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Investigation the Deformations of Shahr-e-Bijar Dam During Impoundment

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ABSTRACT

Dam monitoring is possible by instrumentation at critical points and measurement of various parameters such as pore pressure and deformations, i.e. settlement and displacement. In this study, the monitoring of Shahr-e-Bijar Reservoir Dam is investigated using instrumentation data and numerical analysis. A finite element software package called Plaxis is used for the numerical analysis. According to the results of analyses carried out by the program that are in good agreement with observations and instrumentation data, it can be concluded that these programs are very useful for analyzing and predicting the behavior of earth dams. In this study, a variety of instrumentations used in rockfill dams are introduced and common methods and instruments are examined for measuring various geotechnical quantities. The situation of Shahr-e-Bijar Dam, i.e. deformation and seepage, are analyzed using instrumentation data provided by settlement meters and extensometers, which is measured over a relatively long period, and the results of dam modeling via finite element programs. One of the most important steps of dam construction is operation management and maintenance of such projects after design and construction phases. Accordingly, the results of dam monitoring and back analysis are employed to express the importance of these steps as a significant goal of this study and a practical part of dam operation management and maintenance process is also presented by examination of the results of the instrumentation of an earth dam. In summary, two- dimensional numerical modeling of the dam and its foundation is carried out via Plaxis version 8.2 after monitoring the behavior of Shar-e-Bijar Dam based on the information recorded by instrumentation system of the project and the results of numerical modeling are interpreted and compared with those of dam monitoring. Mohr-Coulomb behavioral model must be applied in this research.

Key words: Plaxis, concrete face rockfill dam (CFRD), impoundment, monitoring, back analysis.

1. INTRODUCTION

Supply of water for human being is one of the most important problems of human societies. The limited resources of fresh water in the world have led humans to utilize various methods to meet their needs, among which surface water control, exploitation of aquifers, artificial recharge of groundwater and consumption optimization solutions may be mentioned. As explained before, surface water control is a way to eliminate water problems. Dam construction and water storage is the best idea to control surface water, particularly earth dams which are mostly constructed for water storage and control due to their superiority over other types of dam. The construction of earth dams is of interest due to their identical nature and compatibility with the earth and high ductility. The performance of these important water structures must always be controlled. Hence, instrumentation and numerical studies are used. In the present study, the lateral deformation of Shahr-e-Bajar Dam is investigated by instrumentation and compared with the results of numerical studies via Plaxis. Studies have been already done on this subject, which are mentioned here as examples. The relationship between monitoring and design aspects of large earth dams (1): It is necessary to estimate the maximum displacement and deformation for a proper design and acceptable monitoring. Each dam gives a different response under loading conditions, so it is not possible to standardize the design of monitoring and surveys in this regard (2). In concrete face rockfill dams (CFRDs), maximum displacement occurs on the upper part of the dam. The geotechnical parameters of structural materials of the dam play a major role in its stability (3, 4). NAM NGUM 2 CFRD behavior during construction and first impounding (5): The 182 m high concrete face rockfill dam (CFRD) is one of the main components of Nam NGUM 2 (NN2) hydropower scheme in Lao PDR. The monitoring system of Nam NGUM 2 Dam has provided useful information on deformation behavior of the dam during construction and first impounding. The maximum settlements at the end of construction are about 2.2 m which corresponds to 1.2% of the dam height. Measured seepage quantities are at present about 260 l/s and the piezometric observations are adequate. No signs of unusual dam deformations or face slab damages are observed. At present, the performance of dam is good and the visual appearance is excellent. The back-calculation of dam deformations and prediction of face slab deflection based on deformations measured during construction give reasonable results (6). Doosti Dam (Iran-Turkmenistan Friendship Dam) (7): In this research, the behavior of earth dams under the influence of material properties change is investigated. The main focus of the research is on the effect of properties of core and shell material on the behavior of earth dams. So Doosti Dam is initially analyzed through Plaxis and the results are compared with the results of instrumentation. When the reliability of results is assured, the parametric analysis is performed by changing the core friction angle, core adhesion, core stiffness, shell friction angle and permeability coefficient of filter and drain. The most important results include: the increase in adhesion, core friction angle and core stiffness that leads to a decrease in deformation and stress transfer; the change in permeability of filter and drain has no significant effect on displacement, core internal stress area and pore pressure at the end of construction; but it increases the stress transfer in the contact area of core and filter (8, 9). Alborz Dam (10): The stability of slopes is an important issue that should be considered during dam construction and after impoundment. Multi-stage construction of embankment is also a good way to build dams. In this research, the slope stability of dam located in Mazandaran province is evaluated by Plaxis and its safety factor is calculated at the end of each stage of earth filling; the factor increases to 2.6909 at the first stage of earth filling after consolidation and at the last layer of embankment, it increases to 1.685 and 1.748 before and after consolidation, respectively, due to the increased pore pressure and decreased effective stress. Nahrein Dam (11): Bolouri Bazzaz and Mobinizad (2010) evaluated the behavior of Nahrein Earth Dam during construction by finite element method and comparison with actual values obtained from instrumentation data. As a result, the continuous control of safety and stability of earth dams is of particular importance during construction, first impoundment and operation. A rise in the speed of embankment increases pore pressure and decreases effective stress in the core during construction and may threaten the stability of dam during first impoundment. The stability of these dams can be controlled by instrumentation. Due to the nonlinear behavior of earth dams, the finite element method and appropriate behavioral models should be used for their analysis. In this research, the stresses and settlement of dam are studied and compared with the results of numerical analysis through instrumentation. Given the similarity of the results of analysis and instrumentation, it is concluded that the results of analysis are close to reality and the selected behavioral model is adequate and reliable for predicting the future stages of dam construction (12). Vanyar dam (Derakhshandi.M et al, 2014) (13): The mechanical behavior of Vanyar dam is studied at the end of construction. Two dimensional numerical analysis is performed based on the finite element method in the largest cross section of the dam. The recorded information by the instrument located in the largest cross section is compared to the numerical analysis results at the instrument location (14, 15). The settlement, pore water pressure and the total perpendicular stress are considered as the evaluation parameters at the end of the construction. The results showed that the settlement (refinement) obtained from the numerical analysis, is consistent with the information acquired from the instrument and verify each other. This shows that the numerical calculations are performed based on the properties of the real used substances (16-19). Shahr-e-Bijar Reservoir Dam, one of the first concrete face rockfill dams in Iran, was constructed 50 km southeast of the city in Gilan province. Given the new and modern structure of this dam, the experience of other CFRDs built or under construction in the world was used. The concrete face was mainly chosen for this dam due to rainy seasons in the region and no dependence of rockfill materials on rainfall. In CFRDs, less materials are required for construction of rockfill dam due to the high shear strength of stone materials and consequently, the increase in slope of upstream and downstream aprons; moreover, another advantage of CFRDs is no dependence upon various construction activities such as geotechnical operations (excavation and injection) and earth filling; free drainage and high friction factor of stone materials used in the rockfill contribute to the strength and stability of CFRDs when exposed to severe earthquakes, so the construction of injection gallery structure can be ignored in certain circumstances. Thus, it is obvious that the implementation time and cost of these types of dam is significantly reduced. Given the sensitivity of concrete face about 30 to 40 cm in thickness which play a sealing role in CFRDs, even partial displacements and deformations may lead to failure of concrete face and irreparable damage, indicating the significance of monitoring during construction and operation. The dam is

91 m high and its crest is 438 m long and extends to 380 m. The reservoir is about 105 million m^3 in volume.

