Combining Appropriate Soil Behavior Models for simulating Taham Rockfill Dam

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Abstract: Studies over determining the behavior and modeling the rock fill dams have always been of great importance, because the built dam shows a 1:1 physical model of the real behavior of a dam and evaluating the behavior of such dams in of prior importance for organizing the principles of designing and introducing new experiences. In this paper the instrumentation system for monitoring of Taham dam is thoroughly examined, which includes: pressure cells and electric piezometers in the critical section of the dam. The recorded results of instrumentation and monitoring system of the dam are as well evaluated. Based on the dominant facts over the project and by applying the technical features of the design and engineering interpretations, technical judgments and filtration is done over fine and possibly damaged (of no right function) instruments. Then based on mechanical parameters of the materials (according to the report of the design stage) and using Geo-Studio software the behavior of the dam is modeled. Numerical analyses are done by using three behavioral models: linear-elastic model, cam-clay model (combined with linear elastic model) and elastic-plastic model in two loading modes of: 1-whole loading process and 2-step-loading process. The body of the dam is considered in two forms of homogeneous and inhomogeneous. In the second mode (inhomogeneous) the geometry of changes of material properties inside the core is supposed vertically. But the geometrical changes in the material properties inside the shoulders supposed in two different alternatives: the first one has the vertical direction of the layers (of filling) and the second one forms right angle with the direction of the stress counters. Comparing the results of the all models with observation data (summaries of instrumentations) shows that the use of elastic-plastic behavioral model, is known to be as the best alternative, if done step-loading and considered as inhomogeneous material in a way that: the changes of material properties inside the core reapplied in the vertical direction and the direction of changed materialism shoulders should form a right angle with the direction of the stress counters.
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Keywords: rock-fill dams, monitoring, numerical modeling

1-Introduction

Tendency for monitoring the rock fill dam bodies for organizing the designing principles and introducing new experiments had been always, and is still, focused by dam building staff. In Iran, too, several case studies on some dams have been carried out and their resulted data have been broadcasted in the few past years, and the aim of the present research was the possibility to provide an acceptable database on organizing the designing principles of soil dams. Such researches have been led by Dr. Mirqasemi and his coworkers during 2003 to 2004, within which the instrumentation systems of “Lar” and “panzdah-e-khordad” dams have been evaluated. A study over “Taham dam” had also been done by FarzinKarimi and AbbasSorush from Amir-Kabir University, they have used “Flac” software, but in their method of modeling; making of the layers and applying the inhomogeneity in the shoulders and in the core have not been focused as one of the main goals.

In this paper, pressure cells and electric piezometers of Taham dam is thoroughly examined in the critical section of the dam.

2-Dam Features and Methodology

2-1. Technical Properties of Taham Dam:

This dam is a rock fill dam with a watertight clay core with the height of 124 meters, crest length of 458 meters, heel width of 535 meters, body volume of 128 million square meters, the maximum unload capacity of 1000 square meters per second, and is located 15 kilometers far from north of Zanjan. The materials which make the body of the dam are as follows:

A. Impervious RCC concrete joint between the core and the foundation

B. Impervious core, which is consisted of a watertight clay core with a very low permeability of about 10 E -7 to 10 E -8 cubic cm per second.

C. Filters

D. drainage in the downstream

E. The shoulder, made from the uncrushed clean river aggregates which are consisted of circle to semicircle seeds and less than 4% of them are smaller than 74 micron. The maximum size of the seeds has not been more than 400 mm.

F. Riprap

3-Modeling the Dam

3-1. Modeling geometry of the dam and body mesh in SIGMA/W software for analyzing stress

For this aim, firstly the geometry of the dam have been as simplified as possible in AutoCAD software for minimizing numerical mistakes, the geometry of the dam have also been as simplified as possible and thin layers such as filters, riprap layer and drainage have also been denied for avoiding unwanted numerical mistakes too (Figure 1). Then this geometrical model have been defined in SIGMA software and the required properties of the material have been belongs according to the requirements of elastic-plastic behavioral model. Afterwards boundary condition and mesh types and patterns have been defined with respect to the related principles.

