CONTROL OF SEEPAGE IN MASONRY GRAVITY DAM THROUGH SUITABLE CEMENTITIOUS GROUTING

Gaurav Banwat[1], Surbhi Jain[2], Jayesh Balchandani[3], Deep Bajoria[4], Kumar Shivam[5]
Department of Civil Engineering, MITCOE, Kothrud, Pune, Maharashtra, India, 411038.
Email- gauravbanwat523@gmail.com

***Abstract*— The purpose of this thesis is to present an overview of the state of the art in dam rehabilitation to highlight the major innovations. This paper covers a detailed study of the seepage problem in the dam, its control measures and design provisions for the seepage control in the dam. Exploring these topics include looking at the various causes in the failures of the dam such as hydraulic failure of the dam, seepage failure and the structural failure of the dam. Also explaining the various grouting techniques which are the integral part of the new dam construction as well as control of seepage in old dams and also have a considerable importance as a remedial tool. In recent years however, there have been highly significant advances in the materials, methods and techniques which have increased remarkably the scope and power of grouting in the remedial applications.**

***Keywords*— Conventional and Finite Element Analysis of distressed gravity dam, grouting and repairing of dam prototype, Conventional and Finite Element Analysis of the prototypes after grouting.**

I. INTRODUCTION

A gravity dam is a dam constructed from concrete or stone masonry and designed to hold back water by primarily utilizing the weight of the material alone to resist the horizontal pressure of water pushing against it. A gravity dam is a massive sized dam fabricated from concrete and designed to hold back large volume of water. By using concrete, the weight of the dam is actually able to resist the horizontal thrust of water pushing against it. This is why it is called a gravity dam. Since gravity dams rely on their own weight to hold back water, it is key that they are built on strong foundation of bedrock. If a gravity dam is straight in plane it is known as Straight gravity dam, while if it is curved in plane it is known as Curved gravity dam. A curved gravity dam (or Arch-gravity dam) however, resist forces exerted upon it both by gravity action and arch action. Further a gravity dam is also classified as Solid gravity dam and Hollow gravity dam. A solid gravity dam has its entire body consisting of a solid mass of masonry or concrete. On the other hand, a Hollow gravity dam has a hollow space left within the body of dam. The reason for which the gravity dams need rehabilitation are mainly the time damage and the destructive effects of flash floods and earthquake effects. In our case the dam is heavily distressed and is facing seepage problem. Never the less the lifetime can be extended if they are regularly maintained.

II. METHODOLOGY

The problem statement of this thesis is as under. A masonry gravity dam is having seepage problem .The top width of the dam is 13.33m, height of the dam is 80.32m and base width of the dam is 73.23m . Suggest a suitable remedy for control of seepage through grouting and analyse the dam for safety.

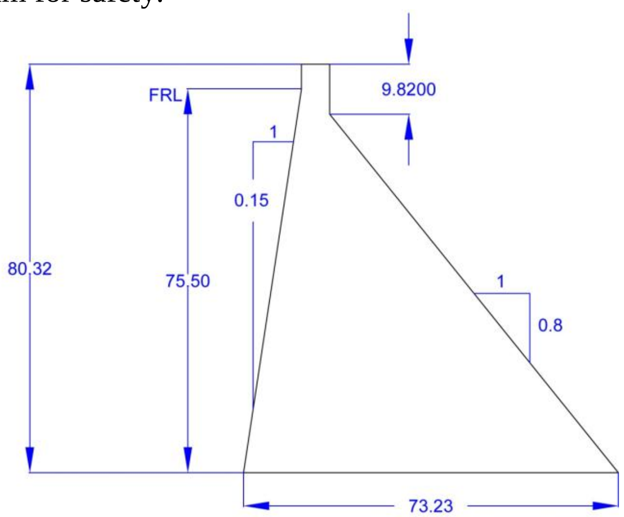

Fig.1 Section of the dam

The methodology adopted for this thesis consisted of three steps:

Step I: Analysis of the distressed gravity dam by conventional gravity method performed manually and by Finite Element Method performed using software LUSAS.

Step II: Grouting of the dam prototypes using two different grout mixtures.

Step III: Analysis of the dam prototype by conventional gravity method performed manually and by Finite Element Method performed using software LUSAS.

