

Design and construction of a coffer dam on Narmada River for Indira Sagar project in central India: a case study of innovative foundation

Conception innovante et construction d'un batardeau provisoire pour le barrage sur la rivière Narmada dans le cadre du projet Sagara en Inde centrale

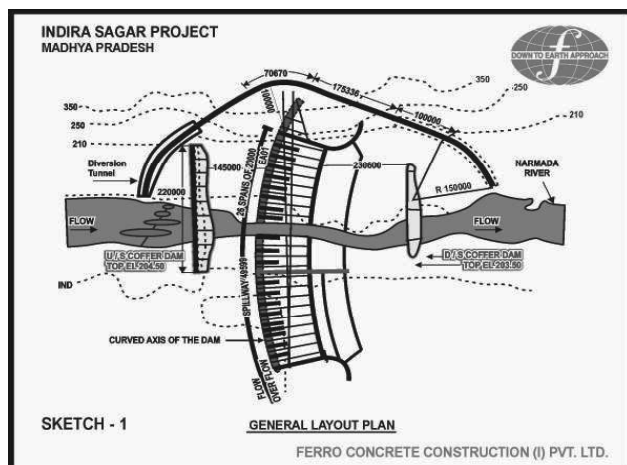
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ABSTRACT: Indira Sagar Project in M.P., a multipurpose project, a 92 m high dam on Narmada river was required to be constructed but during off monsoon period flow of 300 cumecs of river Narmada was to be diverted so that dam can be constructed. For this, it was necessary to construct a 24 m high coffer dam to divert the off monsoon flow through a diversion tunnel from left abutment. This coffer dam was to be founded on a complex geological strata. To construct this 24 m high coffer dam, a new concept of innovative design used for first time in any country to construct a coffer dam, using 5 tons pre-cast blocks as shuttering on both faces of a coffer dam and filling the enclosure with boulders and stonecrete them under water. The work of 24 m high coffer dam has been done underground and under water for 12 m height using stonecrete and balance 12 m by conventional stone masonry.

RÉSUMÉ : Pour la construction du projet de barrage principal de 92m de hauteur sur la rivière Narmada des ouvrages provisoires de détournement de la rivière étaient nécessaires dans un contexte géologique difficile. L'article présente la conception innovante de batardeaux utilisant des blocs creux préfabriqués en béton avec bétonnage sous eau après mise en place d'encrochements.

1 INTRODUCTION

Indira Sagar Project is situated near Punasa about 60 Km. from Khandwa Town in Madhya Pradesh. To construct this dam, it was essential to divert Narmada river during off monsoon period from the original flow route, so that dam can be constructed without any hindrances. For this, conceptually it was necessary to have two important Component i.e. one u/s and d/s coffer dam to stop and divert Narmada river flowing from the original flow route, where proposed main dam was to be constructed and another a diversion tunnel through which Narmada post monsoon flow of 300 cumecs can be diverted during working period. That is how the construction of u/s and d/s coffer dam was necessitated. A sketch showing the various component like, u/s and d/s coffer dam diversion tunnel, proposed main dam etc. is shown in sketch – 1.



2. FOUNDATION AND GEOTECHNICAL PROBLEMS AND GEOLOGY

The Geological survey of India had carried out elaborate geological studies at the Indira Sagar Project dam site. It has been indicated that the dam site is located in the upper vindhyan inter bedded sequence of tough quartz arenites (quartzite), sand stones with minor silt stones. The bed in

general has an ENE-WSW strike and dip by 15-25 towards NNW with exceptional steep dips of 40-45 due to local warping. Bedding shears of 10-25 cm thickness confined to the silt stone beds are common features. The dam area in the river bed is occupied by a number of ENE-WSW trending vertical fault/shear zone, indicating horst/graben structure showing relative vertical displacement of blocks. It is WSW continuation of the Sone-Narmada fault. Mapping of the area has identified about five shear zones ranging steep dipping to vertical. These zones are braided with clayey gouge shear seams of 0.10-0.75 m thickness enveloping competent fractured lenses of quartzites and sand stone of 0.50 m to 2.5 m width sketch-2 shows geological L-section along main dam axis.