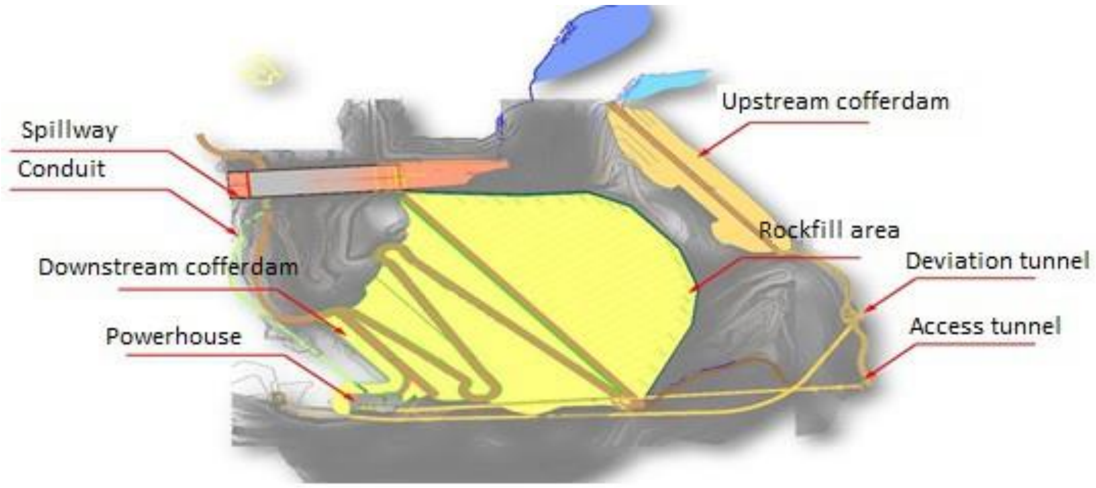


Figure 1. Plan of dam

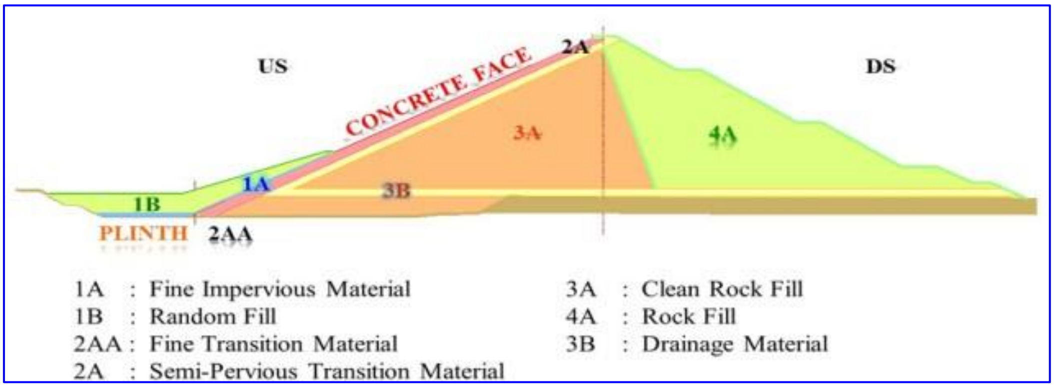


Figure 2. Cross section of rockfill

Table 1. Hydrological specifications of dam project

430 m	*Length of dam crest*
219.5 MASL	Level of dam crest
11 m	Width of dam crest
380 m	Maximum width of dam base
90.5 m	Maximum height of dam from foundation
79.5 m	Height of dam from river bed

The specifications of dam components are the most important factor affecting the design of dam monitoring system (Table 1). Shahr-e-Bijar CFRD consists of different parts such as concrete face, embankment zone under concrete slab, transition zone, drainage zone, shell and main rockfill; so the scheme of dam monitoring system is prepared based on the role and sensitivity of each of component.

2. DAM INSTRUMENTATION

The instrumentation of Shahr-e-Bijar Dam can be divided into three major parts: foundation, inside and outside embankment and concrete face instrumentation (Figure 1 and Figure 2). A variety of instruments are considered in the design of Shahr-e-Bijar Dam, e.g. electric piezometer, electric stress meter, extensometer, deviation meter, electric and magnetic settlement meter and various face instruments such as joint meter and tilt meter.