Step I: Analysis of the distressed gravity dam by conventional gravity method performed manually and by Finite Element Method performed on software LUSAS: Suitable NDT tests were carried out on the distressed gravity dam to calculate the density of the distressed dam which came out to be 2050 kg/m^3. After the density of the distressed dam was calculated the conventional analysis of the dam was done for Load Combination A (Completed reservoir but no tail water and back water or reservoir at empty condition) and Load Combination B (Full reservoir elevation normal dry weather tailwater, normal uplift, ice and silt (if applicable)) and the safety of the dam was checked against overturning sliding and shear which gave out the following results.

Load combination A:

The overturning factor , sliding factor and the shear friction factor all came out to give the values as infinity which inculcated that the dam was safe for Load Combination A.

Load Combination B:

For this combination the dam actually falied in all three checks giving values as: FoS against overturning =0.55(<1.5) ; FoS against sliding = 0.9(<1.2) ,FoS against shear = -0.98(<1).

Similar results were calculated from the stressdiagrams got after FEM analysis . The stress diagrams are as under:

Load Combination A:

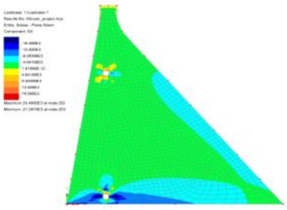

Fig.2Stresses in X-direction

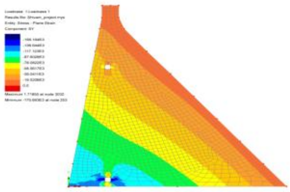

Fig.3 Stresses in Y-direction

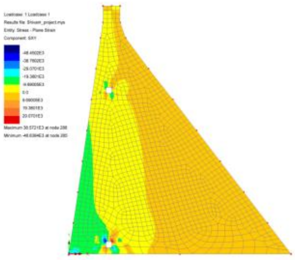

Fig.4 Shear Stresses

Load Combination B:

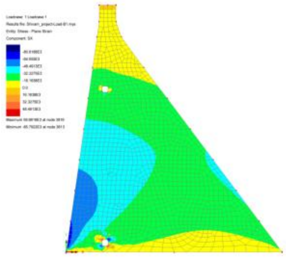

Fig.5 Stresses in X-direction

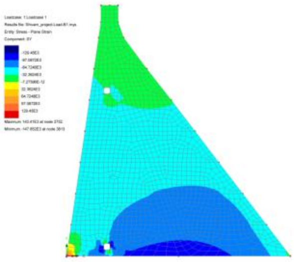

Fig.6 Stresses in Y-direction

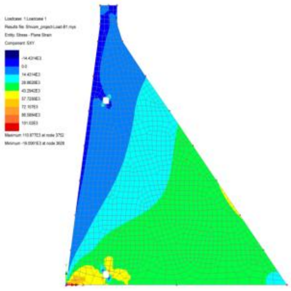

Fig.7 Shear Stresses

Step II: Grouting of the dam prototypes using two different grout mixtures: After the analysis was done for the distressed gravity dam then suitable blocks of sizes 1Mx1Mx1M were prepared using stone masonry which had voids and seepage which resembled the condition of distressed gravity dam. NDT tests were performed on the blocks. The ultrasonic pulse velocity meter was used and the readings were noted as under :

Table NDT on Blocks

Sr. No.	**Time in microseconds**
U1	511, 741
U2	483, 634
U3	506, 519
M1	530, 504
M2	539, 570
M3	516, 527
L1	595, 567
L2	528, 513
L3	551, 517
U4	555, 688
U5	695, 525
U6	536, 576
M4	585, 526
M5	565, 570
M6	516, 553
L4	505, 536
L5	533, 744
L6	527, 529

As the time is known , distance travelled by the wave is known (1M), velocity of the wave can be calculated. This was done just to check the improvement in the density of the block after grouting.

Two types of grout mix were used during the grouting process. One was a mixture of cement(60%), flyash(40%) and water and another contained bentonite(2%), cement(70%) and fly ash(28%). Plasticizers were also used . The mixtrures were then compared for their efficiencies and economy. Before grouting both mixtures were tested under different tests as consistency test, initial and final setting time, compression test, flowability test by marsh cone, settlement test, and pH value to check their consistency and workability.

