11.3 Waterway and Powerhouse

11.3.1 Locations and Outlines

(1) Intake

The intake is to be constructed 400 m upstream of the dam. Meanwhile, the MOL is set 1 m above the sediment level, in order to reduce the FSL as much as possible, with the effective use of reservoir water in mind. It is necessary to determine the elevation of the intake sill, in order to avoid air entering the headrace tunnel, because the headrace tunnel is of the pressure type. The intake type, meanwhile, is considered to accept surface water in the case of the water level near MOL. The water depth from MOL to the intake sill of such existing intake facilities in Japan is Hi;

Hi = 2 x D + 1 to 2 m in margin

Where, D; Diameter of the headrace tunnel (m)

Because detailed structures of such facilities were generally determined using hydraulic model tests, it is recommended that a model test be performed on the intake facilities for the project during the detailed design stage and their details be determined.

The intake is considered to be of a slope or tower type. In the case of the tower type, the intake will be a rigid structure, because the tower is around 50 m high, due to the difference between FSL and the ground level, and the intake structure is designed with a seismic coefficient of 0.15. Hence, the slope type is adopted.

The intake has a portal semicircular wall, 12 m in diameter and 1 m in thickness, to take water with a velocity of 0.6 m/s for maximum discharge. Screens will also be installed in front of the portal, while a roller gate is installed in the gate shaft for maintenance of the waterway.

(2) Headrace Tunnel

A 927 m long headrace tunnel is designed as a single line pressure tunnel with a circular section and there are plans to locate it on the right bank of the Seti River. The tunnel support is selected from the RMR estimated in the geological investigation with reference to existing tunnels of similar size.

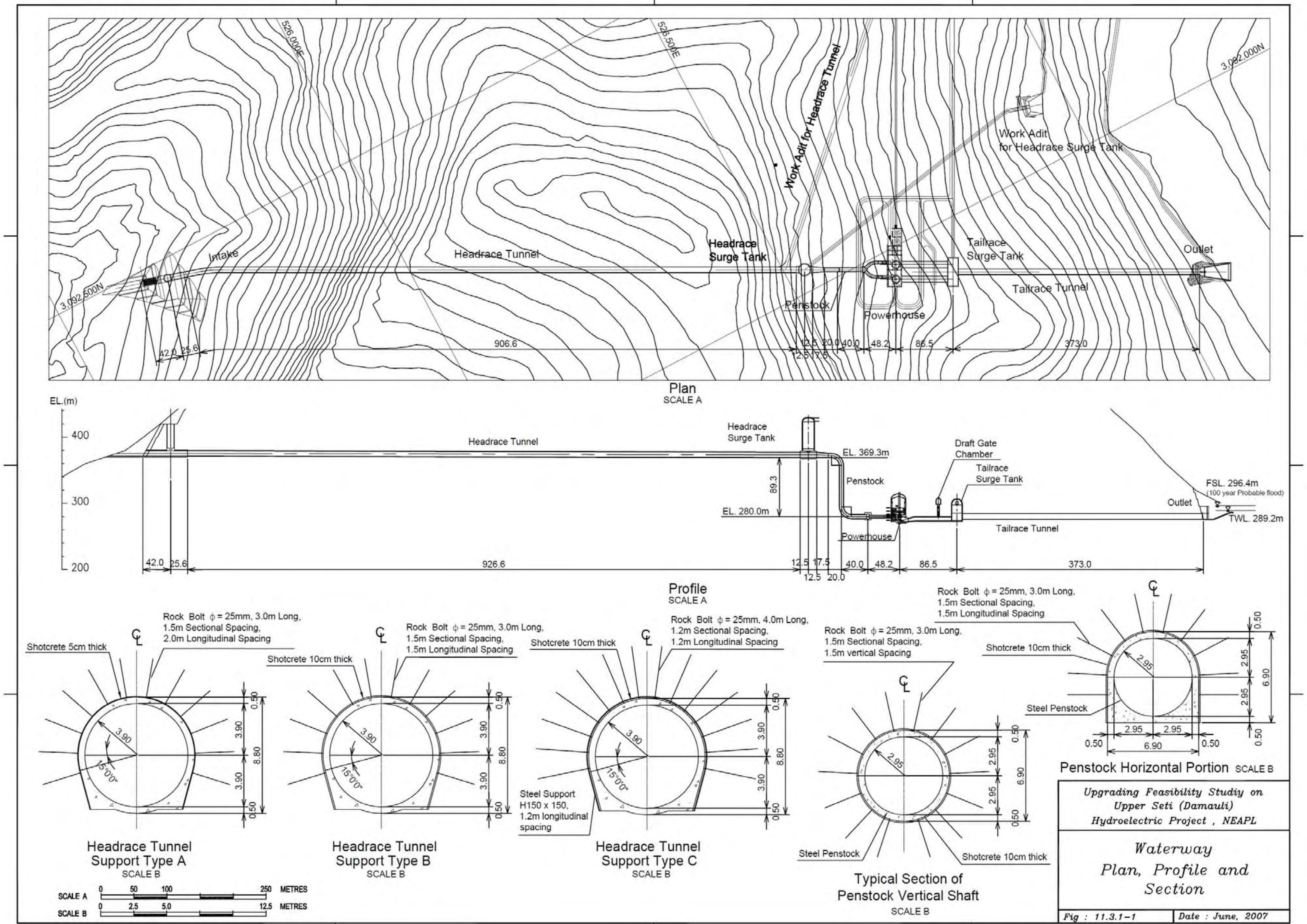
The optimum diameter of the headrace tunnel was determined in order to minimize the construction cost of the headrace tunnel and power revenue loss, due to the head loss for alternative diameters, ranging from 7.4 m to 8.2 m. As shown in **Table 11.3.1-1**, the optimum diameter is determined as 7.8 m.

Table 11.3.1-1 Comparison of the Headrace Tunnel Diameter

Item	Unit	Alternative Diameter				
Tunnel Diameter	(m)	7.4	7.6	**7.8**	8.0	8.2
(1) Annual construction cost	10^3 US$	558.1	576.7	**594.0**	617.0	636.4
(2) Power revenue loss	10^3 US$	234.0	203.0	**176.8**	154.5	135.4
Total Annual Cost (1)+(2)	10^3 US$	792.1	779.7	**770.8**	771.5	771.8

The internal pressure applied to the tunnel surface is estimated at about 4.5 MPa during normal operation and 5.4 MPa during surging. Meanwhile, the concrete lining will be reinforced to resist internal water pressure. In general, the lining thickness of the pressure tunnel is 30 cm to 70 cm. With reference to the existing pressure tunnels of similar size, the thickness of the lining is set at 50 cm.

