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Investigation of Interaction between Rock Materials and Concrete Slabs in Concrete-Face Rock-Fill Dam (CFRD)

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ABSTRACT

In the CFRD dams, a concrete-face with a finite thickness is placed on the upstream side of the dam, which prevents water leakage from the reservoir. The construction of these dams with different heights and various specifications of materials have been welcomed a lot. Therefore, construction of CFRD is appropriate in pumped-storage reservoirs. However, due to the important role of concrete-face, the necessity of optimal studies in order to evaluate the behavior of this type of dams is obvious. In this research, the lower reservoir of Siah Bishe was studied by finite element method in order to investigate the interaction between rock-fill materials and simulated concrete-face and by an appropriate behavioral model in a three-dimensional mode that can simulate the behavior of materials in the body of the dam well. In this research, Plaxis software was used for modeling and static analysis was performed to determine deformations and stresses made in the dam and concrete slab. The elastoplastic behavioral model of Mohr-Coulomb was used to model the behavior of the materials and the technical specifications of the materials used in the body of the dam and concrete-face slab have been applied. The maximum value of settlement calculated by the software from the beginning of the constriction to filling the reservoir under the effect of gravity is 670 millimeter and the maximum settlement after phase 3 in the mode of the full reservoir in long term is 32 millimeter and the maximum horizontal displacement is 52 millimeter. Finally, the results of the settlements were compared to results of the instrumentation. The results indicate the approximation of results of the numerical modeling with results obtained from instrumentation.

Key words: CFRD, Finite Element, Instrumentation, Plaxis Software, Interaction between Materials and Concrete-Face.

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1. INTRODUCTION

The role of sealing in rock-fill dams is on concrete-face in upper part of the dam and any cracking and damage to this coating can lead to water leakage of the reservoir and disruption of the function of the dam. Hence, one of the most important problems of concrete- face rock-fill dams is cracking of the concrete-face (1). Till now, many analyses have been conducted on deformation of the body of dam and its behavior (2-4). Various tests on rock materials indicate a non-linear and non-elastic behavior dependent on stress in rock-fill mass and fracture of the components of the rock leads to significant Volumetric strain (5-8). Non-linear analysis on concrete- face of CFRDs under the static effects using ANYSYS, FERUM software indicates that the probability of failure in connection contact is higher than friction contact between the slab and rock-fill (8). The parameters affecting deformation of the face should be studied. In fact, by deformation of the face, stresses in that are increased and if their amount exceeds the limit, it will damage the concrete slab of the face. The effective parameters are studied using an appropriate behavioral model which well has the capability of simulating the behavior of rock-fill materials in Plaxis software. Given that a little experience about the function of this type of dams (CFRD) is available, prediction of the behavior of the dams and interaction between concrete-face and rock materials affected by effective parameters is very important. Some problems during construction of CFRDs are separation of the concrete slab from body of the dam and tensile stresses in it that causes crack in the slab and, in turn, lead to reduction in safety factor against failures caused by water penetration. Many researches such as [Cattani M et al] (9) and [Hughes MW et al] (10) [Porter et al] (11) [Rezvani et al] (12) and [Campisano et al] (13) and [Fecarotta et al] (14) have carried out case studies and researches concerning the effect of the effective factors. In this research, by evaluating the results from available instrumentation of a CFRD, the effect of factors such as height, specifications of materials of the dam body (rock-fill), slope of the foot, coefficient of friction between the face and materials of the dam body and also thickness of the concrete-face slab was studied through finite element method and was compared to results of in-place available instrumentation.

2. RESEARCH METHODOLOGY

In this research, Plaxis software was used for modeling and then static analyses were performed on the slab to determine the deformations and stresses made in the slab and concrete slab. The elastoplastic behavioral model of Mohr-Coulomb was used to model the behavior of the materials. The mechanical specifications of the materials were applied for different areas of the dam. In this model, the elastic behavior was considered linearly by the isotropic method defined with two parameters of V-E and the plastic behavior was assumed non-linearly. Mohr- Coulomb model in Plaxis software is an elastoplastic model with a yield function including an isotropic hardening and softening in the viscosity.

3. RESEARCH TOOLS

Information required for modeling the lower dam of Siah Bishe including geometric and technical specifications of the materials was collected through evaluation of databases (tables and drawings and documentary data and available reports) on the websites of the Ministry of Energy and Iran Water and Power Resources Development Company and Moshanir Consultant Co. and using scientific articles available on foreign and domestic specialized websites. The finite element software of Plaxis 3DTunnel,1.2 was used to model the dam citing the information collected.

4. GEOMETRIC AND TECHNICAL SPECIFICATIONS OF THE LOWER DAM OF SIAH BISHE (THE STUDIED CASE)

The geometric specifications are as follows:
Upper slope: 1V:1.6H
Maximum height of the dam: 101.5 m

Lower slope: 1V:1.45H
Length of the crest: 332 m

Height of the crest: 1911.50 masl
Maximum width of the base: 360 m

Width of the crest 12 m.

For geometrically modeling of the lower dam of Siah Bishe, coordinates of the points have been completely and accurately extracted from drawings in AutoCAD format provided by Moshanir Consultant Co. and drawn according to Figure 1. In the real model of the lower dam of Siah Bishe with PLAXIS3DTUNNEL,1.2 software, coordinates of 70 points and drawing of 12 clusters have been used.

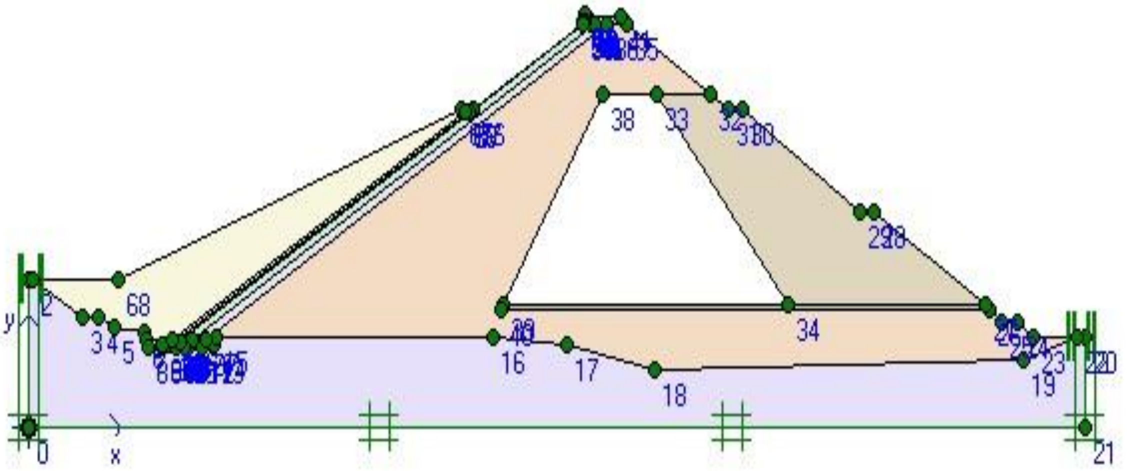


Figure 1. Geometric model of the lower dam of Siah Bishe (based on the drawing)

In this modeling of geometric coordinates of geotechnical specifications and points of the materials, reports available in Moshanir Consultant Co. (the executive report of the project) and information available in Manual of Allpile program and book of Advance soil mechanics written by Das (15) and book of Foundation Analysis and Design written by Poulos (16) have been used. Geotechnical specifications of the materials defined for the model of the dam, in the program, were extracted and have been attached (Table 1 and Table 2). In this study, the overall structure of the dam for long-term behavior of the dam in the drained form has been modeled in order to determine the deformations and curves of displacement and stress-strain and to evaluate the effective parameters in the changes and eventually to adapt to real observations (instrumentation) and also to determine the safety factor of the gable over long-term (stability factor against sliding).

Table 1. Geotechnical specifications of the materials based on the value of SPT

Value of SPT	*Relative density*	*ϕ*	*Specific gravity (kNm²)*	*Sand*
4<N<10	Dr<35%	29<ϕ<33	16.6<G<18.1	Loose
10<N<30	35%<Dr<65%	33<ϕ<38	18.1<G<19.3	Medium
30<N<50	65%<Dr<85%	38<ϕ<40	19.3<G<20.4	Dense

Table 2. Geotechnical specifications of the materials based on the value of SPT

Value of SPT	*E50*	*C*	*Specific gravity (kNm²)*	***Clay***
1<N<4	1.65<e<4.38	4<C<21	15.1<G<17.8	Soft
4<N<10	0.9<e<1.65	21<C<57	17.8<G<20.2	Medium
10<N<16	0.66<e<0.9	57<C<94	20.2<G<20.8	Stiff
16<N<32	0.43<e<0.66	94<C<194	20.8<G<21.5	Very Stiff
Value of SPT	ϕ	C (kNm²)	Specific gravity (kNm²)	**Silt**
4<N<10	27<ϕ<30	10.4<C<29	17.9<G<20.2	Medium
10<N<16	30<ϕ<32	29<C<47	20.2<G<20.8	Stiff
16<N<32	32<ϕ<35	47<C<96	20.8<G<21.5	Very Stiff

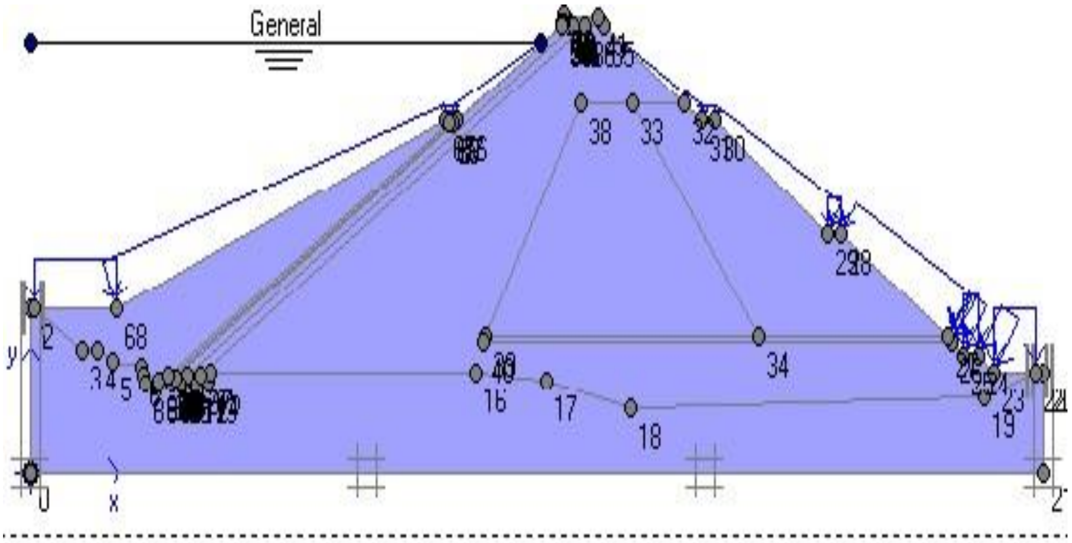


Figure 2. Geometric model of the lower dam of Siah Bishe in the mode of full reservoir

In the modeling for three-dimensional simulation of the dam (Figure 2), the introduction of 27 panels (face slab) with 12 meters wide in both sides (supporting) totally 332 meters high (length of the crest) has been used. Mesh of

3D model of lower Siah Bishe dam is shown in Figure 3.

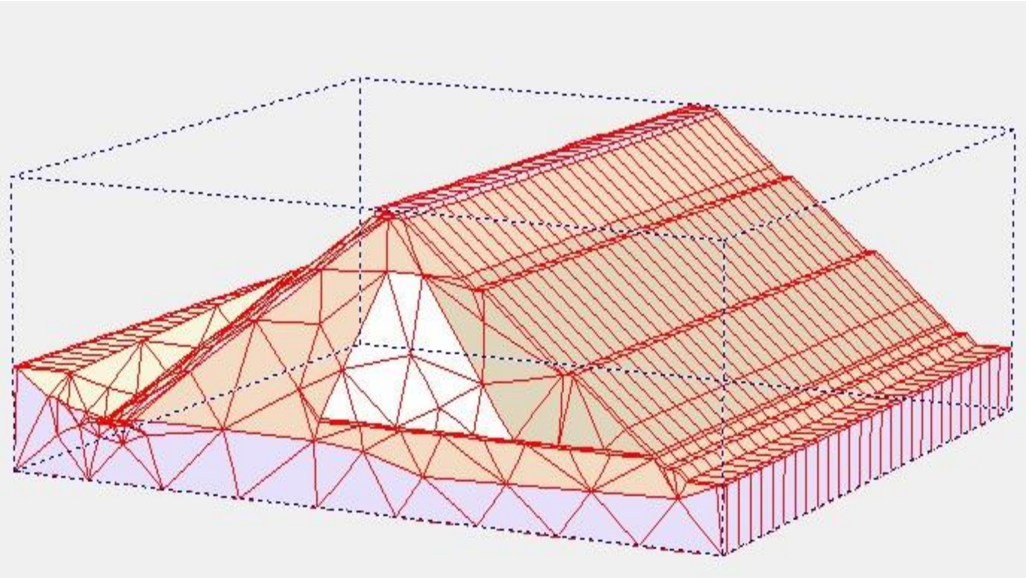


Figure 3. Mesh of 3D model of lower Siah Bishe dam

Permeability of some soils is given in Table 3, Advance soil mechanics written by Das.

