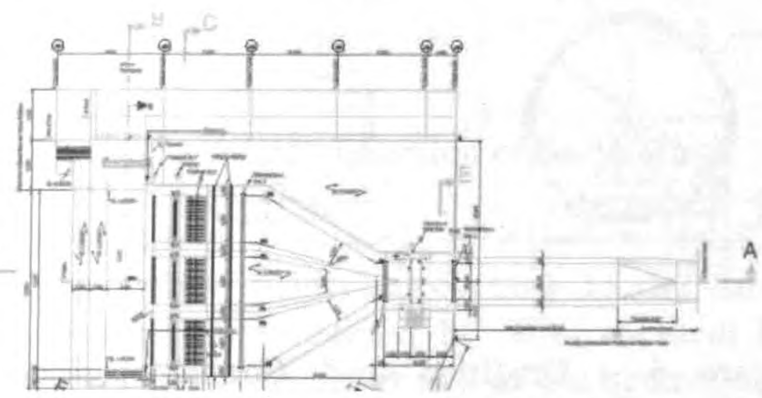


Figure 2 - Intake Facility

The concrete volume of intake dam was more than 60,000m³. Ordinary Portland cement mixed with fly ash was used for the preparation of concrete for the dam body. Concrete placing was done at night to avoid occurrence of cracks due to excess temperature rise of concrete.

The classes of concrete placed in the dam are shown in Figure 3.

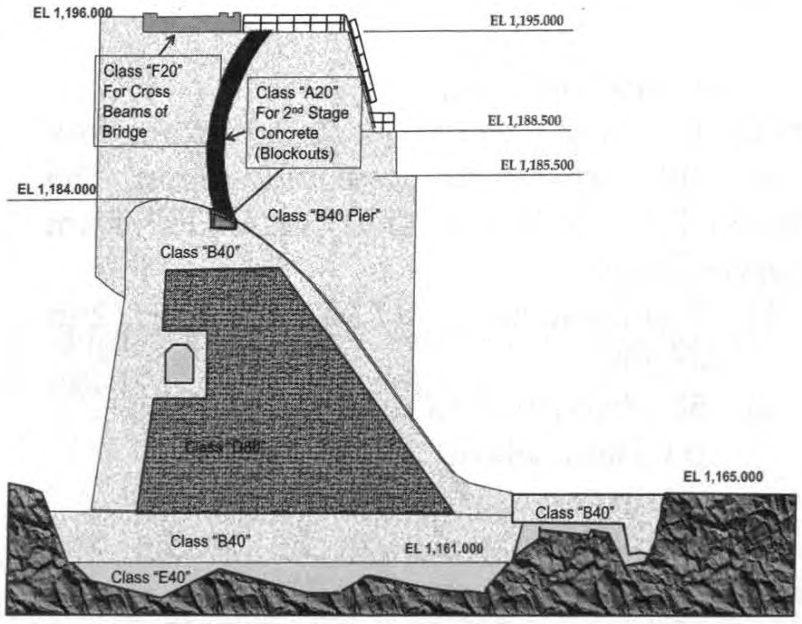


Figure 3 - Concrete Classes in Dam

The details of concrete classes placed in the dam are given in Table 1.

Table 1 - Concrete Types Placed in Dam

Class of Concrete	Part of Dam	Strength of Concrete (N/mm²)	Maximum Aggregate Size (mm)
Class A	2nd stage concrete for block outs	24	20
Class B	Outer part of dam body, apron	18	40
Class D	Inner part of dam body	12	80
Class E	Levelling concrete	12	40
Class F	Cross beam of dam deck	35	20
SCC	Underneath sand flushing structure	20	20

Grouting for Dam Foundation

a) Consolidation Grouting

Consolidation grouting was done to get 5Lu for improvement of water tightness and 10Lu for strengthening weak zones. It was done by drilling 126 holes with total grouting length of 630m (1st holes: 60, 2nd holes: 25, additional holes: 27 and shear zone holes: 14).

