Restoration and Rehabilitation of Old Pagara Masonry Dam by Grouting Technique (A Case - Study)

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ABSTRACT: Pagara Masonry Dam was constructed about 98 years back from now, during the period 1911-1917 in the erstwhile princely state of Gwalior, INDIA. After construction, it had breached and was rehabilitated three times. The masonry dam rests on Sandstone formation which had open joints. As the dam was designed and constructed in the early part of twentieth century, it was deprived of the present design concepts and was left with many deficiencies, which resulted in considerable problems that required rehabilitation three times since its construction. The third rehabilitation was done in the present time, which called for a rational approach of dam safety, including thorough geological investigations, treatment of foundation and body of dam, using grouting and guniting technique, stability analysis, hydraulic studies, etc. It is essential to provide inclined pressure release holes, in the masonry portion from d/s face of the dam to release the pore pressure, as there was no foundation gallery in the old dam. The drill holes for grouting, were done from top of dam, through the body of the dam and 1.0 m into the foundation sandstone rock, along a line about 4.5 m d/s. from the toe of the dam. Spacing of drill holes was 15 m centre to centre. The strengthening of dam, using guniting, pointing and grouting is discussed in detail in this paper along with other geotechnical deficiencies.

1 INTRODUCTION

Concrete and masonry dams in India performed generally well. Many of the old structures, which have masonry block hearting and concrete/ masonry facing have shown little sign of deterioration. Many of the old masonry and concrete dams do not have provision for relief of uplift pressure below the foundation but the stability of these older structures has not been seen as a problem as these were constructed with a fairly massive cross section. But this is not the case with all old dams which have deteriorated due to various causes like internal erosion, sliding, inadequate spillway capacity etc. The internal erosion results in serious failure of dams. To bring such deteriorated dams within the acceptable safety standard is a difficult task since every such problem with these concrete or masonry dams has tended to be specific to the site condition and cannot be generalized for a solution.

Pagara dam (Fig. 1) situated near village Joura, nearly 39 Km. from Morena town in north M.P., India, across river Asan is a composite dam. It consists of 244 m long stone masonry non flow dam, 73 m long masonry waste weir & 1439 m long earthen dam. The maximum height of dam is about 27 m above the deepest river bed level.

The spillway was fitted with 6 falling shutter type of crest gates of 12 m x 1.8 m which are in-operation and remain open. In addition there is an open cut for a length of about 244 m on the right flank. There are two sluices located in the non-overflow section of the dam. One sluice is fitted with a vertical gate of 0.9 m x 1.8 m size and another with a gate of 1.8 m x 5.4 m size.

2 HISTORY OF CONSTRUCTION

This dam was constructed about 98 years back from now, during the period of 1911 to 1917 when knowledge and computational methods in structural design of dams and in hydrology were less accurate than now-a-days. A geological fault zone existed at the junction of earth dam and masonry dam which went unnoticed at the time of design and construction of this dam. The open jointed sandstone formation on which the masonry dam foundation was rested, were not considered for uplift pressure. Drainage galleries to release uplift pressure were unheard of, in the old days. The cut off in the earthen dam had not been anchored to the impervious stratum. All these deficiencies resulted in considerable subsequent trouble and required thorough rehabilitation and upgradation of the dam. The designed flood also needed reconsideration for spillway capacity. This needed a rational approach of dam safety including hydraulic studies, analysis of the stability and mechanical behavior of dam and foundation treatments, gate operation etc. (4)

This dam has breached and was rehabilitated three time since its construction completed in 1917. In following paragraphs, they are discussed in brief.

2.1 First breach/damage and rehabilitation – year 1924 – 1927.

The dam construction was completed in the year 1917. Floods of year 1917 and 1919 caused some damages to the dam. In 1924 floods, excessive leakage developed under the earth dam and the downstream slope of the dam slumped. A sand belt was detected in the shale foundations of the earthen dam and so a concrete cut off was provided at the heel of the earth dam and upstream face of earthen dam was paved with RCC slab up to maximum water level and top of earthen dam was raised by 0.6 m. With these repairs earthen dam was put in operation in 1927.

2.2 Second breach and rehabilitation – year 1943 - 1948.

In the floods of 1943 water levels rose to RL 665 ft which was the Top bund level of non-overflow section of masonry dam. Probably due to excessive uplift pressures in the foundations of masonry dam, masonry dam section failed and breached in about 30 m length. This breached portion was rebuilt with wider base width on the basis of stability considerations then prevailing. These stability considerations were of a very general nature. The dam was put back into operation in 1948.

