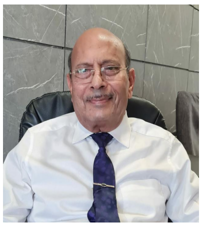
ANCHORED RCC DIAPHRAGM WALL COFFER DAM FOR BISALPUR DAM PROJECT IN RAJASTHAN.
(A case - study)



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ABSTRACT : Construction of dam foundation of Bisalpur masonry dam on river Banas was posing a problem due to presence of medium and coarse sand in the river bed. In post monsoon period, though there remains very little surface flow in the river, but ipso-facto entire river flows through 10 to 12 m thick sand bed. Hence RCC diaphragm wall was conceived to play dual role i.e. to cut off the flow through the sand bed and also to act as coffer dam to divert the surface flow in the diversion channel. 60 cm thick RCC diaphragm wall has been constructed and used as cut off as well as coffer dams on u/s and d/s side of main dam. Wherever depth of diaphragm wall was less than 12 m, post tension anchors of capacity 135 Tons to 170 Tons at an inclination of 45 degrees, were provided through the diaphragm wall and sand bed and grouted in rock. Wherever depth of diaphragm wall was more than 12 m, it was designed as T shaped wall on principle of counter fort retaining wall. This coffer dam cum cut off wall had served its purpose and facilitated the construction of foundation and main dam of Bisalpur project.

INTRODUCTION.

Bisalpur project across Banas river near Bisalpur village, 23 km from Deoli town in district Tonk, Rajasthan, India is an irrigation cum drinking water supply project and consists of main masonry dam, water conductor and canal system. It is a masonry cum concrete dam having length of 574 m. Details layout plan is given in fig. 1 and cross section of dam etc. are given in fig. 2. The maximum height of dam is 27.50 m. The dam abuts hillocks available on both flanks. The project was completed in 1992.

The river bed of Banas is filled up with medium coarse sand which is highly pervious and no work on the main structure of the dam was possible unless working area is rendered dry. Geological details are given under Geology head. Entire post monsoon flow in river passes through 10 to 12 m thick sand deposits and dam foundation on rock below sand bed was not possible due to heavy flow of water existing in the river bed through sand bed. Hence this concept of providing RCC diaphragm wall as a water barrier cropped in so that working area does not have flow of water during construction. The river bed made up of sand was mobile and gets eroded in high floods partially depending upon the intensity of the flood. The sand is deposited again, in receding flood. The one in thousand year flood at the dam site is estimated to be of the order of 35,000 cumecs.

MAIN OBJECTIVE :-

To construct the main masonry dam, two problems were to be taken care of, which were going to be encountered during construction.

The first one was to provide two cut offs on u/s and d/s of the proposed main dam, through the entire depth of coarse sand, suitably anchored in the bed rock so that main working area becomes practically dry during foundation excavation and construction of main dam structure could commence.

The second objective was to provide a suitable temporary structure during the construction of the main dam which can divert the winter and summer discharges of river surface water flow away from the working area i.e. construction of u/s and d/s coffer dam which can divert the flow through the diversion channel on the right flank of the proposed dam site. Height of this coffer dam was envisaged to be 2 m above the average river bed.

The most economical and best solution to achieve both the objective i.e. cut off through the sand and coffer dam to divert the river flow away, was conceived as R.C.C. diaphragm wall suitably anchored in the base rock which can handle the hydrology of this river and dam site, during the flood as well as during the construction period from October to May of coming years.

GEOLOGY

Main Dam : Proposed Bisalpur dam site is located at about 250 M, upstream of the steep gorge, forming on the river Banas cutting through quartzite hill on both sides. The abutments expose the Delhi quartzite and quartz mica-schist, underlying Aravali gneisses and schist. In the river section, the bed rock is marked by thick alluvial deposition consisting of medium to coarse sand in thickness of 10 to 12 meters. The type of rock below this sand deposit is fairly impervious (water tight) having permeability of the order of 5 to 25 lugeons. Few pre-construction bore-holes were done to know the permeability of sand and Rock strata. Details are indicated in Table – 1 as below :-