The total cement take was 8,156kg and the unit cement take was 12.77 kg/m in average. Lugeon values of 85% non-exceedance probability were below 5Lu (target) in 2nd holes and 3rd holes. All 1st and 2nd grouting holes exceeding 5Lu (target Lu value) were improved, and Lu values in additional holes (2nd hole or 3rd hole) showed less than 5Lu.

b) Curtain Grouting

Curtain grouting was carried out to form low permeability zone in the dam foundation. The targeted Lugeon Values (Lu) for UKHP Dam are given below.

1) 2Lu from surface of bedrock to H/2 in depth
2) 5Lu from H/2 to H in depth (H: Dam height)

113 holes with total length of 2,035m was carried out at 408 stages (Pilot: 55 stages, Primary: 39 stages, 2nd: 81 stages, 3rd:105 stages, Add: 5 stages, Check: 75 stages, and Diversion: 48 stages).

Total cement take was 11,783.83kg; the unit cement take is 6.12kg/m. Water tightness of the dam foundation was improved in accordance with the grouting procedure from Primary hole to the following holes. Grout-ability was fairly good. All stages exceed 2Lu (target Lu value) in standard holes (with two additional holes) were improved by grouting.

The curtain grouting details and check holes are shown in Figure 4.

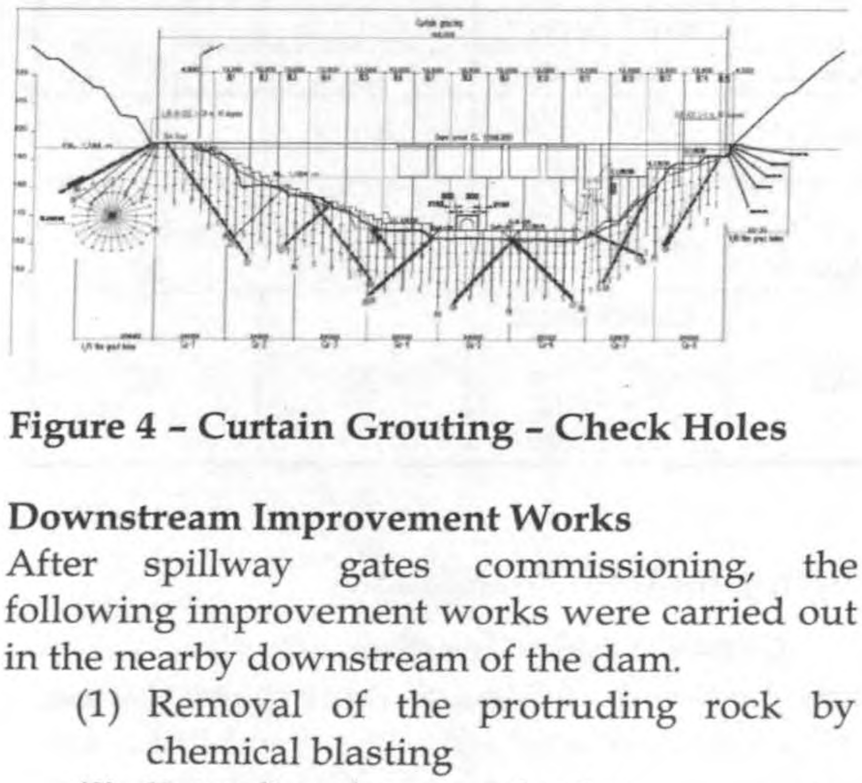


Figure 4 - Curtain Grouting - Check Holes

Downstream Improvement Works

After spillway gates commissioning, the following improvement works were carried out in the nearby downstream of the dam.

(1) Removal of the protruding rock by chemical blasting
(2) Extending the apron by 3m
(3) Filling pockets in the bedrock
(4) Placing rock anchors
(5) Filling concrete at edges; and
(6) Extension of training (guide) wall on the right bank.

The improvement work performed in the downstream of dam can be seen in the photograph in Figure 5.