Table 3. Permeability of some soils

K(m/sec)	*Type of Soil*
100-1	Clean Sands
1-0.01	Coarse Sand
0.01-0.001	Fine Sands
0.001-0.00001	Silty Clay
<0.000001	Clay

5. RESULTS FROM INSTRUMENTATION (VALIDATION) (EVALUATION OF SETTLEMENTS MEASURED IN SITU)

Settlements measured by 32 sensors in situ have been recorded. The maximum settlement read based on data of the instrumentation (indicating the maximum value of settlement by sensor 2) since the beginning of the construction to filling the reservoir and placing the dam in the balance mode has been recorded 475 millimeter. The maximum value of settlement calculated by the software affected by the weight of the dam is equal to 670 millimeter that indicates more hardness of the materials and applying a safety factor considered by the software. But considering failure mechanism (full tank mode) after the third phase, the maximum settlement calculated in the dam is 32 millimeter in long-term, while the whole data results of the instrumentation (read in 32 sensors) is approximately zero in two months after complete drainage that indicates the accuracy of the modeling for the dam. The graph (Figure 4) shows the behavioral situation of settlement by sensor 32 with the maximum cumulative settlement of 154 millimeter in altitude code of 1810.070. The graph (Figure 5) shows the situation of settlement in sensor 17 that indicates cumulative settlement of 219 millimeter.

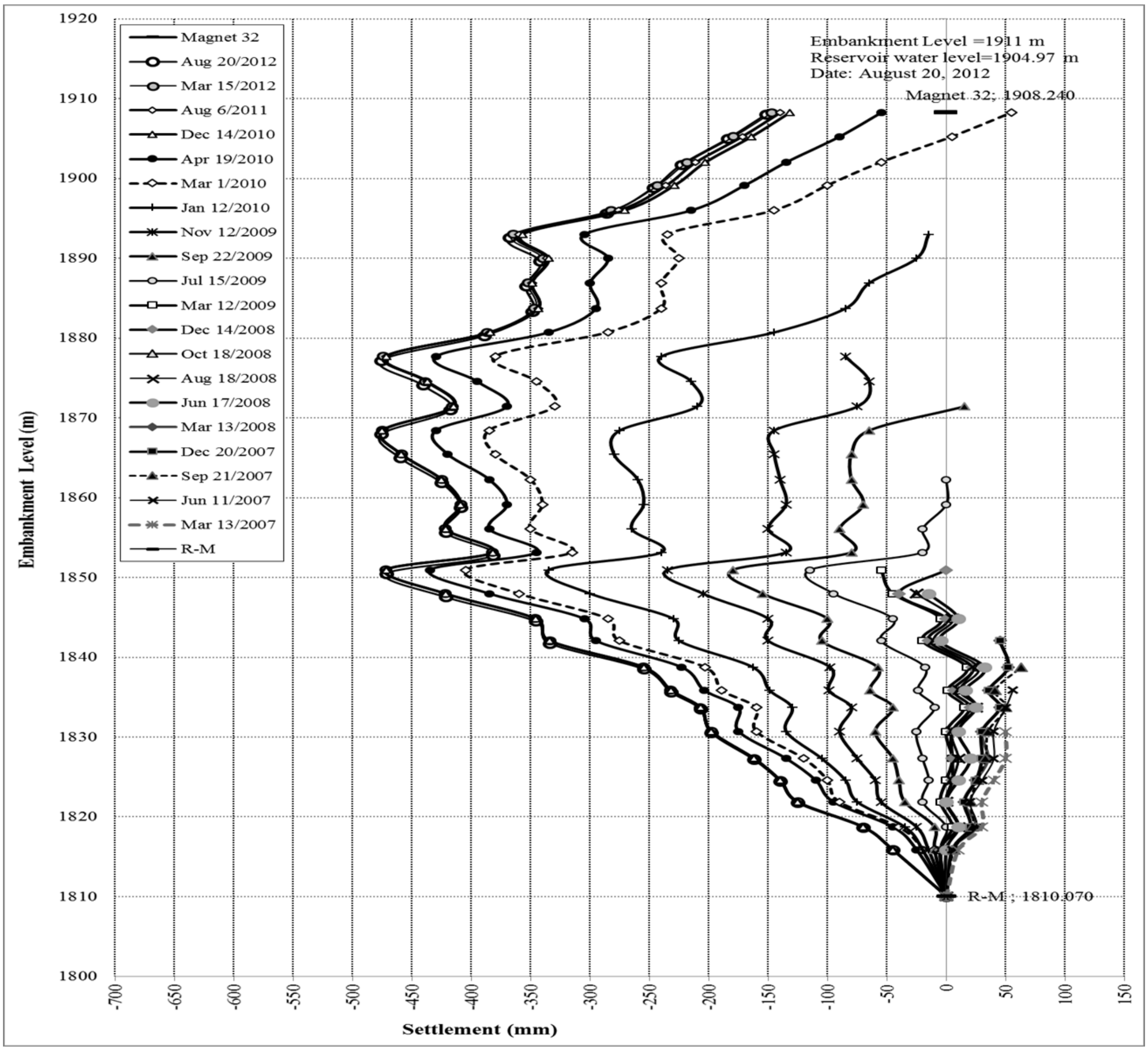


Figure 4. Graph of cumulative settlement by sensor 32 (magnet 32)

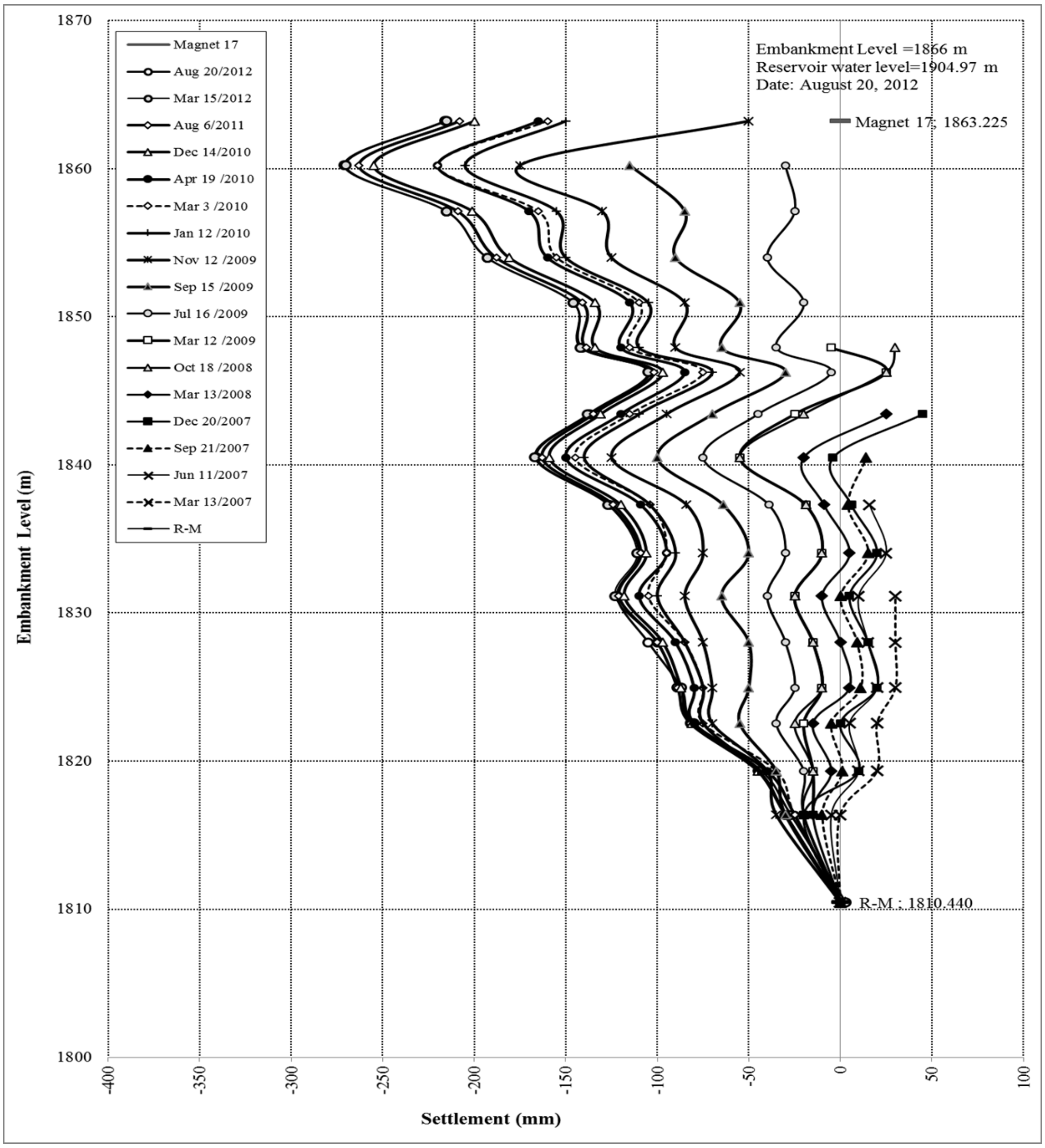


Figure 5. Graph of cumulative settlement by sensor 17 (magnet 17)

6. EVALUATION OF HORIZONTAL DISPLACEMENT MEASURED IN SITU

Evaluation of results of horizontal cumulative displacements by 13 sensors indicates that the maximum horizontal settlement from the beginning of filling the reservoir to a period of three years in the reading range is 0 to 15 millimeter (with the desire to a minimum displacement of zero). The maximum horizontal settlement has been calculated 52 millimeter by the software. The approximation of results of the instrumentation with this value considering the decreasing desire of horizontal displacement in the dam indicates the accuracy of the modeling. The graph (Figure 6) shows horizontal cumulative displacement of the dam in a period of 6 years. The maximum displacement in this mode from filling the reservoir to next is approximately 15 millimeter.

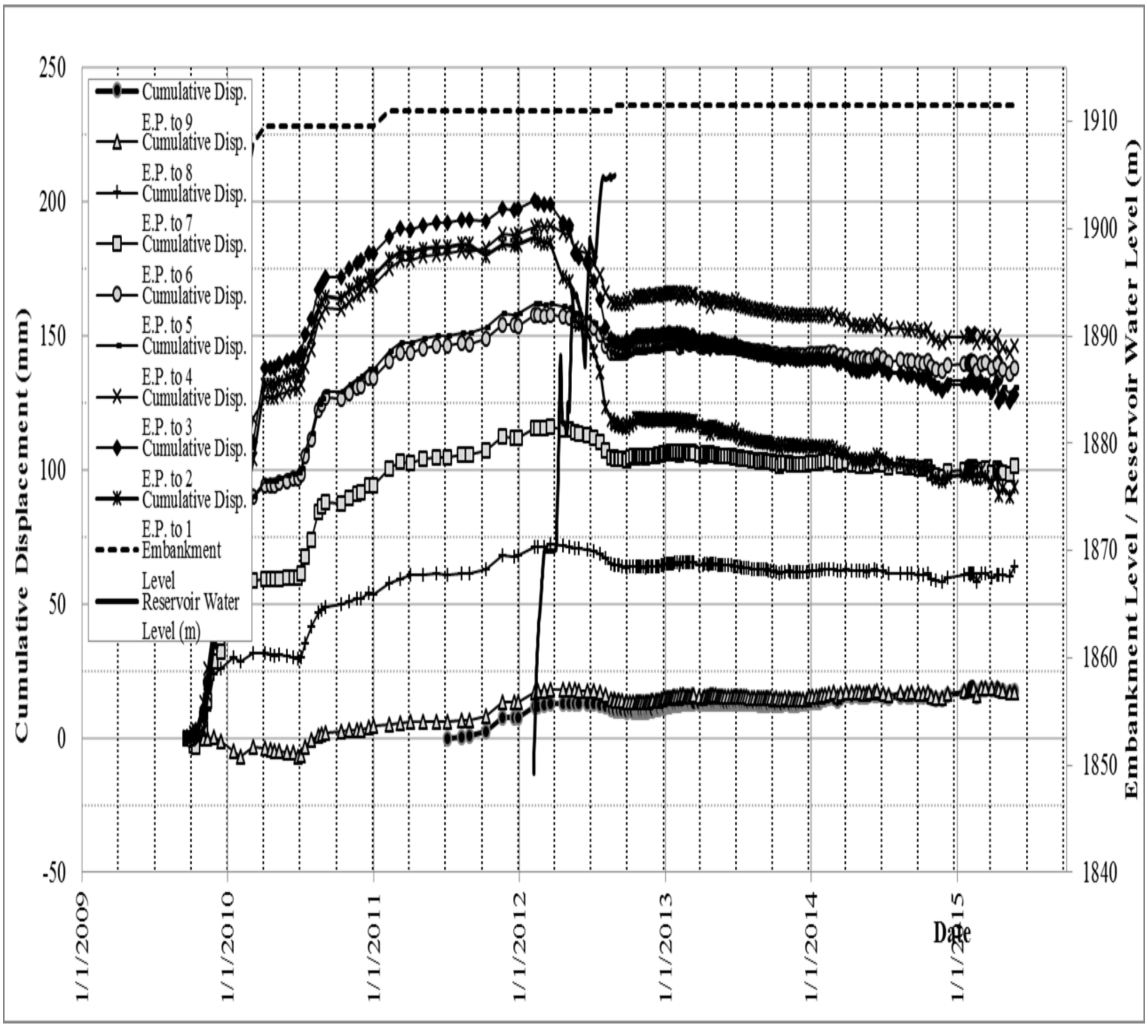


Figure 6. Graph of cumulative horizontal displacement by (9) sensors in altitude code of 1870

7. EVALUATION OF HORIZONTAL DISPLACEMENT ALONG THE LONGITUDINAL AXIS (Z) MEASURED IN SITU

In static analysis of the Siah Bishe Dam model considering the presence of supporting condition in both sides of the dam along the longitudinal axis with joint condition, displacement values by the software do not match the observations and displacement values in this direction are naturally considered zero. The result for values of horizontal displacement observations along the longitudinal axis of the dam indicates the maximum displacement from 0 to 20 millimeter. The dynamic analysis should be evaluated in order to determine the behavior of the dam in this direction. The graph (Figure 7) shows horizontal cumulative displacement along the longitudinal axis of the dam in altitude code of 1890.