Later on after the grouting was completed the blocks were allowed for curing for a period of 90 days. They then were again checked for improvement in density by the NDT test performed using ultrasonic pulse-velocity meter. The lesser the time required by the wave to cover the distance the more was the degree of the improvement in the density. The readings after grouting were as under:

Sr. No.	**Time in microseconds**
U1	263, 285
U2	394, 389
U3	277, 286
M1	374, 290
M2	331, 320
M3	289, 299
L1	340, 325
L2	331, 276
L3	255, 267
U4	392, 402
U5	313, 334
U6	282, 264
M4	372, 311
M5	261, 304
M6	291, 306
L4	323, 307
L5	336, 347
L6	316, 313

Seeing the readings of the NDT after grouting it is clear that the density of the blocks have increased to a great extent. After this cores of sizes 30 cm in diameter and 60cm in length were taken out from the blocks using a core cutter machine. This cores were then tested for their compression strength under a compression testing machine for the improvement in the strength. The remaining scrap was then collected for calculating the density of the block after grouting. The density of two blocks with different grouts were calculated as under:

Block grouted with flyash and cement:

Total mass = 86.2 kg

h_{avg} = 55.3 cm

r_{avg} = 14.55 cm

Volume = 36779.09 cm^3

$$\text{Density} = \frac{86.2}{36.779*10-3} = 2.34\text{x } 10^3 \text{ kg/cm}^3$$

Failure load = 217 KN
Wt of dry stones = 42.95 kg
% wt of dry stones = $\frac{42.95*100}{86.2}$ = 49.82%
65% of 86.2 kg = $\frac{65*86.2}{100}$ = 56.03 kg
volume of dry stones = 7.3 x 10^{-3} m^3
volume of 65% of stones (V)=
$\frac{42.95}{0.0073} = \frac{56.03}{V}$
V=$\frac{56.03}{42.95}$x 7.3 x$10^{-3}$$m^3$
Volume of motor = volume of core - volume of 65% stones
= (36.779x10^{-3} - 9.5x2$10^{-3}$)
= 27.259x10^{-3} m^3
Weight of dry mortar = 86.2 - 42.95 = 43.25 kg
Weight of 35%mortar =
$\frac{W}{V} = \frac{W'}{V2}$
$\frac{43.25}{0.029475} = \frac{W'}{0.027259}$
W' =39.99kg
Total weight of modified core = 39.99 + 56.03 = 96.02 kg
Density of modified core = $\frac{96.02}{0.036779}$ = 2610.72 kg/m^3

Assuming that we have achieved the designed density as 2350 kg/m^3.

Block grouted with flyash , cement and bentonite:
Total Mass = 80.85 kg
Havg = 52.4 cm
Ravg = 14.525 cm
Volume=36779.09 cm^3
65%of 86.2 kg = $\frac{65*80.85}{100}$ = 52.55 kg
volume of dry stones = 8.25 x 10^{-3} m^3
volume of 65% of stones (V) =
$\frac{45.3}{0.00825} = \frac{56.03}{V}$
V=$\frac{56.03}{45.3}$x 8.25 x$10^{-3}$$m^3$ =10.20x$10^{-3}$$m^3$
Volume of motor = volume of core - volume of 65% stones
=(3634.713x10^{-3} - 10.2x10^{-3})
=24.21x10^{-3} m^3
Weight of dry mortar=80.85-45.3=35.55kg
Weight of 35%mortar
$\frac{W}{V} = \frac{W'}{V2}$
$\frac{43.25}{26.463} = \frac{W'}{24.51}$
W' =32.92kg
Total weight of modified core = 32.92+52.55=85.47kg
Density of modified core = $\frac{85.47}{0.03471}$= 2462 kg/m^3
Assuming that we have achieved the designed density as 2350 kg/m^3.
After getting the improved density of 2350 kg/m^3, the analysis was done for the improved density block and was checked for safety against overturning, sliding and shear.