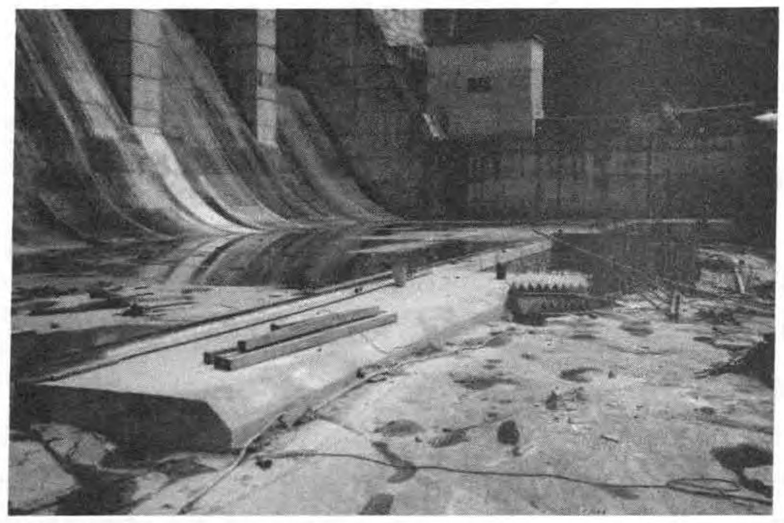


Figure 5 – Downstream improvement works

2.2 Waterway

The waterway consists of headrace tunnel, penstock inclined shaft and tailrace tunnel totalling 13.8km in length from the Inlet to outlet.

Headrace Tunnel

The headrace tunnel of the UKHP has a horse shoe shape cross section with an inner diameter of 5.8m for the unlined part of the tunnel and 5.0m inner circular diameter for concrete lined part of the tunnel. The headrace tunnel length is 8.0km from Inlet to Pundal Oya (Adit No.2) and 4.44km from Pundal Oya to Surge tank which total to 12.44km.

Lining of Tunnel

Depending on the geological conditions, some parts of the tunnel was lined with concrete and shotcrete.

The typical cross sections of concrete lined, shotcrete lined and un-lined tunnel are shown in Figure 6 and 7.

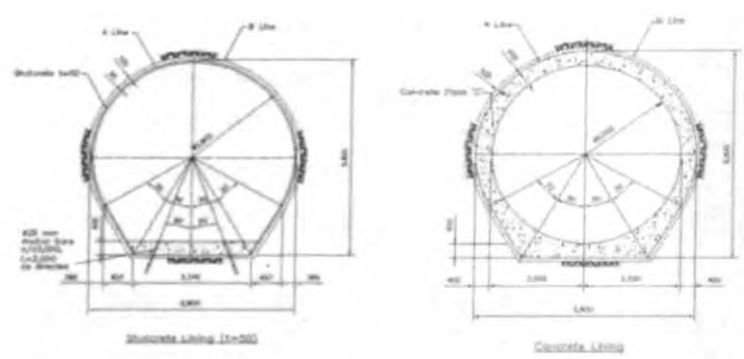


Figure 6 - Un-lined and Concrete Lined Sections of Headrace Tunnel

Figure 7 - Shotcrete Lining t=50mm and t=100mm with Wire Mesh

The total lengths of the concrete and shotcrete limning in the headrace tunnel are given in Table 2.

Table 2 - Lining in Headrace Tunnel

Type of Tunnel Lining	Length (m)
Reinforced Concrete	1,931
Shotcrete (t=50mm and t=100mm with wire mesh)	2,083
Unlined	8,427
Invert concrete	10,410
Total length	**12,441**

Upstream Surge Tank
After giving due consideration for damping of surging waves, the upstream surge tank was designed with following features.

Surge tank type : Restricted orifice
Internal diameter : 12m
Vertical height : 98m

The vertical section of the upstream surge tank is shown in Figure 8.

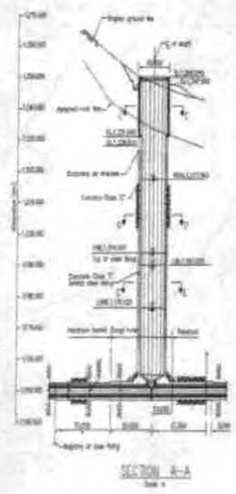


Figure 8 - Vertical Section of Surge Tank

Penstock
The section below surge tank to the turbine centres was connected by penstock steel liner pipe which was bifurcated at the upstream and connected to two turbines in the Powerhouse.