2.3 Third damages and rehabilitation of dam year 1994-1995. (Presently under discussion, below)

Gravity section of Pagara dam was constructed with lime mortar and subsequently partly reconstructed after its breach in 1943 and is thus more than 98 years old dam on date. The dam had also been once over topped. It has shown distress in form of wetness of slope, slushiness etc. Body of masonry dam was profusely leaking. Hence it was felt necessary in the year 1993, to accurately assess the present condition of dam in respect of hydrological and structural adequacy. In this paper this third time damage and rehabilitation has been discussed in details.

3 IDENTIFICATIONOF CAUSES OF PRESENT DISTRESS.

Based on the Investigations carried out by Geological Survey of India and Central Soil and Materials Research Station, following conclusions were drawn.

3.1 Seepage through foundation of earth dam was not effectively controlled resulting the d/s slushy condition, bulging on the d/s slope of earthen dam.

3.2 Existence of geological fault zone at the junction of masonry and earth dam which was not treated at the time of construction.

3.3 The masonry dam was founded on sand stone formations which had open joints, These joints had not been treated. There existed high permeability in the upper layer of foundation rock.

3.4 Distress (Fig. 2) was due to ageing, which comprises of deterioration of construction materials (i.e. cracking, erosion and weathering etc.) and foundation failure. The failure may occur even under usual operating conditions due to increase in normal loads (i.e. silting, uplift and decrease in resistance i.e. by leakages crack propagation, weathering, erosion etc.) leading to complete failure of structure.

3.5 On the downstream face of masonry, very heavy spouts of water (Fig. 3) were coming out. The entire downstream face was wet and most of the masonry joints were leaking. This further confirms that mortar from the joints has been eroded and lot of voids has been created in the body of the masonry. The body of the masonry dam was porous and safety of this structure was under danger zone.

3.6 There are problematic reaches in the earthen dam, predominant leakage locations were at ch. 15, 17, 32 and slushiness observed between Ch. 13 to 17, Ch. 22 to 23, Ch. 26 to 28 and Ch. 31 to 41.

3.7 Inadequate spillway capacity, which in turn may increase the surcharge height above the stipulated MWL over topping the NOF portion, leading to complete failure of dam.

3.8 Vertical cracks in non overflow section at few locations.

3.9 Erosion at the heel of masonry dam due to clear overflow of spillway discharge.

3.10 Missing agreement of the statistical computation of that time to the present Indian standards.

4 REMEDIAL MEASURES FOR PRESENT DISTRESS.

4.1 To compute the 1000 year flood as the normal design flood and ensure that the dam and the auxiliary structures of the spillway would not undergo any damage with the computed Project maximum

flood. The encroachment in the free board and extent of damages that are likely to occur may be estimated. However hydrological rehabilitation is not discussed in this paper. Only structural rehabilitation is discussed.

4.2 To ensure the structural adequacy, following remedial measures were recommended and carried out. (1)

4.2.1 Masonry Dam

To gunite the entire up stream face of dam with wire mesh reinforcement. It was recommended that the reservoir be emptied and dam face thoroughly cleaned and the gunite applied in one continuous operation to ensure proper bonding.

4.2.2 Raking of all masonry joints on d/s face of dam and re-pointing them with good cement mortar.

4.2.3 Grouting the body of the dam and upper layers of the foundation to fill in all the voids created by leaching etc. using cement grout.

The test grout pattern is proposed in two rows one meter apart and holes being spaced at 3 m. c/c staggered. The first row of grout holes were one meter from the u/s. face of dam. After test section, different reaches of masonry dam was proposed to be grouted accordingly. Layout of grout holes is shown in Fig. 1.

It is essential to provide inclined release holes in the masonry portion from d/s face of dam, to release the pore pressure because there is no foundation gallery. The holes must penetrate through body of the dam and 1 m into the foundation rock along a line about 5 m d/s from the toe of the dam. Spacing of hole may be 15 m centre to centre.

4.2.4 Earth Dam

The existing earth dam section should be brought to a proper and uniform profile in the entire length.

4.2.5. To provide downstream toe loading with inverted filter in the identified seepage reaches.

4.2.6. Relief wells shall be provided in the predominantly seepage zones.

4.2.7 The drainage ditch on the downstream side of earth dam had caved in and discontinuous in places. It was suggested that a continuous drainage trench 1 m x 1 m may be excavated for the full length of the earth dam and back filled with broken rock and gravel to lead the seepage as well as rain water to the existing natural drainage.