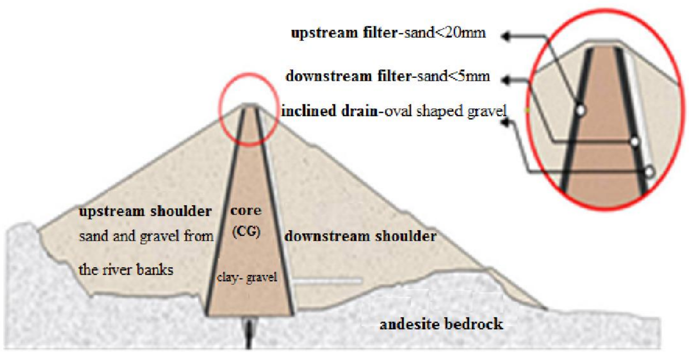

Figure 1. Geometry of the dam and body mesh in SIGMA/W software

4-Comparing the results of applying different numerical models in analyzing stress

4-1-linear elastic models

Applying this behavioral model, four models have been made, and the results improved gradually. Finally, average of stress differences resulted from the fourth numerical model were found to be 3.5% in height of 1778 and 18.6% in height of 1790 based on the recorded amounts with monitoring instruments(reported instrumentation's data). In both heights the results were closer to the real numbers than other three models. And the whole average of difference in the fourth model is 11%, which is acceptable. Moreover the amount and distribution of the settlement have been also controlled, and unfortunately the location of the settlement contours does not seem right.

Table 1. Variation of mechanical parameters in four linear-elastic models

Model	region	$\gamma\,(\frac{kn}{m^3})$	φ'	c	E Modulus	Poisson's Ratio
1	core	17.5	26.7	50	50000	0.35
1	shoulder	23.5	40	0.0	80000	0.3
2	core	14.8	26.7	50	42500	0.35
2	shoulder	20	40	0.0	80000	0.3
3	core	14.8	26.7	50	42500	0.35
3	shoulder	20	40	0.0	110000	0.3
4		14.8	26.7	50	40000	0.25
4	shoulder	20	40	0.0	110000	0.3

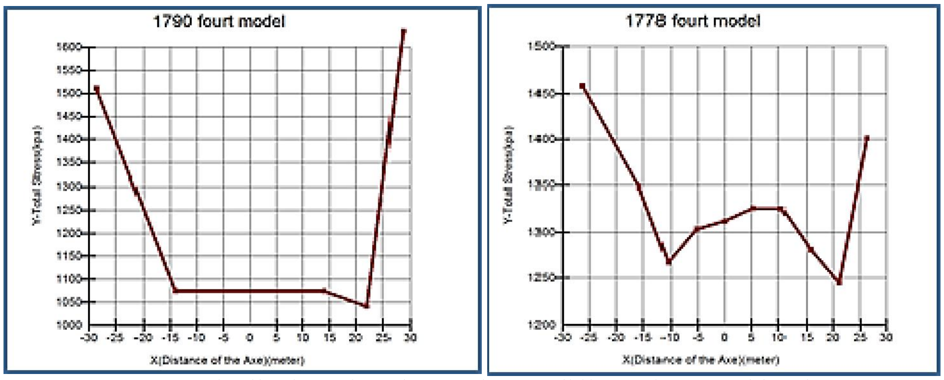

Fig 2. Distribution of total stress in two different inspected level

Table 2. Difference of linear-elastic model with the Summary of Instrumentation (%), (level: 1778)