The Penstock having inside diameter of 4.3m to 1.45m was installed underground in the 793m section from EL1,150m at the bottom of the Surge Tank to Powerhouse at EL687m and on bifurcation at the lower horizontal section (two lanes of 49m) with the connection made to main inlet valve (MIV). The profile of the penstock is shown in Figures 9 and 10.

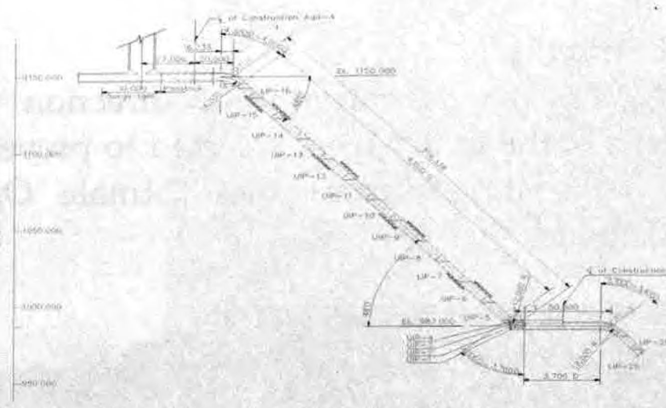


Figure 9 - Upper Horizontal, Upper Inclined and Middle Penstock

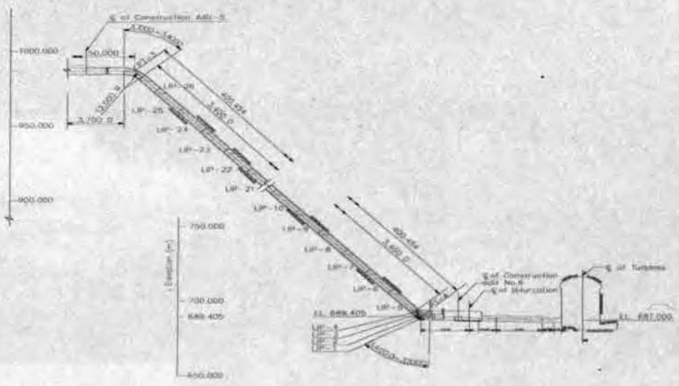


Figure 10 - Lower Inclined and Lower Horizontal Penstock

Tailrace Tunnel and Outlet
Considering the geological condition of the tailrace tunnel profile, it was decided to have concrete lining for the whole 475m length of tailrace tunnel similar to the headrace tunnel concrete lined section.

The photograph taken after completion of concrete lining is shown in Figure 11.

Figure 11 - Photograph taken after Completion of Concrete Lining inside Tailrace Tunnel

Two draft gates were installed taking into consideration of the future high water level of Kotmale Reservoir.. The details of the downstream surge chamber are given below:

Surge tank type : Restricted orifice
Internal diameter : 8m
Vertical height : 57.7m
Upper Chamber : Width 4m; Height 12m

Outlet Structure
The location configuration and direction of discharge of the outlet were selected to prevent inflow of sediment from the Kotmale Oya during floods.