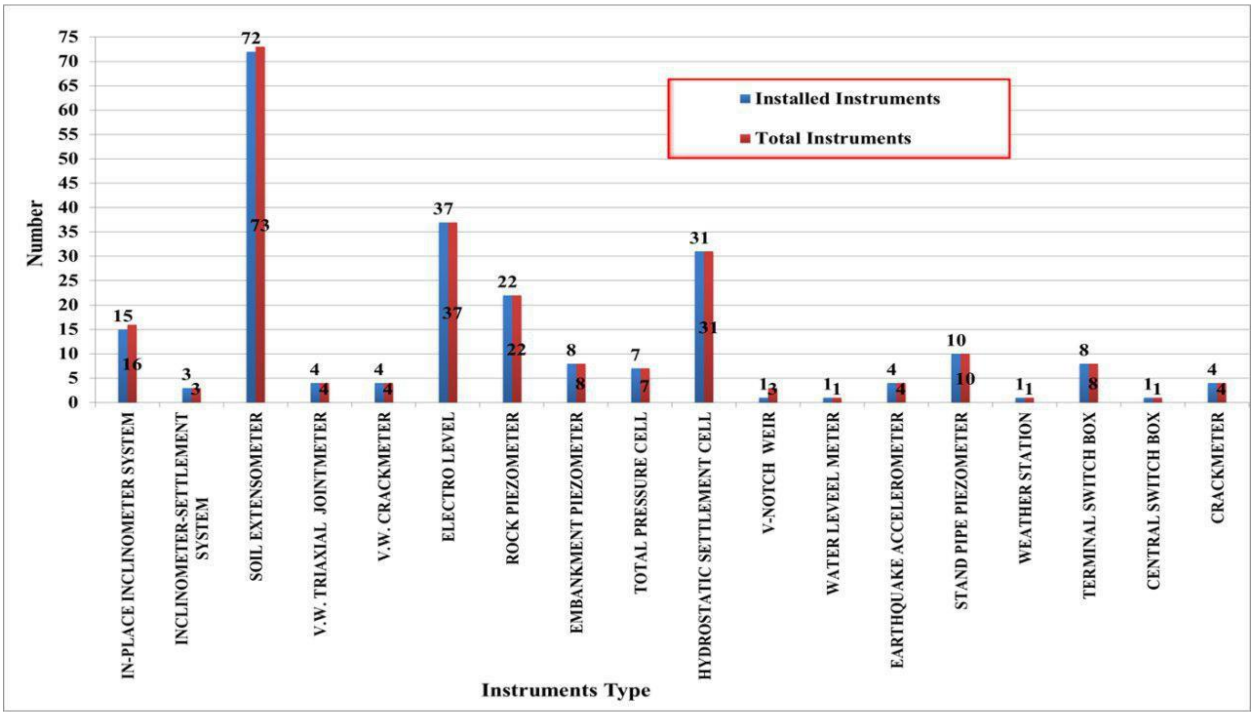


Figure 3. Comparison of installed instrumentation in Shahr-e-Bijar Dam in predicted number (design)

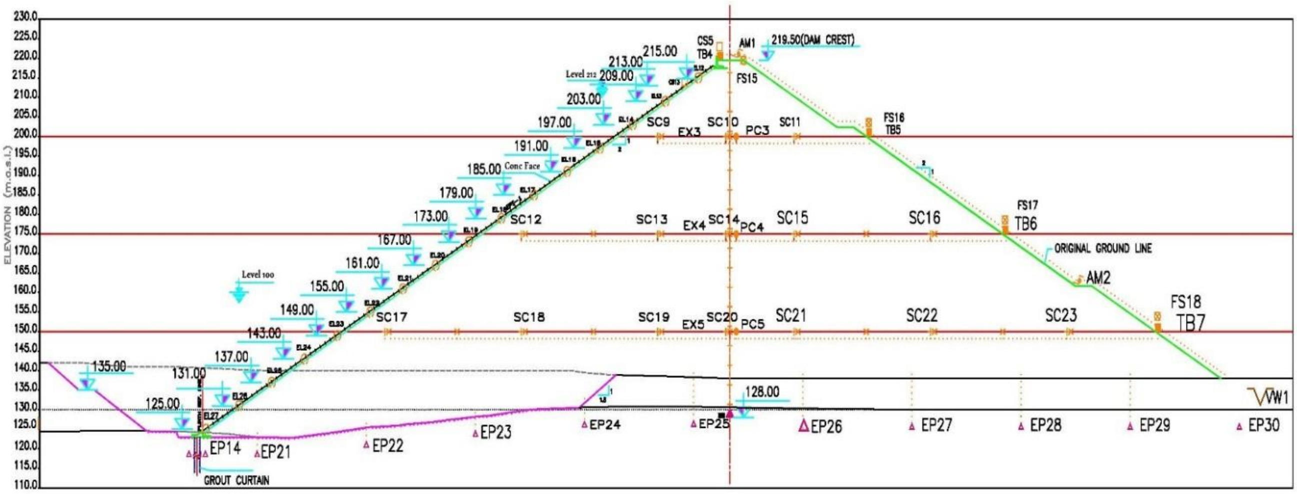


Figure 4. Instrumentation layout of Shahr-e-Bijar Dam

The cross section 9 shows the instruments embedded within the rockfill at 375 km (Figure 3 and Figure 4). A longitudinal section is also provided for the center of dam to locate some instruments. In these 4 sections, instruments are located at 3 levels of 150, 175 and 200 m. This study is focused on installation and measurement of extensometer and settlement meter.

3. APPLIED NUMERICAL ANALYSIS

In this study, the results of extensometers, displacements and settlement meters are compared with numerical analyses. It is attempted to model the boundaries of various rockfill components as closely as possible to actual conditions. Hence the dam is consisted of a shell. It is a CFRD with no core and other parts of rockfill are considered in modeling of the cross section. The position of extensometers and settlement meters are presented in the Table 2 and Table 3.

Table 2. Position of settlement meters in rockfill

Position on DS, US axis (m)	Level (m)	Coordination	SC No.
U/S 25.570	383872.128	X	**SC9**
	4096259.02	Y	
	200.375	Z	
D/S 1.570	383852.764	X	**SC10**
	4096244.523	Y	
	200.375	Z	
D/S 23.890	383832.568	X	**SC11**
	4096229.103	Y	
	200.375	Z	
U/S 26.03	383872.126	X	**SC13**
	4096259.467	Y	
	175.38	Z	
U/S 0.86	383852.330	X	**SC14**
	4096243.907	Y	
	175.38	Z	
D/S 24.40	383832.066	X	**SC15**
	4096228.834	Y	
	175.38	Z	
U/S 26.072	383872.488	X	**SC19**
	4096259.060	Y	
	151.481	Z	
U/S 1.173	383852.577	X	**SC20**
	4096244.109	Y	
	151.467	Z	
D/S 23.75	383832.748	X	**SC21**
	4096299.140	Y	
	151.442	Z	

Table 3. Position of extensometers in rockfill

Position on DS, US axis (m)	Level (m)	Coordination	EX No.
U/S 25	383871.784	X	**EX3-1**
	4096258.16	Y	
	200	Z	
Axis	383851.791	X	**EX3-2**
	4096243.127	Y	
	200	Z	
D/S 25	383831.915	X	**EX3-3**
	4096227.959	Y	
	200	Z	
U/S 75	383911.627	X	**EX4-1**
	4096288.425	Y	
	175	Z	
U/S 50	383891.759	X	**EX4-2**
	4096237.252	Y	
	175	Z	
U/S 25	383871.811	X	**EX4-3**
	4096258.201	Y	
	175	Z	
Axis	383851.953	X	**EX4-4**
	4096243.017	Y	
	175	Z	
D/S 25	383831.949	X	**EX4-5**
	4096228.024	Y	
	175	Z	
D/S 50	383812.077	X	**EX4-6**
	4096212.84	Y	
	175	Z	
D/S 75	383792.212	X	**EX4-7**
	40966197.651	Y	
	175	Z	
U/S 125	383951.406	X	**EX5-1**
	4096318.72	Y	
	151.05	Z	
U/S 100	383931.534	X	**EX5-2**
	4096303.334	Y	
	151.05	Z	
U/S 75	383911.581	X	**EX5-3**
	4096288.50	Y	
	151.05	Z	
U/S 50	383891.707	X	**EX5-4**
	4096273.31	Y	
	151.05	Z	
U/S 25	383871.742	X	**EX5-5**
	4096258.25	Y	
	151.05	Z	
Axis	383851.894	X	**EX5-6**
	4096243.07	Y	
	151.05	Z	