The fault zone includes the shearing (Sz-5), by virtue of its disposition and continuity, extends beyond the coffer dam located about 80 m upstream of the exposed section and opens in to the water pool, created by the upstream coffer dam in spite of being directly connected to this water pool, created by the upstream coffer dam. In spite of being directly connected to this water pool with a head difference of about 18-20 m the exposed section is completely dry and points to the near impervious nature of the fault zone material. Permeability test carried out in the new test holes in the fault zone confirm this observation (< 1 lugeon).

Except in the highly crushed zone/intrusion dyke, the fault zone material looks well compacted and was expected to have a high in situ density in the range of 2.2-2.3. The shear strength parameters were high and grain porosity may not exceed 20 %. The material did not show any significant deterioration notwithstanding the fact that there has been water to a depth of 1-2 m standing on it for a considerable time.

Even though the strata for foundation of coffer dam looked positive, for further dam design and stability of coffer dam foundation, detailed geotechnical investigation were necessary to eliminate geological surprises. Due to lukewarm report about highly Crushed zone/Intrusion dyke the foundations of coffer dam needed additional treatment to make it water tight. Further site investigation were carried out as given in the table below.

It may be observed that during pre-construction stages, to determine the detailed design parameters, following method of site investigations were performed :-

| | | |
|---|--------------------------|--|
| 1 | Geological mapping. | Over 0.75 Sq.Km on 1:1000 scale. |
| 2 | Core drilling | Double tube barrel – over 3000 m Triple tube barrel – over 500 m |
| 3 | Trenches | Three parallel trenches of +30 m. Six cross trenches of + 15 m |
| 4 | Shafts | Six shafts of 9.5 to 18m depth, 3.5 m dia. |
| 5 | Drifts | Four drifts of +16 – 23 m. |
| 6 | Bore hole camera studies | In 2 drill holes to study cavitations in silt stone/bedding shear zones. |

This Data indicated that the sheared /crusted rock mass shall get consolidated if consolidation grouting is carried out and after completion of coffer dam, curtain grouting is also recommended, 1 m from the u/s face of coffer dam. Both these treatments were absolutely necessary in view of typical geotechnical problem faced. These treatments were carried out.

3. COFFER DAM - UPSTREAM AND DOWNSTREAM

The u/s coffer dam was necessitated to stop and divert the post monsoon river flow, to facilitate construction of main dam. This post monsoon flow ranging from 300 cumecs to 100 cumecs was required to be diverted from a diversion tunnel which was under construction through the left abutment.

As the construction of diversion tunnel was getting delayed considerably, provision of six sluices in the body of u/s coffer dam was envisaged to pass the post monsoon flow.

3.1 Concept.

The work consists of design and construction of upstream and downstream coffer dam of Indira Sagar Project. This was the new concept of design used for first time in any country to construct a coffer dam using 5 tons pre-cast blocks as shuttering on both faces u/s and d/s side of a dam, and filling the enclosure with boulders and stonecrete them under water. All work of coffer dam has been done underground and under water upto RL 193.5 m.

The maximum height of u/s coffer dam was 24 meter, 12 m under water and 12 m above water. The lowest foundation level in river bed was ± 180.60 m. For under water portion 5 ton hollow pre-cast c.c. blocks were casted and placed on the u/s and d/s face of dam, as a shuttering in a cell of 15 m length with the help of divers. Before placing the blocks, river bed was leveled by using blasting under water and with special technique, PC blocks were placed. Boulders were filled in the enclosure of a 15 m long cell and grout pipe with safety reinforcement were placed. The cell of 15 m was thoroughly caulked from outside, so that river flow does not have any effect in the cell. A colloidal grout, made out of sand, cement water and super plasticiser was pumped through the grout pipe at bottom and level of grout slowly built up from down upward. Thus colloidal grout (colcrete) replacing the water in the voids of the boulder and converting the boulder mass into concrete. This under water work was carried out upto 193.50 m level. About six pre-fabricated construction sluices of 2 m x 3 m were placed to take care of post monsoon discharges upto 300 cumecs as the diversion tunnel was under construction and was not ready.