Bore hole	Depth of Bore hole	Type and depth of strata	Core recovery	Permeability
1	2	3	4	5
1	0 – 10 m	Sand	--	> 10^{-3} cm/sec.
	10 – 15 m	Rock Aravalli gneis	88 %	15 Lugeon
	15 – 21 m	Rock Aravalli gneis	94 %	12 Lugeon
2	0 – 11 m	Sand	--	> 10^{-3} cm/sec.
	11 – 14 m	Rock Aravalli gneis	85 %	21 Lugeon
	14 – 19 m	Rock Aravalli gneis	93 %	18 Lugeon
3	0 – 12 m	Sand	--	> 10^{-3} cm/sec.
	12 – 14 m	Rock Quartz mica schist	82 %	23 Lugeon
	14 – 18 m	Rock Quartz mica schist	89 %	17 Lugeon
	18 – 22 m	Rock Aravalli gneis	94 %	11 Lugeon
	22 – 26 m	Rock Aravalli gneis	98 %	5 Lugeon

TABLE -1

NOTE : 1.3 Lugeon = 10^{-5} cm/sec.

Coffer Dam : Though the alignment of u/s and d/s coffer dam was based on the geological investigation done earlier in 1985 and 1986 but it was essential to *carry out* further geological investigation during the construction. Hence *additional few* bore holes on the proposed alignment of the coffer dams were under taken. On the u/s coffer dam the same results of previous investigations were confirmed i.e. the maximum depth of rock was found at 12.00 m depth from the river bed. But for downstream coffer dam, some surprises were awaiting the construction engineers. The river bed rock had suddenly dipped to a depth of 50 m, in the central portion of the d/s alignment and hence again a new alignment of d/s coffer dam was identified, based on the geological bore holes and it can be seen that for about 140 m length the alignment was shifted to 30 m towards the dam axis, to circumvent the sudden dip of rock. However in new alignment of d/s coffer dam maximum depth of rock was found as 28 m, depth from the river bed. Refer plan and section in fig. I and 2.