4. RESEARCH HYPOTHESES

Natural soil is rarely in classical (homogeneous, isotope) state. Therefore, engineering judgments are of particular importance to estimate soil engineering properties using theories, relationships and charts. Engineers are surprised and confronted with a lot of underground problems such as liquefaction, problematic layers, landslide, etc., which they need advanced knowledge and technology to deal with. In fact, inaccurate design calculations and errors in laboratory results may lead to irreparable damage. Today Plaxis has been developed and supplied as a comprehensive and advanced program, welcomed by geotechnical engineers in the world. In fact, it can be said that the need of engineers and the comprehensive features of this software have motivated its presentation. Plaxis is the advanced finite element software for analyzing deformations and stability in geotechnical engineering projects. In important geotechnical issues, an advanced behavioral model is usually required for nonlinear and time-dependent modeling of soils, depending on the target. This software can model step-by-step cut and fill under a variety of loading and boundary conditions using 6-node and 15-node triangular elements. The Plaxis environment and its method for assigning materials and models are presented below (Figure 5, Figure 6 and Figure 7):

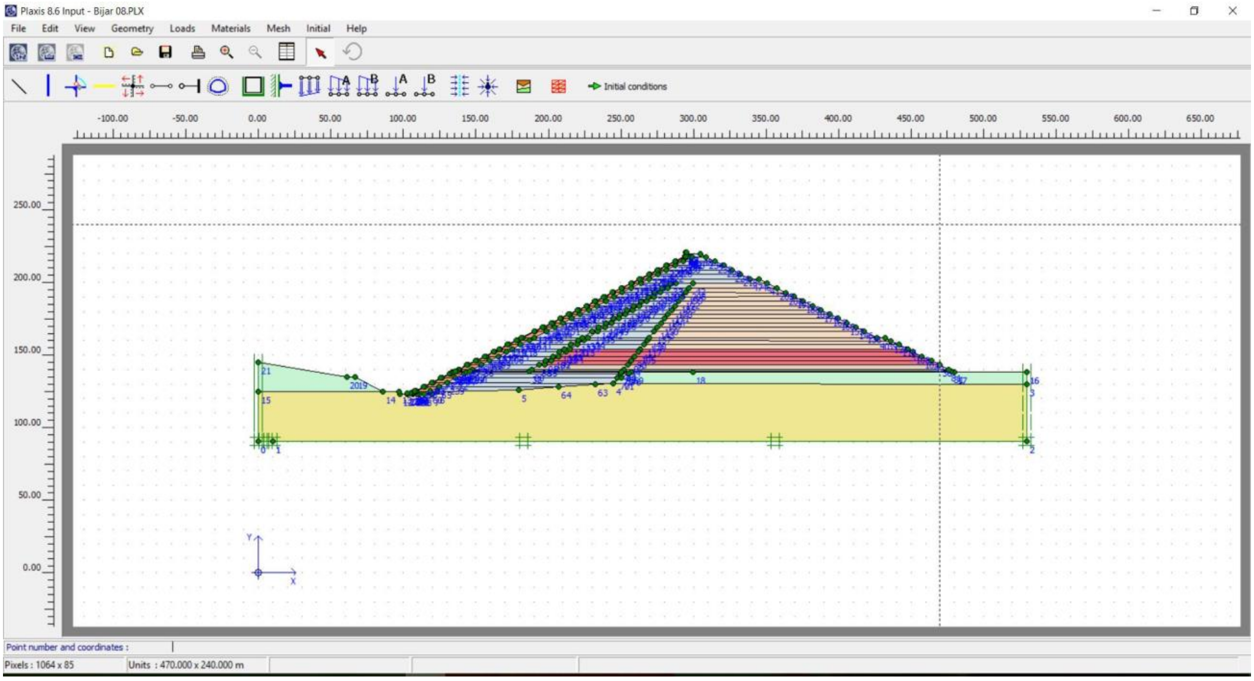
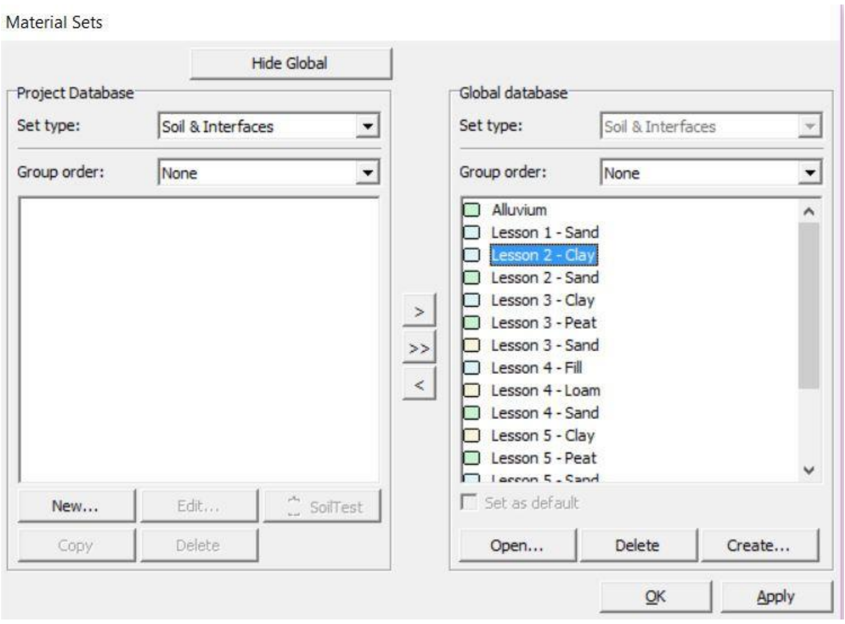


Figure 5. Environment of Plaxis

The material set is used to define the soil and its characteristics in the software. In this menu, the soil type can be defined. The soil profile can be defined by edit bottom.