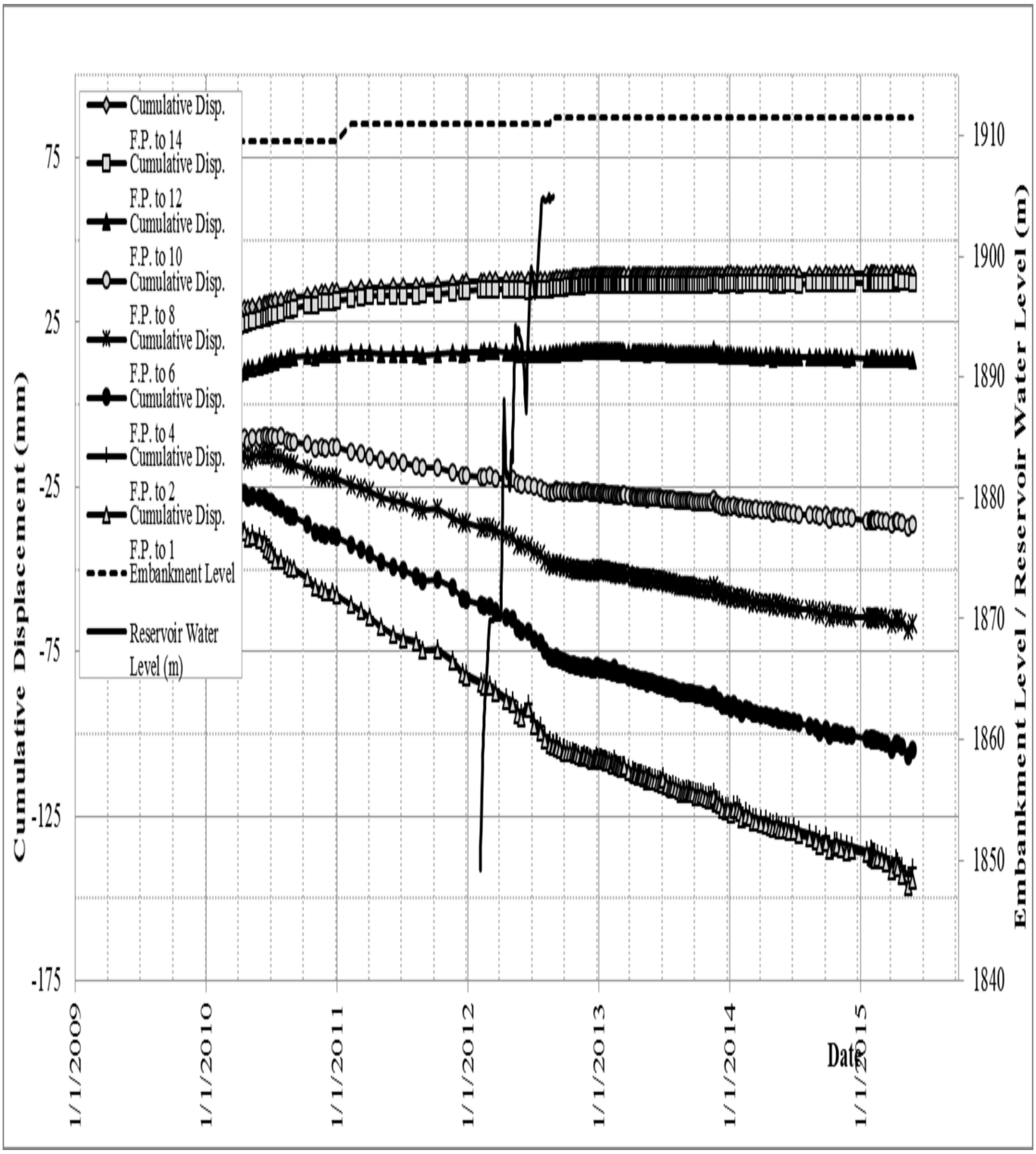


Figure 7. Graph of cumulative horizontal displacement (z) by (14) sensors in altitude code of 1890

8. EFFECT OF PARAMETERS AFFECTING THE VALUE OF STRESS IN THE DAM CHANGE IN TECHNICAL SPECIFICATIONS OF THE MATERIALS

In order to evaluate the change in parameters on value of stress applying numerical changes in technical specifications, we analyze the changed model of the dam through the software and the numerical method and extract the results. In this mode, according to Table 4 and Table 5, the main and changed values (technical specifications of the materials and friction angle between the concrete-face and the cushion layer) have been evaluated to investigate the changes on value of stress in the dam.

Table 4. Technical specifications of the materials in the real mode of the dam

Dilation angle (Degree)	*Friction angle (degree)*	*Adhesion (KN/M2)*	*Modulus of elasticity (KN/M2)*	*Poisson's ratio -*	*Saturated unit weight (KN/M3)*	*Dry unit weight (KN/M3)*	*Type of materials*
0.0	25.0	550.0	1.9E6	0.25	27.0	26.0	FONDATION
0.0	38.0	0.3	1E5	0.25	24.0	23.1	ROCK-2A
0.0	36.0	0.3	1E5	0.25	23.0	22.1	ROCK-2AA
0.0	38.0	0.3	1E5	0.25	24.0	23.0	ROCK-2B
0.0	38.0	0.3	1E5	0.25	24.0	23.3	ROCK-2C
0.0	50.0	0.3	1E5	0.25	23.5	22.8	ROCK-3A
0.0	50.0	0.3	1E5	0.25	23.5	22.8	ROCK-3B
0.0	50.0	0.3	1E5	0.25	24.0	23.2	ROCK-3C
0.0	38.0	0.3	1E5	0.25	24.0	23.3	ROCK-3D
0.0	27.0	18.5	3500	0.25	21.7	20.1	SAND CLY-1A
0.0	33.0	30.0	5500.0	0.25	23.4	21.3	SAND CLY-1B
-	-	-	2.5E7	0.17	25.0	25.0	CONCRETE
-	-	-	2.4E7	0.17	24.0	24.0	CONCRETE-WALL

Table 5. Technical specifications of the materials in the changed mode (1)

Dilation angle (Degree)	*Friction angle (degree)*	*Adhesion (KN/M2)*	*Modulus of elasticity (KN/M2)*	*Poisson's ratio -*	*Saturated unit weight (KN/M3)*	*Dry unit weight (KN/M3)*	*Type of materials*
0.0	25.0	550.0	1.9E6	0.25	27.0	26.0	FONDATION
0.0	39.0	0.3	1E5	0.25	25.0	24.1	ROCK-2A
0.0	37.0	0.3	1E5	0.25	24.0	23.1	ROCK-2AA
0.0	39.0	0.3	1E5	0.25	25.0	24.0	ROCK-2B
0.0	39.0	0.3	1E5	0.25	25.0	24.3	ROCK-2C
0.0	51.0	0.3	1E5	0.25	24.5	23.8	ROCK-3A
0.0	51.0	0.3	1E5	0.25	24.5	23.8	ROCK-3B
0.0	51.0	0.3	1E5	0.25	25.0	24.2	ROCK-3C
0.0	39.0	0.3	1E5	0.25	25.0	24.3	ROCK-3D
0.0	29.0	19.5	3500	0.25	22.7	21.1	SAND CLY-1A
0.0	34.0	30.0	5500	0.25	24.4	22.3	SAND CLY-1B
-	-	-	2.5E7	0.17	25.0	25.0	CONCRETE
-	-	-	2.4E7	0.17	24.0	24.0	CONCRETE-WALL

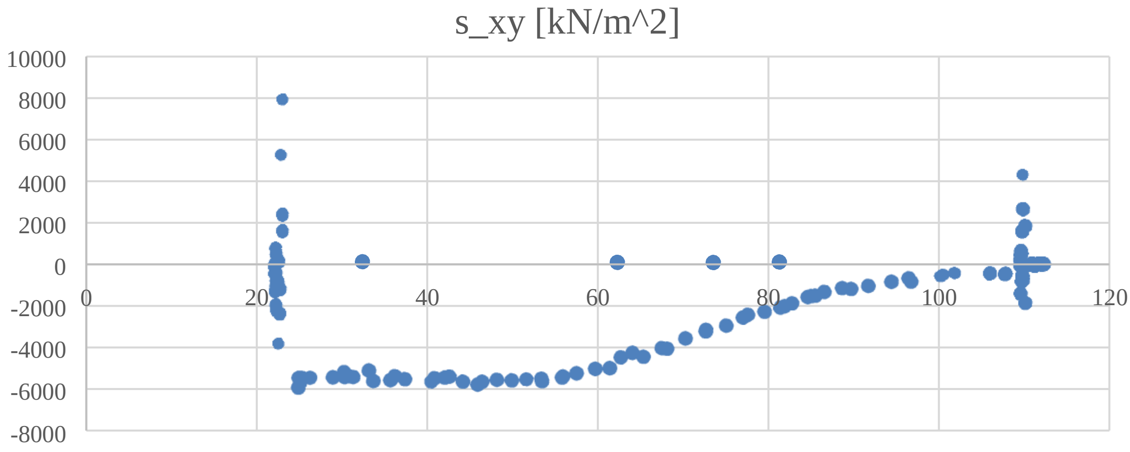


Figure 8. Maximum position of tensile and compressive shear stresses located on concrete slab along the height of the dam in the changed model (1)

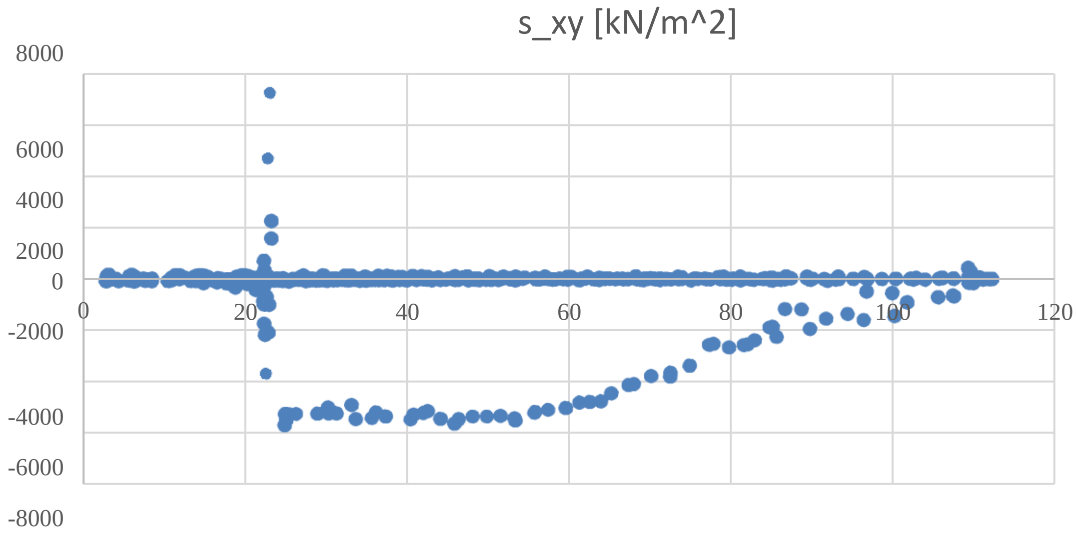
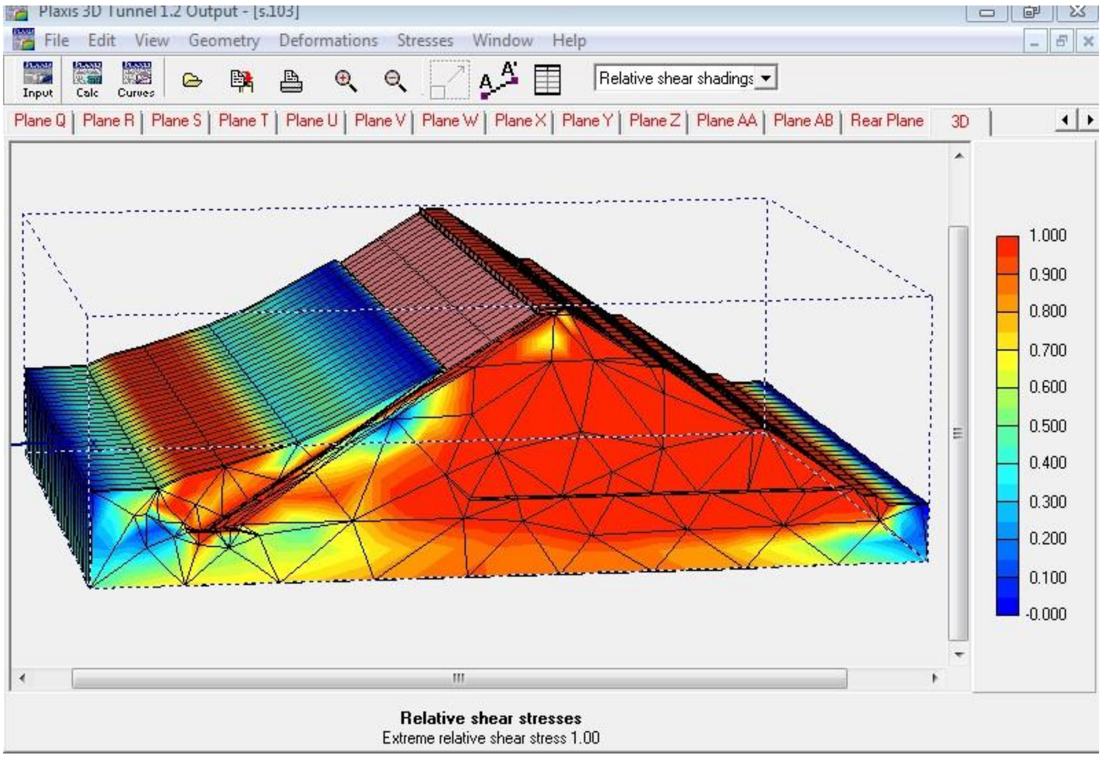