Step III: Analysis of the dam prototype by conventional gravity method performed manually and by Finite Element Method performed using software LUSAS: The calculated density of the blocks after grouting was then used for the conventional as well as Finite Element Analysis and was checked for the stability. The analysis was done for Load Combinations A (empty condition), B (Full reservoir elevation normal dry weather tailwater, normal uplift, ice and silt (if applicable)) and E (Filled dam along with earthquake forces). The results after analysis were as under:

Load Combination A:
FoS for overturning = Infinity (>1.5) ; safe
Shear friction factor = Infinity (>1) ; safe
Load Combination B:
FoS for overturning = 1.59 (>1.5) ; safe
Shear friction factor = 1.39 (>1) ; safe
Load Combination E:
FoS for overturning = 1.16 (<1.5) fails
Shear Friction Factor = 1.25 (1.0) safe

Same results were calculated from the values of the stresses obtained by Finite Element Analysis using LUSAS software.
The stresses are as shown under:

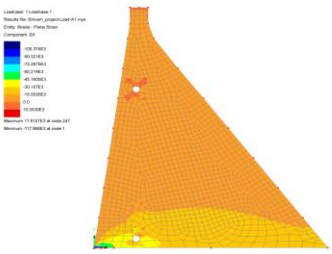

Fig.8 Stresses in X- direction

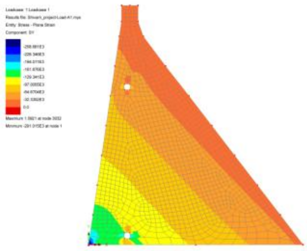

Fig.9 Stresses in Y- direction

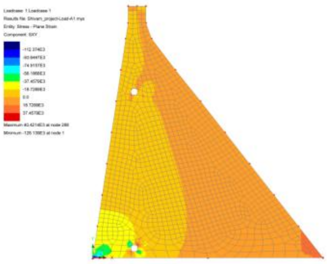

Fig.10 Shear Stresses

Load Combination B:

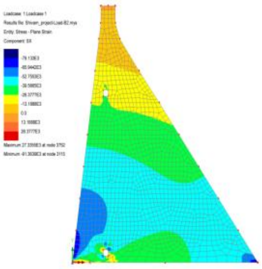

Fig.11 Stresses in X- direction

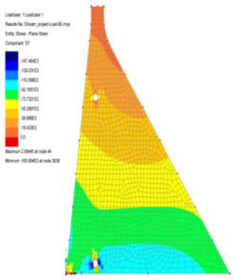

Fig.12 Stresses in Y- direction

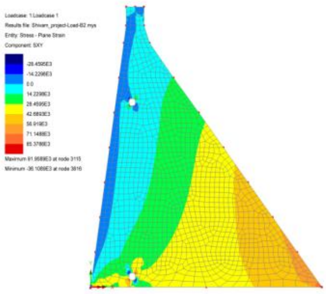

Fig.13 Shear Stresses

Load Combination E:

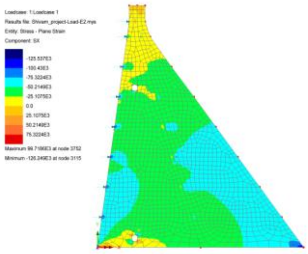

Fig.14 Stresses in X- direction

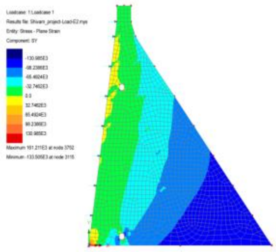

Fig.15 Stresses in Y- direction

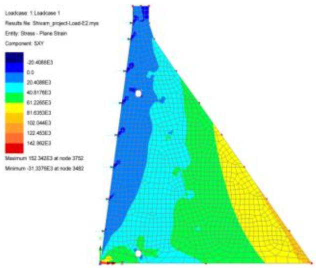

Fig.16 Shear Stresses

III. CONCLUSIONS

After performing analysis by conventional gravity method and finite element method the following are the conclusions we came with:

1. After grouting with both the grout mixtures the design density of 2350 kg/m^3 was achieved.
2. The tensile stresses and the compressive stresses have been observed to be lower than the permissible limits, factor of safety against overturning, sliding and shear also were under permissible limits for Load Combinations A, B.
3. The tensile stresses and the compressive stresses have been observed to be higher than the permissible limits, factor of safety against overturning also was beyond the permissible limit for Load Combination E i.e. extreme load condition even for the designed density of dam masonry.
4. To attain stability of dam against the extreme load condition the base width of the dam needs to be increased to a

suitable value and again the analysis needs to be performed for the dam section with increased base width.

5. From the analysis performed it is learnt that the grout mixture with the use of bentonite will be economical for treating the dam.

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