Material Sets

Project Database

Set type: Soil & Interfaces

Group order: None

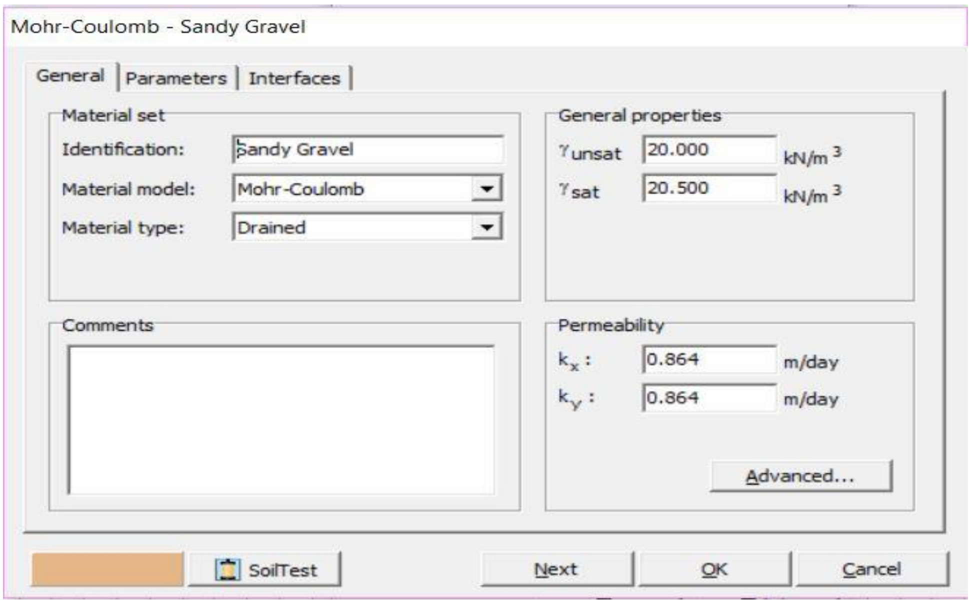
Global database

Set type: Soil & Interfaces

Group order: None

Figure 6. Material set

Plaxis has Mohr-Coulomb and hardening soil models by default, so the drained Mohr-Coulomb model is applied in this research.


Mohr-Coulomb - Sandy Gravel

Identification: Sandy Gravel

Material model: Mohr-Coulomb

Material type: Drained

γ_{unsat} 20.000 kN/m ^{3}

γ_{sat} 20.500 kN/m ^{3}

k_x : 0.864 m/day

k_y : 0.864 m/day

Figure 7. Behavioral model set

5. COMPARISON BETWEEN THE RESULTS OF IMPOUNDMENT TIME ANALYSIS BY SOFTWARE AND INSTRUMENTATION

In this section, the behavior of Shahr-e-Bijar Dam impoundment time is studied and compared with the results of instrumentation. It is a comparison between parameters of extensometers and settlement meters, which are described in the following (Figure 8, Figure 9, Figure 10, Figure 11, Figure 12, Figure 13 and Figure 14).

6. INVESTIGATION AND MONITORING OF EXTENSOMETER DATA ON ROCKFILL DAM (TRANSVERSE AND LONGITUDINAL DEFORMATIONS)

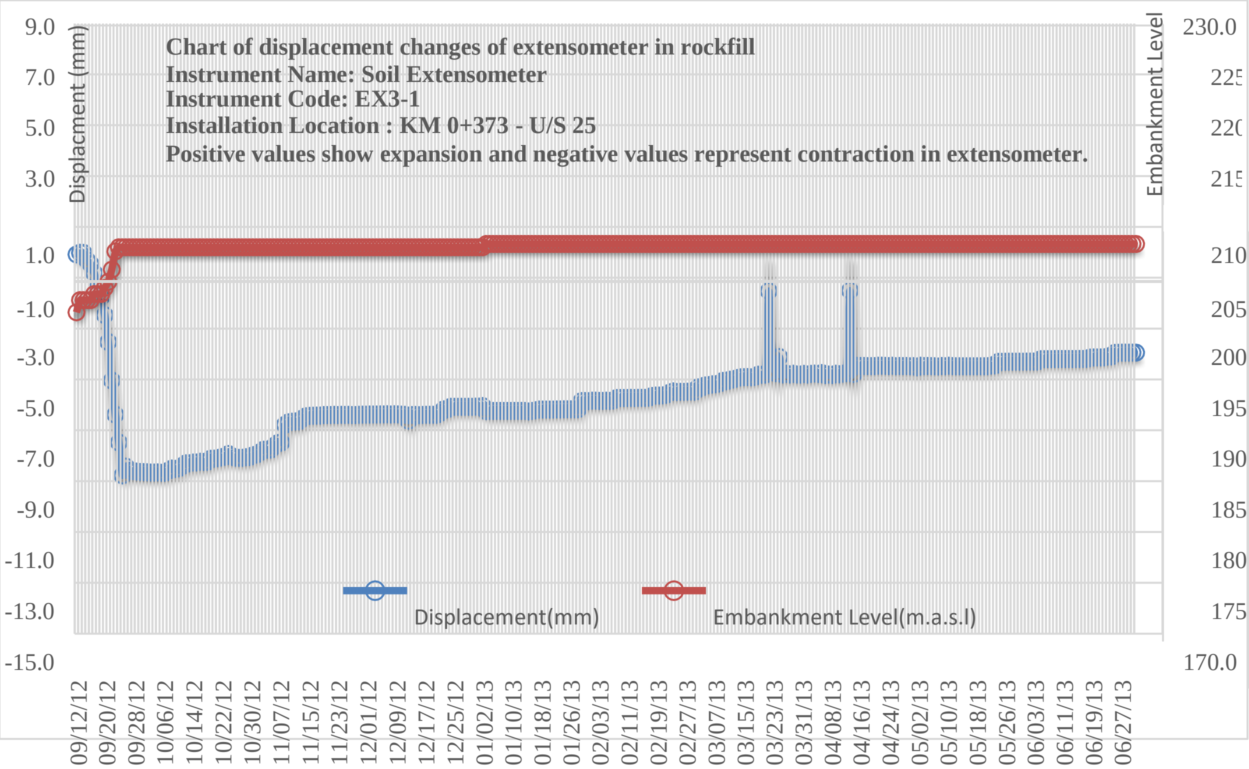


Figure 8. Chart of displacement changes of extensometer for instrumentation EX3-1