Figure 9. Maximum position of tensile and compressive shear stresses located on concrete slab along the height of the dam in the real model

Considering Figure 8 and Figure 9, by changing in technical specifications of the materials in the body of the dam according to Table 4 and Table 5, the effect of these changes on development of tensile and compressive shear stresses on the face layer is clearly obvious and by increasing the friction coefficient and density of materials of the cushion layer (that causes changes in friction coefficient between the concrete-face and the cushion layer) it is concluded that the hardness difference in the face layer and the cushion layer in both real and changed models of the dam is the main factor for creation of stresses and strains in the face and the body of the dam, so that increase of friction can cause increase in tensile stress in the face but has no significant effect on the values of maximum compressive stress on the concrete-face. On the concrete slab, the development ratio of shear tensile stresses is higher than compressive stresses and by an increase in the height the compressive stresses are reduced and tensile stresses are increased. In the full reservoir mode, the maximum shear tensile stress is at the beginning of the concrete-face and the maximum shear compressive stress is in the primary half of the concrete-face along the slope. In studies on a hypothetical model of CFRD through finite element method (two-dimensional), it has been concluded that increase in friction coefficient increases tensile stress but has no significant effect on the value of compressive stress in the concrete-face, and increase in hardness of the materials in the lower half of the body of the dam causes the maximum compressive strain in the middle of the concrete-face which is important considering the suitable compressive strength of the concrete (17-20). Therefore, the results are consistent with the previous studies appropriately.



Relative shear stresses
Extreme relative shear stress 1.00

Figure 10. The status of the relative shear stress in the real model of the dam

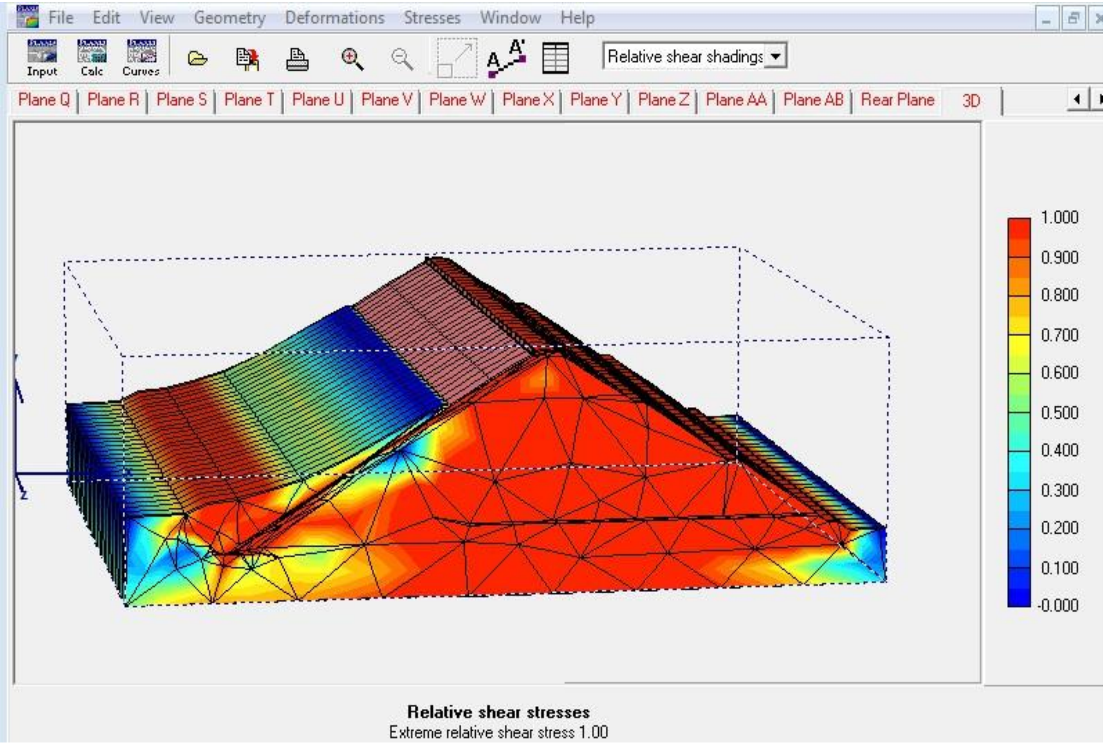
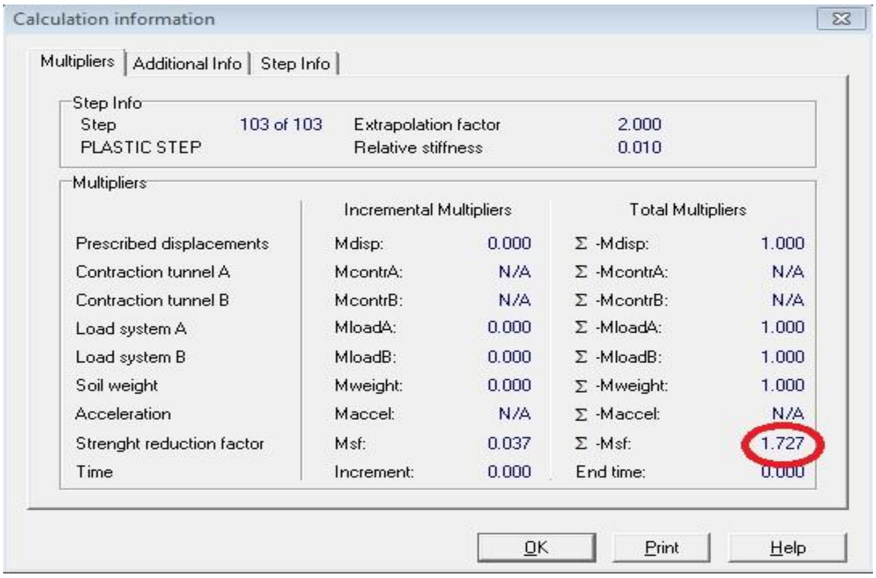


Figure 11. The status of the relative shear stress in the changed model of the dam

According to Figure 10 and Figure 11, the relative shear stress in the full reservoir mode in both models is 1 at the base and 0.7 in the middle and approaches 1 by increasing the height of the dam.



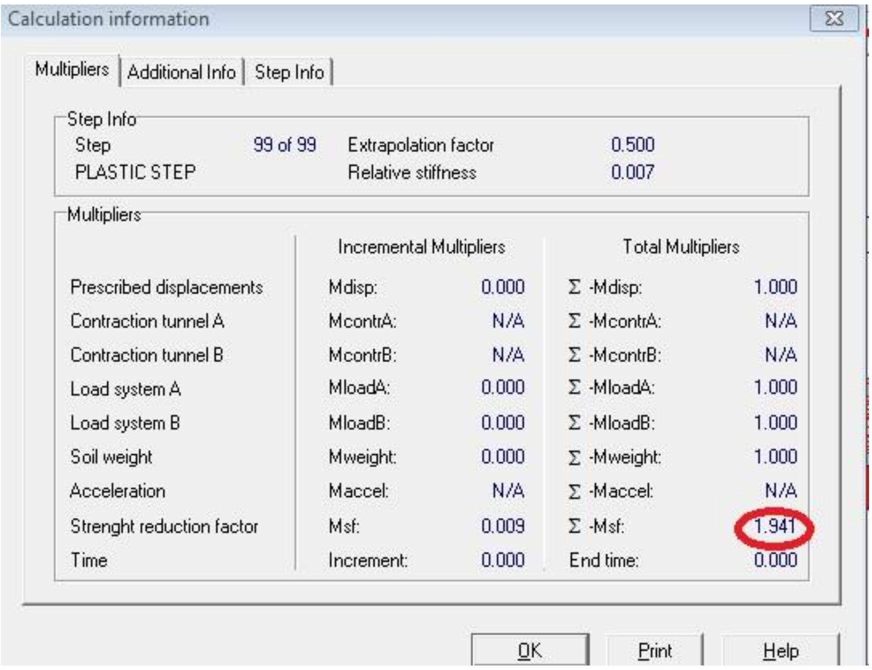
Step Info

Step	103 of 103	Extrapolation factor	2.000
PLASTIC STEP		Relative stiffness	0.010

Multipliers

	Incremental Multipliers		Total Multipliers	
Prescribed displacements	Mdisp:	0.000	Σ -Mdisp:	1.000
Contraction tunnel A	McontrA:	N/A	Σ -McontrA:	N/A
Contraction tunnel B	McontrB:	N/A	Σ -McontrB:	N/A
Load system A	MloadA:	0.000	Σ -MloadA:	1.000
Load system B	MloadB:	0.000	Σ -MloadB:	1.000
Soil weight	Mweight:	0.000	Σ -Mweight:	1.000
Acceleration	Maccel:	N/A	Σ -Maccel:	N/A
Strenght reduction factor	Msf:	0.037	Σ -Msf:	1.727
Time	Increment:	0.000	End time:	0.000

Figure 12. Stability safety factor in the real model of the dam



Step Info

Step 99 of 99 — Extrapolation factor 0.500

PLASTIC STEP — Relative stiffness 0.007

Multipliers

	Incremental Multipliers		Total Multipliers	
Prescribed displacements	Mdisp:	0.000	Σ -Mdisp:	1.000
Contraction tunnel A	McontrA:	N/A	Σ -McontrA:	N/A
Contraction tunnel B	McontrB:	N/A	Σ -McontrB:	N/A
Load system A	MloadA:	0.000	Σ -MloadA:	1.000
Load system B	MloadB:	0.000	Σ -MloadB:	1.000
Soil weight	Mweight:	0.000	Σ -Mweight:	1.000
Acceleration	Maccel:	N/A	Σ -Maccel:	N/A
Strenght reduction factor	Msf:	0.009	Σ -Msf:	1.941
Time	Increment:	0.000	End time:	0.000

Figure 13. Stability safety factor in the changed model of the dam

Considering Figure 12 and Figure 13, the stability factor of the dam has been increased by increase in density (density of materials of the dam body) and increase in friction coefficient of the materials of the dam (especially the cushion layer).

9. EFFECT OF PARAMETERS OF HEIGHT AND THICKNESS OF SLAB ON DEVELOPED STRESSES

To evaluate the effect of height and also thickness of the concrete-face slab on the value of stress, another model is simulated for behavioral analysis and the results are evaluated. In this mode, height of the dam is increased by 6 meters and head of dam drainage height is changed from 105.2 meters high to 110.8 meters. In this model to evaluate effect of thickness on value of stress, by increase in the height no change is made in thickness of the slab based on the formula (T= 0.3+0.003H) and in fact by increase in the height, slope of the upper and lower foot of the dam has been increased and this change in the slope has been applied on the concrete-face as well. Figure 14 is the geometric model of the dam evaluated in this stage.