A typical section of the headrace tunnel is shown in **Fig. 11.3.1-1**.



Headrace Tunnel
Intake
Headrace Surge Tank
Work Adit for Headrace Tunnel
Work Adit for Headrace Surge Tank
Tailrace Surge Tank
Tailrace Tunnel
Outlet
Penstock
Powerhouse
Plan
SCALE A
Profile
SCALE A
EL. 369.3m
EL. 280.0m
Draft Gate Chamber
FSL. 296.4m
(100 year Probable flood)
TWL. 289.2m
Headrace Tunnel Support Type A
Headrace Tunnel Support Type B
Headrace Tunnel Support Type C
Typical Section of Penstock Vertical Shaft
Penstock Horizontal Portion SCALE B
Rock Bolt φ = 25mm, 3.0m Long, 1.5m Sectional Spacing, 2.0m Longitudinal Spacing
Rock Bolt φ = 25mm, 3.0m Long, 1.5m Sectional Spacing, 1.5m Longitudinal Spacing
Rock Bolt φ = 25mm, 4.0m Long, 1.2m Sectional Spacing, 1.2m Longitudinal Spacing
Rock Bolt φ = 25mm, 3.0m Long, 1.5m Sectional Spacing, 1.5m vertical Spacing
Shotcrete 5cm thick
Shotcrete 10cm thick
Steel Support H150 x 150, 1.2m longitudinal spacing
Steel Penstock
Upgrading Feasibility Studiy on Upper Seti (Damauli) Hydroelectric Project , NEAPL
Waterway Plan, Profile and Section
Fig : 11.3.1-1
Date : June, 2007

(3) Penstock

The 195 m long steel penstock is designed as an underground type in a single line tunnel. A circular section is adopted for the vertical shaft and a circular section with a flat bottom for the horizontal tunnel to facilitate construction. It is bifurcated at the area upstream of the powerhouse to accommodate two lines of steel penstock.

The optimum diameter of the penstock tunnel was determined in order to minimize the construction cost and power revenue loss due to the head loss for each alternative diameter ranging from 5.7 m to 6.1 m. As shown in **Table 11.3.1-2**, the optimum diameter is 5.9 m.

Table 11.3.1-2 Comparison of the Penstock Tunnel Diameter

Item	Unit	Alternative Diameter				
Tunnel Diameter	(m)	5.7	5.8	**5.9**	6.0	6.1
(1) Annual construction cost	10^3 US$	388.8	401.4	**413.8**	427.0	444.1
(2) Power revenue loss	10^3 US$	313.7	298.7	**285.1**	273.1	262.2
Total Annual Cost (1)+(2)	10^3 US$	702.5	700.1	**699.0**	700.1	706.3

The working space between the steel liner and the surface of the excavated rock is 0.5 m and it will be filled by concrete after the installation of the steel liner, while backfill grouting at the crown of the tunnel and contact grouting around the whole perimeter of the steel liner will be applied along its entire length.

The typical section of the penstock is shown in **Fig. 11.3.1-1**.

(4) Headrace Surge Tank

The surge tank was designed to apply the restricted orifice type, which is generally the most economical type for medium scale hydropower. The following are the main features of the surge tank designed based on the surging calculation:

Orifice diameter:	3.7 m
Diameter of chamber:	17.0 m
Upsurge level (at FSL)	EL. 423.3 m
Downsurge level (at MOL):	EL. 382.5 m

A total 1,000 m of a long work adit is required for the construction of the headrace tunnel and the surge tank. Therefore, by providing concrete lining on the work adit of the headrace tunnel, it can be used as an alternative for the headrace surge tank. When the invert slope of the work adit is set at 1:10, a lining section of length about 585 m is required for the up-surging on the load rejection. As shown in **Table 11.3.1-3**, the latter alternative is more expensive than the restricted orifice type surge tank due to the construction of the long concrete lining. In addition, a longer construction period will be required, since the extended concrete lining can be constructed upon completion of the penstock work.

Table 11.3.1-3 Comparison of the Surge Tank

Alternative	Restricted orifice type surge tank	Modification of Work Adit
Construction cost (US$)	4,946,000	4,989,000

(5) Work Adit

The work adit for the headrace tunnel and vertical penstock is branched from the access tunnel at the station of 330 m and connected just upstream of the headrace surge tank. Considering the transportation of the steel penstock, the section of the work adit is set at 7.0 m wide and 7.0 m high, while the length of the work adit is about 640 m from the branch point of the access tunnel.

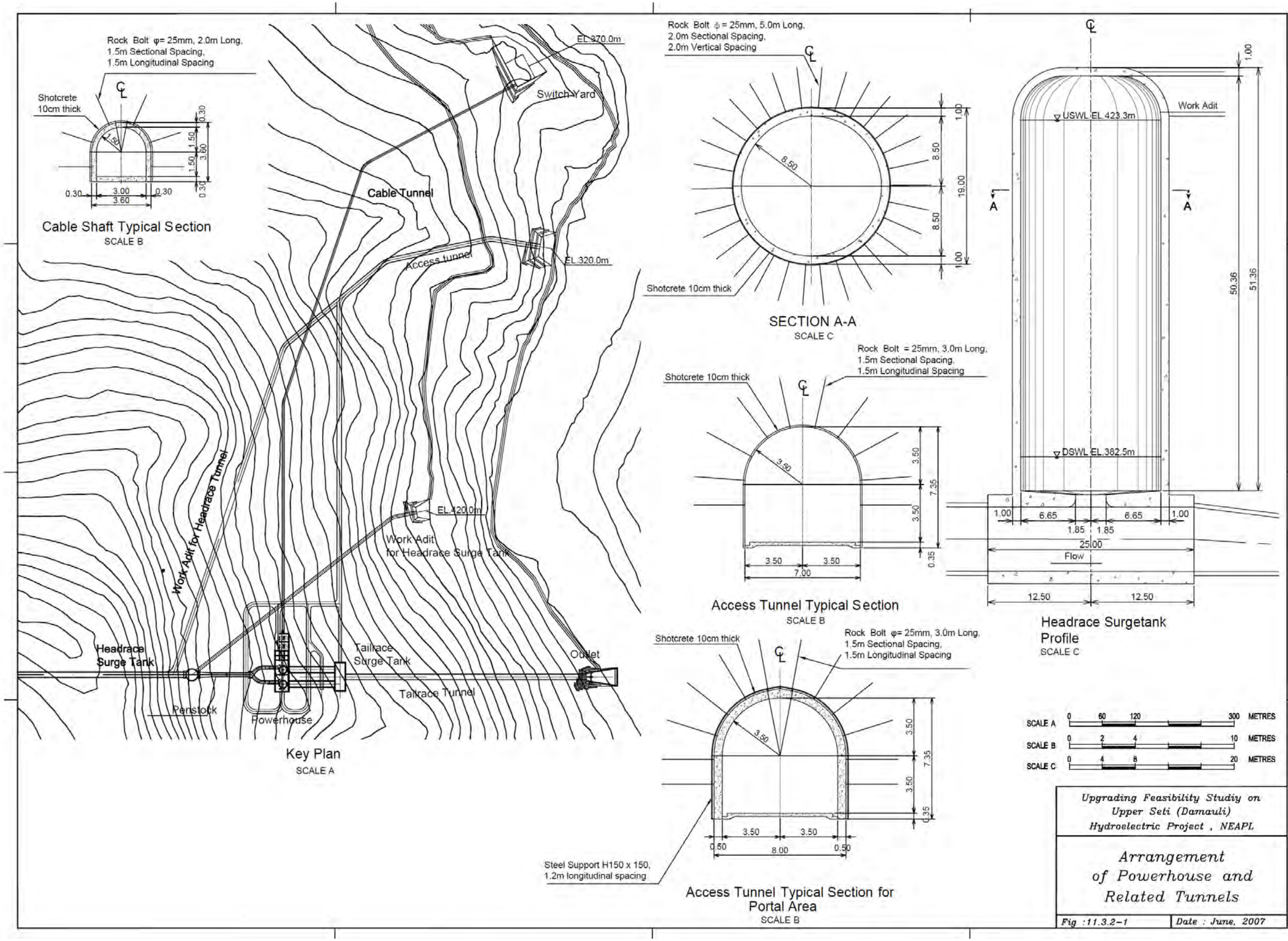
A further work adit is provided for the excavation of the chamber of the headrace surge tank, which is connected to the arch of the surge tank chamber. The section of the adit is set at 4.4 m wide and 4.5 m high to facilitate the transfer of construction equipment. The portal of the work adit is constructed at EL.420 m around the tailrace outlet, while the length of the work adit is 440 m. Upon completion of the project, this adit will be operational as an air supply tunnel for the surge tank.