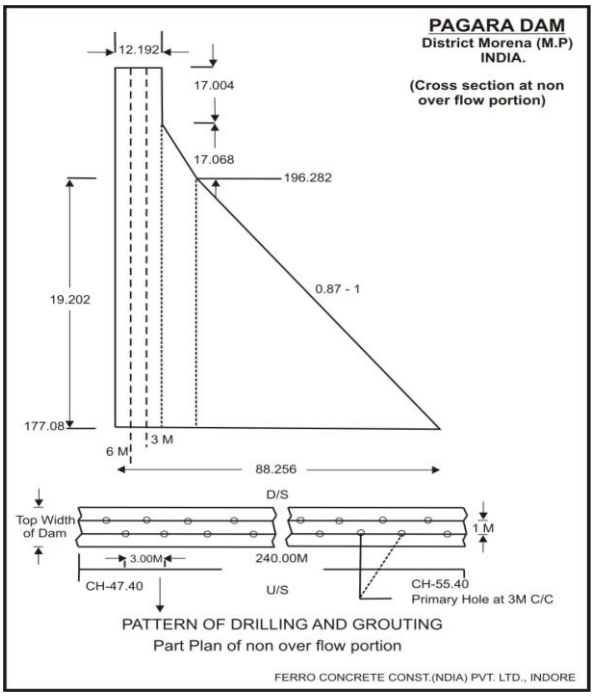

Fig. 1 Section of non-over flow, Pagara Dam. Showing drilling & Grouting pattern in plan.

5. STRUCTURAL REHABILITATION OF MASONRY DAM

5.1 Details of execution of guniting of u/s face, pointing of d/s face and grouting plan of main body of dam foundation (5) are discussed below :-

5.1.1 Guniting of U/s Face of Dam

In the first phase, guniting on the upstream face was started. The main component of guniting work as executed (3) as below:

Raking of the masonry joints on the upstream face:

Raking of joints has been done by lowering down the cradle platform (Jhula) from top of dam along with one skilled mason. With the help of chisel and hammer, mason has skillfully opened the joints and removed the old mortar about 50 mm in depth. With the help of 10 numbers of such set up, it was possible to tackle the entire face within a short period of three months.

Simultaneously with the help of jet of water and air, entire u/s surface of dam was cleaned along with the raked joints.

50 mm x 50 mm hard drawn wire mesh of 3.15 mm diameter wire, has been fixed to the u/s face of dam with the help of long bolt cum nail of 250 mm length, in a such a way that top remains protruded about 40 mm from the masonry face to receive the wire mesh. The spacing of bolt cum nails were 1 m c/c both ways.

Wire mesh is tightened to the bolt cum nails with the help of 100 mm x 100 mm mild steel plate of 10 mm thickness with the help of nut.

A dry mix of cement and sand in 1:3 proportion has been applied with the help of Guniting machine all over the surface. Water cement ratio of 0.38 has been used. Thickness of gunite applied was 50 mm in average.

Curing for 28 days has been done by sprinkling water throughout the surface of the dam.

5.1.2 Raking and Pointing of D/s. Face of Dam

Raking of joints has been done by lowering down the cradle platform from top of masonry dam with a skilled mason. With the help of chisel and hammer old mortar from the joints between the masonry stones were taken out up to 50 mm depth.

The face of masonry and joints were washed and cleaned with the help of air and water jet.

When water is gushing out from the various joints, seepage water is localized through 20 mm G.I. pipe embedded in the masonry joint so that water from the nearby surface starts coming through the pipe and later on, when pointing is done in surrounding area, this pipe can be closed and seepage water brought under control.

Pointing has been done in conventional manner in 1:3 mortar.

Curing for 28 days has been done on the entire d/s. face surface.

6. GROUTING

Drilling and grouting operations have been (2) executed as below:

6.1 Drilling has been done by using Rotary cum percussive drilling rigs (Percussion method) with water flushing system. Though in some states Rotary (Diamond) drilling is recommended for drilling in weak and porous masonry dam, but it is very expensive and slow in progress.

6.2 First of all, a casing of 80 mm diameter is fixed at the location of the hole, at least 0.5 m in the masonry by drilling a suitable dia. hole and fixing a mild steel casing by caulking and grouting it, in the drill hole.

6.3 Drilling in masonry has been performed in descending order method in the front row first, where holes were marked at 3 m c/c. in stages of 6 to 9 meters. The first stage so drilled is washed with jet of air and water till all the drill cutting comes out.

6.4 Water test (cyclic) was conducted in every stage. Permeability of strata is measured in terms of Lugeon. Lugeon is water absorption during the water test in liters/minute/meter depth of hole conducted under a standard pressure of 10 kg/cm^2.

6.5 For grouting following machinery and equipment has been used.

High speed mixer: For mixing of cement with water, high speed mixers known as colloidal-mixers are used. It is important to use these mixers so that grout does not bleed while grouting.

Double drum agitator: From colloidal mixer, grout is taken to double drum agitator, where measured quantity of grout is supplied to the grout pump. These are basically pedal mixer run by compressed air motor or electrically operated motor.

