Arch Dam Failure Diagnosis Applying Micro-Planes Damage Based Framework

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Abstract: A recently new developed set of constitutive equations which simulating the mechanical behavior of plane concrete have been implemented for monitoring the probability of cracking phenomenon within an arch concrete dam . The applied constitutive model was build on the basis of combination of micro-plane theory and damage framework. This model had been verified through comparing numerical results with experimental ones. The case study is a high elevated concrete arch concrete dam entitled Liroo dam. Obtained analysis results demonstrated that under proposed earthquake excitations, dam experiences some cracks near its middle crest. [Journal of American Science. 2010;6(12):102-107]. (ISSN: 1545-1003).

Keywords: Arch dam, Micro-planes, Cracks, Constitutive relations, Concrete

1. Introduction

In the field of structural analysis of concrete arch dams subjected to hydrostatic, thermal and earthquake loads many efforts have been performed until today (Noorzaie, et. al., 2002, Sadrnejad and Labibzadeh, 2006, Labibzadeh et. al., 2010, Labibzadeh and Khajehdezfuli, 2010, Labibzadeh, 2010). However, these analyses mostly done based on the hypothesis of macroscopic stress and strain fields. Mentioned assumption leads to some extent of limitation in obtaining desired level of accuracy of analysis results mainly due to the application of stress and strain invariants in derivation of material constitutive relations. Holding this issue in mind, in this study an attempt has been made to overcome such shortcoming through using a meso scale behavioral model named micro-planes in simulation. Micro planes model has been proposed for the first time by (Taylor, 1938) according to the plasticity model and after that (Bažant, et. al., 1984, 1985, 1988, 1997, 2000) has expanded the micro planes theory with strain softening and showed its ability in explanation of cracking and strain softening damages in brittle materials such as concrete. In this model the main concern is to present behavior of materials of different type in a scale between macro and micro scales called meso scale. In this paper, a recently developed micro-planes damage based model (Labibzadeh and Sadrnejad, 2006, Sadrnejad and Labibzadeh, 2006) has been implemented to failure analysis of an arch concrete dam named Liroo dam. Such a work had been done just one time in the past (Labibzadeh and Sadrnejad, 2007) and satisfactory results had been obtained which demonstrated the applicability of the proposed model. Liroo dam is a high elevated (height of the dam=200m) concrete arch dam which has been designed by Dez-Ab consulting engineers company and it is going to be constructed in north of the Khouzestan Province of Iran in near future.

2. Materials and Methods

Figure 1 outlines the procedure which should be followed to obtain the constitutive modulus matrix used in the fundamental stress-strain relation in material modeling. This flowchart has been pursued through any iteration in a nonlinear iterative solution method used in a developed finite elements code to evaluate the concrete behavior at any integration sampling point. The sequences which must be proceeded to the proposed three dimensional finite elements code have been shown schematically in figure 2. In each load step, the procedure described in figure 1 will be followed through any iteration until craving approximation may be achieved. According to devoted algorithms outlined in figures 1 and 2, a computer program has been developed based on the well-known F.E.M approximation method. This code then would have been implemented for analyzing the Liroo arch dam. The plan of the arches, the crown cantilever and profile of the line centers of the dam were shown in figures 3 and 4. As it can be seen from those two pictures the dam is a two-centered double curvature arch dam. The height of the dam equals to 220m from its base. The thickness of the crest and base of the dam are 10m and 35m respectively. The modulus of elasticity for the mass concrete was inserted as 25000 MPa into program and Poison's ratio was considered as 0.17.