11.3.2 Powerhouse

(1) Layout

Due to the alternative layout study in **Chapter 10**, Option IIIb (an underground powerhouse option) is selected. There are plans to locate the underground powerhouse within the sound dolomite layer, and the powerhouse cavern is selected as a bullet type, with efforts to facilitate the construction in mind, while the turbine level is set at EL. 280 m to secure sufficient draft head to avoid cavitation. The size of the cavern is 22 m in width, 42 m in height and 90 m in length for housing 2 units of generating equipment and the main transformers.

The portal of the access tunnel is located at EL.320 m, which is connected to the erection bay of the powerhouse. The generated power is transmitted to the switchyard, which is located at EL.370 m, via the cable tunnel and a 220 kV GIS is arranged with a control building in the switchyard. The layout of the underground powerhouse, the access tunnel, the cable tunnel and the switchyard is shown in **Fig. 11.3.2-1**.


Rock Bolt φ= 25mm, 2.0m Long, 1.5m Sectional Spacing, 1.5m Longitudinal Spacing
Shotcrete 10cm thick
Cable Shaft Typical Section
SCALE B
EL.370.0m
Switch Yard
Cable Tunnel
Access tunnel
EL.320.0m
EL.420.0m
Work Adit for Headrace Surge Tank
Work Adit for Headrace Tunnel
Headrace Surge Tank
Tailrace Surge Tank
Tailrace Tunnel
Outlet
Penstock
Powerhouse
Key Plan
SCALE A
Rock Bolt ϕ = 25mm, 5.0m Long, 2.0m Sectional Spacing, 2.0m Vertical Spacing
Shotcrete 10cm thick
SECTION A-A
SCALE C
Rock Bolt = 25mm, 3.0m Long, 1.5m Sectional Spacing, 1.5m Longitudinal Spacing
Shotcrete 10cm thick
Access Tunnel Typical Section
SCALE B
Shotcrete 10cm thick
Rock Bolt φ= 25mm, 3.0m Long, 1.5m Sectional Spacing, 1.5m Longitudinal Spacing
Steel Support H150 x 150, 1.2m longitudinal spacing
Access Tunnel Typical Section for Portal Area
SCALE B
Work Adit
USWL EL.423.3m
DSWL EL.382.5m
Flow
Headrace Surgetank Profile
SCALE C
SCALE A 0 60 120 300 METRES
SCALE B 0 2 4 10 METRES
SCALE C 0 4 8 20 METRES
Upgrading Feasibility Study on Upper Seti (Damauli) Hydroelectric Project , NEAPL
Arrangement of Powerhouse and Related Tunnels
Fig :11.3.2-1
Date : June, 2007