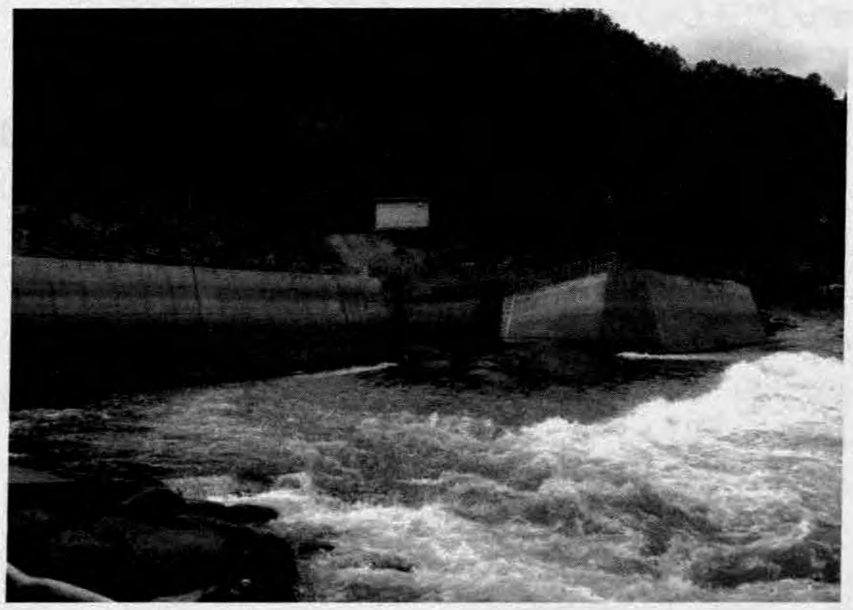


Figure 12 - Photograph of the Outlet

2.3 Powerhouse Complex:

The Powerhouse is located underground approximately 250m below the ground surface. Considering the economic aspects and ease of maintenance work, the transformer and GIS rooms were located underground at the Cable Tunnel end of the Powerhouse. It comprises two (2) units of vertical axis Francis Turbines and vertical axis 3-phase generators. The dimension of the underground powerhouse is as follows.

Length	: 50.5m
Width	: 19m
Height	: 36.5m.

The powerhouse longitudinal and cross sections are shown in Figures 13 and 14.

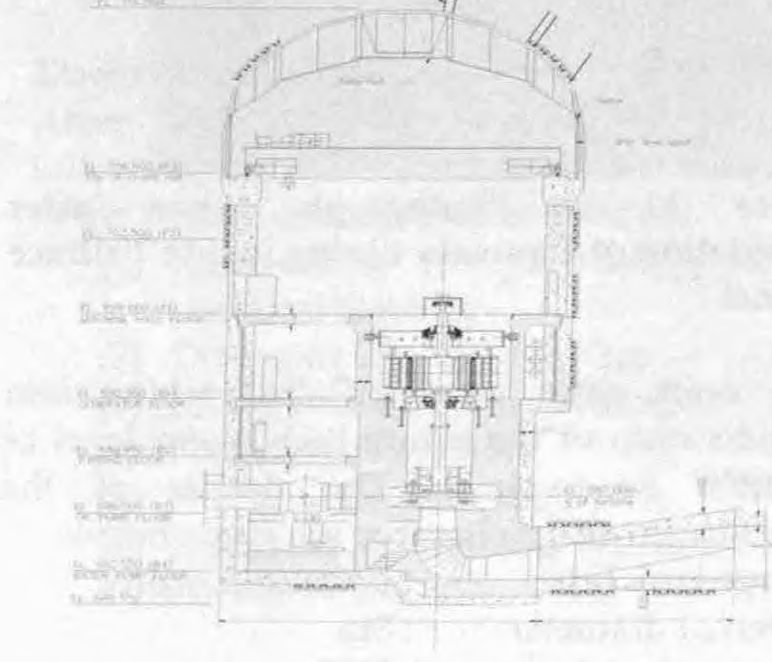


Figure 13 - Cross Section of Underground Powerhouse

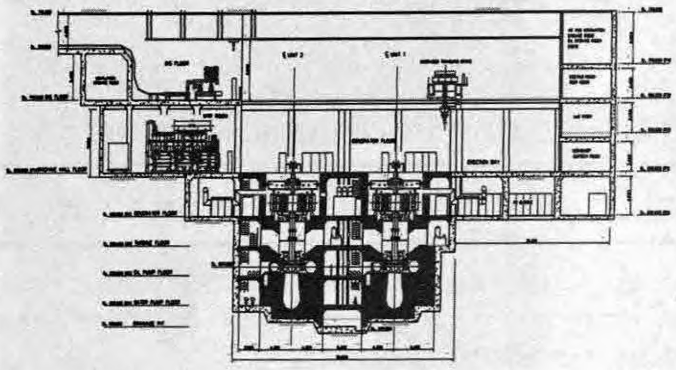


Figure 14 - Longitudinal Section of Underground Powerhouse

The layout of the underground powerhouse with part of the penstock and its bifurcations, Adits 6 and 7, access tunnel, cable tunnel, draft tube tunnels, tailrace tunnel, outlet, outdoor switchyard and control building are shown in Figure 15.