difference of fourth linear-elastic model with instrumentation data (%)	difference of third linear-elastic model with instrumentation data (%)	difference of second linear-elastic model with instrumentation data (%)	difference of first linear-elastic model with instrumentation data (%)	total stress fourth linear-elastic model (kpa)	total stress third linear-elastic model (kpa)	total stress second linear-elastic model (kpa)	total stress first linear-elastic model (kpa)	total stress instrumentation level : 1778 (kpa)	ditance of axis (meter)	name of instrument
		-	-		-	-	-	-	+32/5	pc1
		-	-		-	-	-	-	+26	pc2
		-	-		-	-	-	-	+16	pc3
-9	+3	+4	+30	1325	1500	1520	1900	1455	+6	pc4
-0.7	+9	+14	+40	1304	1440	1500	1850	1313.7	-6	pc5
-1	+13	+18	+46	1345	1550	1620	2000	1368	-16	pc6
		-	-		-	-	-	-	-26	pc7
		-	-		-	-	-	-	-32/5	pc8

Table 3. Difference of linear-elastic model with the Summary of Instrumentation (%), (level: 1790)

difference of fourth linear-elastic model with instrumentation data (%)	difference of third linear-elastic model with instrumentation data (%)	difference of second linear-elastic model with instrumentation data (%)	difference of first linear-elastic model with instrumentation data (%)	total stress fourth linear-elastic model (kpa)	total stress third linear-elastic model (kpa)	total stress second linear-elastic model (kpa)	total stress first linear-elastic model (kpa)	total stress instrumentation level :1790 (kpa)	distance from axis (meter)	name of instrument
+1	+17	+28	+61	1038	1200	1322	1660	1025	+22	pc9
+19	+35	+49	+87	1070	1210	1338	1670	892	+14	pc10
+36	+54	+73	+117	1070	1210	1360	1700	782	-14	pc11

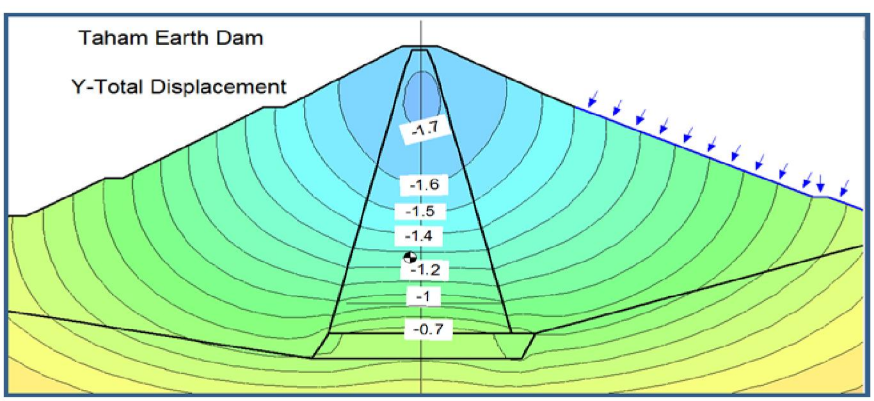

Fig 3. Distribution of settlements in fourth model

4-1-1-Inspection of settlement in forth linear-elastic model: The following figure is the graphical outcome of the deformation in numerical model of number four. It can be seen that the maximum stress occurs in the central part of the core and the upper part of it and is 1.7 meters, which accords with what is expected of a correct model, but the curve shape of settlement contours do not seem right.

4-2. Compound Models (cam-clay + linear elastic)

The four models were made using this behavioral model. There is still a wide gap between the results of the fourth model and an ideal one, which seems unachievable because since in the conditions that the specific gravity of the material is in its lowest level, we can observe irrational settlements in the clay core, and meanwhile:

Decreasing agents of settlement in clay core (mechanical parameters) that make settlement amount closer to rational numbers, caused the resulted stress from the numerical models being more distant from the recorded data in the instrumentation.

This contrast causes the settlement become so unreal when such changes are applied in the mechanical parameters for the aim of making the stress results near to the real pressure cells' data, and on the contrary when cam-clay parameters change according to the improvement of settlement conditions: the stress results being depart from the amounts that are recorded by the instrumentation.