Electrically operated double cylinder pumps have been used to pump the grout in the hole. These pumps are reciprocating, piston type, capable of producing 50 kg/cm^2 pressure and having a pumping capacity of 100 to 300 Lit per minute liquid in the hole. From the agitator, grout comes to the pump and from pump it is injected in the hole through packer and grouting header fitted with a pressure gauge.

6.6 Grouting has been executed as per IS 6066 by starting with thin mix of 1:10 cement to water and thickening the same as the grouts intake increases and ending with 1:1 by weight.

6.7 The grout is left in the first stage to set after grouting for 24 hours and then by re-drilling the set grout, second stage of 6 to 9 m depth is drilled and same procedure as described above is followed till a hole reaches to full depth. Drill holes were taken 3 m in rock foundation to grout the upper layer, which was highly permeable.

6.8 After grouting the holes of the first row for about 30 m. length, the second row drilling and grouting is also performed simultaneously and the entire length of dam is completed.

6.9 Grouting pressure :

Maximum grouting pressure has been kept different in various stages as below:

0 to 6 m	- 2 kg/cm^2
6 to 12 m	- 3 kg/cm^2
12 to 18 m	- 4 kg/cm^2
18 to 24 m and more	- 5 kg/cm^2

6.10 Near the sluice, at Pagara dam, very loose masonry with lot of voids were observed which were taken care of, by drilling and Colgrouting 6 numbers drill holes, using sand cement grout with the help of Colcrete mixer and Colmono pumps.

6.11 Colgrouting is a process of making grout out of cement, sand and water mixing them thoroughly in colcrete mixer and pumping the grout in the drill holes by using Colmono pumps.

6.12 After completion of primary holes, 30% of secondary holes were drilled in the centre of the two rows. These 30% holes were chosen near the holes, where grout intake was very high.

6.13 After secondary holes, a diamond drill hole at every 30 m c/c was drilled to find out the condition of masonry after grouting and water test taken.

6.14 It was found that good core recovery up to 97 % has been achieved and water test shows the result of less than 2 to 5 lugeons. Following Photographs shows condition of Pagara Dam before grouting (Figs. 2 & 3) and after grouting treatment (Fig. 4).

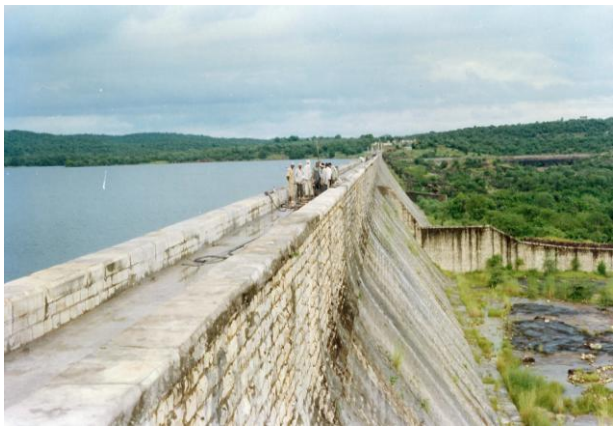

Fig. 2 Pagara Dam before treatment

Fig. 3 Leakage through the Dam before treatment

Fig. 4 Pagara Dam after treatment

7. SALIENT FEATURES AND DATA FOR GROUTING OF PAGARA DAM.

- Length of masonry dam grouted. 244 m
- Average depth of grout curtain. 18.00 m
- Width of grout curtain. 2.00 m
- Volume of cement injected in entire dam 352.00 MT
- Grout consumption per meter of drilling. 50.00 kg.
- Quantity of percussive drilling executed. 6934 m
- Quantity of re-drilling executed. 7197 m
- Quantity of diamond drilling executed. 144 m
- Quantity of Guniting executed 2340 sq.m.
- Quantity of pointing executed. 9366 M^2
- Pregrout permeability (Average) More than 100 Lugeon
- Post Grout permeability 2 to 5 Lugeon

8 CONCLUSIONS AND RECOMMENDTIONS

With the use of cement grout, a very badly leaking masonry dam, having voids and high porosity was completely made water tight and structurally sound.

It is essential to provide pointing on the u/s and d/s surface of dam before starting of grouting.

For grouting a badly leaking masonry dam, cement grout is sufficient. At few places wherever porosity is very high, colloidal grout of sand and cement can be used.

It is recommended to use high speed colloidal mixers to mix and prepare grout for the masonry dam. Conventional pedal mixers should be avoided.

Drilling of inclined release holes from D/s face of dam is essential to release the pore pressure because there is no foundation gallery.

9. REFERENCES

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