BACKFILL CONCRETING FOR STEEL LINED DEEP PRESSURE SHAFT – A CASE STUDY.

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SYNOPSIS: Teesta-III HE project (1200MW) involves the construction vertical shaft 650m deep each. The steel liner erection and backfilling concrete in a traditional way i.e. one activity at a time would have taken more than 30 months and therefore activities were planned concurrently to reduce the completion time. Accordingly the backfill concrete was planned from bottom of the shaft by deploying specially designed pump having capacity to pump upto 800m height. Concrete pipes were also designed to withstand such high concrete pressure including the pipe joining clamps. The self-compacting concrete with fly ash was used as backfill concrete behind the steel liner so as to ensure perfect contact between the rock surface concrete and steel liner. A comprehensive and detailed planning was done for the complete work with special emphasis on quality and safety. The paper deals with planning and constructional aspects of works. Such unique and innovative approach of implementation was attempted successfully for the first time in India.

I. INTRODUCTION

The Teesta River is the western most tributary of the Brahmaputra River and covers most of the state of Sikkim. The potential of Teesta is planned to be harnessed through a cascade of six projects out of which Teesta-V (510MW) is already in operation by NHPC (A Government of India Enterprise).The Teesta III HE project is conceived as a run of the river scheme on the main Teesta river in North district of state of Sikkim to utilize a drop of about 800m between Chungthang and Singhik villages. The project with an installed capacity of 1200 MW is being developed by Independent power producer (IPP) through M/S Teesta Urja Limited incorporated as special purpose vehicle for execution and operation of the Teesta III HE project .The project envisages diversion of the Teesta water upto 175cumecs by constructing a 60 m high Concrete face rock fill dam(CFRD) at about 400m downstream of confluence of Lachen chu and Lachungchu (the two limbs of Teesta).This diverted water is carried to the Power House through a 7.5m diameter and 14 Km long head race tunnel which terminates in to 160m deep 13m dia restricted orifice type surge shaft .The water from surge shaft is further conveyed through two circular steel lined pressure shaft of 4m dia each to feed 6 generating units vertical Pelton turbine of 200MW each housed in an underground Power House located near Singhik. The 1Km long 8X8.5m D shape tail race tunnel shall carry the water back to the river.

II. PRESSURE SHAFTS

The two no's 4m dia steel lined pressure shaft have been provided from surge shaft to carry water for Power generation .The steel liner takes off horizontally for a length of 56m from surge shaft and has vertical drop of 650m.The Butter fly valve has been provided 24m downstream of the surge shaft to isolate the water conductor system from Power house whenever required. After the vertical shaft the penstock runs in an inclined gradient of1V:5H for a length of 467 m each and then runs horizontally with two bifurcations of 3.25 m dia and further 2.5m dia to feed three units each. To facilitate excavation of shafts and erection of steel liners etc, Adits at bottom of vertical shaft from cable access tunnel (CAT) and one at near bottom of inclined pressure shafts from main access tunnel (MAT) has been constructed .The layout of pressure shaft is shown in fig-1.

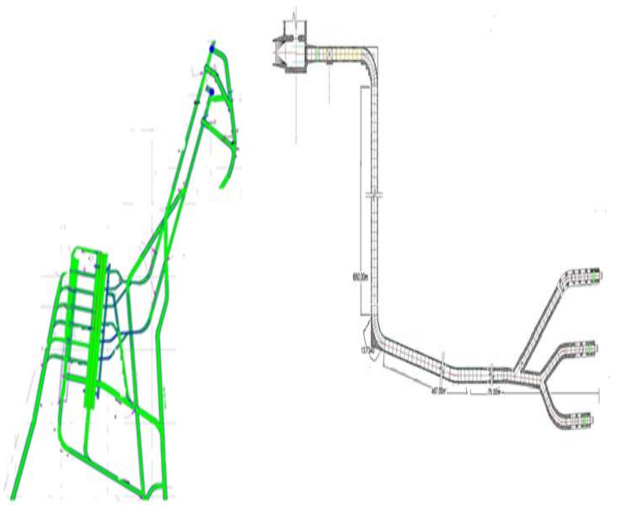

Fig-1-Schematic Plan and section of Pressure Shaft

The excavation of pressure shaft was done by specialized contractor M/S Shaft Sinkers of South Africa. Conventional drilling and blasting was employed followed by mucking through a CAT 305 CCR Mini hydraulic excavator and into 6Ton capacity Kibbles hoisted to the pressure tunnel head where the contents discharged via sinking chutes. Side walls were supported with shotcrete 75mm thick and 25 dia 3500 long rock bolts @1500 c/c both ways staggered. The 4 booms hydro pneumatic jumbo with telescopic booms was deployed for drilling operation. The excavation of left deep vertical shaft was started in Aug 2009 and completed in March 2011. The excavation of second shaft was started in Sep 2010 and completed up to 575m by South African Shaft Sinkers by Sep 11. However after the earth quake of Sep 2011, the Shaft Sinkers withdrew and balance 72m was completed through local contractor using raise climber.