Stone masonry was constructed above water level over the underwater works from RL 193.5 m and raised upto RL 204.50 m.

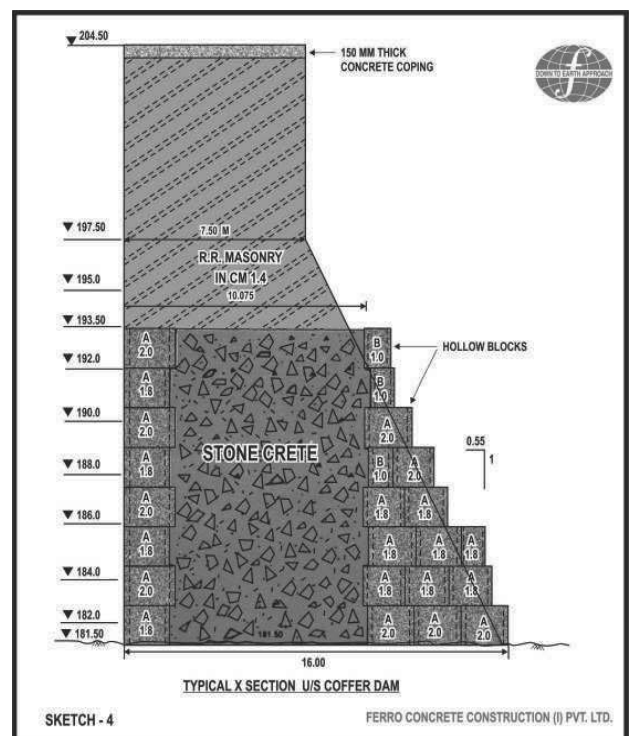
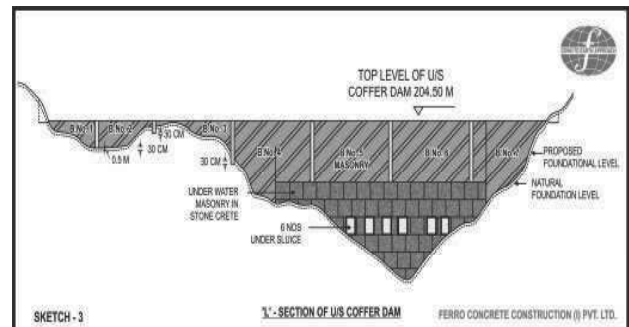
3.2 Design.

Height of u/s coffer dam was 24 m with the lowest foundation level kept at 180.6 and top of coffer dam as RL 204.5m. It has been designed on the principle of gravity dam, duly checked, for stability in various condition like Reservoir empty and Reservoir full etc. with following parameters :-

3.2.1 Cofferdam:

- Above water level, Random rubble masonry with a compressive strength of 10.5 N/mm² (cement mortar 1:4 approximate) with selected stone placed in u/s and d/s face.
- Under water stonecrete masonry in 1:2 and 1:3 concrete with P.C.C. Blocks on u/s & d/s faces.
- PCC blocks in M-15 grade Concrete.
- Coping : Concrete of M20 grade (c.c. 1:1.5:3) with 20 mm graded metal.

It may be observed that for underwater work, PCC blocks were kept on u/s and d/s section of the coffer dam and they were considered as a homogenous part of the full section. Dam cross section and L-section can be seen vide sketch – 3 and 4.



4 CONSTRUCTION SEQUENCE OF COFFER DAM U/S.

Following is the Construction sequence.

4.1 Casting yard for Pre-cast hollow blocks.

A casting yard having all facilities to cast hollow blocks under controlled conditions was made on left bank. The pre-cast/hollow blocks of size of 1.5 m x 1.5 m x 1.5 were casted in this yard. Suitable storage for form work and construction materials like stone grit, sand, water curing tank etc. were arranged on this platform to keep adequate stocks at site. The yard was equipped with form vibrators etc. and the traveling gantry with 10 T capacity. One electric hoist was fitted at this platform. The blocks were handled and loaded in flat bottom trucks by said gantry to carry it upto working platform on left flank from where, finally they were taken for construction using crawler mounted cranes at site.