Table 4. Variation of mechanical parameters in Compound Models

φ' (°)	c (MPa)	γ_{sat} ($\frac{KN}{m^3}$)	K m/sec	c_c	c_s	M	λ	κ	OCR	e	(poisson's Ratio)	Model
26.5	0.05	14.8	1.5E-9	0.23	0.04	1.057	0.1	0.017	1	0.8	0.35	1
26.5	0.05	14.8	1.5E-9	0.23	0.04	1.057	0.15	0.017	1	0.8	0.35	2
26.5	0.05	14.8	1.5E-9	0.23	0.04	1.057	0.15	0.017	1	0.8	0.2	3
26.5	0.05	14.8	1.5E-9	0.23	0.04	1.057	0.25	0.04	1	0.8	0.2	4

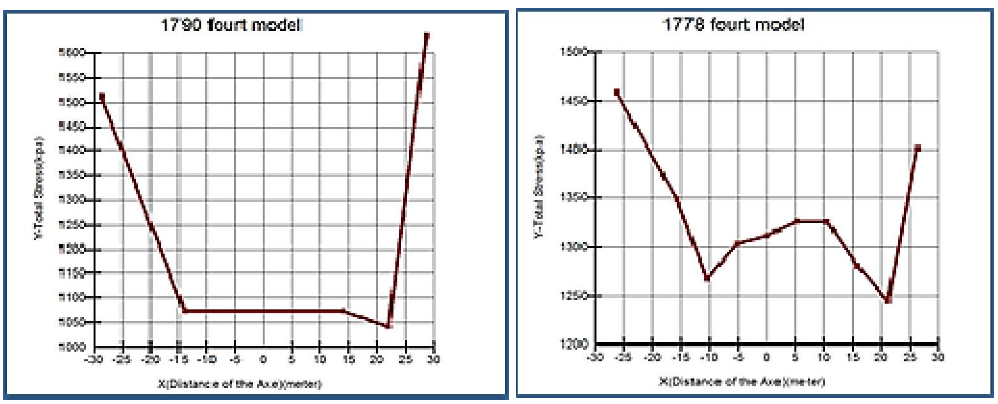

Fig 4. Distribution of Resulting stress in two different inspected level

Table 5. Difference of Compound Models with the Summary of Instrumentation (%), (level: 1778)

difference of fourth compounent model with instrumentation (%)	difference of third compounent model with instrumentation (%)	difference of second compounent model with instrumentation (%)	difference of first compounent model with instrumentation (%)	total stress fourth compound model (kpa)	total stress third compound model (kpa)	total stress second compound model (kpa)	total stress first compound model (kpa)	total stress instrumentation level:1778 (kpa)	distance from axis	name of instrument
-	-	-	-	-	-	-	-	-	+32/5	pc1
-	-	-	-	-	-	-	-	-	+26	pc2
-	-	-	-	-	-	-	-	-	+16	pc3
+23	+49	+38	+51	1790	2175	2010	2200	1455	+6	pc4
+33	+59	+50	+60	1755	2090	1980	2115	1313.7	-6	pc5
+32	+57	+34	+64	1810	2160	1840	2250	1368	-16	pc6
-	-	-	-	-	-	-	-	-	-26	pc7
-	-	-	-	-	-	-	-	-	-32/5	pc8

Table 6. Difference of Compound Models with the Summary of Instrumentation (%), (level: 1790)

difference of fourth compound model with instrumentation (%)	difference of third compound model with instrumentation (%)	difference of second compound model with instrumentation (%)	difference of first compound model with instrumentation (%)	total stress fourth compound model (kpa)	total stress second compound model (kpa)	total stress second compound model (kpa)	total stress first compound model (kpa)	total stress instrumentation level:1790 (kpa)	distance from axis	name of instrumen
+42	+73	+67	+81	**1460**	1780	1720	1860	1025	+22	**pc9**
+65	+117	+91	+109	**1480**	1940	1710	1870	892	+14	**pc10**
+93	+139	+116	+134	**1510**	1870	1690	1833	782	-14	**pc11**