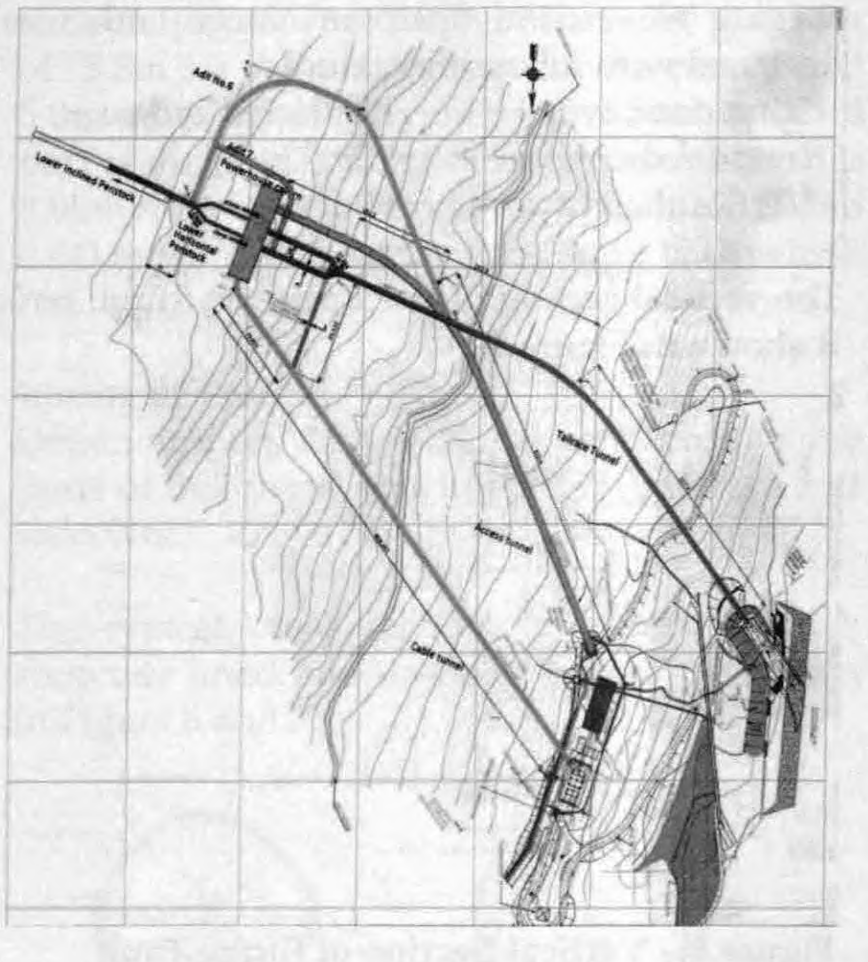


Figure 15 - Layout of Powerhouse Complex and Outdoor Switchyard

The outdoor switchyard was constructed at EL735.50 at the right bank of Kotmale Oya and the section between the transformer room and switchyard 450m in length is connected by a cable tunnel. Access tunnel of width 5m and length 450m was constructed between the outdoor switchyard area and erection bay of the Powerhouse.

2.4 Head Pond:

Natural Profile of Kotmale Oya
The discharge of 22,000m^3/s corresponds to a frequency of about 1,000 year, while observed

maximum flood after 1948 is 890m³/s. This also matches with the January 1974 flood.

The low laying land at five (5) locations in around head pond area which were also affected by the flood in January 1974 was reclaimed.

The major reclaimed areas as follows.

- Nanuoya Settlement area on the right bank of Kotmale Oya near (upstream) of confluence of Nanu Oya and Kotmale Oya.
- Rathneelakelle Settlement area on the right bank of Kotmale Oya near (downstream) of confluence of Nanu Oya and Kotmale Oya.
- Tamil School and Middleton Settlement area on the left bank of Kotmale Oya near confluence of Nanu Oya and Kotmale Oya.
- Devsiripura Settlement area on the right bank of Kotmale Oya near Sumana Maha Vidyalaya.
- Kumaragama and Walkers Settlements area on the left bank of Kotmale Oya near Talawakelle railway station.