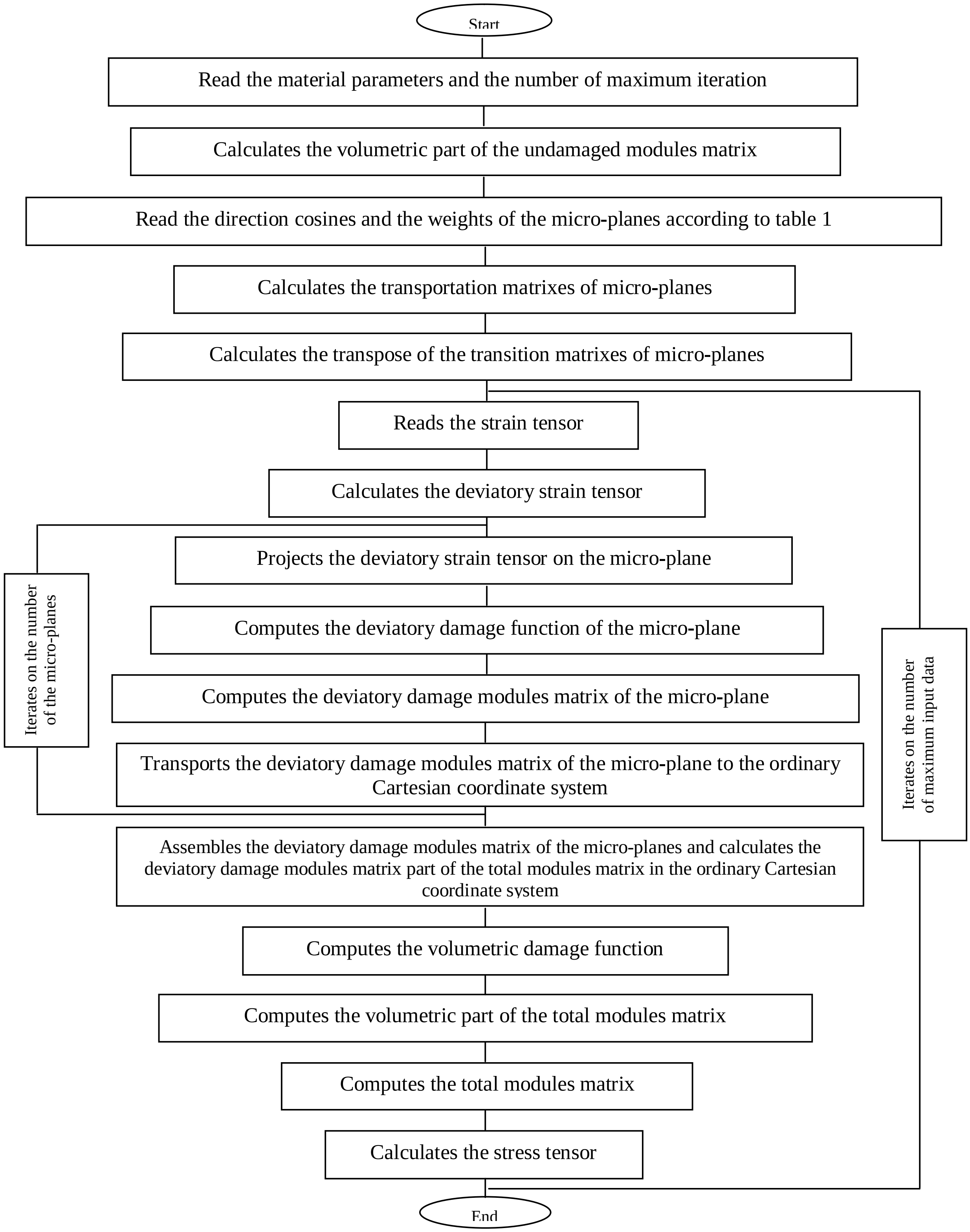

Figure 1. Operation sequence of the proposed micro-plane damage model developed in the VISUAL FORTRAN computer language