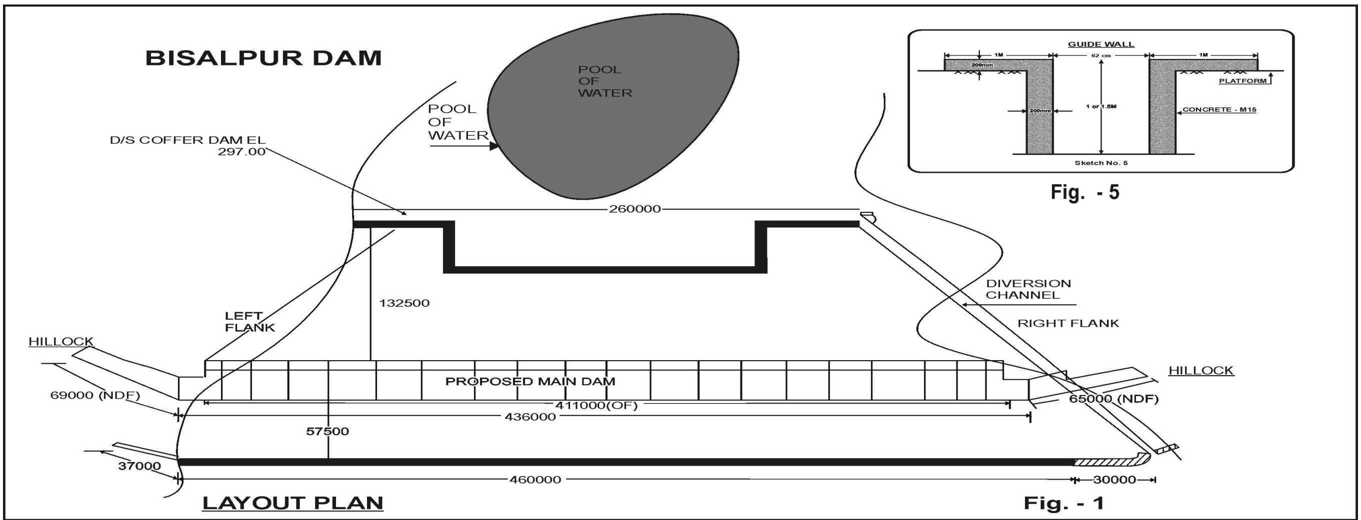


Fig. - 5

Fig. - 1

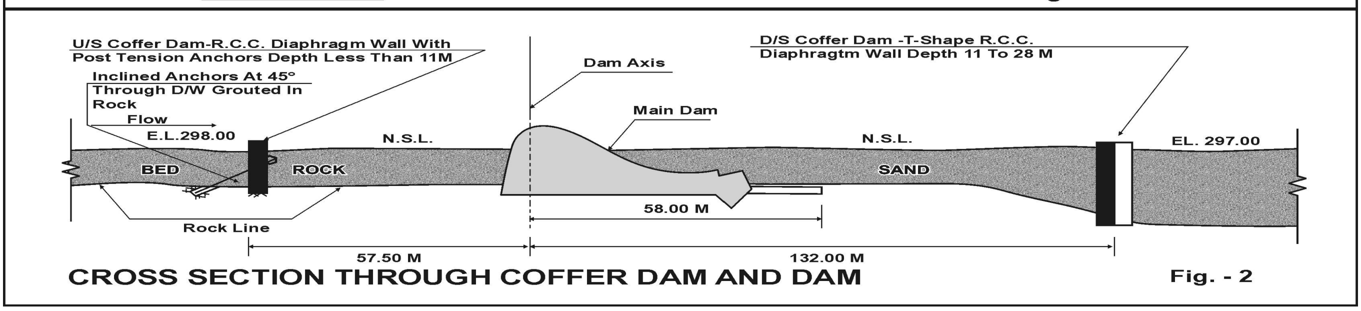


Fig. - 2

DESIGN PHILOSOPHY OF RCC DIAPHRAGM WALL.

Let us understand, design philosophy of the R.C.C. diaphragm which has been identified to serve two purposes, i.e. u/s and d/s cut off and the coffer dam to divert the river during construction period through the diversion channel.

Looking to the wide range of variation in the availability of rock in the river bed i.e. from 2 m. depth to a maximum depth of 28 m, several alternate proposals were discussed and suggested but on economical and practical considerations two types of designs were identified, the first one was applicable to diaphragm wall having depth from 2 m to 12 m and second one having depth from 12m to 28m.

1. Design of u/s R.C.C. Diaphragm wall upto 12 m depth.

(i) It can be seen that critical condition of this R.C.C. diaphragm wall structure shall be subjected during the construction period, when u/s side of u/s coffer dam shall have the full head of water upto top of coffer dam plus the surcharge of submerged weight of sand and on d/s side there is nothing to support this wall as the excavation of main dam shall commence. Hence a RCC diaphragm wall of 60 cm thick with 60 kg reinforcement steel and M-20 concrete, was found satisfactory refer fig. 3.

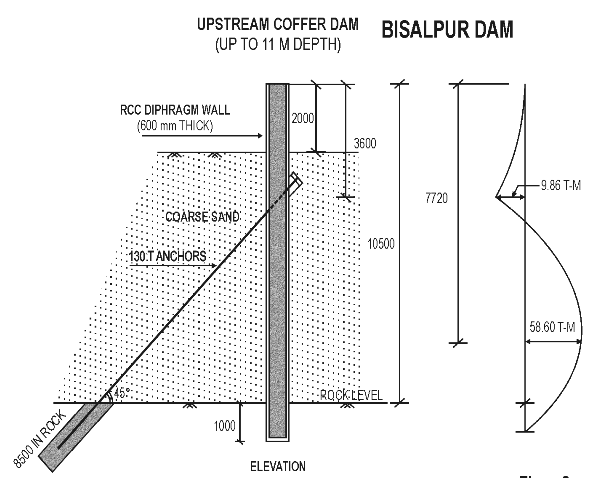


Fig. - 3

(ii) But another important aspect to be considered was that, during the flood time after construction of diaphragm wall, there was a possibility that RCC diaphragm wall may get tilted on the d/s side, due to active earth pressure and velocity of water, and sand bed getting scoured on the d/s upto the rock level. This important design aspect was overcome by providing a suitable post tension anchor of 130 Tons from 3.6 m from top of coffer dam at 45^0 at 2.5 m c/c/ in the entire length of diaphragm wall where depth of rock was available upto 12 m. depth. This anchor was to be drilled and grouted atleast 8.5 m. in rock i.e. it involved a drilling at 45^0 through the sand strata of 12 m depth, then to drill further 8.5 m in rock which consists of quartz mica schist.