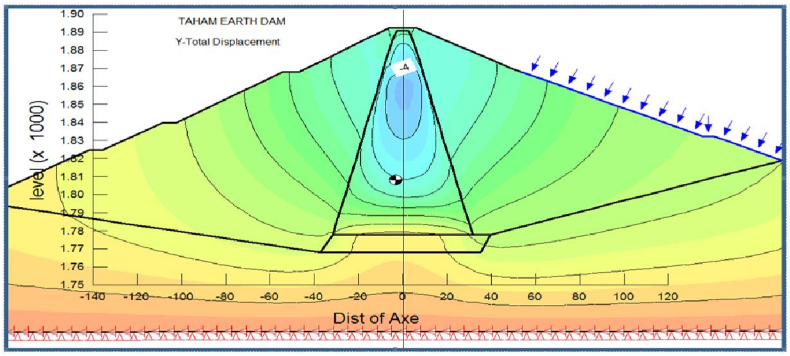

Fig 5. Distribution of settlements in fourth model

4-2-1. Examining settlement conditions in fourth numerical model of (cam-clay + linear elastic)

It can be seen that the maximum stress occurs in the central and upper parts of the core, which is in accordance with what is expected from a correct model, but curving shape of stress contours do not seem right. And also the maximum level of settlement is 4 meters which is very high and is quite far from reality.

4-3- Elastic-Plastic Models

4-3-1. Elastic-Plastic model (with applying the primary conditions of stress in the construction and building the dam in fifteen time steps)

Three different models were made by using this behavioral model. And in addition, in this model, before modeling the dam, in field of project the existing stress conditions were modeled, and then constriction of dam was modeled in fifteen time steps.

For this aim, in the third model, firstly the primary stress in the foundation (before building the dam) have been calculated, the foundation of the dam were analyzed and its deformations were totally eliminated. Then the model was ready to adapt the new conditions which are making new layers of filling in several steps. In this condition with making each layer, analysis is continued until reaching balance. At the end, by defining the final layer, the final condition is modeled.

In the third model, elasticity modulus of the core is reduced from 110000 to 80000 so that it becomes completely equal to the reported number.

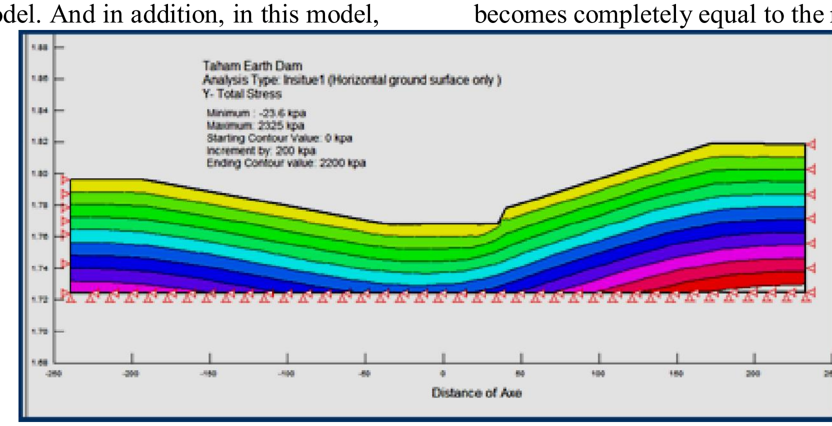

Fig 6. Initial stress in field of constriction (before constriction of the dam)