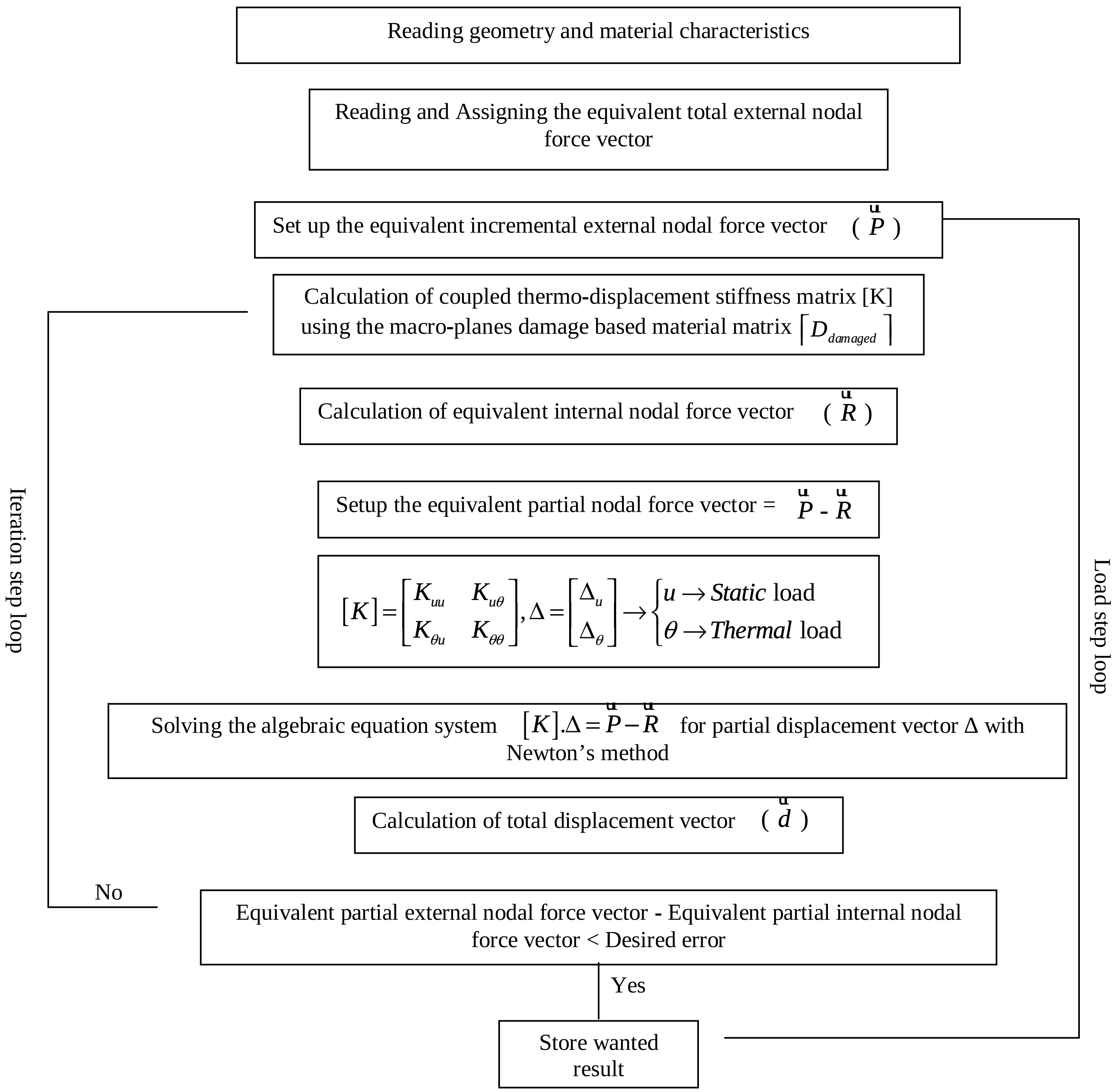

Figure 2. Operation sequence of the proposed F.E. solution method

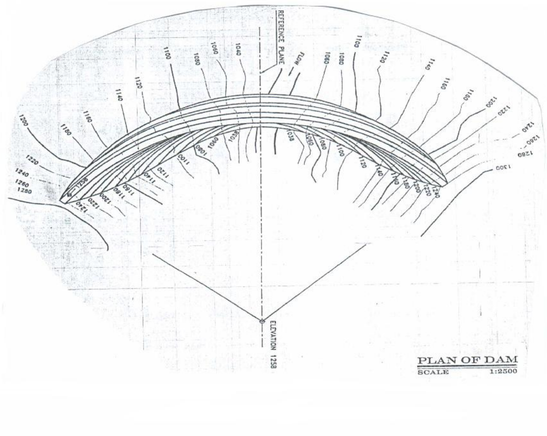

Figure 3: Liroo dam: Arches plan

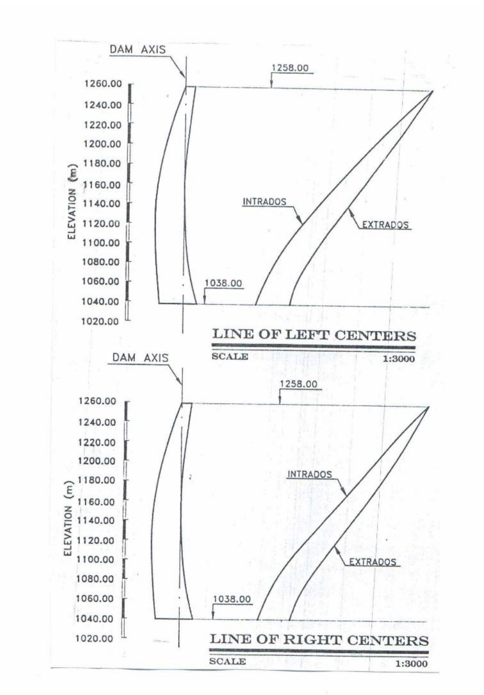

Figure 4: Liroo dam: Lines of the centers

3. Results and Discussions

Before applying the developed computer program for dam analysis, its ability for concrete failure simulation has been verified through analyzing some benchmark problems. One of them was an anti-symmetric four point shear test. The thickness of the beam was 38 mm. figure 5 shows the beam and its mesh. A total number of 428 brick 8-noded elements were used in the model.