2. **DESIGN OF D/S RCC DIAPHRAGM WALL WITH 12 M TO 28 M DEPTH.**

RCC diaphragm wall was required to be provided in the reaches where rock level was from 12 m to 28 m depth. It may be observed that post tension Anchors were not suitable for RCC diaphragm walls having more than 12 m depth because of stability reasons and design requirement of 1 m thick diaphragm wall which was not practical to construct due to non-availability of proper equipment and on economy consideration.

RCC diaphragm wall having more than 12 m depth, has been designed on the principle of counter fort retaining wall. The design of this diaphragm wall is differing from the earlier one in two aspects due to its deeper depth.

(i) During flood time, after Construction of diaphragm wall it shall be subjected to the load exerted by surcharge of sand and water. Due to deeper depth anchors are not viable, hence T shape diaphragm wall are provided on the principle of counter fort retaining wall.

(ii) To overcome the turning moment vertical anchors of 170 T were provided at the cross arm of T-Section at 2.65 m from front face of diaphragm wall. Refer fig. 4.

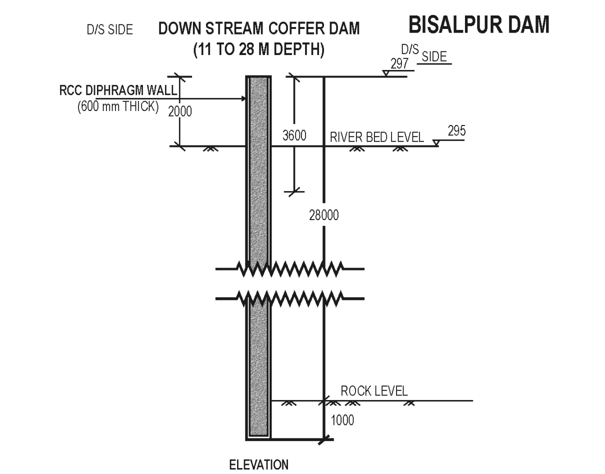


Fig. - 4

CONSTRUCTION SEQUENCE FOR RCC DIAPHRAGM WALL AND ANCHORS.

a) RCC Diaphragm wall :

Following is the construction sequence :

(i) Construction of Platform.

A platform using selected soil is constructed along the alignment of diaphragm wall for the movement of cranes, vehicles etc. The width of platform is as per requirement but generally kept as 20 m. The top of platform is kept at least 1.5 m above the water table in the area.

(ii) Panelling and construction of guide walls.

The total linear length of diaphragm wall is generally *kept as* 2 to 6 m and in this project it is 5 m length. A guide wall in M15 Concrete is constructed along the alignment. This guide wall (*see fig. 5*) prevents subsidence of trench at the surface and guides the grab for trenching of the panel.

(iii) Trenching and chiselling of panels.

Generally, excavation is carried out with an earth cutting grab, mechanical or hydraulic, handled by a crawler mounted crane or by reverse or direct mud circulating drilling machine mounted on a traversing trolley, travelling on rail tracks. As the excavation advances the trench is filled up with bentonite slurry of correct consistency and hydration to provide support to the excavated faces. The level of slurry in the trench is maintained by supplying fresh slurry from the slurry storage tanks. When hard strata or obstruction due to boulders is encountered during excavation, a heavy fabricated chisel is used to break through the rock or boulders. The grab is once again used to remove fragmented rock pieces and thus trench in a panel is taken upto designed depth which is generally 0.6 m to 1 m in rock.

(iv) Lowering of stop end pipes.

Fabricated tubes confirming to the thickness of the wall known as stop end pipes is lowered one each at the end of the panel trench upto the bottom of the trench with the help of crawler mounted crane. The purpose of insertion of these tubes is to provide smooth semi-circular ends to the panels after concreting, as also to confine the spread of concrete only to designated dimensions of the panel. The convex surface of the panel end after retraction of the stop end pipes after concreting of panel also helps in guiding the tool for excavation of adjoining panel. The joint between the two panels shall be kept imperfect shapes other circular for stop end pipes are also in use to provide different shape to joints between the panels.