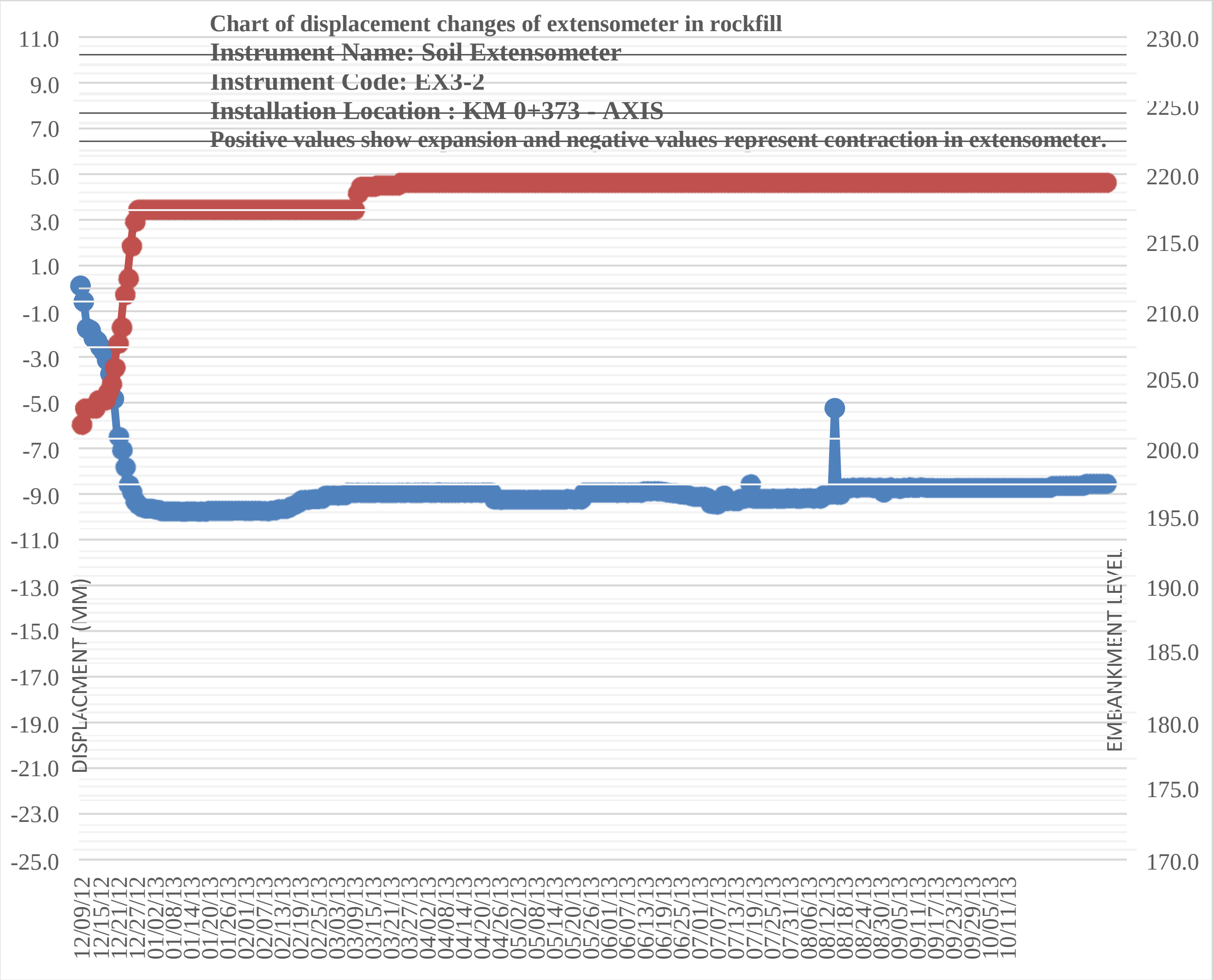


Figure 9. Chart of displacement changes of extensometer for instrumentation EX3-2

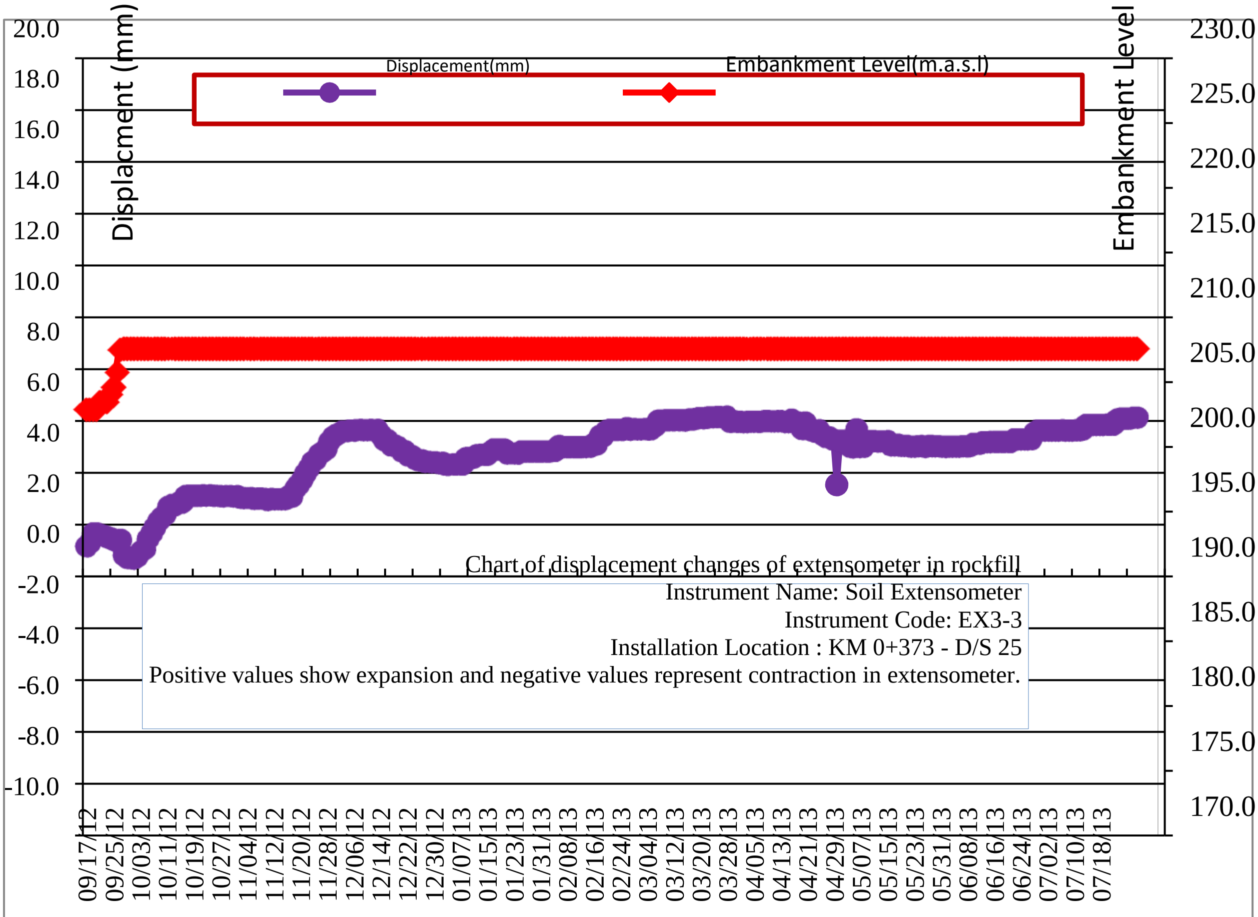


Figure 10. Chart of displacement changes of extensometer for instrumentation EX3-3