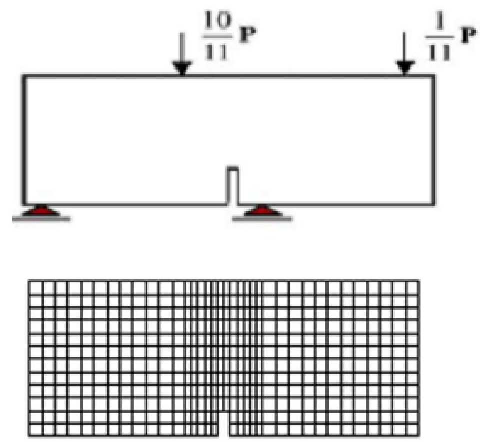

Figure 5. Single-edge-notched beam subjected to anti-symmetric four-point shear loading.

Material parameters are $E = 27000\,MPa$ and $\upsilon = 0.2$. As the load (P) increases, a crack starts growing from the left corner of the notch and continues its growth upwards to the left side of the loading platen. Figure 8 shows the crack path in the actual test. As it can be seen there is a good conformity between model result and experimental ones.

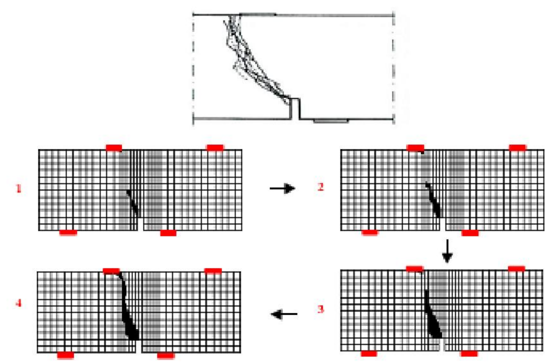

Figure 6. Comparison between simulated crack path and actual crack path

After getting the confidence on accuracy and correctness of model calculations, the Liroo dam was modeled by it. The finite elements model of the dam and its abutments has been viewed in figure 7. Total number of 652 brick elements and 1146 nodes are consumed in dam modeling. The modulus of elasticity of dam concrete was considered 30000 MPa and that of foundation was assigned 20000 Mpa. The Poison's ratio for both of the dam and its foundation was considered as 0.2.

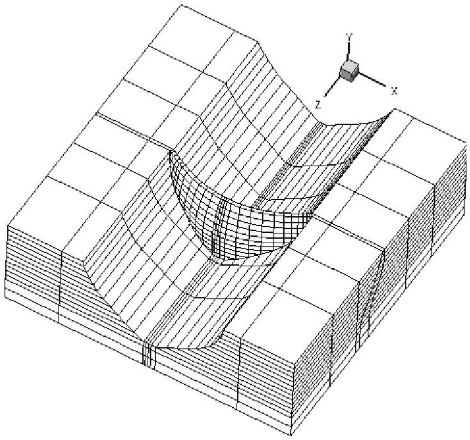

Figure 7. Liroo arch dam F.E. model

After completing the F.E. model of the dam, the gravity and hydrostatic loads were being applied to the model. Then, failure analysis was performed according to the manner discussed earlier and the following results were obtained.

