SEEPAGE CONTROL IN MASONRY GRAVITY DAMS THROUGH DAM BODY GROUTING - A CASE STUDY

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ABSTRACT

Masonry dams exhibit leakages/seepage due to poor quality construction, leaching of cementitious material, cracking, design deficiency and ageing effect. The leakages/seepages affect structural stability of the dam due to development of high pore pressure, reduction in mass density and strength parameters. To restore the structural integrity of the dam and make the distressed structure serviceable again, various methods are adopted either one or in combination. Generally for controlling leakages/seepages, dams are grouted using cementitious grout material. The objective of rehabilitation is to reinstate the structural integrity, improve durability, prevent leaching of materials, restore water tightness, and improve the appearance of structure. This paper discusses a case study of seepage control through cementitious grouting in Domihira dam situated in Palghar district of Maharashtra. In the present case study, cementitious grout mix has been designed based on extensive laboratory and masonry model studies conducted at CWPRS, Pune to improve mass density, impermeability as well as strength characteristics of the masonry dam. Extensive laboratory studies have been carried out for assessing the suitability of cementitious grout system by varying the ratio of ingredients such as cement, fly ash, silica fume, admixture, water etc. and conducting various tests such as flowability test- Marsh cone time of afflux, pH value, bleeding potential, jellification time, dispersion in water, compressive strength etc. After finalization of grout mix design, masonry blocks of size 1 m × 1 m × 1 m have been constructed with lean cement mortar and grouted with designed grout mix. Various tests such as NDT tests during pre and post-grouting stage, water loss tests and finally crushing test on extracted masonry cores, have been conducted on constructed masonry blocks to study the improvement in quality of masonry. The test results indicated significant improvement in mass density, impermeability and compressive strength of the casted masonry blocks and accordingly finalized cementitious grout mix design has been recommended to the Project Authority. The dam has been grouted using design mix grout in two stages from top and upstream face at an effective spacing of 1.5 m c/c. After grouting leakage/seepage of water dam body has stopped completely and significant improvement in mass density and strength parameters has been achieved.

1. INTRODUCTION

Dams are good as long as they are performing under structurally sound conditions, but are a threat to public safety in case of their failure, causing considerable loss of life and property. Nature often interferes with any change caused in the environmental factor in the form of unprecedented floods or unpredictable earthquakes damaging dams.The deterioration in dams results in many distresses in the dam body in the form of cracks, heavy seepage, settlement and deformation, malfunctioning of gates etc. Seepage water carries lime resulting in the formation of encrustations which block the drain pipes rendering them ineffective in relieving pore/uplift pressure. Unwarranted seepages in a dam are a sign of distress and need to be attended immediately. For gravity dams, distress is seldom attributed to a single factor and therefore knowledge of possible cause of distress, its diagnosis, repair material and technique is essential. Repair and strengthening of existing masonry dams by grouting is one of the economically viable options to impart effective functionality, durability and safety to the existing structure without physically altering the external aesthetics of the same.

2. MASONRY DAMS AND THEIR NEED FOR RESTORATION

Moisture absorption by the weak zone, temperature effects, leaching, excessive pore pressure, construction deficiency, decrease in the mass density of the dam, mechanical strength, reduction in water tightness, earthquakes or floods, construction joints etc, are the main causes of occurrence of seepage in masonry dams. Seepage is defined as interstitial

movement of water through a dam, the foundation, or the abutments whereas leakage can be defined as flow of water through holes or cracks. In spite of taking due care in planning, design and execution stages; many of such structures have shown signs of distress in the form of excessive seepage or leakage.

Indian standard specifies safe limits for seepage if water loss does not exceed 2.5 and 5 lungeons in the upstream and downstream portions of the dam respectively. Lungeon is the measure of defining permeability which is the water loss in litres per minute per meter depth of the drill hole under a pressure of 10 atmospheres maintained for a period of 10 minutes in drill holes of 46 to 76 mm diameter. The value of water loss obtained from the test is the overall value of seepage through masonry including loss into cracks, joints etc.