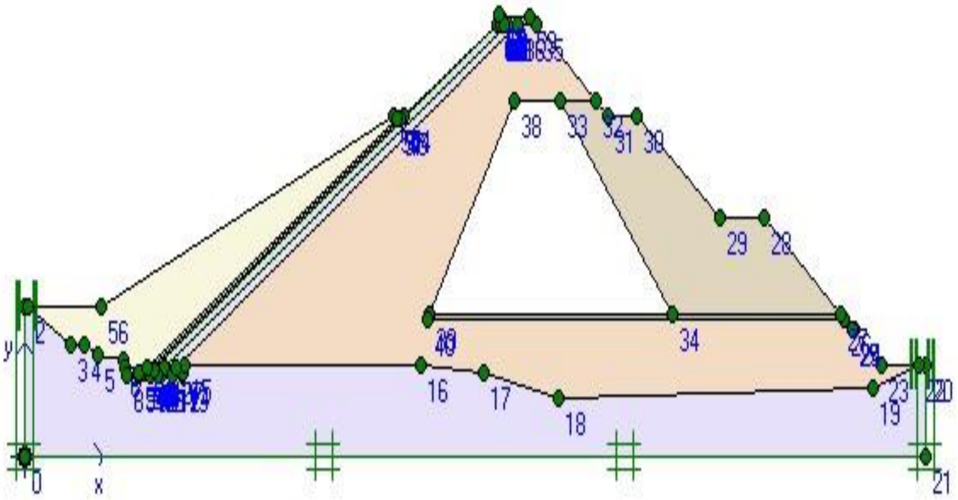


Figure 14. Model of the dam evaluated (changed)

Geometric specifications of the dam in the real model (Figure 15):

Upper slope: 1V:1.6H
Maximum height of the dam: 101.5 m
Lower slope: 1V:1.45H
Length of crest: 332 m
Height of the dam crest: 1911.50 masl
Maximum width of the base: 360 m

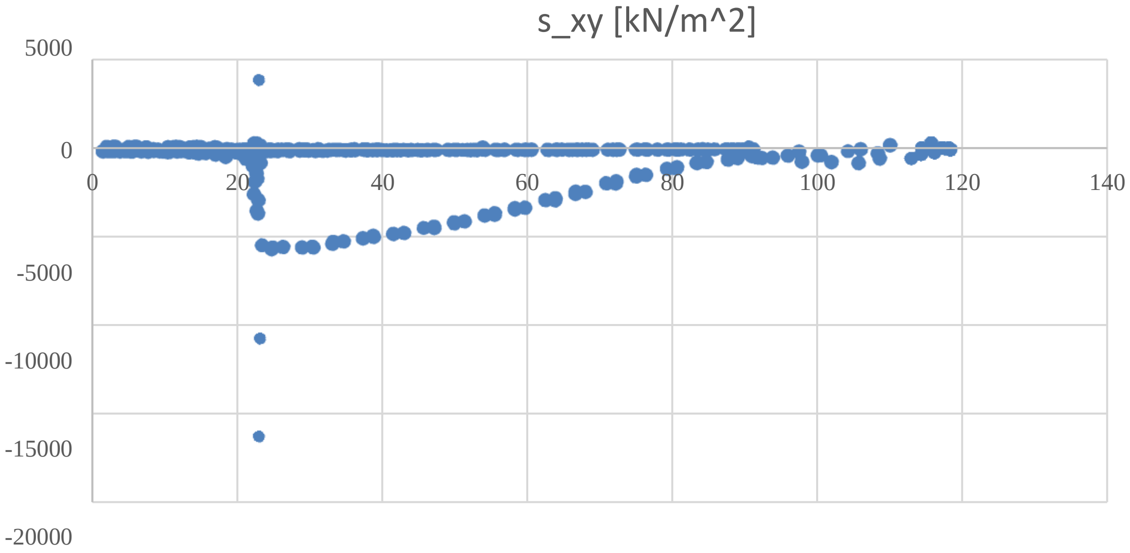


Figure 15. Geometric specifications of the dam in the real model

Geometric specifications of the dam in the model evaluated (changed):

Upper slope: 1V:1.49H
Maximum height of the dam: 107.5 m
Lower slope: 1V:1.19H
Length of crest: 332 m
Height of the dam crest: 1917.50 masl
Maximum width of the base: 360 m
Width of the crest: 12 m

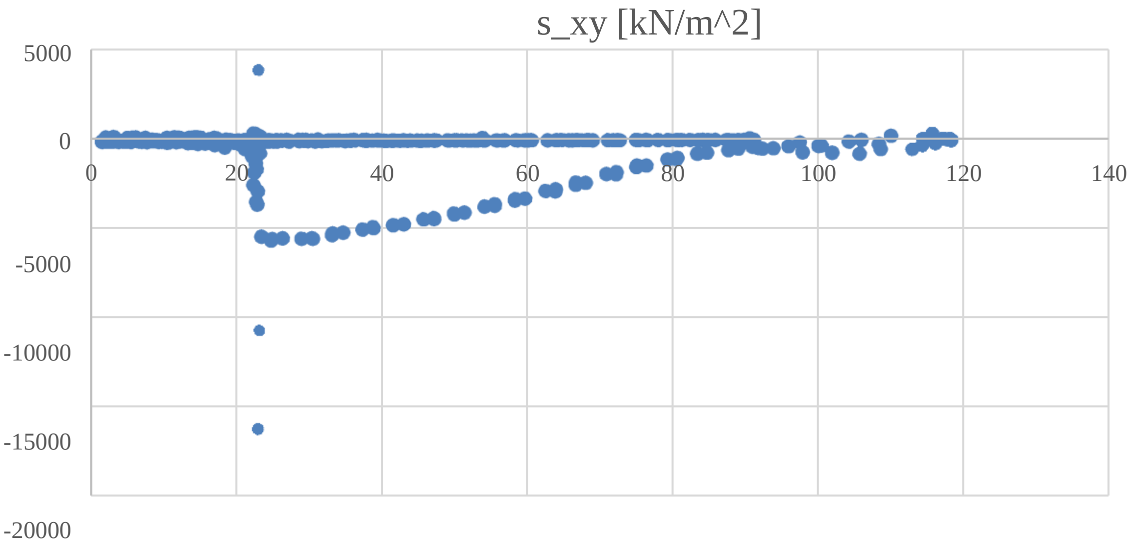
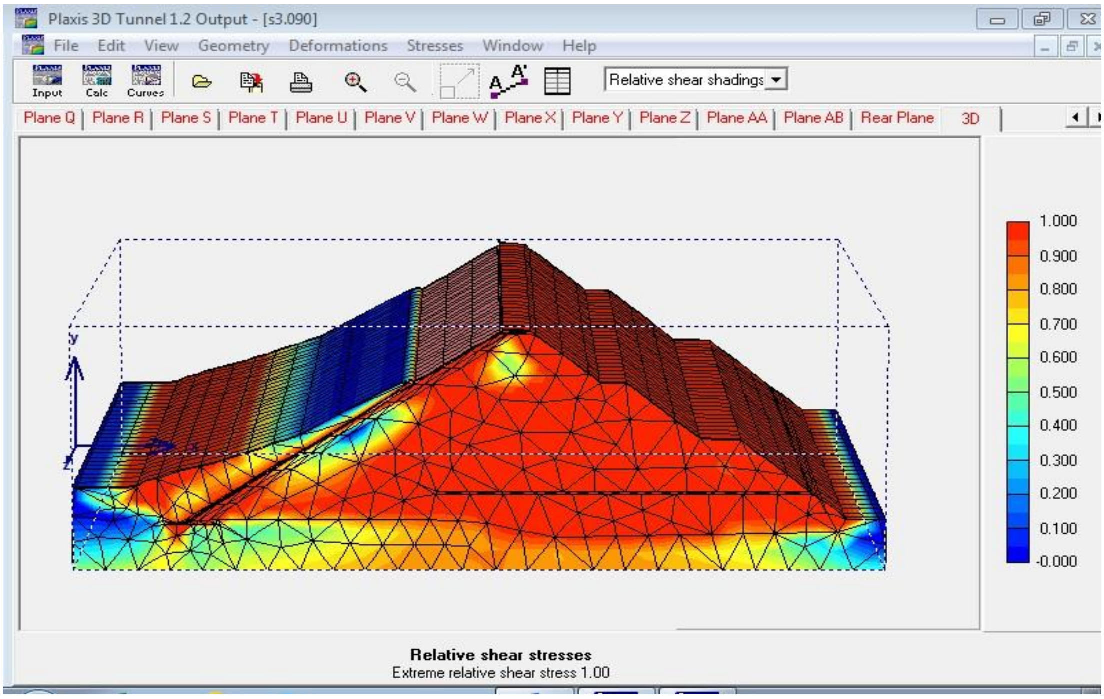


Figure 16. Maximum position of tensile shear and compressive stresses located on the concrete slab along the height of the dam in the changed model (2)



Relative shear stresses
Extreme relative shear stress 1.00

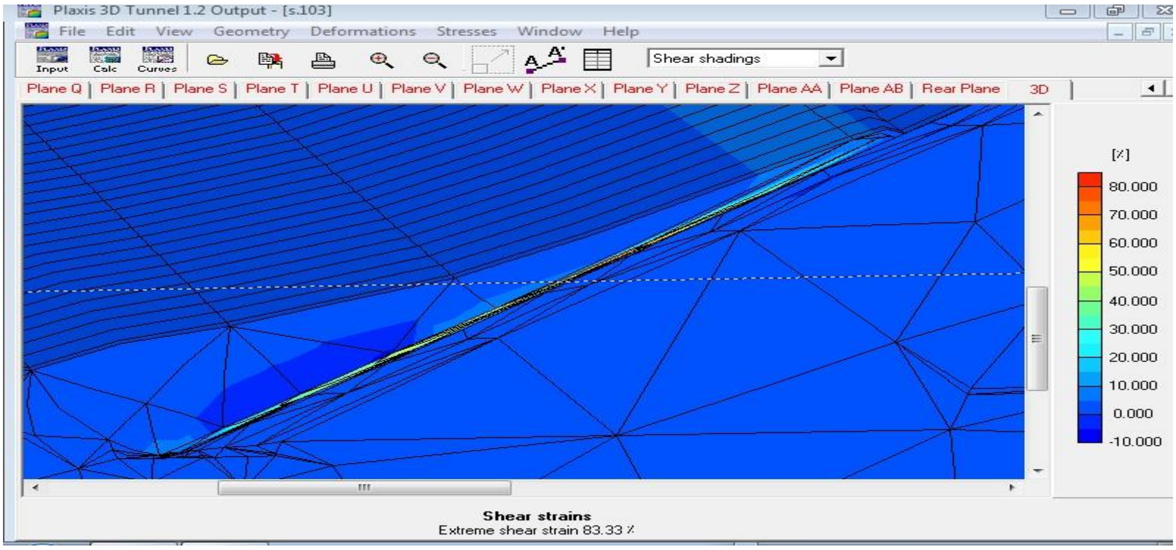
Figure 17. Situation of the relative shear stress in the changed model of the dam (2)

Based on Figure 16 and Figure 17 indicate values and distribution of shear stresses along the height of the dam, the maximum tensile shear stress in the real model of the dam is equal to 7251.9kn/m2 and the maximum compressive shear stress in equal to -5769.9kn/m2. These values for the changed model of the dam affected by changes of the height and thickness of the slab is equal to

3835.5kn/m2 for the maximum tensile shear stress and is equal to -16293.9kn/m2 for the maximum compressive shear stress. Therefore, under the effect of the effective parameters on increase of height and non-increase of a thickness of the slab along the height, the value of tensile shear stress is reduced by approximately 1.9 times but the maximum shear compressive stress is increased by 2.82 times. In this mode, the development rate of compressive stresses is more than tensile ones but the value of compressive stresses is reduced by the increase of the height. According to previous studies of [Ozkuzukiran et al., 2006] (4) and [Massirra et al., 2005] (3), the values of stress in the concrete-face can be controlled to a large extent by increase of thickness of the concrete-face, but high increase of thickness makes no significant change in values of the developed stresses in the face. The results are consistent with the studies.

10. EFFECT OF PARAMETER OF SLOPE OF FOOT ON THE MAXIMUM STRAIN VALUE OF THE FACE AND COMPRESSIVE DEVELOPMENT

To evaluate the effect of this parameter on the changed model (2), we have increased the upper slope of the dam from 32 degree to 34 degree and the lower slope of the dam from 34.6 degree to 40 degree and the required result is extracted by evaluating forms and shapes of the strain Figure 18, Figure 19, Figure 20 and Figure 21.