(v) Lowering of Reinforcement cage.

A properly fabricated reinforcement cage generally welded at all joints is then lowered in the trench with the help of the crane. Many times when the cage is more than 10 to 12 m length, the cage is made in more than one piece with adequate length of the longitudinal bars for proper lapping and insitu welding. 80 mm dia. m.s. pipes are left @ 3m for grouting foundation rock and joints of diaphragm wall and foundation rock. Finally after insertion to the proper depth it is suspended on the guide walls. All inserts, cut outs in final wall and dowel bars for future connection of slabs to walls are fabricated with the cage.

(vi) Lowering of tremie pipes.

Tremie pipe made up of section of 1.2 m to 1.5 m length for concreting are lowered through the cage at pre-determined position with the help of crane. Generally two tremies are used, but if the panel length is 2 to 3 m single tremie is used. Some times due to particular shape of the panel 3 tremie pipes are also used. Tremie pipes are then fitted with hoppers to receive the concrete in batches.

(vii) Mixing, conveying and pouring of concrete in panels.

Concrete is mixed in a central batching plant and transported to the site of excavated panel using tippers, fitted with special chute or if the lead is more and travel time is also longer the transportation is done in transit mixers. Generally M-20 or M-25 Grade of concrete with 150 mm to 200 mm slump is being used. The coarse aggregate of 20 mm and down size is being used for better workability.

The surging concrete in hopper, drives out all the bentonite slurry from the tremie pipe due to its higher density from the bottom of pipe, and finally spreads at the bottom of the trench. After deposition of concrete of a batch at the bottom of the trench there is no bentonite slurry left in the pipe and next load of concrete shall not come in contact with bentonite slurry in the pipe. The fresh batch of concrete shall push the earlier laid batch upwards if the bottom of the tremie pipe is kept embedded in the spread of earlier concrete of first load at the bottom of the trench. The concrete mix is designed to be fluid & cohesive. The w:c ratio is generally kept as 0.45 to 0.55 and slump more than 150 mm.

Gradually the level of the concrete rises at the bottom of the trench. The displaced bentonie is pumped away to a collection pit. As the concrete level rises, the tremie pipe in pieces are withdrawn section by section.

(viii) Jacking of stop end pipes.

The stop end pipes are withdrawn once the concrete starts setting, using hydraulic jacks and hydraulic power pack slowly. A special jacking arrangement is required to pull out stop end pipes without disturbing concrete resting against it. At any given point of time the bottom of the tremie pipe is ensured to be embedded in surrounding concrete by atleast 1 to 2 meters to avoid contamination of concrete at the interface of bentonite slurry and concrete. Only the first load comes in contact with slurry. The same interface keeps on raising with advancing concrete and the concreting of panel is thus completed. Generally this contaminated concrete is made to flow out the final stages of concreting or chipped out later on to expose the fresh concrete.

(ix) Sequencing of panels.

Once the first panel is completed, then either the alternate panel method is adopted for the next operation or consecutive panel method is used. If the sequence of construction of panel to be followed is alternative panel method, then in that case first alternative panels are constructed, known as 'primary panels' using two stop end tubes. After completion of these primary panels for certain length of wall, the panel left out between two panels, known as 'secondary panel', are constructed. No stop end pipe is required for secondary panels since the ends of secondary panel is already defined by convex surface of concrete of primary panels on either side of it, thus giving a continuous wall. The concrete of secondary panels flows into the convex ends of the primary panels to give joint between primary & secondary panel a perfect half round shape.

Another sequence of construction equally popular is know as, 'consecutive panel method' requiring one stop end pipe only at the next end of the consecutive panel. However the next consecutive panel is not started earlier than 48 hours of concreting of previous panel, to allow enough setting time and strength to the concrete of earlier casted panel to prevent it from damage.

(x) TAM Grouting of panel joints.

It is necessary to grout from the u/s side of the panel joint to make the joint absolutely leak proof. This calls for tube-A-machette grouting. Here one or two holes are drilled on the u/s of the panel joint, a tube-A-machette is inserted and sheath grouting is performed. After 7 days of sheath grouting, individual rubber sleeves are grouted with cement bentonite grout with less than 5 % bleeding. A measured quantity of grout is required to be pumped through individual sleeve. Due to this grouting the panel joint becomes absolutely water tight.