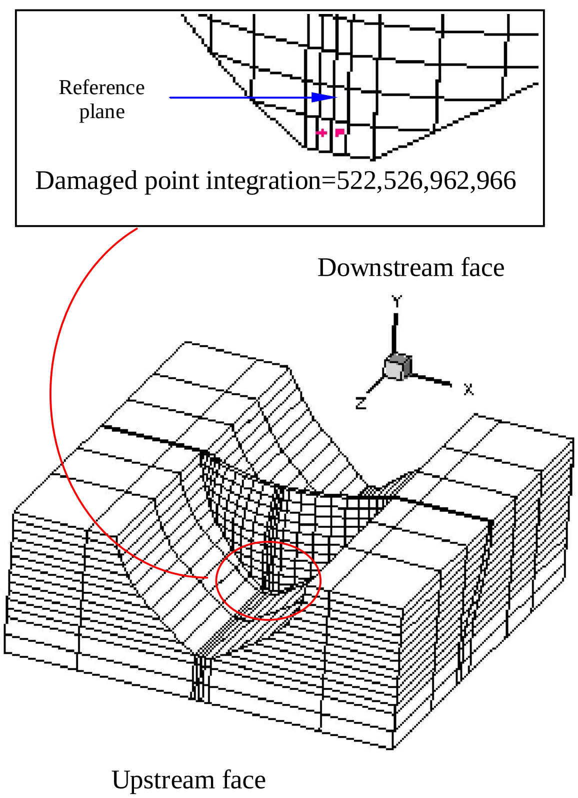

Figure 8. Damaged or failure points of the dam

As it is cleared from figure 8, at four integration points on the upstream face of the dam adjacent to the foundation (approximately 4m above the contact line), fracture phenomenon can be happened. Figure 9 shows the position and direction of the fractures. These cracks align in a plane that it is normal to the faces of dam and propagate through the thickness direction. The angle between crack lines and faces of the dam is about 45 degrees.

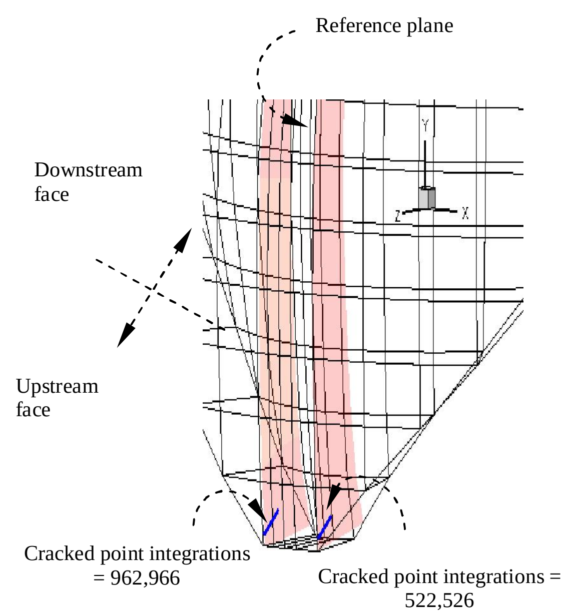

Figure 9. Position and direction of the cracks

It is also necessary to say that in all four cracked points the fractured micro-planes are as micro-planes number 9 and 10. These micro-planes have been illustrated in Figure 10.

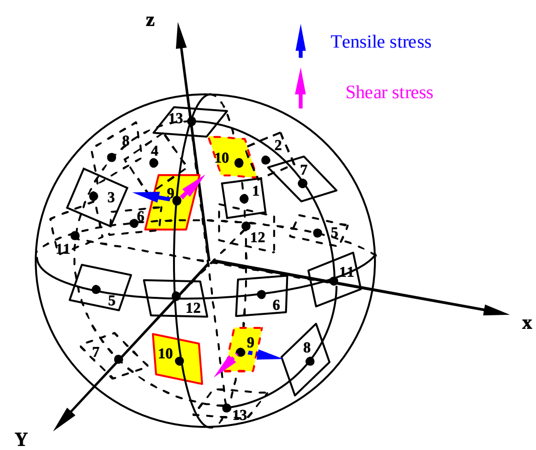

Figure 10. Damaged micro-planes

At these micro-planes there exists a combination of the tensile and shear stresses. So, it can be derived that the main reason of cracking of the dam in specified region would be the cotemporary actions of tension and shear forces. This can be interpreted as follows: under the action of the hydrostatic loads resulted from the reservoir of dam, there would be a strong value of tension at the upstream face of the dam in vicinity of the foundation and concomitant to that strong shears through the thickness of the dam . However, from the action of the gravity loads, there would be a large quantity of compression right there at the same time. So, under the combined effects of these two main mentioned loads, there would be planes i.e. micro-planes on which the worse situation can be occurred from the stress point of view. This situation is the action of tensile and shear stresses and the planes would be plane designated as 9 and 10. Resultant stress becomes greater than the maximum allowable tensile strength of plane concrete and consequently the failure would be happened.

4. Conclusion

After reviewing the results it was cleared that under the action of hydrostatic and gravity loads, Liroo dam can be exposed to fracture on upstream face of the dam adjacent to the foundation in combined tensile-shear mode and the design should be reviewed exactly again.

Acknowledgements:

Author is so grateful to Dez-Ab consulting engineering company for their aid in gathering data.

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