Shear strains
Extreme shear strain 83.33 %

Figure 18. Maximum main shear strain (tensile and compressive) on the protective layer and the concrete slab in the real model of the dam

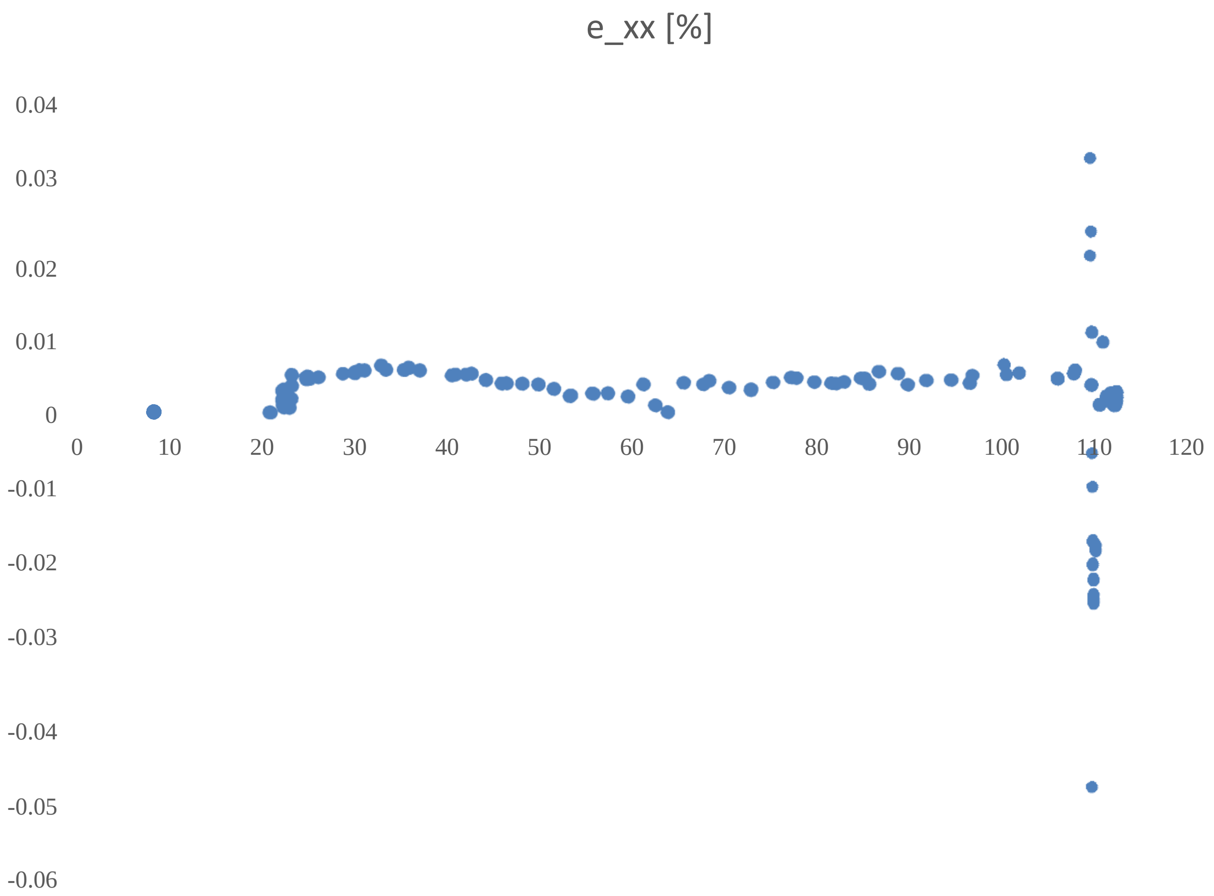
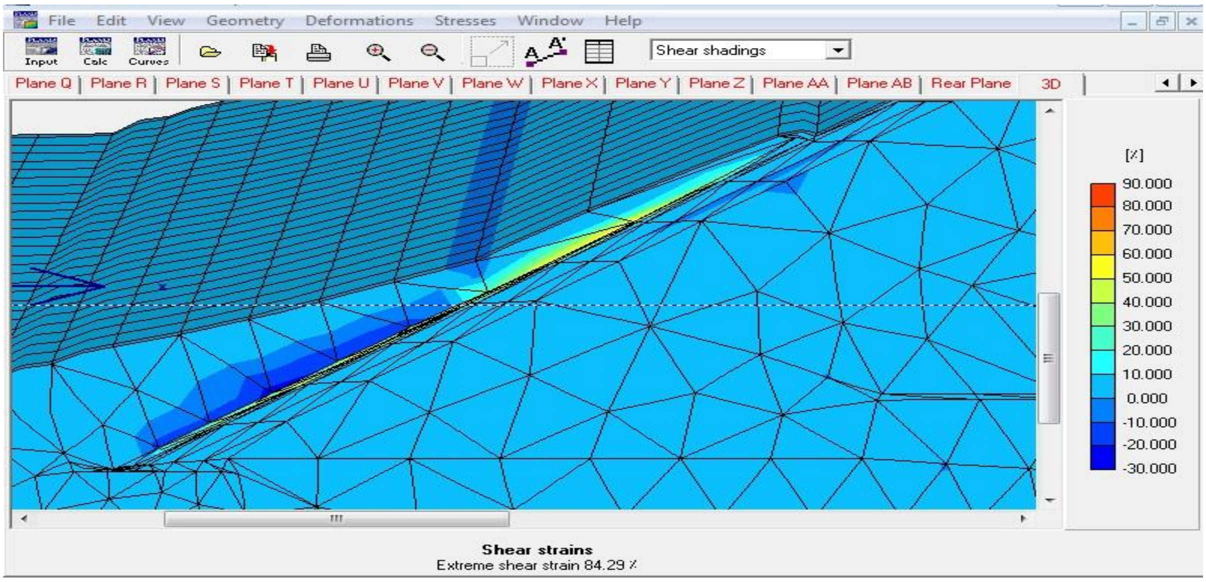


Figure 19. Maximum main shear strain (tensile and compressive) on the protective layer and the concrete slab in the changed model of the dam (2)



Shear strains
Extreme shear strain 84.29 %

Figure 20. Maximum coordinates and value of horizontal strain (tensile and compressive) along the height of the concrete slab in the real model of the dam

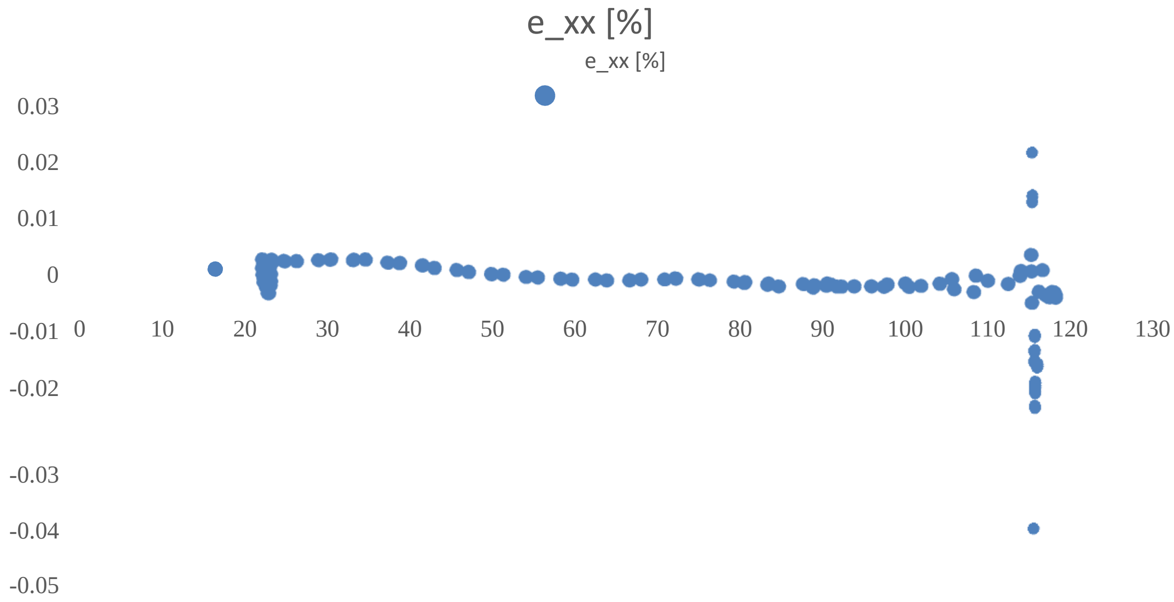
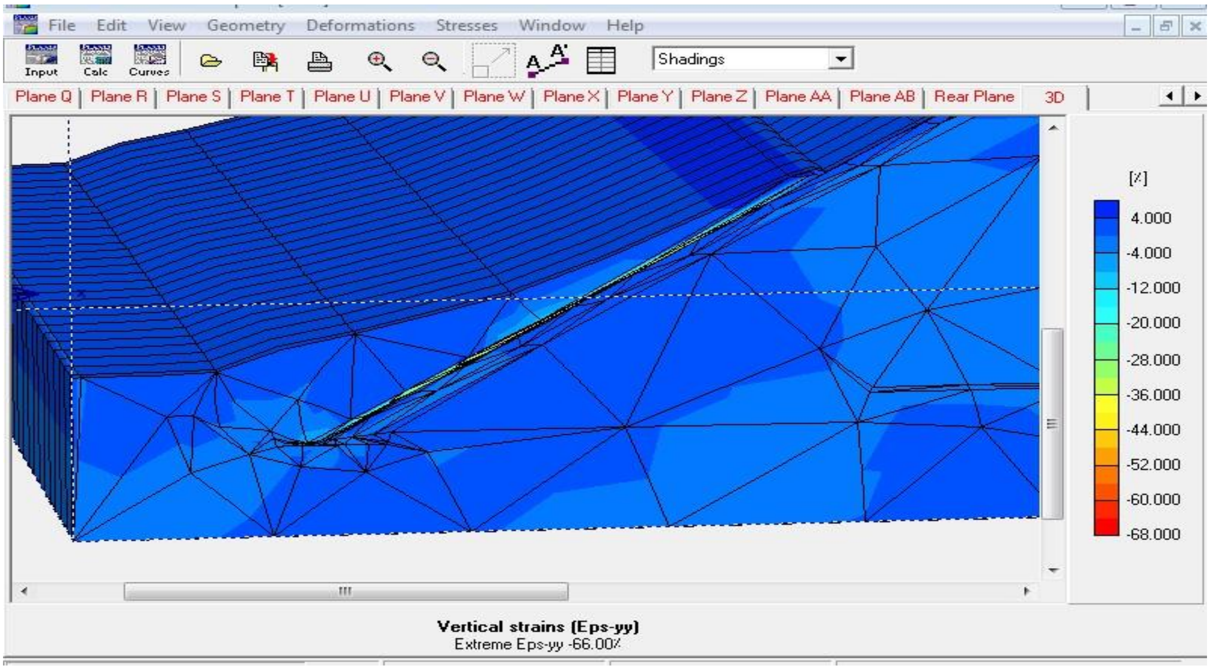


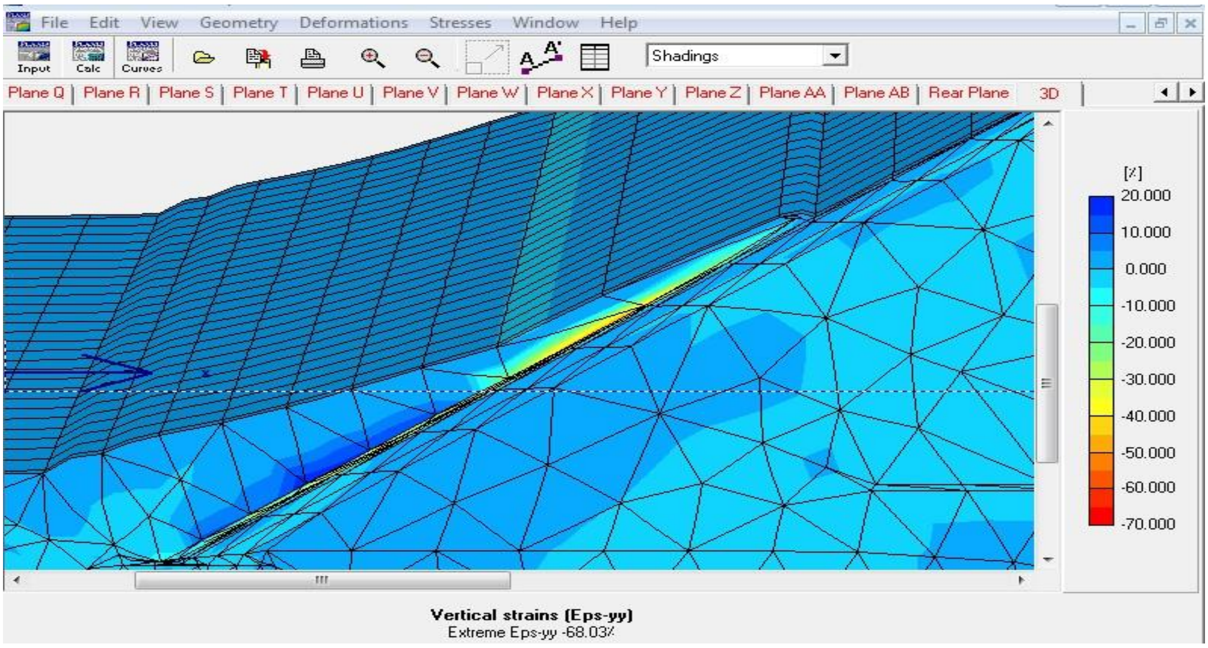
Figure 21. Maximum coordinates and value of horizontal strain (tensile and compressive) along the height of the concrete slab in the changed model of the dam (2)

By evaluating Figure 19 and Figure 21 showing maximum coordinates and values of horizontal strains (tensile and compressive) along the height of the dam, in both real and changed models of the dam (2) it indicates the effect of parameter of slope of foot in the upper side of the dam on value of horizontal values (tensile and compressive) so that by increase in slope of upper foot of the dam, value of horizontal tensile strain is reduced from 0.032 percent to 0.024 percent and value of horizontal compressive strain is reduced from 0.049 percent to 0.041 percent and this means that approximately by 2 degree of increase in upper slope of the dam foot and no change in increase of thickness of the face slab, the value of tensile and compressive strains has been reduced and the development ratio of compressive strains is more in both modes.