3. GROUTING

Grouting is the process of filling up voids or cavities in any part of a system, in order to consolidate the mass into one integral unit by means of injecting cementitious/ epoxy material in fluid state under pressure with suitable viscosity to penetrate into the unit to a uniform distance around the point of grouting. Grouting aims at filling of the cavities/fissures with selected material to impart impermeability improvement in strength and weight of the structure. It is necessary that the material should fill the water passages from upstream to downstream to avoid premature blocking on the downstream side causing development of pore pressure. Usually cement grouts with or without addition of admixtures, epoxy grouts with or without fillers and chemicals such as acrylic are being used in most of the cases. Cementitious grouting is the most common for masonry dams due to its cost effectiveness and similarity with the constituents of mortar used in the construction.

3.1 Dam Body Grouting

Grouting the body of dam is one of the effective cures for most of the dams and has been successfully implemented for reducing seepage in so many dams all over world. In India, many dams namely Varasgaon, Shirwata, Walwhan, Bhandardara and Radhanagari dams in Maharashtra; Pagara and SakhyaSagar dams in Madhya Pradesh; Hemavathy and Talakalale dams in Karnataka and Karjan dam in Gujarat have been grouted towards controlling seepage and improving structural safety.

Presently no specific BIS code exists for the design grout mix for dam body grouting. Specifications of grout materials, grout mix proportion particularly water cement ratio, grout pressures, grout hole spacing, precautions during handling etc., are absolutely necessary for effectiveness of grouting. Choice of grout materials and mixes is dependent on pattern, size and continuity of the cavities/fissures, quantity of seepage water flow and desirable enhancement of mass density towards improvement in strength requirement of dam body.

3.2 Selection of Grout Material

The selection of the type of grout material and additives depends upon workability, dimensional stability, adhesion/ bond with the base material, chemical resistance and strength properties. The grouts used for dam body grouting includes ,(i) Flyash/Pozzolona/Sand- cement; (ii) Cement based -conventional; (iii) cement based – quick set; (iv) Chemical grouts – sealing (v) epoxy resins – sealing and structural bonding.

The workability of the grout material should be such that it should spread freely into the crack/gap, reach up to the end point of the crack and evenly bridge the surfaces and should not be lost through surface damages. Dimensional stability indicates that after setting inside the crack, the grout material should not undergo too much volumetric changes resulting voids in the grouted structure. The grout material selected should be able to negotiate with the existing aggressive conditions without dissolving in seeping water and attained initial setting reasonably fast. The grout must have strength in compression, tension, and shear and flexure mode and should be thermally compatible. Proper material can be selected on the basis of the evaluation of properties in laboratory.

4. LABORATORY EXPERIMENTATION FOR SELECTION OF SUITABLE CEMENTITIOUS GROUT SYSTEM

Before carrying out dam body grouting, suitable grout mix design is essential to achieve desirable results towards controlling seepage in masonry gravity dams. For assessing suitability of various types of grout mix, it is always advisable to check the performance of the grout by conducting various tests in laboratory before conducting trial application of grouting in sample masonry structures. The following tests are generally carried out for designing proper grout mix.

4.1 Flowability Test by Marsh Cone Apparatus

The test is conducted to assess the ability of the grout mix to spread in the dam body. The marsh funnel is a simple device used for measuring viscosity by observing the flow time in sec of the measured quantity of grout mix solution. For conducting flow test, Marsh cone funnel is held vertically with the end by closing the orifice using finger. The grout system of with a quantity of 945 ml is poured into the cone and the finger is released and flow time of the grout mix is recorded by a stop watch. The flow time goes on reducing at higher w/c ratios. The optimum flow time near to

30 seconds or slightly higher is suitable for proper spread of grouting in the masonry and also restrict escape of grout solution through surfaces of dam body and porous drains under dry conditions. For saturated conditions alongwith heavy seepage, flow time more than 40 sec by reducing w/c ratio has been observed to be effective without much loss of grout.

4.2 Settlement/ Segregation test

The test is conducted to devise the time of grout mix consumption. The properly mixed grout is taken in a measuring cylinder of standard size capacity (Preferably 1 liter measuring jar). The stability of the suspension is observed upto a period of 2 hours. For a stable grout mix the difference between water level and settled grouting after 2 hours should be 5 to 7% i.e. 50 to 70 ml preferably below 5%.

4.3 Gelification test

This test is conducted to observe the minimum time required for starting setting of grouting. Grout mix is kept in small containers and process of gelification is observed by tilting the small containers to observe the resistance to flow of grout solution. The total quantity of the grout mix should be consumed before the onset of gelification process. Also this can further be confirmed by pouring grout mix into the still water stored in a flat bottom container. The grout will not dissolve into the water unless disturbed. Generally gelification process should start after 3 to 4 hrs. Accordingly quantity of accelerator is estimated so that chocking of grouting pipe line is avoided.