(2) Underground Powerhouse

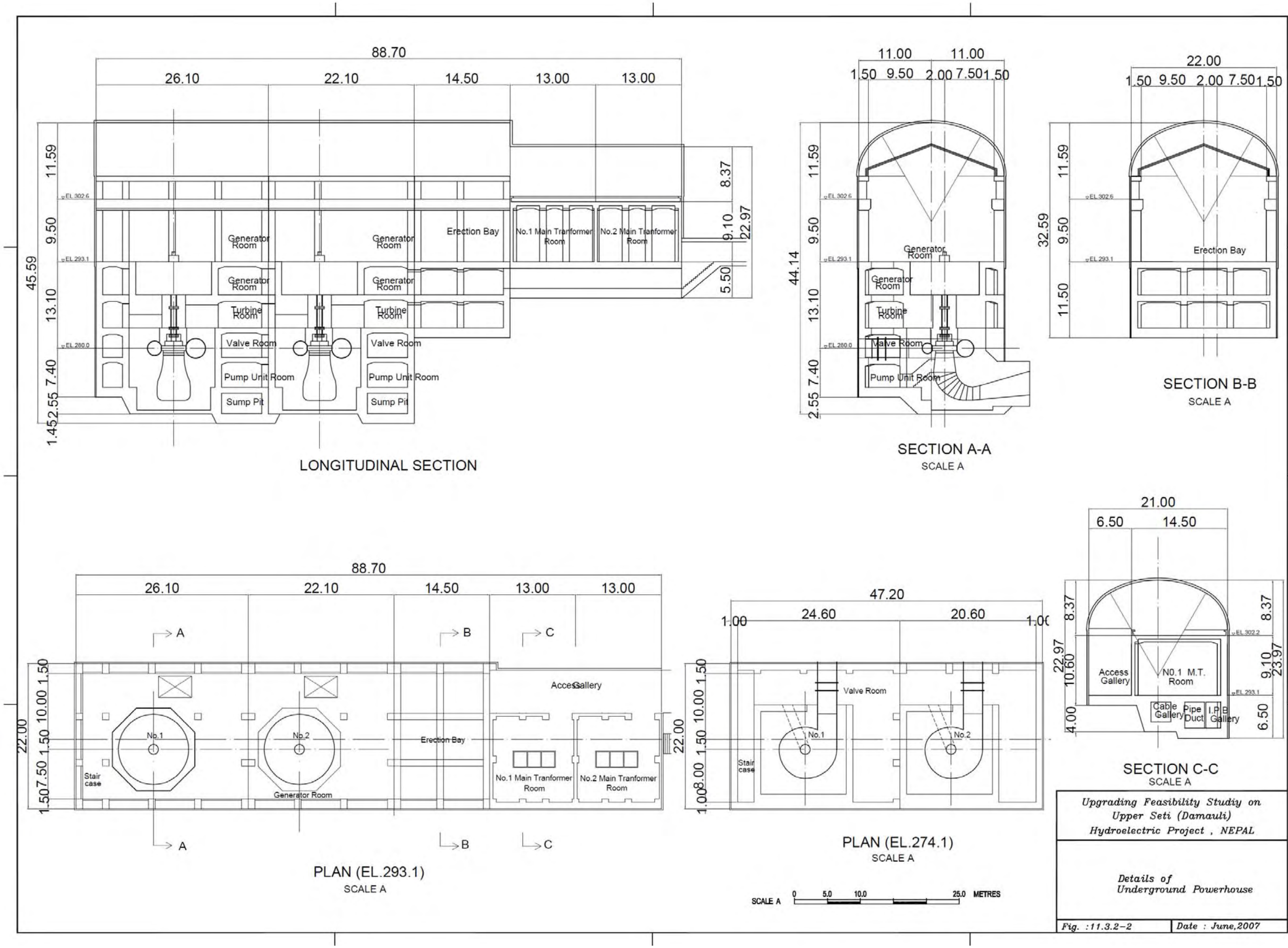
The powerhouse consists of a three-unit monolith, consisting of the machine bay housing the generating equipment, erection bay and the main transformer bay. The scale of the underground cavern was decided as mentioned blow by considering the space required for the installation of the generating and auxiliary equipment, turbine equipment, concrete foundations and working space.

1) The spacing between the units is set at 22.1 m, based on the dimension of the spiral casing of the turbine and the thickness of the initial and secondary concrete around the casing.
2) The size of the erection bay was determined so that the erection work of the stator and rotor could be done simultaneously. The space is 19.0 m in width and 14.5 m in length, including the non-working range of an overhead traveling crane.
3) The space of the main transformer bay was determined to take into account the size of the main transformer, working and inspection space and the required partition wall thickness. Two main transformer rooms of 12.0 m in width and 11.5 m in length are arranged in parallel in the longitudinal direction.

The bifurcated penstock line (i.e. two lines) from the spherical branch enters the powerhouse at the turbine setting level. The inlet valves are arranged at the end of the penstock pipes and connected to the spiral case.

The generator floor, main transformer room and erection bay are situated at EL. 293.1 m. The erection bay is arranged between the machine bay and main transformer room to facilitate transport of the equipment.

The details and room arrangement of the powerhouse are shown in **Fig. 11.3.2-2**.


88.70
26.10
22.10
14.50
13.00
13.00
Generator Room
Turbine Room
Valve Room
Pump Unit Room
Sump Pit
Erection Bay
No.1 Main Tranformer Room
No.2 Main Tranformer Room
LONGITUDINAL SECTION
SECTION A-A
SCALE A
SECTION B-B
SCALE A
SECTION C-C
SCALE A
Access Gallery
N0.1 M.T. Room
Cable Gallery
Pipe Duct
I.P.B Gallery
Stair case
No.1
No.2
PLAN (EL.293.1)
SCALE A
PLAN (EL.274.1)
SCALE A
SCALE A 0 5.0 10.0 25.0 METRES
Upgrading Feasibility Studiy on
Upper Seti (Damauli)
Hydroelectric Project , NEPAL
Details of
Underground Powerhouse
Fig. :11.3.2-2
Date : June,2007

(3) Stability of Powerhouse Cavern

The excavated cavern is stabilized by the following support system:

- Shotcrete: To protect the excavated surface and prevent the development of partial loosening of the rock mass from blasting.
- Rock Bolt: To prevent the development of partial loosening of the rock mass by anchoring.
- PS Anchor: To prevent the development of the distressed rock zone and exert confining pressure on the rock mass.

The stability of the cavern for the underground powerhouse was subject to the bullet type, while analysis of the stability during excavation was carried out utilizing the two-dimensional finite element method (FEM).