III. ADOPTED WORK METHODOLOGY

The erection of steel liner and back fill concrete behind the steel liners in such deep shaft is a difficult and time consuming activity .Initially it was planned to lower 6 Mtr ferrules and do concreting from top by placing concrete pump at Adit 5 facility area. But this arrangement of concreting from top would have hindered steel liner work because of

- The transportation of ferrules and its erection would have interfered with laying of concrete pipe line and concreting works.
- With 150 -200mm deep stiffner along the periphery of the ferrules it would have interfered with the laying of concrete pipe lines in shaft well.
- Concreting from top would have posed more problems because of air trapping and pipeline choking on one hand and segregation of concrete ingredients on the other.
- Approach to Conc. pipeline only through the welding platform etc.
- No concurrent working i.e.: independent working for steel liner works and concreting works separately not possible and thus time cycle too long.

The steel liner works mainly comprise erection & welding of ferrules, NDT tests and concreting works thereafter. To compress the work program it was decided to do concurrent activities and accordingly multistage platform was fabricated i.e. Welding Platform separate and NDT &miscellaneous activities to be done through another Platform attached through the main Welding Platform. Further it was decided to do concreting from bottom using a separate Platform so that concreting activity could be made independent of ferrule erection work. However the planning of concreting from bottom required special type of high pressure concrete pump which could pump up to 800m and also separate climbing platform from bottom to top for laying of concrete pipeline and other miscellaneous works. Considering the apparent advantages of concreting from bottom it was decided to do concreting from bottom end of the shaft and have separate platform for concreting and facilitate manpower to reach the working area in shaft.

IV. CONCRETE PLANNING

A. Selection of Concrete Pum

The concreting in the vertical shaft is proposed to be done from bottom by Schwing Stetter 4800E model pump having a capacity to pump concrete for a height upto 800m. The pump is twin-cylinder Piston pump with rock valves driven by hydraulic oil. The pump is mounted on a universal construction site chassis with inflated tyres. The detailed technical parameter of pump is furnished in table 1.

Table-1
Pump 4800 E 180/ 125
Specification & details

Sr. no	Technical Parameter		
1	Engine Power	200KW	
2	Nominal speed	1500RPM	
3	Pumping cylinder dia X stroke	180X2000 mm	
4	Differential cylinder DN/dn/Stroke	150/90X2000 mm	
5	Differential cylinder drive*	Piston Side	Rod Side
a	Maximum no of stroke / minute	14	21
b	Maximum theoretical concrete delivery	43	66
c	Maximum concrete pressure	243	156
6	Delivery pumping line(HD) upto	150	
7	Dead Wt. including oil	8000 Kg	
8	Maximum Hydraulic oil Pressure	350 Bar	
9	Capacity of Feeding hopper	600 lit	

The Concrete pump along with concrete pipe line 125 mm dia was procured from the manufacturer for the purpose .However since the concrete pressure will be reducing from bottom to the top it was planned to reduce the pipe thickness gradually from 8.8mm upto250 m and 7.1mm upto550m and 4mm thick up to end.100 mm diameter hole in the steel penstock at an interval of 12m have been done for concreting .The details of the concreting cum grout hole are furnished in fig-2.

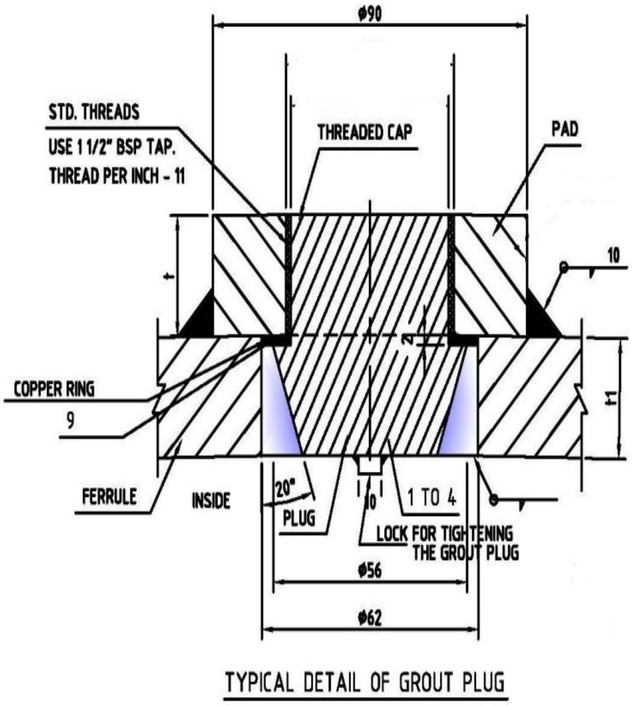

Fig -2

B. Arrangement of Concrete Platform:

The steel liner erection work comprise of activities ferrule erection & welding, NDT & repairs and backfill concrete. The activities are planned to be done concurrently by having separate platform for each activity. The platform for concrete is attached to main welding platform with the help of 8T capacity chain pulley block having lift of 10m for NDT tests and repairs. The concrete platform consists of three stages with a man-cage for manpower and material movement. The platform is working independently with the help of erection hooks and chain pulley blocks as furnished in fig-3.