4.4 pH value

For checking the nature of grout solution i.e. acidic/ alkaline pH test is conducted. The value of pH of the grout mix is determined by using a digital pH meter. Before determining the pH value, the digital pH meter is calibrated using a standard solution to get proper results. The nature of the grout solution should preferably be maintained alkaline in nature to prevent the acidic attack on cementitious material and stones of the dam body structure. The pH value of grout mix above 8.5 is considered suitable.

4.5 Compressive strength

For qualitative assessment of grout mix, compressive strength is generally estimated by casting cube specimens of size 50 mm or 70 mm prepared using grout mix solution at different water cement ratios as per the proportions of grout mix. The cast specimens are demoulded after 24 to 48 hours of casting and air cured for a period of 3, 7 & 28 days. After curing, the cube specimens are subjected to loading in a uniaxial compression testing machine. The compressive strength of the specimen is then calculated by dividing the maximum applied load at failure of the specimen during the test by the original contact area of the cube specimen.

5. FIELD TEST FOR SELECTION OF SUITABLE CEMENTITIOUS GROUT SYSTEM

For conducting grout application trial, 1 cubic meter of masonry blocks have been cast using lean cement mortar and by leaving voids in the blocks as per estimation of in-situ mass density of dam body. Blocks have been cured upto 28 days. From the above tests the grout mix with proportion exhibited proper results as per standard code of practices and are adopted in grouting of masonry blocks constructed near the laboratory. Trial grouting of masonry blocks are carried out by varying cementitious content and w/c ratio. The grout application is carried out in the masonry blocks by using grout pumps by applying a pressure upto 2 kg/cm^2 and also by free gravity flow. The grouting is carried out from top of the blocks in vertical direction in ascending order. The grout is allowed to cure under dry air conditions for a period of more than 28 days and the following tests are conducted on the grouted test blocks.

5.1 Non Destructive Tests on Masonry blocks

Non-destructive tests on masonry blocks by ultrasonic pulse velocity method are carried out to evaluate the quality of masonry. The pulse velocity method is a nondestructive method, as the technique uses mechanical waves resulting in no damage to the masonry element being tested. A test specimen can be tested again and again at the same location, which is useful for monitoring masonry undergoing internal structural changes over a long period of time. The basic idea on which the pulse velocity method is established is that the velocity of a pulse of compressional waves through a medium depends on the elastic properties and density of the medium. For good quality masonry, pulse velocity should be more than 3000 m/s.

5.2 Water Loss Test

The water loss of the trial blocks is carried out by passing a known quantity of water under pressure through the nozzle fixed at the center of the block. The tests are carried out before and after grouting. Before grouting water is expected to leak from all sides of the masonry blocks. After the grouting significant reduction in leakage of water takes place from the masonry blocks if grout mix design has been carried out properly.

6. CASE STUDY - DOMIHIRA DAM, MAHARASHTRA

Domihira dam constructed across Domihira river, is located in Palghar district, near Thane in Maharashtra. It is a composite gravity dam with earthen portion of length 705.45 meters and masonry Non Gated Ogee Spillway of length 58 meters as shown in Figures 1, 2 & 3. The earthen portion of the dam has maximum height of 51.5 meters from the deepest foundation level and masonry spillway portion is of 20 m height along with two masonry flank walls extending from upstream to downstream of the dam. The construction work of the dam was completed in the year 2009 and full storage was impounded during the same year. Just after first impoundment of reservoir during 2010, heavy seepage has been observed at RL 352 m on spillway portion, construction joints and below RL 357 m on the right and left flank walls. Due to pressure of heavy leakage, apron concrete of glacis has damaged after every filling. To arrest seepage through foundation strata, some grouting work has been carried out in the dyke portion, but it has not been much successful in reducing seepage (Figures 4 & 5).

Fig. 1, 2 & 3 : Seepage observed through the spillway and cavities on the glacis concrete

Fig. 4 & 5 : View of seepage observed in right and left flanks of Domihira dam.