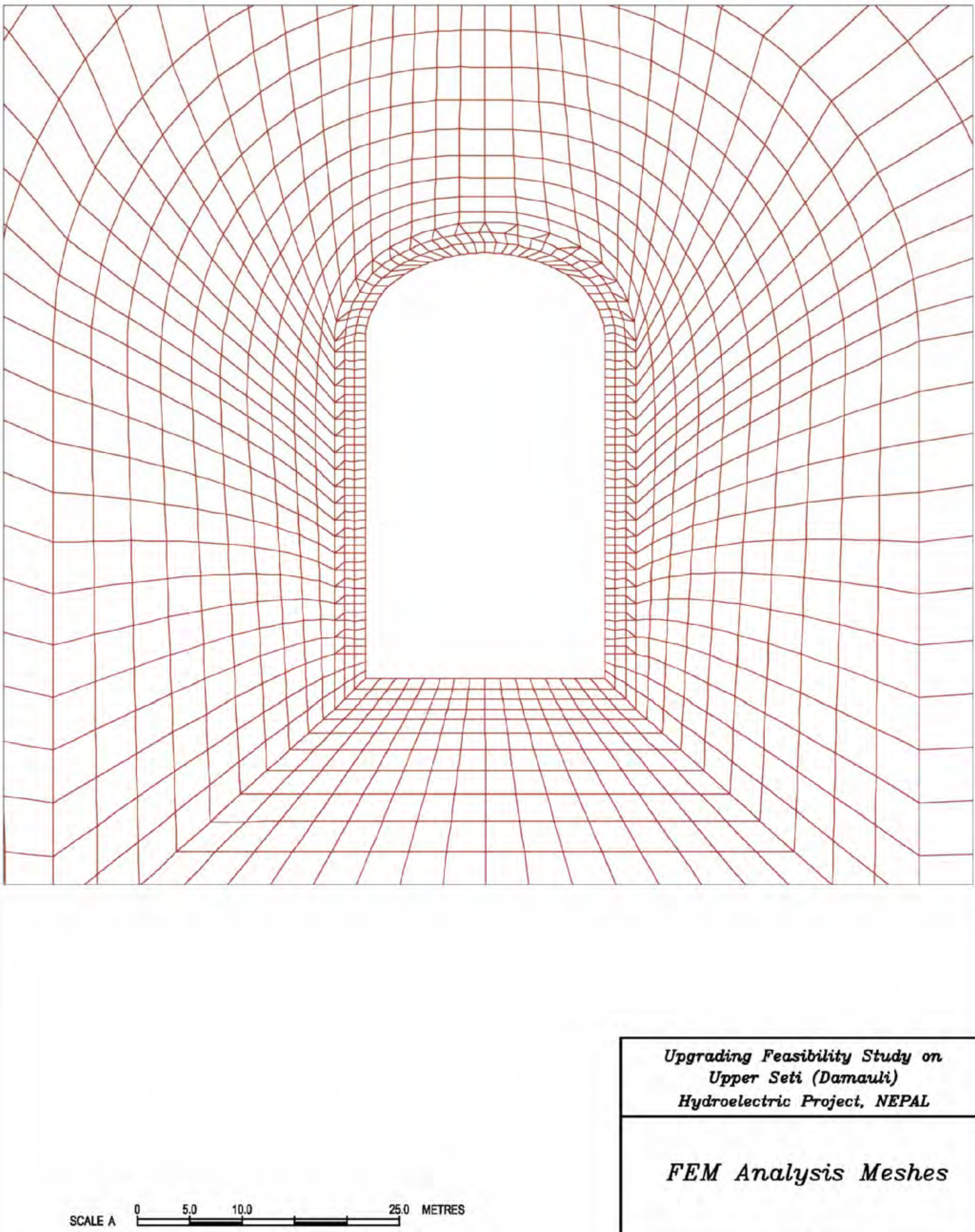
The required numner of PS anchors will be calculated so as to support the loosened rock mass of the side walls of the cavern, which is obtained by the stability analysis mentioned above.

At the time of carrying out the stability analysis the geological conditions surrounding the underground powerhouse was assumed.

The mesh models created for FEM analysis are shown in **Fig. 11.3.2-3**, while the design values used for stability analysis are summarized in **Table 11.3.2-1**.

Table 11.3.2-1 Design Values

Item	Dolomite	Phyllite / Slate	Disturbed Zone I	Disturbed Zone II
Modulus of Elasticity (MPa)	6,000	4,300	2,400	4,200
Poisson's Ratio	0.25	0.25	0.30	0.25
Shear strength (MPa)	3.0	2.2	3.0	3.0
Internal friction angle (deg)	47.5	43.0	47.5	47.5
Unit weight (kN/m^3)	27.2	27.1	27.2	27.2



Upgrading Feasibility Study on
Upper Seti (Damauli)
Hydroelectric Project, NEPAL

FEM Analysis Meshes

Fig : 11.3.2-3 | Date :February,2007

Initial stresses at the powerhouse cavern are estimated on the basis of covering depth as follows:

$\sigma_y = \gamma \cdot H$

$\sigma_x = \nu / (1 - \nu) \cdot \sigma_y$

$\tau_{xy} = 0$

where, σ_x : Horizontal stress (MPa)

σ_y : Vertical stress (MPa)

τ_{xy} : Shear stress (MPa)

ν: Poisson's Ratio of Rock

γ: Unit Weight of Rock (kN/m^3)

The modulus of deformation was determined taking into account the influence of blasting during the excavation work. Since the magnitude of the influence of blasting varies depending on the depth from the excavated surface, the disturbed areas are empirically categorized into zone-I (surface to 1.0 m depth) and zone-II (1.0 m to 3.0 m), with the design values of those zones shown in **Table 11.3.2-1** above.

The stress distribution is shown in **Fig. 11.3.2-4**, where the distressed rock zone is defined as the area with a safety factor of less than 1.2. The safety factor is calculated as the ratio (r + d min)/r, where "r" is the Mohr's circle radius and "d_{min}" is the minimum distance between the failure envelope line and Mohr's circle. As shown in **Fig. 11.3.2-5**, the distress zone reaches about 17.5 m.