Vertical strains (Eps-yy)
Extreme Eps-yy -66.00%

Figure 22. Vertical strain (tensile and compressive) in the area of concrete slab and the upper protective layer of the real model of the dam



Vertical strains (Eps-yy)
Extreme Eps-yy -68.03%

Figure 23. Vertical strain (tensile and compressive) in the area of the concrete slab and the upper protective layer of the changed model of the dam (2)

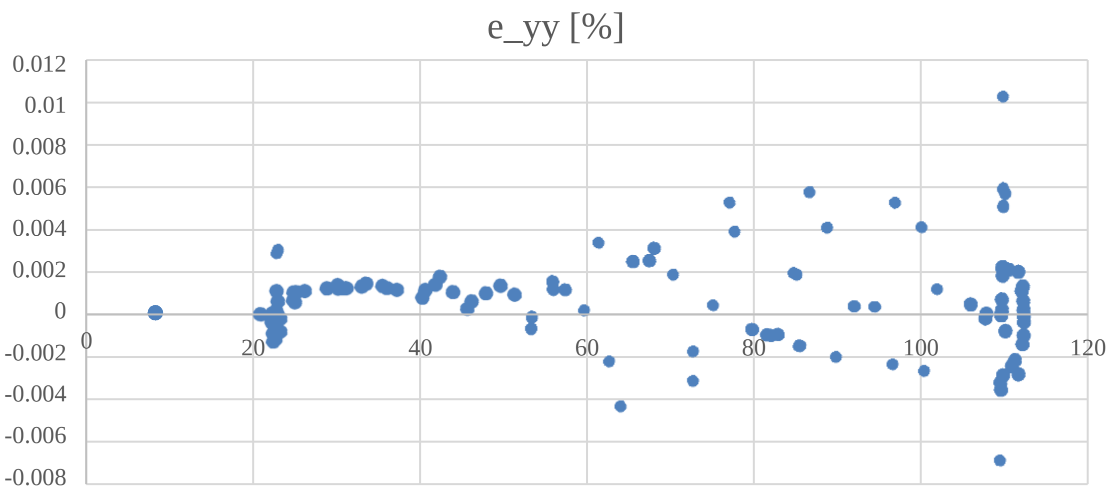


Figure 24. Vertical strain on the concrete slab along the height in the real model of the dam

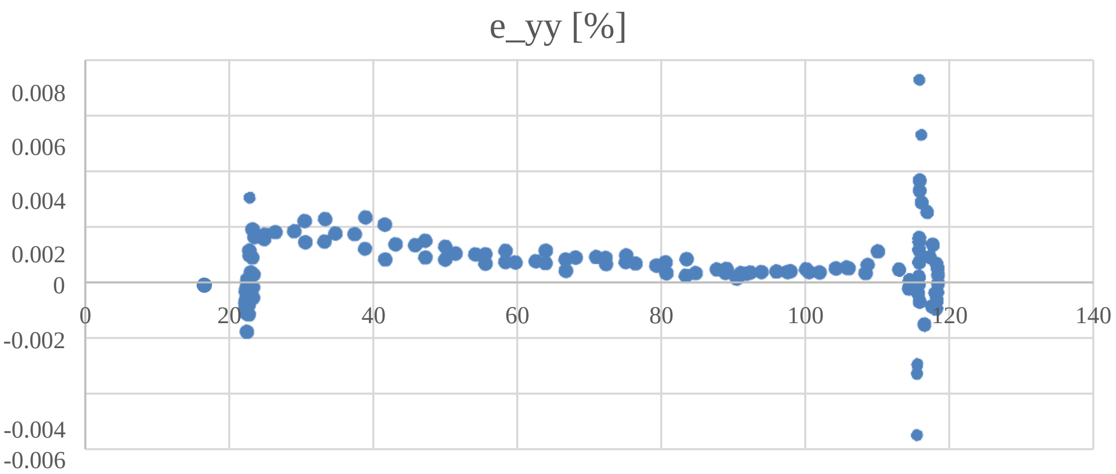
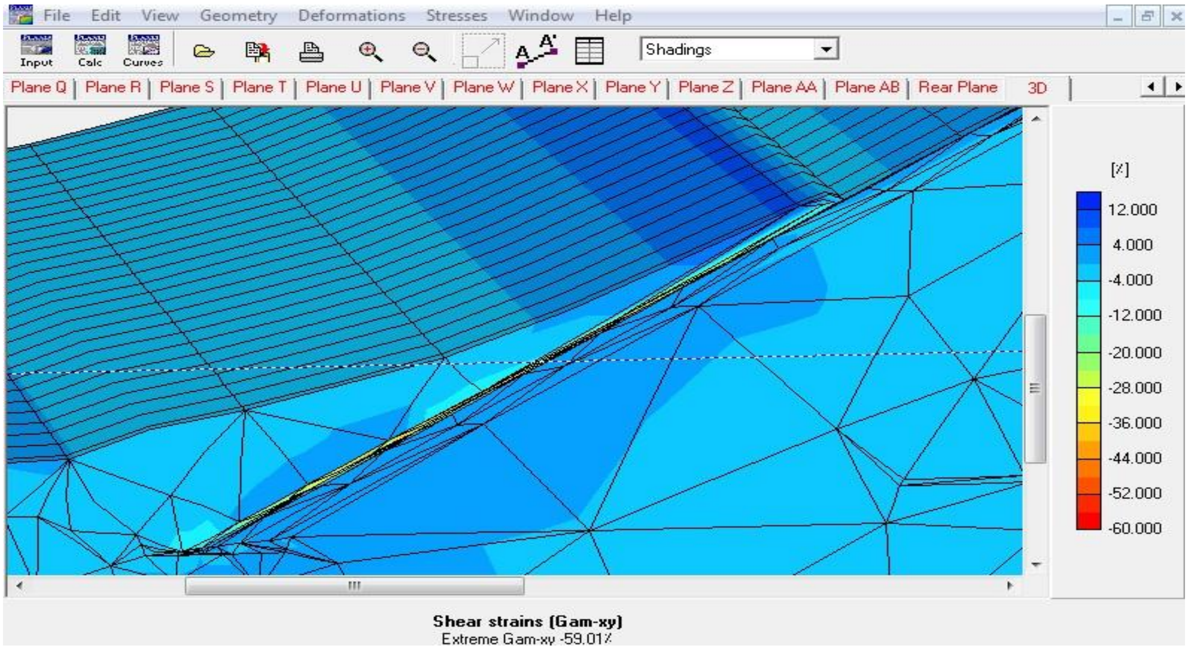


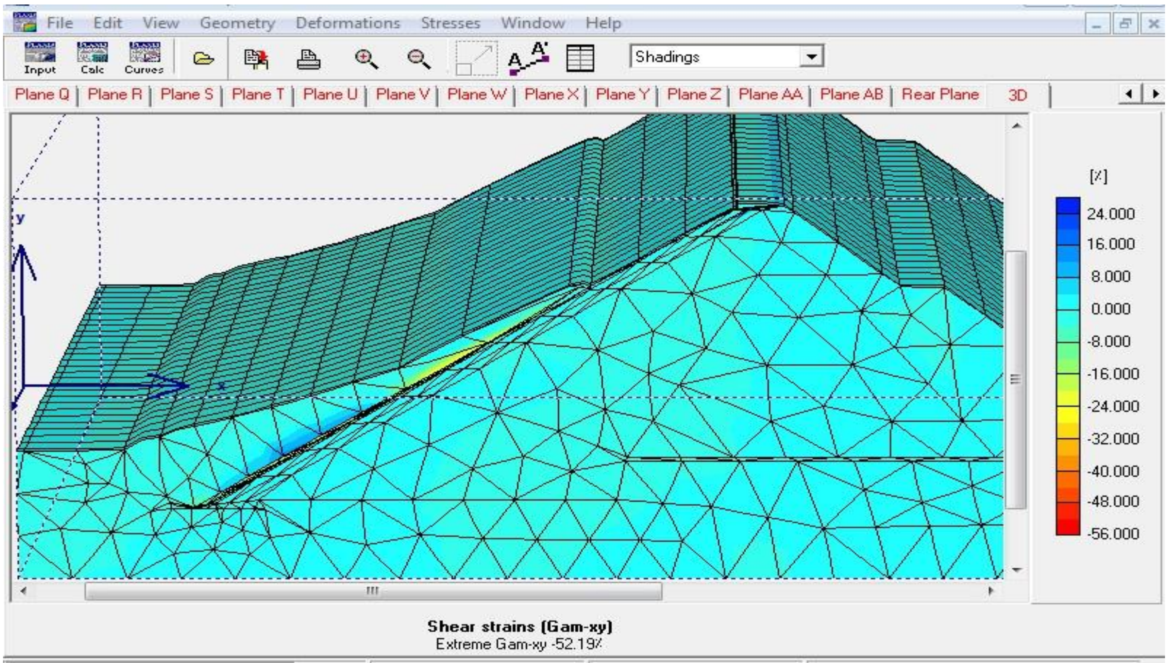
Figure 25. Vertical strain on the concrete slab along the height in the changed model of the dam (2)

By analyzing Figure 22, Figure 23, Figure 24 and Figure 25 (location and values of vertical strains on the concrete slab along the height of the slab), changes in values of vertical strains (tensile and compressive) on the effect of increase in parameter of slope of foot and non-increase in thickness of the face slab are obvious. Based on Figure 24 and Figure 25, the maximum value of vertical tensile strain is 0.01 percent in the real model of the dam and is 0.007 percent in the changed model of the dam and the maximum values of vertical compressive strains are -0.006 percent and -0.005 percent, respectively.



Shear strains (Gam-xy)
Extreme Gam-xy -59.01%

Figure 26. The maximum main shear strain (tensile and compressive) on the protective layer and the concrete slab in the real model of the dam



Shear strains (Gam-xy)
Extreme Gam-xy -52.19%

Figure 27. The maximum main shear strain (tensile and compressive) on the protective layer and the concrete slab in the changed model of the dam (2)

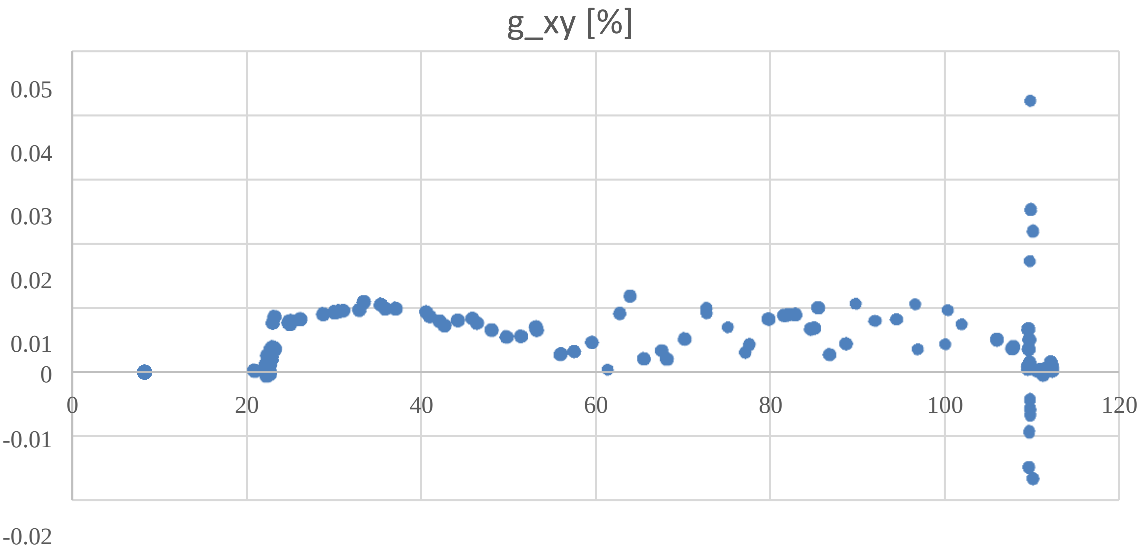


Figure 28. Shear strains perpendicular to axis of the dam along the height in the real model of the dam