In this regard, the Project Authorities has requested CWPRS, Pune to carry out laboratory studies towards cementitious grout material mix design for controlling seepage through dam body of Domihira dam. Laboratory studies have been conducted on many combinations of mix design by varying proportions of cement, flyash, silica fume, admixtures and quantity of water.

On inspection from u/s face (Figures 6 &7) prominent cavities and loss of pointing mortar at many places on the face of the spillway portion of dam, inner and outer portions of both left and right guide walls/flanks have been observed.

Fig. 6 & 7 : U/s portion of Domihira dam showing cavities in spillway portions and flank walls

The dam body and both the right and left flank walls have been observed to be in a very hazardous condition needing some urgent strengthening measures in order to avoid further damages and restore its structural integrity. Hence, CWPRS Scientists suggested Project Authorities to carry out cementitious grouting for spillway portion upto foundation interface from top of the dam and key wall at spacing of 3 m, from u/s side of dam body in horizontal direction and grouting of guide wall from u/s side in lateral direction on priority basis.

6.1 Grout Mix Design

Following material has been supplied by Project Authority for conducting the laboratory studies:

1. Grade 43 OPC cement as per requirement
2. Flyash (Superpozz) in sealed bags
3. Fine silica fume in sealed bags
4. Three admixtures from four different manufacturers namely Admixture1 to 4.
   (a) Admixture for binding of grout mix to surrounding masonry
   (b) Accelerator for enabling setting of grout mix
   (c) Water reducing admixture

Four sets of admixtures has been received from the Project Authorities and used for designing the grout mix

6.2 Laboratory Tests on Grout Mix

The final design of cementitious grout mix has been taken up by CWPRS during December 2018 and numerous trials using various proportions of cement, flyash, silica fume and three types of admixtures from four different manufacturers by varying the water cementitious ratio have been carried out in laboratory. Various tests such as flow-ability by Marsh cone, settlement, Gelification, pH value and compressive strength of the grout mix has been carried out in the laboratory. Based on the selected mix, sample masonry blocks has been grouted and tested. After conducting the trials and discussions held at site, various grout mix proportions have been suggested using horizontal inclined grouting for the spillway portion and horizontal and vertical grouting for flank wall.

6.3 Grout Methodology

6.3.1 *Spillway portion*

It has been suggested to drill inclined horizontal holes for grouting from the upstream face of spillway portion up to the spillway glacis without puncturing the glacis concrete of upstream face at a horizontal spacing of 3.0 m and vertical spacing of 1.5 m in a staggered manner as shown in the drawing below. For grouting, it has been suggested to carry out the grouting operation of 1st row from bottom left to right initially, and the second row drilling and grouting has to be carried out from left to right in the similar manner after completion of first row grouting. . The grout is to be carried out from inward to outward pattern. Grouting should be carried till refusal at nominal pressure of 1 to 2 kg/cm2 at the grout mix location and additional natural head for bottom regions. In upper region above mid height the grout pressure at mixer may be increased upto 2 kg/cm2. A typical grout pattern is shown in Figure 8.