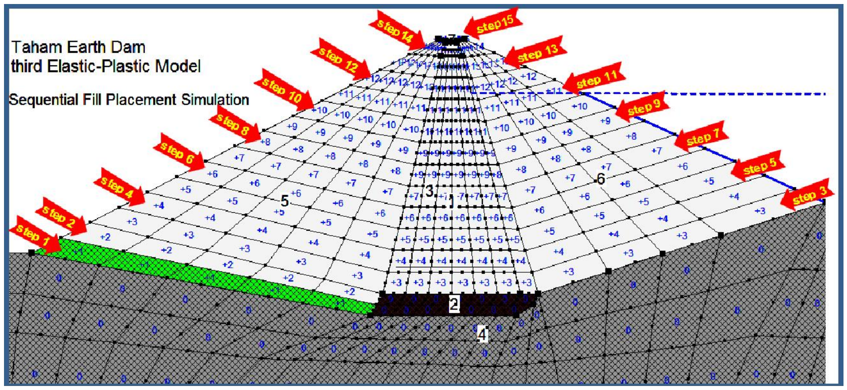

Fig 7. Meshing and defining the geometry of dam in 15 time-steps

Table 7. Variation of mechanical parameters in four elastic-plastic models

model	*region*	*E Modulus* (Kpa)	φ' (°)	*c* (*MPa*)	γ_{sat} ($\frac{KN}{m^3}$)	ψ (°)	υ (*poisson's Ratio*)
1	*core*	45000	26.5	0.05	17.5	2	0.35
1	*shoulder*	80000	40	0	23	8	0.3
1	*foundation*	90000	41	0	28	8	0.3
2	*core*	35000	26.5	0.05	17.2	2	0.2
2	*shoulder*	110000	40	0	20	8	0.4
2	*foundation*	90000	41	0	28	8	0.3
3	*core*	35000	26.5	0.05	17.2	2	0.2
3	*shoulder*	80000	40	0	20	8	0.4
3	*foundation*	90000	41	0	28	8	0.3

Furthermore, since defining the time steps of its construction is not possible with triangular elements, the body of the dam was meshed again and fifteen organized mesh layers were used for defining the elements.

It was seen that the average of resulted stress from the second elastic-plastic model with recorded instrumentation data in the height of 1778 were equal to 8.6% and in the height of 1790 equal to 36.3%, and the total average of the whole result differences of numerical model and the result of instrumentation in the third model is 22.45%, which seems quite high.

But it is very important that in this model, among all the other ones, we reached the correct distributions of the settlement's contours for the first time during this research, and also the maximum amount of settlement in the center of the clay core were much closer to reality than the amounts resulted from the last models (2.5 to 4 meters), and was reduced to 1.35 meters.

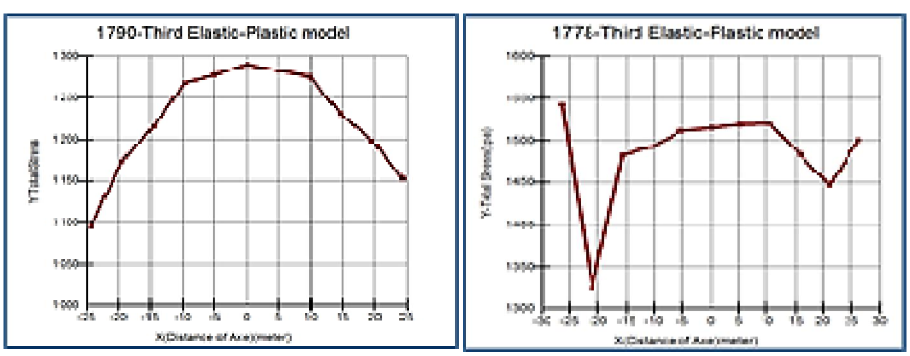

Fig 8. Distribution of Resulting stress in two different inspected level

Table 8. Difference of elastic-plastic Models with the Summary of Instrumentation (%), (level: 1778)

difference of third E-P model with instrumention (%)	difference of second E-P model with instrumention (%)	difference of first E-P model with instrumention (%)	total stress third elastic-plastic model (kpa)	total stress second elastic-plastic model (kpa)	total stress first elastic-plastic model (kpa)	total stress instrumentation level:1778 (kpa)	distance from axis	name of instrumen
-	-	-	-	-	-	-	+32/5	pc1
-	-	-	-	-	-	-	+26	pc2
-	-	-	-	-	-	-	+16	pc3
+4	-10	+26	1518	1300	1840	1455	+6	pc4
+14	-0.2	+38	1508	1280	1823	1313.7	-6	pc5
+8	-0.7	+31	1480	1260	1795	1368	-16	pc6
-	-	-	-	-	-	-	-26	pc7