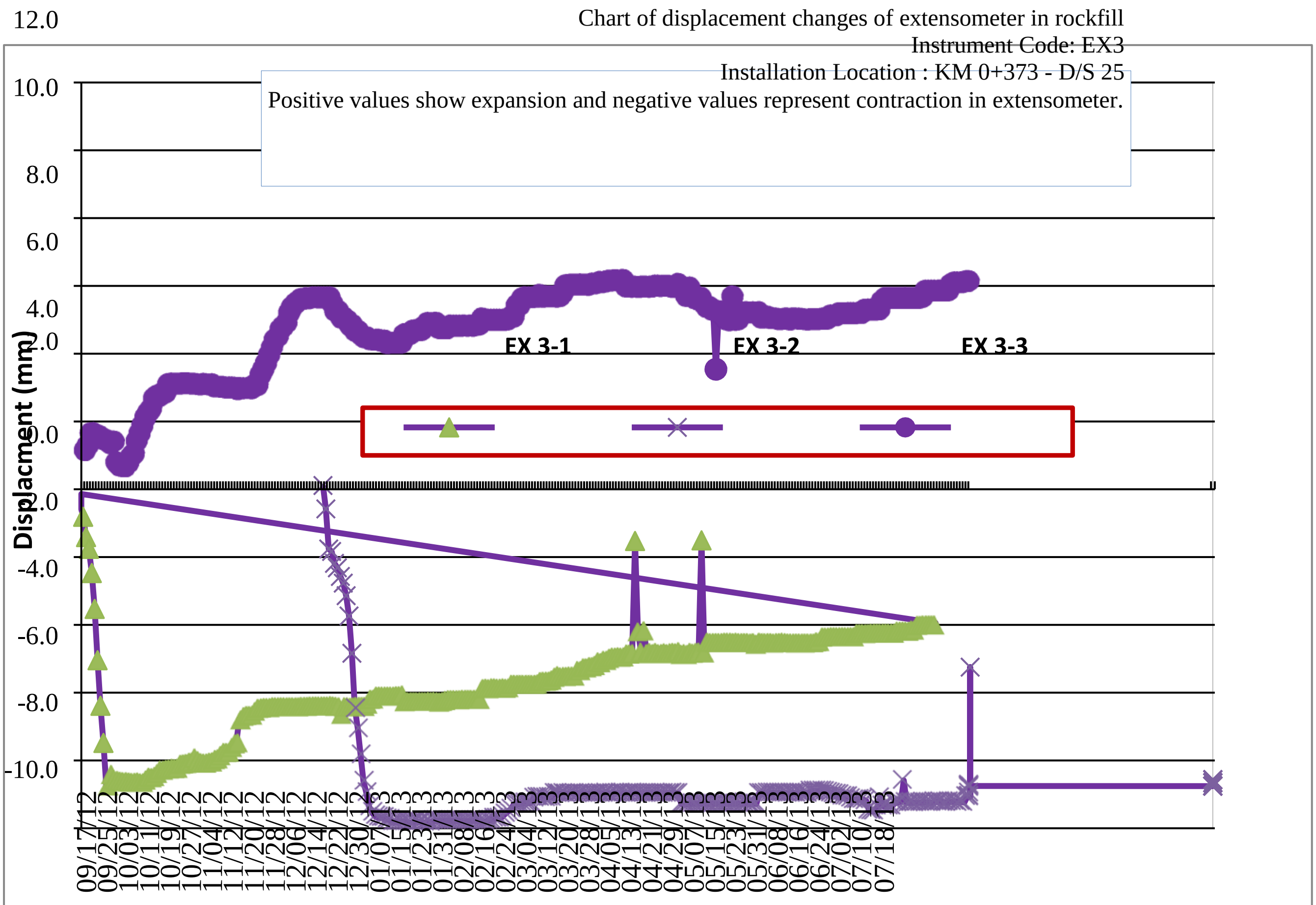
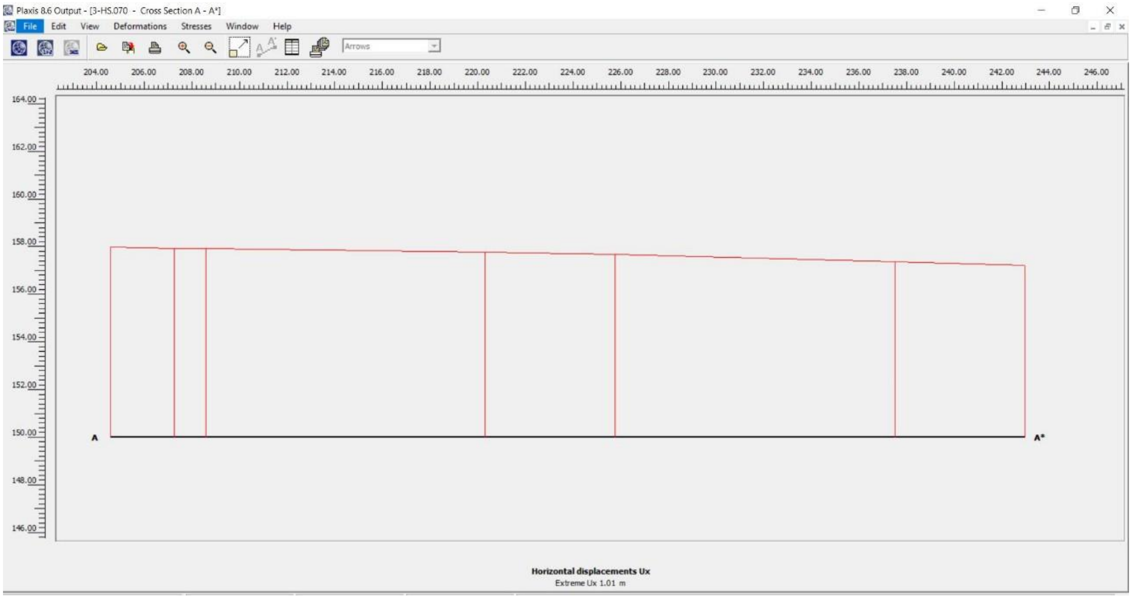