The dam with FSL 1,194masl creates a headpond extending for about 3.5km upstream.

Backwater Effect

From Backwater analysis, the backwater effect will diminish at about 2.5km from the dam if the dam is operated at FSL (1,194masl) and 1.2km if operated at MOL (1,190masl) a discharge of 1,000m³/s (which represent the experienced maximum flood in 1947). Similarly, at the dam design discharge Q_{100}=2,000m³/s the backwater effect will diminish at about 2.4km from the dam site when it is operated at FSL, and 1.2km operated at MOL.

Therefore, land reclamation works and riverbank protection works were done in the area which will be mainly affected by the backwater effect during high floods.

Live Storage

As shown in the Height vs Capacity curve in Figure 15, the FSL 1,194m amsl and MOL at 1,190m amsl will provide a live storage capacity of 0.822MCM.

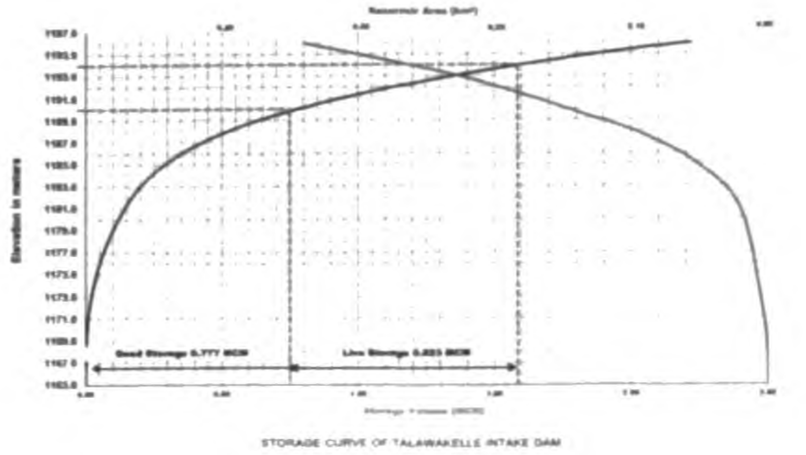


Figure 16 - Height - Capacity Curve of Head Pond

3. Main Features of Structures

3.1 Dam and Intake Facility:

The intake dam has five (5) radial gates of size 10m x 10 m and a sand flush gate.

The main features are summarized below.

Type	: Concrete gravity
Height	: 35.0m
Crest length	: 180m
Crest level	: 1196 m-amsl
Design flood	: 2,000m³/s (1,000yr return flood)
	: 3,300m³/s (10,000yr return flood)
Intake capacity: 36.9m³/s	

From the hydraulic viewpoint the dam location is the best site for the run-of-river type diversion. It is located just downstream end of the curve stretch after meandering of river and intake is provided on the concave side of a curve to minimize the inflow of trash and harmful sand.

As there is no sand trap facilities provided, the plant operation during the flood of more than 450m³/s (10 year return flood) is not allowed. For this flow, sediment particles more than 0.3mm may inflow in to the waterway.

The spillway capacity of the dam is sufficient to pass 10,000 year return flood of 3,300m³/s under 1,196m amsl. The sand flush way and sand flush gate are provided for effective sediment flushing.

The dam has the facility to release around 6m³/s to maintain the St. Clair Waterfall during day time.

Waterways

The waterways was designed to carry the maximum flow of $36.0m^3/s$ for the generation of 150MW. As the bottom elevation of the outlet structure (EL699m amsl) of Upper Kotmale Hydropower Station is lower than the high water level (EL703m amsl) of the existing Kotmale reservoir. Therefore Upper Kotmale tail water level is influenced by the Kotmale reservoir water level. The energy output decrease due to this is not significant.

At the upper horizontal section of the penstock 20m downstream of the surge tank a work Adit No.4 is provided with dewatering facility for headrace tunnel and entrance for the inspection of headrace tunnel which has a sand and rock trap at the end of the headrace tunnel.