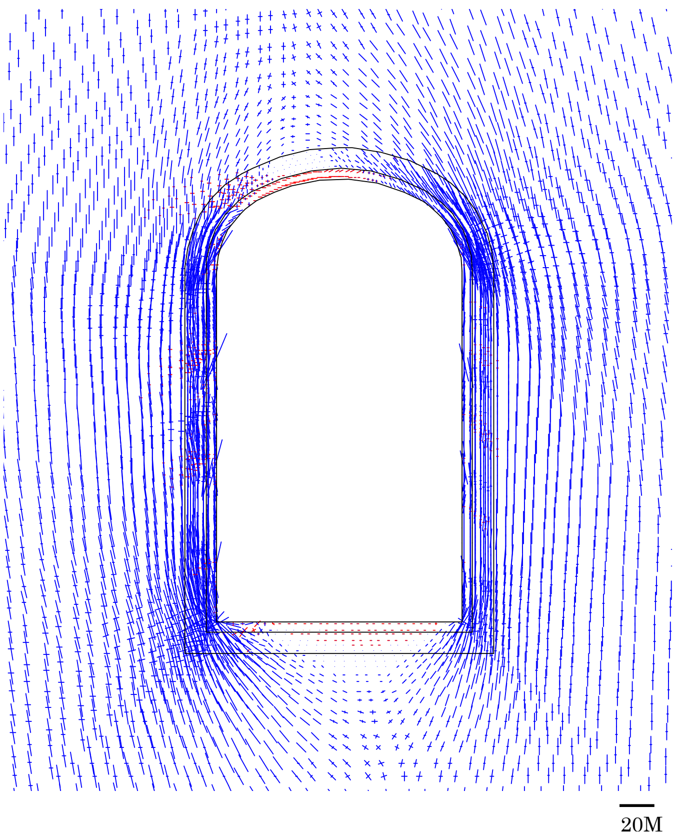


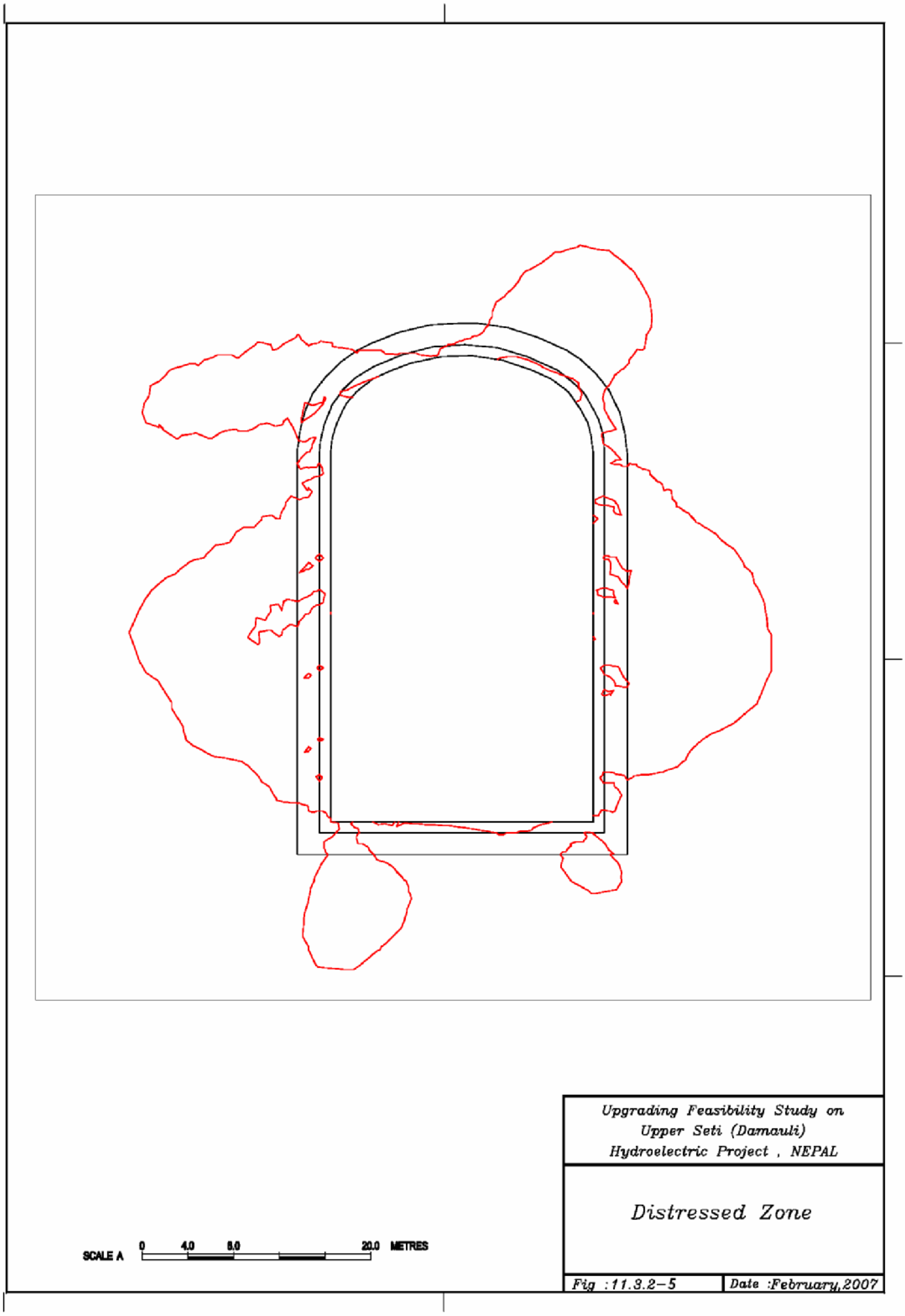
Fig. 11.3.2-4 Stress Distribution

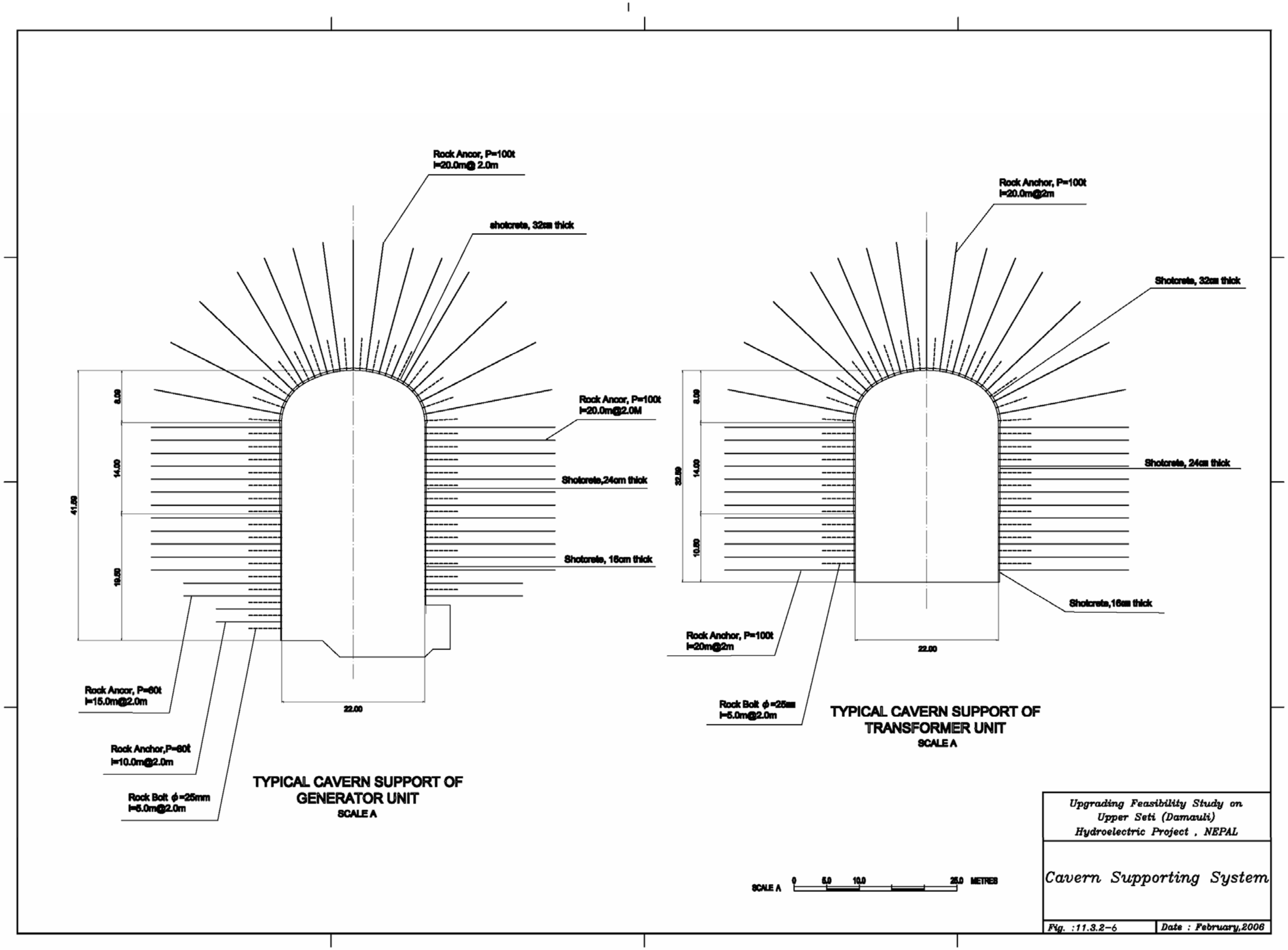
PS anchoring is essential to prevent any collapse or sliding of surrounding rock of the cavern. The PS anchors shall be arranged properly to prevent the development of a distressed zone and to exert confining pressure on the rock mass.