(xi) Grouting of foundation rock & joints between diaphragm wall bottom and rock.

It is essential to leave 80 mm dia. m.s. Pipe in diaphragm wall to achieve two objectives a) to grout the joints between RCC diaphragm wall and rock (b) to grout the rock below diaphragm wall. For this purpose 6 m drill holes are done in the rock through 80 mm m.s. pipe, left in the diaphragm wall and after washing and taking permeability test, it is grouted as per IS-6066.

b) POST – TENSION ANCHORING.

The most difficult and tricky part was to provide the post tension anchors of 130 T and 170 Tons at 45^0 inclination at every 2.5 m length. After 28 days of concreting of a panel of 5 m the process to provide 130 and 170 Tons Anchors was started.

The first step was to drill at 45' inclination a suitable dia hole through the RCC panel in the sand upto the rock and encase the hole with 100 mm M.S. casing pipe, it was very essential to case the hole upto rock, because of sandy strata and that too inclined at 45' from horizontal. This feat was performed through indigenous rotary drill machines and bentonite slurry was used for circulation while drilling.

The second step was to drill 75 mm dia. hole in rock upto 8.5 m depth at 45^0 through the already installed 100 mm casing pipe. This drilling in rock was performed by using percussive drilling rigs powered by compressed Air at 7 kg/cm^2.

The third step, was to clean the entire stem of drill hole by alternate jet of water and compressed air.
The fourth step was to prepare a Tendon, made out of 9 Nos. of 12.7 mm dia. High Tensile strand wire. This Tendon was prepared in such a way, that, it provides enough convergent and divergent points in Tendon length, to be anchored in the rock.

The fifth step, is to insert this tendon in the drilled hole in rock, through the diaphragm wall and the 100 mm casing pipe. There is a plastic pipe of 12 mm inner diameter, which also goes along with the Tendon, upto the bottom of drilled hole. The sixth step is to pump the measured quantity of grout of 1:2 consistency cement to water through the 12 mm plastic pipe. The grout quantity is so measured, which is enough to fill the entire length of hole in the rock. The grout is allowed to set for minimum two weeks before post tensioning of this anchor begins.

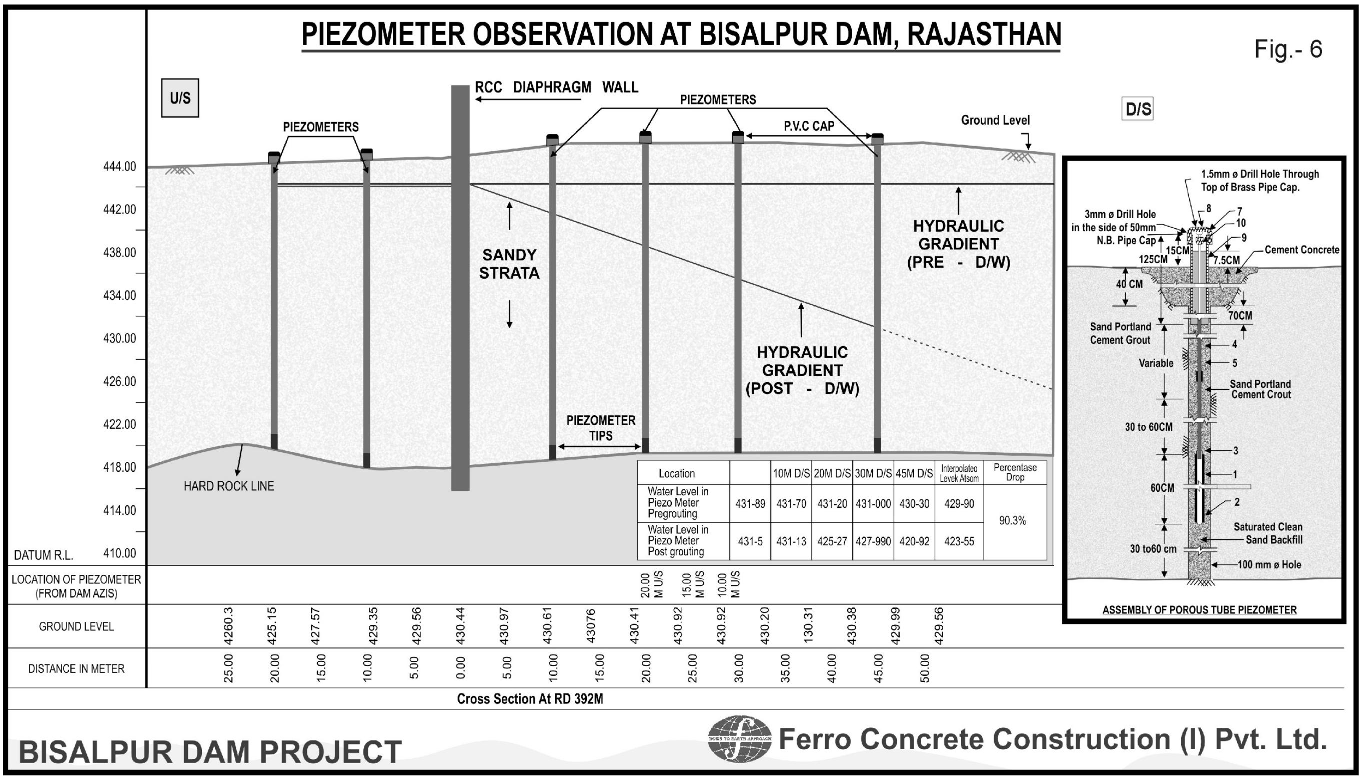
The sixth step is to stress this tendon with the help of a special hydraulic jack. The individual strand is stressed one by one and is locked at the u/s surface of the RCC diaphragm wall by special conical locking device. Like wise anchors at every 2.5 m c/c was provided in the entire length of the u/s and d/s RCC diaphragm wall. Further vertical anchors of 170 Tons were provided at the junction of T beam.