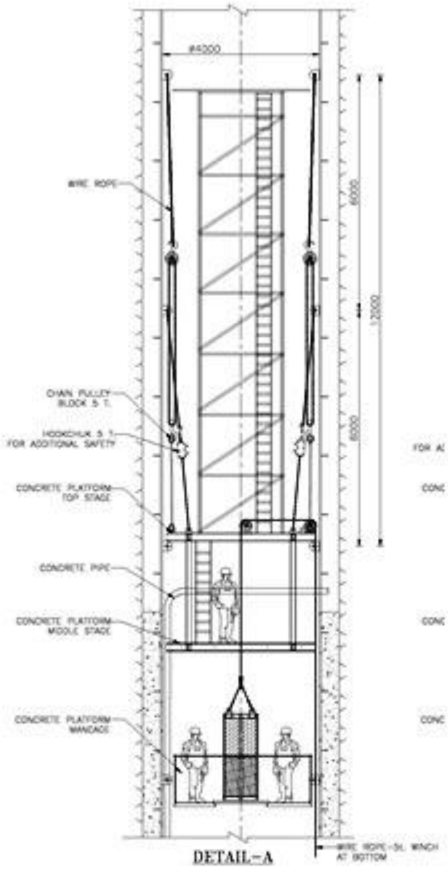

Fig- 3

The erection hooks are provided at 6m/9m spacing and the platform is hinged with erection hooks at a distance of 12m from the top stage and is moved upward and downward by way of chain pulley blocks. For additional safety hook-chuck arrangement of 5T capacity is also provided. The top stage concrete platform rests on erection works in the ferrule and as concreting gets completed the platform is moved 6m/9m upward with the help of chain pulley block and is held on hooks and the hook chuck arrangement is shifted upward to further 6m/9m hooks. For access to 6m/9//12m hooks additional scaffolding arrangement of 12m height provided at center of platform and chain pulley blocks is shifted 12m upward. For movement of man-cage with man and material man-cage is operated with the help of winch from bottom of vertical shaft.

C. Concrete mix design and placement

It was decided to lower the ferrules in the length of 6m& 9m limit out the maximum handling weight of 35 ton pay load. Therefore the winches of 65 ton capacity were selected and headgear steel structure of 25 mtrs height was erected accordingly. It was decided to concrete two ferrules i.e.12m at a time. The annular space between rock and steel ferrule which was of the order of 500mm and therefore it was not possible to vibrate concrete with external vibrators. Use of external vibrator was all the more difficult as 200mm deep stiffeners were provisioned along the ferrule periphery and thus restricting the flow of normal concrete. The traditionally vibrated concrete is subjected to compaction by way of vibration/ tamping which is a discontinuous process. In the case of internal vibration even when correctly done, the volume of concrete within the area of influence of the vibrator does not receive the same compaction of energy. Similarly in the case of external vibration, the resulting compaction is essentially heterogeneous depending on the distance to the vibrating source. This leads to concrete with uneven compaction and hence different permeability's which enhances the selective ingress of aggressive substances that can propagate possible deleterious actions (CO_2, chloride, sulphate, water, oxygen, alkalis, acids etc). Therefore the consequences of improper/inadequate vibration shall lead to honey combing, segregation, bleeding etc and thus shall have very negative impact on permeability and hence durability of concrete. Self-compacting concrete with the right properties will be free from these shortcomings and result in a material of consistently low and uniform permeability, offering less weak points for deleterious actions and hence better durability. Therefore it was decided to use self-compacting concrete. The trials were done with OPC and PPC cement with and without fly ash and the average shrinkage parameter for different mixes are summarized in Table-2.

Table-2 Shrinkage value of different type of concrete

Concrete Mix	Vertical direction%	Horizontal dir. Along length (%)	Horizontal dir. Along breath (%)
M20A20 SCC with PPC+ Fly Ash	+0.033	0	0
M20A20 SCC with PPC+ Fly Ash+ Aluminium Powder @ 2 gm/100Kg of cement	+0.066	0	(-)0.04
M20A20 SCC with PCC	(+)0.033	(-)0.04	(-)0.02
M20A20 SCC with OPC	(+)0.43	(+)0.0002	(+)0.43

The design mix as adopted for the work is furnished in Table-3.