Table 9. Difference of elastic-plastic Models with the Summary of Instrumentation (%), (level: 1790)

difference of third E-P model with instrumentation (%)	difference of second E-P model with instrumention (%)	difference of first E-P model with instrumention (%)	total stress third E-P model (kpa)	total stress second E-P model (kpa)	total stress first E-P model (kpa)	total stress instrum-entation (kpa)	distance from axis	name of instru-ment
+17	-0.4	+57	1200	980	1615	1025	+22	pc9
+37	-14	+82	1225	1020	1623	892	+14	pc10
+55	-26	+104	1215	990	1600	782	-14	pc11

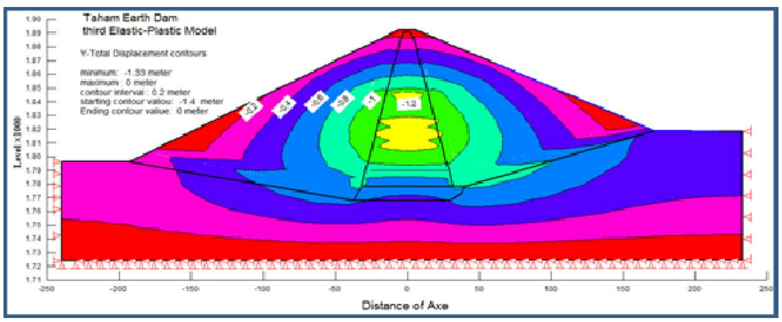

Fig 9. Distribution of settlements in third E-P model

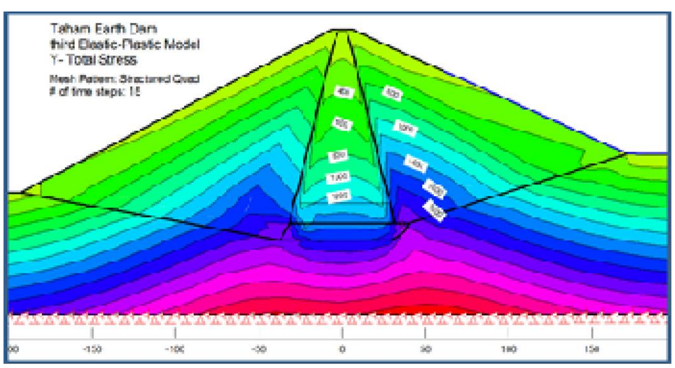

Fig 10. Distribution of stress in third E-P model

4-3-2. stress conditions in the third numerical elastic-plastic model

With considering the organization of stress contours in the following figure it could be said that shape of organization of the stress contours is near to what is expected from a correct numerical model.

The arching coefficient is also between 0.53 to 0.66, which in comparing with the arching difference graph in the clay core of the height of 1790 from section 10(critical section) witch report the arching percentage between 0.38 and 0.65 is acceptable.

5- Conclusion

In the end it could be said that these points must be considered in order to achieve the best numerical model for soil dams.

1. The use of elastic-plastic behavioral model, is known to be as the best alternative, if done step-loading and considered as inhomogeneous material in a way that: the changes of material properties inside the core are applied in the vertical direction and the direction of changed materials in shoulders should form a right angle with the direction of the stress counters.

2. Considering inhomogeneous material in the core and shoulders while making the numerical model and modeling different layers of one material based on its characteristics and mechanical parameters in different heights and considering the slope flayers based on the conditions of project.

3. Modeling step-loading caused from building the dam while making the numerical model (using time steps).

4. Using elastic-plastic behavioral model instead of linear behavioral models or combining them with (cam-clay) behavioral model.

5. Using a non-linear plastic theory for modeling the other elements of the dam (including the shell, foundation or bedrock) in while using (cam-clay) behavioral model for the core of the soil dams.

6. Using the three-dimensional numerical analysis in which there is the possibility to make changes in the third dimension, and eliminating the restrictions of using plan strain conditions.

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