Thus the work of coffer dam cum cut off having a total length of 680 m (420 m u/s + 260 m d/s) for Bisalpur dam was completed in a record period of 12 working months. During foundation excavation of main dam between the two diaphragm walls it was observed that maximum seepage was less than 2 cusecs, due to which construction of main dam could be completed in 3 years.

INSTRUMENTATION:-

Instrumentation for measuring drop of head across diaphragm wall, following arrangements were made.

1. Four Piezometer lines were installed in the river bed portion @ 100 m c/c on the u/s of u/s diaphragm wall and d/s of d/s diaphragm wall.
2. In each line about 6 Piezometers were installed. Two Piezometers on u/s of diaphragm wall and four on the d/s of d/s diaphragm wall.
3. Type of Piezometers installed were porous tube type.
4. Pre and post diaphragm wall installation readings were taken regularly.
5. Based on these Piezometer readings pre and post mean hydraulic gradient were drawn.
6. It was observed that drop of head across the diaphragm wall at 90 m distance is more than 90 %, practically in the entire length of diaphragm wall coffer Dam. For details kindly see Fig. 6.



Location		10M D/S	20M D/S	30M D/S	45M D/S	Interpolateo Levek Atsom	Percentase Drop
Water Level in Piezo Meter Pregrouting	431-89	431-70	431-20	431-000	430-30	429-90	90.3%
Water Level in Piezo Meter Post grouting	431-5	431-13	425-27	427-990	420-92	423-55	

SALIENT FEATURES OF COFFER DAM RCC DIAPHRAGM.

1. Total length of coffer dam diaphragm wall
   a) U/s -- 420 m
   b) D/s -- 260 m
2. Total quantity of 60 cm thick RCC diaphragm wall 12,000 M^2
3. Reinforcement Steel used. 790 MT
4. Cement consumed 4,230 MT

5. Post Tension Anchors used.

a)	135 Tons	296 Nos.
b)	170 Tons	204 Nos.

6. Total cost of work (1988 level) Rs. 8.40 Crores

7. Completion period 12 Months.

CONCLUSIONS :-

1) Coffer dam for the Bisalpur dam had been successfully constructed and performed well during construction period for more than 5 years

2) RCC Diaphragm Wall is successfully used as positive cut off for dams but can also be used as a coffer dam to divert, run off of the river and can be constructed in a very short period.

3) The total seepage through the Diaphragm wall covering 12000 SM area, was less than 2 cusecs.

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