Table-3 Concrete Mix details of self-compacting concrete
Grade –M20A20
Characteristic strength-20 N/mm²
Target mean strength-25 N/ mm²
Cement-315 Kg
Fly ash-135 kg
Sand-919 Kg
A10- 375 Kg
A20-376 Kg
Water-180 Kg
W/(C+F)0.40
Superplasticiser- Adfo- Atcarpol (2011)
Slump (Flow)-700mm (0 min); 690mm (after 30min)

The fly ash was used to the extent to limit the cement content without impacting the ultimate strength of concrete and also to have slower shrinkage parameters then a normal concrete. The fly ash blending not only reduces water demand but also improves pumping because of improved workability and compatible plasticity. The SCC with PPC cement with fly ash was found to have better shrinkage characteristics than OPC cement. The lower than for, those without in the initial period owing to the plasticizing effect of the fly ash and their slower hydration. The fly ash properties used for the work are also furnished in table 4.

Table-4

Sr. No.	Chemical Tests	As obtained	Permissible as per IS 3812
1	SiO2 +Al2O3+Fe2O3	72.9	70
2	SiO2 Min	36.2	35
	MgO	3.02	5
	Total S in SO3	0.82	3
	Total Alkali as N92,Max	0.77	1.5
	Total Cl Max	0.018	0.05
	Loss on ignition Max	3.09	5.0
	Fireness (Blairess valve)	346	320
	Soundness (Auto clave) Max.	0.28	0.8

The mix designs were finalized after doing extensive trial in the project laboratory. The self -compacting concrete of M20A20 grade was used in vertical and inclined sections of the penstock as backfill concrete between steel liner and excavated rock surface. However M25A20 grade normal concrete was used in RCC jacketing around the liner in PS-manifolds and bifurcations. Non shrinkage compound was used for M25A20 grade of concrete in horizontal section and also in M15A40 grade concrete which was used for Adit plug.

The requirement of concrete was only 7 cum/m and therefore one batching plant of 30 cum/hrs capacity was found sufficient to cater to the requirement. However two silos, one for cement and another for fly ash were erected along with weighing arrangement. Usually the concreting took about 6-8 hrs for 12m depth involving about 85-90 cum volume of concrete. During startups of concreting the pipe chocking was observed owing to lack of fine particles at the concrete front, causing friction between particles of coarse aggregate. During pumping quantum of fine particles decreases at the concrete front as they stick to the pipe wall to lubricate the concrete as they need to fill the space in the connection between pipes. Chocking of pipe at the start was most frequent phenomena and was prevented by pumping a priming mortar in the pipes before the pumping of safe compacting concrete started. The proper care and agility of pumping crew prevented the pipe chocking to a great extent.

V. SAFETY

The working in such deep shafts and handling such heavy materials in restricted area and with people working in that congested place especially in view of concurrent activities at different layers, elaborate safety precautions were taken to ensure a safe and healthy working environment. Following safety measures were taken to during the erection of ferrule and concreting works.

- While lowering the ferrule manpower were cleared from the shaft.
- Checking of all communication systems including close circuit TV installed on the lifting Platform, welding platform etc.
- All electrical systems checks to be conducted before start of work.
- Evaluation/Rescue arrangement in working condition at work site.
- Routine and regular check on safety systems like presence of safety staff, safety gear checking etc.
- Check on winches wire rope and pulleys etc. Double breaking arrangement on winches
- Periodic inspection of the temporary scaffolding, maintenance of every winch motor, gear box, wire rope and certification by Mechanical Incharge.
- Checking of temperature, humidity, oxygen level, CO2, CO, H2S levels at welding location in the shaft using gas analyzer.
- While concrete pump in operation, there is a risk of injury on and below the machine from running plants and bursting delivery lines or hydraulic hoses as well as a risk of falling on slippery surfaces.
- In the hopper area, there may be danger of getting trapped between travel mixer and the hopper and of being sprayed with concrete.
- Operational safety of concrete pump checked regularly by Mechanical Incharge

VI. CONCLUSION

The concurrent working in shaft i.e. erection of steel liner and concreting simultaneously and independent of each other was the unique concept in such deep shaft and it requires lots of planning in selection of right kind of lifting arrangement, head gear steel structure, special winches and wire ropes for steel liner erection and self-climbing device for concreting works. Selection of pump and deployment of skilled manpower for operation was the reason behind the success of work. The use of self-compacting concrete with fly ash shall act as a benchmark for future projects. The special emphasis on safety measures by way of appraising the whole lots of working people of this area with the various facets of safety measures and precautions being practiced was the reason for smooth and hassle free working .Deployment of safety team at the two shafts helped in avoiding accidents in this hazardous work.

VII. ACKNOWLEDGEMENTS

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