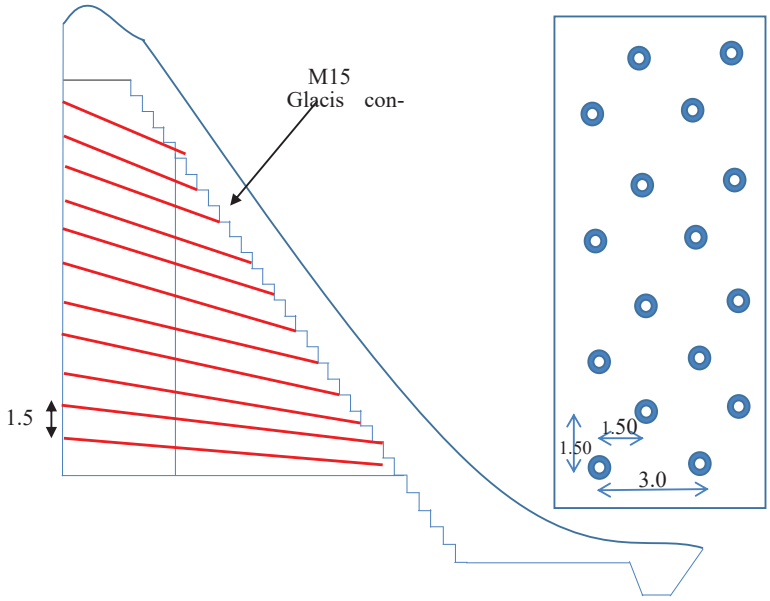

Fig. 8 : Domihira Dam Grouting Pattern on upstream face

6.3.2 *Flank wall*

For the both flank walls, since the structure is very weak, initially the grouting shall be carried out horizontally from the upstream face up to the mid portion of the walls at a horizontal spacing of 3 m and vertical spacing of 1.5 m in a staggered manner. Once the horizontal grouting is completed the vertical grouting from the top of the walls can be carried out by adopting a spacing of 3 m c/c. Grouting and testing Process in site as shown in Figures 9, 10 & 11.

Fig. 9 & 10 : Grouting in Progress in Domihira dam

Fig. 11 : Testing of Marsh cone flow value in Domihira dam site before grouting

6.3.3 *Suggestions for Grouting*

- The downward inclined drilling in transverse direction on the upstream face should be carried out by drilling in slow motion with small dia. bits without disturbing the existing masonry.
- Cement grouting from upstream face of the distressed spillway starting from dam base upto top of the dam should be carried out by limiting the grout pressure preferably below 2.0 kg/cm^2 without removing any weak material from the surfaces in the upper reaches of the dam. While at higher depths from top of the dam, the grout pressure near the mixing plant should be kept around 1 kg/cm^2 to travel the grout through grout line without choking it. The resulting high grout pressure at higher depths due to standing column of grout mix will be for very short duration and get reduced due to dispersion of grout in the surrounding masonry without causing any damage.
- Quality control of grouting should be maintained by conducting tests on site such as marsh cone test, settlement test, setting time etc.
- The sampling frequency tests for Marsh Cone, Settlement and pH value need to be followed at site as per the guidelines prescribed in USWES manual EM 1110-2-3506 and may be kept at least "Once per mix design per day on all mixers".
- For monitoring the compressive strength of grouts, the test sample casted shall consist of approximately 1500 ml of grout and shall be representative of the material in the mixer (ASTM C 942) and its frequency as prescribed in USWES manual EM 1110-2-3506 is "Mix testing program only" i.e. as per mix design and lot wise of ingredients including admixtures. For Domihira dam, at least 6 Nos. of 70 mm size grout cubes may be cast and tested for a period of 7 and 28 days for each mix design.
- After the completion of grouting works of spillway portion and flank walls, shotcreting of the u/s faces of both the spillway portion and flanks walls need to be carried out (Figures.12 & 13).

Fig. 12 & 13 : View from top and d/s of Domihira dam after Grouting

6.3.4 *Effectiveness of Grouting*

The Project Authorities informed that the grouting of spillway portion, has been completed as per the recommendations of CWPRS. As reported by the Project Authorities, the grouting of the spillway portion of Domihira dam has been completed in three stages i.e. June 2018 to 05th July 2018, Jan 2019 to March 2019 & April 2019 to May 2019 and the total consumption of cement bags has been observed to be about 20,000 bags with a total grout intake of about 1532 MT. The total cement intake per Cum of dam masonry worked out to about 1.92 bags/m^3 and dry grout intake of about 146 kg/ m^3. Hence, mass density of dam body masonry has enhanced by more than 5% resulting in improvement of structural safety of dam.

Due to grouting, the seepage/leakage through the spillway portion has been observed to be completely stopped (Figures 14 & 15). Since, the grouting and shotcreting of the flank walls is required to carried out, seepage of water has been observed through the flank walls. The overall seepage rate has reduced from 300 lps to about 60 lps after the successful grouting of the spillway portion.

Fig. 14 & 15 : View of spillway after grouting.

7. CONCLUSIONS

Based on the studies discussed in this paper following conclusions are drawn:

1. Dam body grouting using proper mix design is a very important and effective tool to control seepage and improve structural safety of the distressed masonry dams.
2. Design of cementitious grout mix is important and necessarily be done by conducting laboratory tests on different materials. After conducting the suitability tests in laboratory on so many mix proportions, a suitable design mix is arrived at for carrying out grouting in the field.
3. Due to grouting in masonry spillway portion of Domihira dam in Maharashtra, the seep-age/leakage through the spillway portion has been observed to be completely stopped. The overall seepage rate inclusive through flank walls has reduced from 300 lps to about 60 lps after the successful grouting of the spillway portion.

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