Following the calculation of the PS anchors, 20 m long PS anchors with a design tension force of 100 t will be placed at intervals of 2.0 m and 2.0 m on the upper part of the side walls. In the lower part of side walls, PS anchors of 15 m in length with a design tension force of 60 t and 10 m in length with the same design tension force will be placed at intervals of 2.0 m and 2.0 m. In the arch portion, 20 m long PS anchors with design tension force of 100 t will be placed at intervals of 2.0 m and 2.0 m.

Rock bolts of 5 m length will be arranged between the PS anchors. The thickness of the shotcrete is a maximum of 32 cm, with reference to other projects.

The supporting system is shown in **Fig. 11.3.2-6**.


Upgrading Feasibility Study on
Upper Seti (Damauli)
Hydroelectric Project , NEPAL
Distressed Zone
Fig :11.3.2-5
Date :February,2007
SCALE A
0
4.0
8.0
20.0
METRES


Rock Ancor, P=100t
l=20.0m@ 2.0m
shotcrete, 32cm thick
Rock Ancor, P=100t
l=20.0m@2.0M
Shotcrete,24cm thick
Shotcrete, 16cm thick
8.00
14.00
41.50
19.50
22.00
Rock Ancor, P=60t
l=15.0m@2.0m
Rock Anchor,P=60t
l=10.0m@2.0m
Rock Bolt ϕ=25mm
l=5.0m@2.0m
TYPICAL CAVERN SUPPORT OF
GENERATOR UNIT
SCALE A
Rock Anchor, P=100t
l=20.0m@2m
Shotcrete, 32cm thick
Shotcrete, 24cm thick
Shotcrete,16cm thick
8.00
14.00
32.50
10.50
22.00
Rock Anchor, P=100t
l=20m@2m
Rock Bolt ϕ=25mm
l=5.0m@2.0m
TYPICAL CAVERN SUPPORT OF
TRANSFORMER UNIT
SCALE A
SCALE A
0
5.0
10.0
25.0
METRES
Upgrading Feasibility Study on
Upper Seti (Damauli)
Hydroelectric Project , NEPAL
Cavern Supporting System
Fig. :11.3.2-6
Date : February,2006

(4) Access Tunnel

An access tunnel is provided for the transportation of generating equipment, main transformer, parts of the steel penstock, construction materials, and excavated material and as access for operation and maintenance after completion. In addition, the access tunnel is used for air ventilation.

The entrance is set at EL .320.0 m and is connected with the underground powerhouse at the erection bay, where the elevation is EL. 293.1 m. The total length of the access tunnel is 745 m, and its average slope is below 8.0 % for the passage of heavy equipment. The typical section, meanwhile, is a vertical leg horseshoe-shape, with clearance of 7.0 m in width and 7.0 m in height. The required space is determined with the two-way passage of construction equipment and transportation of generating equipment taken into consideration.

Two kinds of lining are adopted, one of which is a concrete lining of 50 cm thickness and the other a shotcrete lining of 10 cm thickness. The concrete lining is applied to the entrance of tunnels and the tunnel bottom is paved with 20 cm thick concrete to facilitate the traffic passing.

The details of the access tunnel are shown in **Fig. 11.3.2-1**.

(5) Switchyard

A switchyard is provided at EL. 370 m on the steep slope area. To minimize the open excavation volume, GIS (Gas Insulated Switchgear) is adopted, while a control building will also be constructed in the switchyard area. Based on the facility requirements, the following area is needed:

GIS and Tower of Transmission Line:	22 m x 10.5 m
Control Building:	16 m x 10.5 m

A cable tunnel is provided to install the power cable between the powerhouse and the switchyard. The tunnel is designed as having section 3 m wide and 3 m high for the installation and maintenance of the cable.

The cable tunnel is composed of 155 m long inclined portion and 860 m long horizontal portion. During the operation, the tunnel is expected to function as ventilation for the powerhouse.

(6) Drain Holes

To mitigate the water pressure acting on the powerhouse cavern, a drainage system of ground water around the powerhouse will be required. Drain holes will be provided along the arch and side walls of the powerhouse and arranged between the PS anchors and rock bolts. If considerable leakage water is observed during the construction of the access tunnel, long drain holes will be drilled from the work adit around the powerhouse.

11.3.3 Tailrace

(1) Tailrace Surge Tank

Water used for generating is released into the Seti River via the pressure type tailrace tunnel. A tailrace surge tank has to be provided at the conjunction of the tailrace and draft tunnels to prevent negative pressure from being generated upon load rejection. The tailrace surge tank is shown in **Fig. 11.3.3-1.** The section of the tailrace surge tank is bullet shaped, being 15 m in width, 32.5 m in height and 40 m in length

Upstream of the tailrace surge tank, a draft gate chamber is required to operate the draft tube gate. The gate chamber is 8.5 m in height, 6.5 m in width and 30 m in length.

(2) Tailrace Tunnel

The total length of tailrace tunnel is 365 m and the tunnel section is a circular shape. Tunnel surface is covered with a concrete lining to minimize the head loss. The optimum diameter of the tailrace tunnel was determined to minimize construction of the tailrace tunnel and power revenue loss, due to the head loss for alternative diameters, ranging from 7.8 m to 8.6 m. As shown in **Table 11.3.3-1**, the optimum diameter is 8.2 m.