4.2 Precast Hollow Blocks :-

It was proposed to use hollow-precast blocks in the u/s and d/s of the dam profile under water. This enclosure were termed as stonecrete cell. At a time, 15 m length of coffer dam was undertaken in hand. Selected rubbles were filled within this enclosure along with colgrout pipes to carry out under water work. These colgrout pipe of 80 mm ϕ were kept in a grid of 3 m and individual pipes were surrounded with a circular coil made of 6 mm, Tor to protect them during boulder filling. These blocks in addition to forming the enclosure have helped to stop flow of water within the enclosure as well as in voids of the rubbles.

The shape of the blocks on upstream and down streams faces of the coffer dam were nearly confirming to the designed profile.

To provide necessary interlocking amongst the blocks, male and female grooves were provided in each block. The blocks of special dimensions for maintaining uniform level of courses were casted as per requirement. The necessary shear keys and lifting hooks were provided in each block. The blocks were casted in the rigid steel forms so as to ensure uniform dimensions and minimum tolerances. The blocks were cast in advance and stacked in the casting yard.

4.3 Preparation of Foundation.-

The left and right flanks which were much above water level of river were excavated to reach sound rock level to accommodate the length of coffer dam. Right flank in particular, was braided with clayey gougey shear seam of varying thickness from 2m to 6m. On the left flank excavation bedding shears of 16 to 25 cm thickness confined to the silt stones were commonly seen. Few photographs of the excavation and shear seam are exhibited below.

Foundation preparation in the river portion comprised of removal of silt, debris, loose rock and leveling of bed rock by underwater blasting wherever necessary. This was done using expert divers.

In order that the precast blocks from the pattern masonry walls required to be raised in uniform courses, the precise soundings were taken and loose materials were removed from its underneath. The area was leveled using special sizes of the blocks, or executing under water concreting for leveling course. It was observed that foundation rock was undulated at places. Hence levels were taken at a grid of 2 m and drawn on graph sheet. The gap between the leveled foundation and underneath of the blocks were caulked to achieve reasonable water tight joint.

4.4 Launching of Blocks.

After the river bed is cleared of loose materials and leveled to receive the first course of the blocks as described under preparation of foundation para (III) above, the pre-cast hollow blocks were lifted from the working platform and carried by crane and lowered in position in the cell. Before lowering the PCC blocks, a steel frame made of 100 mm M.S. angle, is first lowered in place on 40 mm bed of stone chips and this frame is leveled horizontally on this bed. Expert divers had positioned the blocks at proper places either on the u/s or d/s of the enclosure as required, but within these steel frames which were leveled horizontally on the bed of 40 mm stone chips.



Each operation of block launching consisted of placement of blocks in the bottom course, to be followed by blocks in upper course. Till they were placed upto the level of 193.50 M. The launching of blocks is shown in photograph above.

Normally the blocks will be placed in required courses on up-stream and downstream sides of the u/s and d/s coffer dams. As the blocks are required to be in course it will be imperative to break the joints between the courses. Proper care was taken to break these joints in subsequent courses. As a matter of abundant precaution, the space in between the rows of blocks, will be filled with selected rubble near the blocks and around the pipes placed for colgrouting, so that the same does not get disturbed while filling up of rubble/stones in the cell

4.5 Packing of Rubbles.

After the blocks are carefully launched and erected on either side in courses and the space in between intersped with colcrete pipes, as stated above, rubble will be placed to fill-up the entire space between the rows of blocks in a 15 m cell. This rubble filling shall be done layer by layer in a systematic way using the large buckets with drop bottoms, handled by cranes.

4.6 Stonecreting Operations.

The stonecrete process consists of making a grout of cement, sand and water in which cement has been so completely hydrated by high speed mechanical mixing, that the grout attains a colloidal form. This grout is stable and particularly fluent. It contains no chemical admixtures which might ultimately be harmful. When colloidal grout is poured in rubble aggregate the voids in the rubble filling are completely filled by penetration and the whole mass sets as a dense, solid concrete which is termed as "STONECRETE".