The water tightness test performed for the headrace tunnel indicates that there is a slight net increase of inflow of water inside the tunnel.

The inspection done during the recent shutdown of the plant for the repair of the main inlet valve demonstrates that few rocks were fallen from the inner surface of the unlined portion of the headrace tunnel which was excavated by conventional drill and blast method.

Powerhouse

An underground powerhouse was constructed for the following reasons.

- Considering the future raising of Kotmale Dam by 30m and economical aspect due to it, it was decided to go for a Francis type turbine instead of adopting a Peloton type.
- Compared with underground powerhouse, the construction cost of a semi-underground powerhouse is 1 ½ time higher.
- Semi-underground powerhouse will need a thicker penstock compared to the underground penstock which transmits part of stress to the surrounding rock. Therefore, it makes double cost for penstock compared with underground type.
- From the results of geographical survey, an underground type powerhouse needs no concern about landslides as the rock around the powerhouse is stable.

Head Pond

The live storage of about 0.825MCM will be sufficiently enough for the daily regulation needed for the plant.

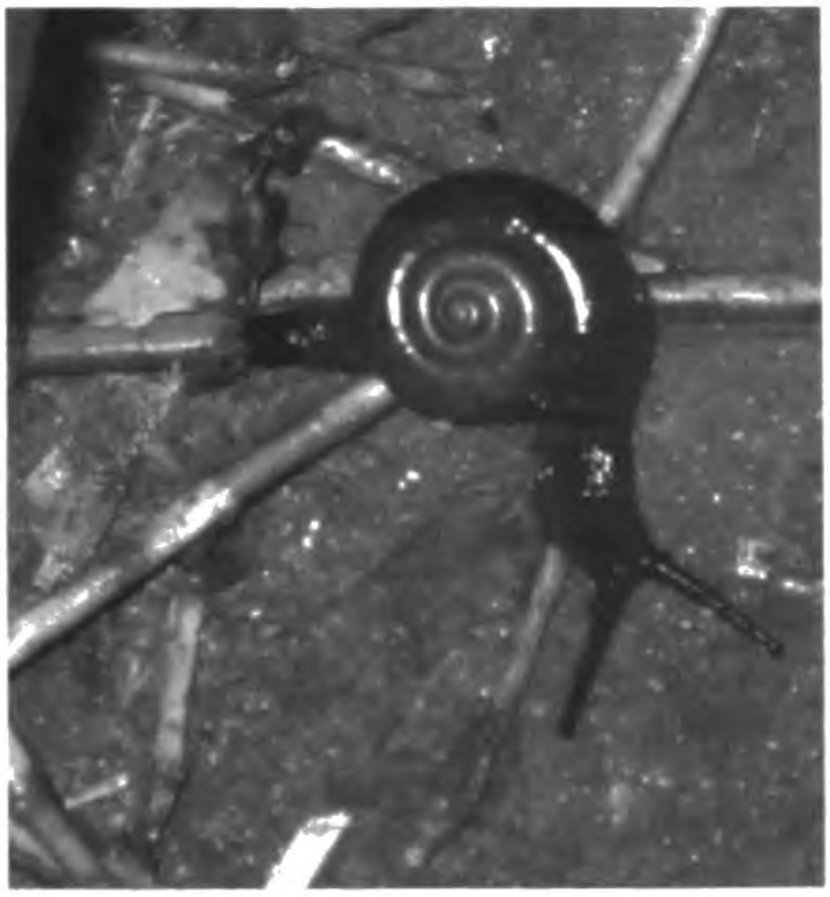
After implementation of telemetering flood warning system, the water level in the Head Pond can be regulated in advance to control the raising of water level in the Head Pond during high floods.

4. Conclusions

The civil structures were constructed in accordance with the Japanese Standards and where ever possible the American and the British standards were adopted.

The civil structures under UKHP will cater for the present requirements to generate power from 150MW capacity Upper Kotmale Hydropower plant and have provisions for the future tributary diversions as originally planned and raising of the Kotmale Dam in the future.

In addition, it will provide an optimum development for the implementation of an upstream regulating reservoir in Kotmale Oya basin in the near future.



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