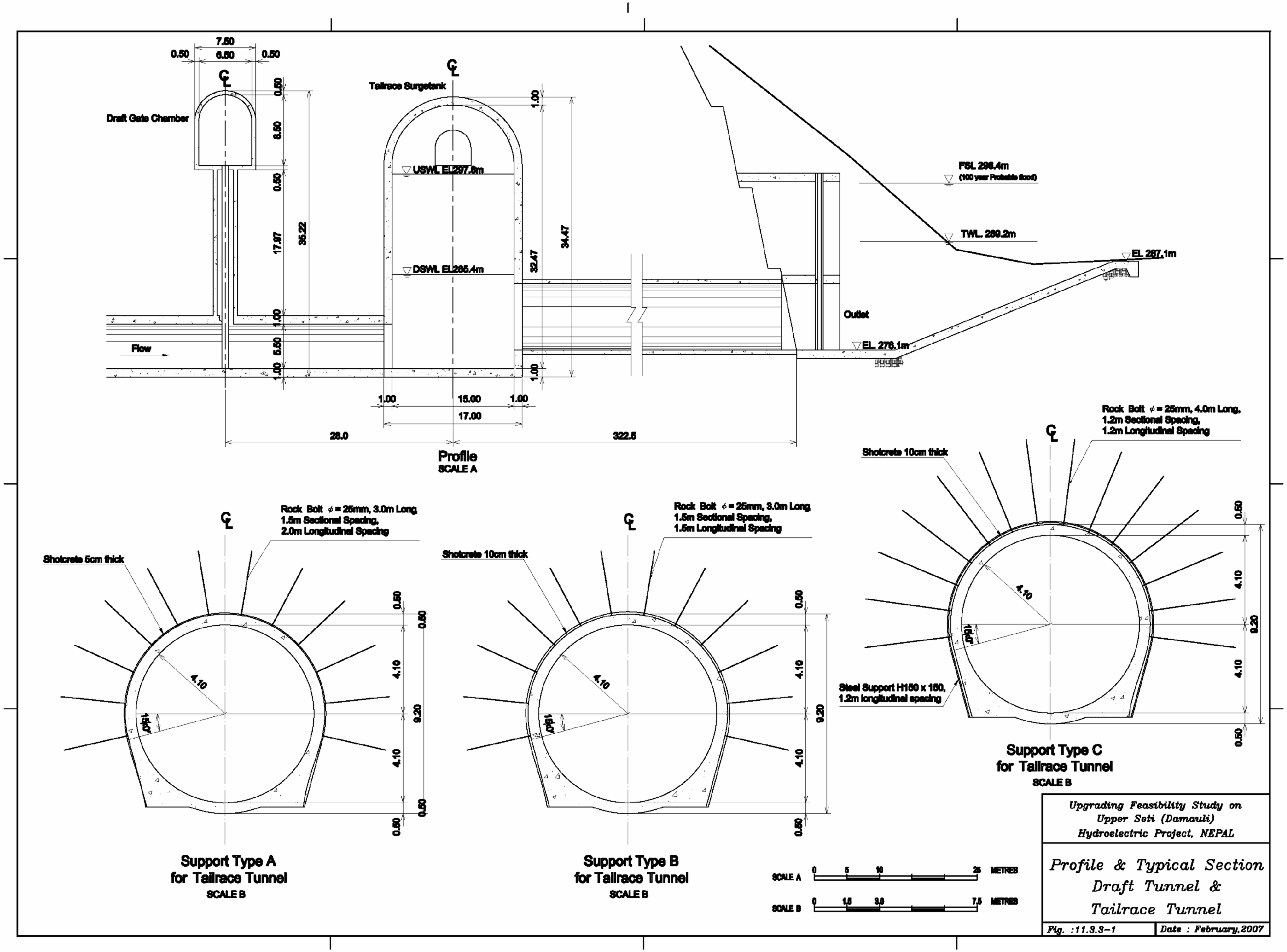
Table 11.3.3-1 Comparison of Tailrace Tunnel Diameter

Item	Unit	Alternative Diameter				
Tunnel Diameter	(m)	7.8	8.0	**8.2**	8.4	8.6
(1) Annual construction cost	10^3 US$	178.0	185.1	**190.8**	196.3	203.5
(2) Power revenue loss	10^3 US$	56.2	49.1	**43.1**	37.9	33.4
Total Annual Cost (1)+(2)	10^3 US$	234.2	234.2	**233.9**	234.2	236.9

A 50 cm thick concrete lining is also applied in the tunnel section, while the typical section of the tailrace tunnel is shown in **Fig. 11.3.3-1.**

(3) Tailrace Outlet

The tailrace outlet is located 3 km downstream from the confluence of the Seti and Madi Rivers, with tail water level set at EL. 289.2 m based on the condition of the Electro-mechanical Equipment. The width of the outlet is set at 25 m to secure the required tailwater level. The alignment of the outlet channel is arranged in parallel with the Seti River flow to prevent debris from entering into the tailrace outlet.


Draft Gate Chamber
Tailrace Surgetank
USWL EL297.8m
DSWL EL285.4m
FSL 296.4m
(100 year Probable flood)
TWL 289.2m
EL 287.1m
Outlet
EL 276.1m
Flow
Profile
SCALE A
Rock Bolt ϕ = 25mm, 4.0m Long, 1.2m Sectional Spacing, 1.2m Longitudinal Spacing
Shotcrete 10cm thick
Steel Support H150 x 150, 1.2m longitudinal spacing
Support Type C
for Tailrace Tunnel
SCALE B
Rock Bolt ϕ = 25mm, 3.0m Long, 1.5m Sectional Spacing, 2.0m Longitudinal Spacing
Shotcrete 5cm thick
Support Type A
for Tailrace Tunnel
SCALE B
Rock Bolt ϕ = 25mm, 3.0m Long, 1.5m Sectional Spacing, 1.5m Longitudinal Spacing
Shotcrete 10cm thick
Support Type B
for Tailrace Tunnel
SCALE B
SCALE A 0 5 10 25 METRES
SCALE B 0 1.5 3.0 7.5 METRES
Upgrading Feasibility Study on Upper Seti (Damauli) Hydroelectric Project, NEPAL
Profile & Typical Section Draft Tunnel & Tailrace Tunnel
Fig. :11.3.3-1
Date : February,2007

11.3.4 Hydro-mechanical Equipment

(1) Penstock

One complete lane of a tunnel type steel penstock with one bifurcation and two branches will be provided to supply the maximum water discharge of 127.4 m^3/s for two water turbines, each of 65.1 MW output.

The penstock has a diameter varying from 5.9 m at the beginning point and 4.0 m at the branch pipes and an approximate total length of 155 m.

The steel penstock extends from downstream of the headrace surge tank to each turbine inlet, via an upper vertical portion, a lower horizontal portion and a bifurcation.

(2) Draft Tube Gates and Monorail Hoist

One set of slide type draft tube gates and monorail hoist will be provided in the section of the draft tunnel for the inspection, maintenance and repair of the two sets of water turbines and generating equipment.

The monorail hoist consists of hoisting units and a traveling unit will be used for the operation of the gate.