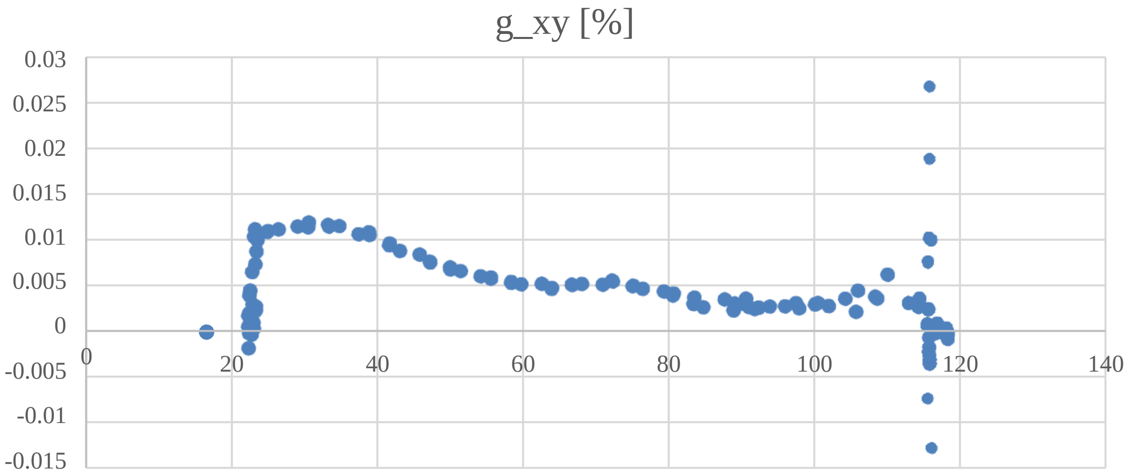
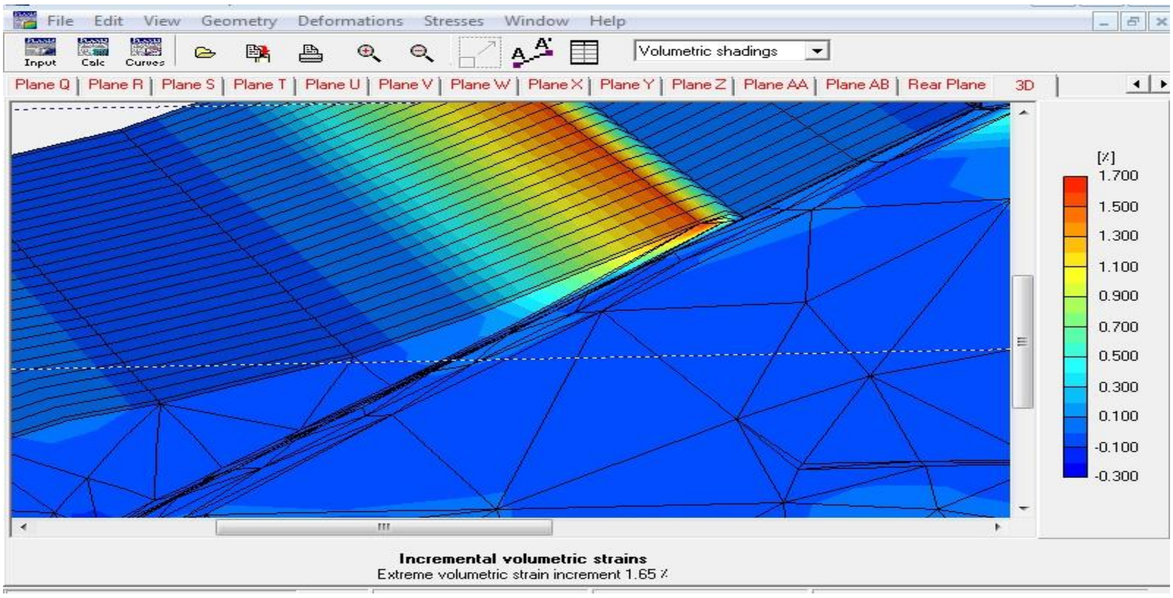


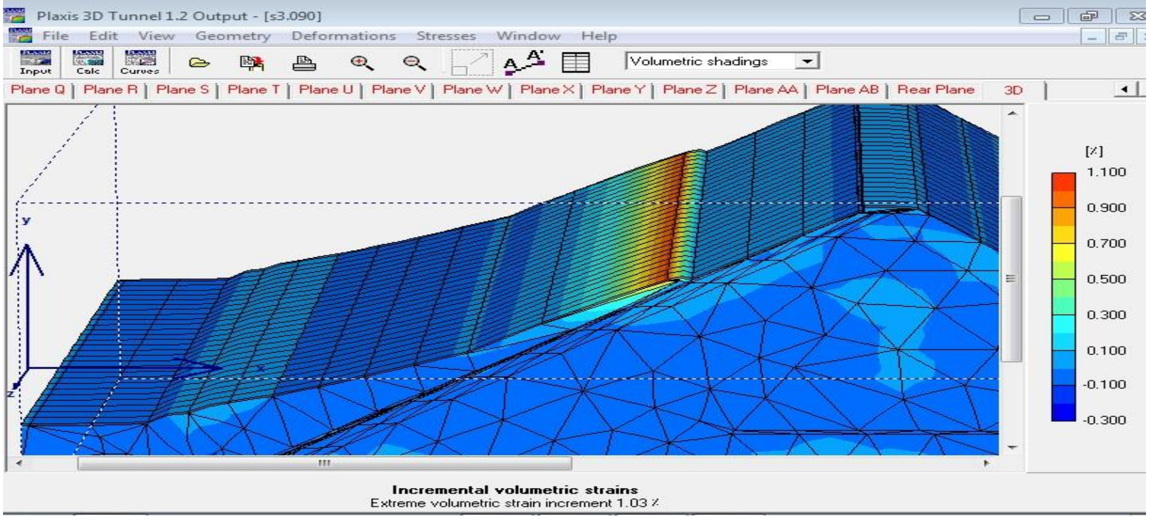
Figure 29. Shear strains perpendicular to axis of the dam along the height in the changed model of the dam (2)

Considering Figure 26, Figure 27, Figure 28 and Figure 29, location and values of main shear strains (tensile and compressive) on the concrete slab are specified and we see the maximum shear tensile strain of 0.042 in the real model and 0.027 percent in the changed model. The maximum shear compressive strain is -0.017 and -0.013 in the real and changed the model of the dam, respectively. The development rate of shear compressive strain is more in both (Figure 30, Figure 31).



Incremental volumetric strains
Extreme volumetric strain increment 1.65 %

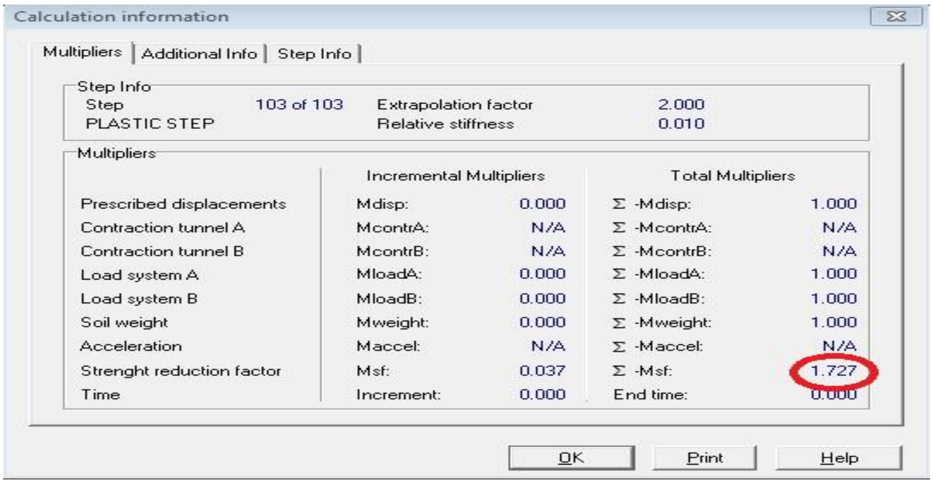
Figure 30. Incremental volumetric strain on the concrete slab and the upper area in the real model of the dam



Incremental volumetric strains
Extreme volumetric strain increment 1.03 %

Figure 31. Incremental volumetric strain on the concrete slab and the upper area in the changed model of the dam (2)

Considering results of Studies of Oyanguren, effect of slope of foot on the behavior of the concrete-face is not so obvious and what can cause selection of an appropriate slope for foot of the dam is situation of the foundation and specifications of the materials in the body of the dam (2), the above numerical results are consistent with previous studies.

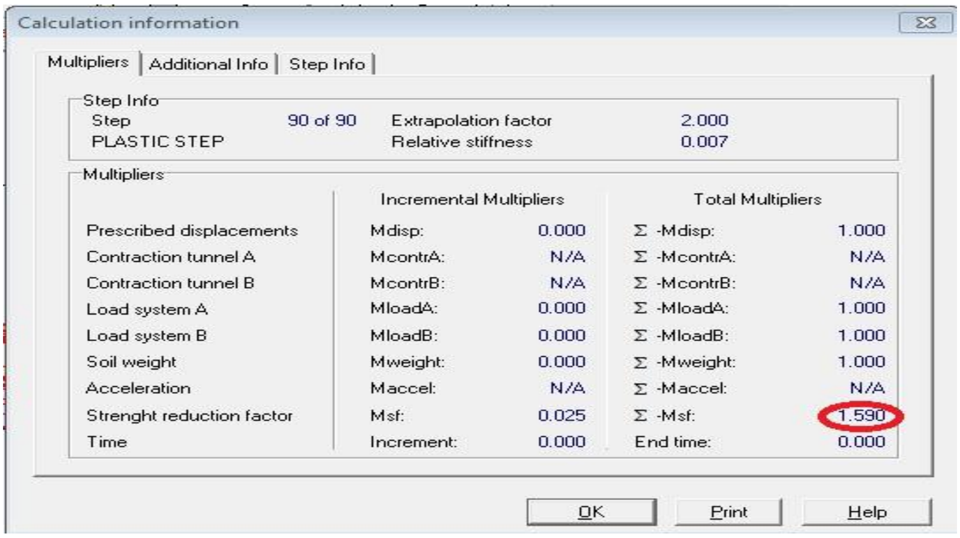


Step Info
Step 103 of 103
PLASTIC STEP
Extrapolation factor 2.000
Relative stiffness 0.010

Multipliers

	Incremental Multipliers		Total Multipliers	
Prescribed displacements	Mdisp:	0.000	Σ -Mdisp:	1.000
Contraction tunnel A	McontrA:	N/A	Σ -McontrA:	N/A
Contraction tunnel B	McontrB:	N/A	Σ -McontrB:	N/A
Load system A	MloadA:	0.000	Σ -MloadA:	1.000
Load system B	MloadB:	0.000	Σ -MloadB:	1.000
Soil weight	Mweight:	0.000	Σ -Mweight:	1.000
Acceleration	Maccel:	N/A	Σ -Maccel:	N/A
Strenght reduction factor	Msf:	0.037	Σ -Msf:	1.727
Time	Increment:	0.000	End time:	0.000

Figure 32. Stability safety factor for the real model of the dam



Step Info

Step	90 of 90	Extrapolation factor	2.000
PLASTIC STEP		Relative stiffness	0.007

Multipliers

	Incremental Multipliers		Total Multipliers	
Prescribed displacements	Mdisp:	0.000	Σ -Mdisp:	1.000
Contraction tunnel A	McontrA:	N/A	Σ -McontrA:	N/A
Contraction tunnel B	McontrB:	N/A	Σ -McontrB:	N/A
Load system A	MloadA:	0.000	Σ -MloadA:	1.000
Load system B	MloadB:	0.000	Σ -MloadB:	1.000
Soil weight	Mweight:	0.000	Σ -Mweight:	1.000
Acceleration	Maccel:	N/A	Σ -Maccel:	N/A
Strenght reduction factor	Msf:	0.025	Σ -Msf:	1.590
Time	Increment:	0.000	End time:	0.000

Figure 33. Stability safety factor for the changed model of the dam (2)

Effect of increase in slope of foots with an increase in height of the dam on the stability of the dam against sliding, considering values of stability safety factor calculated by the software in both modes, indicates a reduction in stability factor of sliding from the numerical value of 1.727 to 1.590, Figure 32 and Figure 33.

11. SUMMARY AND CONCLUSION

In this research, results from evaluations are approximate to observations (the instrumentation) and confirms accuracy of the modeling, the effect of change on parameters in structure (technical specifications of the materials, geometric model of the dam with specific slope in upside and downside, height, different friction coefficients of materials) considering the long-term stability condition of the dam in the full reservoir mode (mechanism of failure) with an acceptable safety factor against sliding has been studied, there is an acceptable consistency between results of this research and the similar studies. Summary of the results is as follows:

1- Having complete information (technical and geometric specifications) helps us in modeling a CFRD through the finite element method in three-dimensional mode and extracting results close to real observations and provides the ability for behavioral analysis of the dam for exploitation in a long-term period.
2- Hardness difference in the concrete-face layer and cushion layer and the friction coefficient are the main factors of making stresses and strains between the face and body of the dam so that increase of friction can increase tensile stress in the face but has no significant effect on maximum compressive stress values in the face.
3- Value of slope of a foot is effective on the value of settlement of the face in the upper half of the face slab but has no significant effect on value of tensile and compressive strains.
4- To construct CFRDs with high and higher stability factor, simulation and modeling through the finite element method can be used in order to analyze the behavior of the dam in designs.
5- Increase of thickness of the slab is an effective parameter on controlling the values of stress in the concrete-face.
6- By the increase of height, a value of settlement of the concrete-face encounters the increasing rate (in the evaluation of specified points on the slab) that leads to the development of tensile strains in the face especially the primary area of the face.

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AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

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