4.7 Preparation of Colloidal Grout.

The Colloidal grout was prepared in double drum colcrete mixer consisting of sand, cement and water in desired proportions to obtain colloidal grout. In colloidal mixer, the

wetting of solid ingredients results from the shearing action which takes place in the specially designed impellers and matching casings of the colloidal mixers. The colloidal grout of specific gravity upto 1.8 to 2 is obtained using these high velocity mixers. Colloidal grout has enough fluidity to flow like grout and does not get separated when it comes in contact with water. It displaces water from the voids of stone/rubbles due to high specific gravity.

The double drum stonecrete mixer produces colloidal grout at the rate of 5 to 10 M³/hr. of 1:2 mix or 6 to 12 M³/hr. of 1:3 mix. When colloidal grout is stored without agitation in tanks after mixing, a little settlement is to be expected because sand invariably contains some oversize particles. When it is pumped direct by the mixer to the work in normal practice, the oversize particles do not have time to settle out.

4.8 Placement of Colloidal Grout.

Colloidal grout does not mix with water unless agitated with it.

The colloidal grout so prepared is pumped, through 80 mm Φ pipes placed in the rubbles using special roto or colmono pumps. The grout will be pumped at the bottom of pre-packed stones under pressure and will be allowed to rise uniformly in the cell displacing all the water from the voids due to its gravity. Once the grout travels upto the top of the course, the colgrouting is stopped when it emerges out of boulders at a level of 193.50 m of working platform level. After which the crawler mounted cranes will be advanced to tackle the next cell of the coffer dam till entire length 220 m length of u/s coffer dam is completed from one end. Construction sluices were left in the u/s coffer dam for diverting the water in final stages of closure of the coffer dam.

4.9 Construction Sluices.

Pre fabricated M.S. sluice barrel were lowered in the central portion of u/s coffer dam keeping invert level at RL 186. In all, six sluices of 2 m x 3 m were installed. Rigid steel boxes were provided in the blocks for forming the approach tunnel for sluices. The construction sluices were installed under water with the help of the expert divers and is shown in photograph below.



4.10 Masonry Works above water level.

Construction of masonry in the flank blocks and above water level on stonecrete platform, upto top of coffer dam was done using conventional method of construction. The coffer dam above RL 193.5 was constructed in masonry upto RL 204.5 M and is shown in photograph. This was taken up immediately after the construction upto RL 193.5 under water using stonecrete. A coping 150 mm thick was laid at RL 204.5 m on the masonry using M-20 grade concrete.

5. DRILLING AND GROUTING.

5.1 Consolidation Grouting.

Looking to the geology, it was recommended to adopt a grid of drill holes at 3 m c/c on both side, besides about 82 Nos. of special grout holes were identified keeping in mind the location of various fault zones.

Depth of consolidation grout holes was 6 m in foundation rock.

6. CURTAIN GROUTING.

It was recommended to provide a single row of grout curtain, 1 m from the u/s face of the coffer dam, spacing of holes were kept as 3 m c/c. Depth of grout curtain holes in foundation rock was kept as 15 m.

This grout curtain was provided in stages of 5 m of drilling and grouting in descending order method.

It was observed that in consolidation grouting, intake of cement was 45 kg/meter and in curtain grouting it was 26 kg./meter.

7. D/S. COFFER DAM:

The construction of d/s coffer dam was done using the same methodology as explain under para 3 sub para I to IX. The top of d/s coffer dam was kept as 203.50 m i.e. 1 m below the u/s coffer dam. The main purpose of this coffer dam was, not to allow the river water which was diverted through the diversion tunnel (back water) in the d/s of the river.

Closure of Sluices 6 Nos. in coffer dam:

It was essential to ensure following works completed before closure of sluices were taken in hand :-

8 CONCLUSION

Coffer Dam u/s and d/s, for the Indira Sagar Project had been successfully constructed and performed well, as a result the work of 92 m high I.S.P. main dam could be expeditiously carried out on mighty Narmada River.

The unique and innovative design, using 5 Tons Pre-cast hollow blocks with underwater stonecrete technique for the first time in the country, has successfully been used in Indira Sagar Project.

9 REFERENCES

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