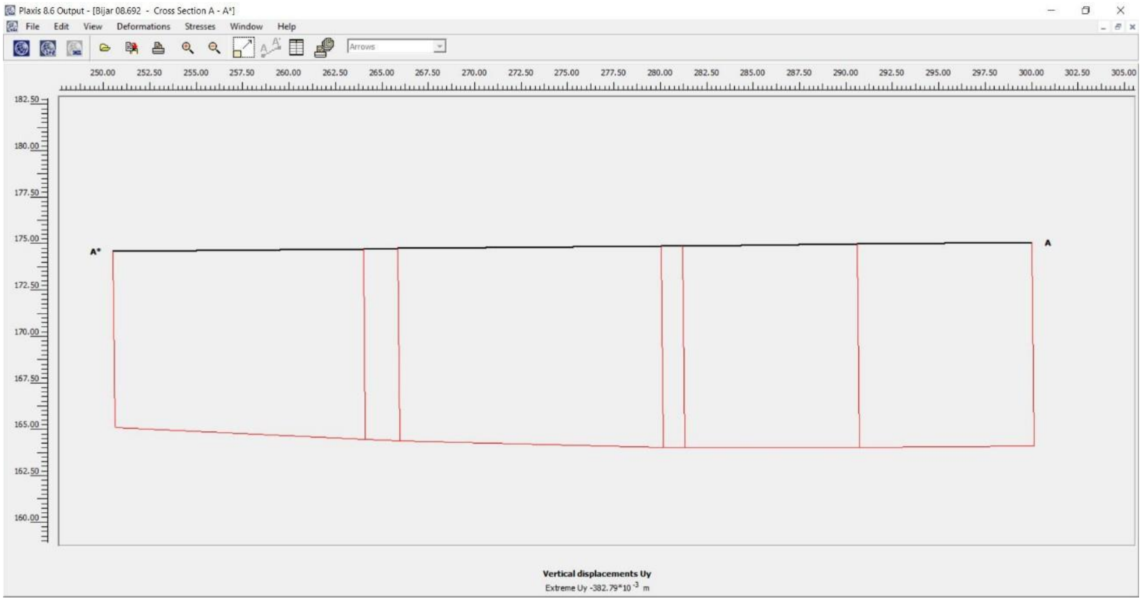
Figure 11. Chart of displacement changes of extensometer for instrumentation EX3



Horizontal displacements Ux

Extreme Ux 1.01 m

Figure 12. Horizontal displacement changes during impoundment at level of 150 m in Plaxis



Vertical displacements Uy

Extreme Uy $-382.79*10^{-3}$ m

Figure 13. Horizontal displacement changes during impoundment at level of 175 m in Plaxis

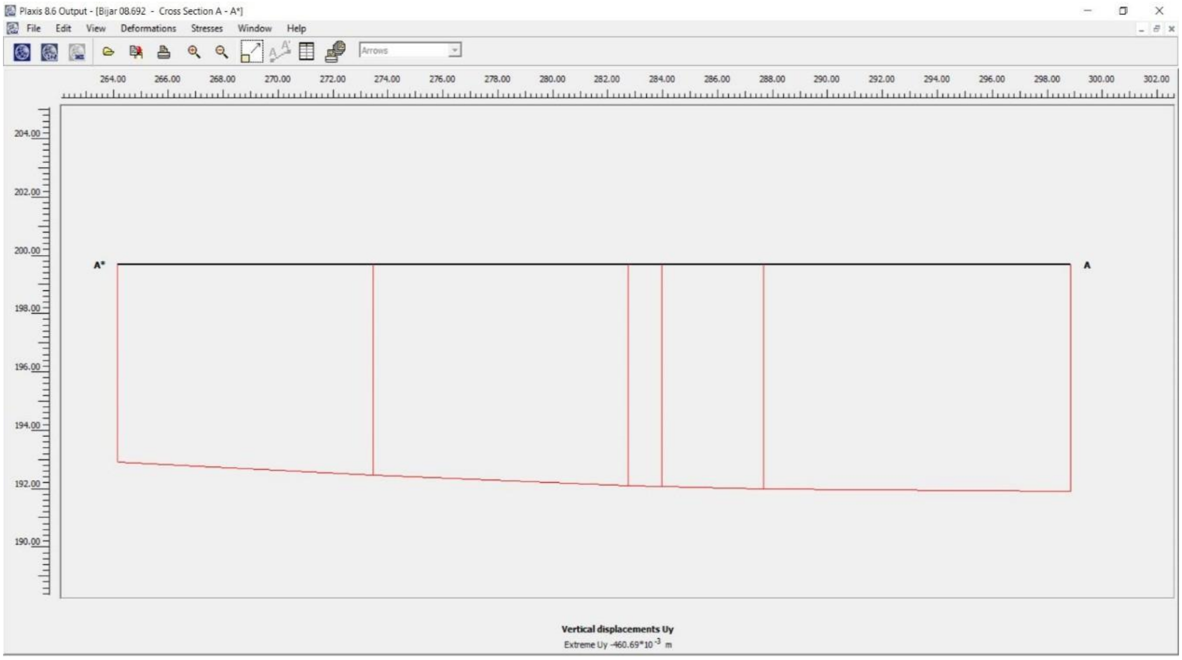


Figure 14. Horizontal displacement changes during impoundment at level of 200 m in Plaxis

Table 4. Comparison of settlement measured by instrumentation and software

Impoundment displacement (mm)	Y	X	Extensometer
-3.94	4096258.163	383871.784	EX 3-1
-8.56	4096243.127	383851.791	EX 3-2
-2.92	4096288.425	383911.627	EX 4-1
15.99	4096237.252	383891.759	EX 4-2
-40.14	4096318.722	383951.406	EX 5-1
14.05	4096288.497	383911.581	EX 5-3
15	**Plaxis**		

Soil Extensometer is used to measure the tension or compression according to the results of strains occurred in geotechnical materials (Table 4). Soil Extensometer consists of a vibration transducer embedded in a sealed piston chamber, capable of displacement of 200 mm. The ends of piston are threaded to connect a steel rod and to provide a gauge set with a specified length. To eliminate the friction between the rods and the covering material, the PVC telescopic tubes are used to cover the rods. A set of rods and sensors are connected together in series, all finally linked to a fixed point. In all cross sections of Shahr-e-Bijar Dam, fixed points are constructed in form of a concrete box with a 2-meter IPE 160. The ends of last rods are connected to an iron column (Figure 15 and Figure 16) and the rest are connected to each other along the trench by channels spaced 20 m apart.

Figure 15. Fixed point at level of 175 m in Shahr-e-Bijar Dam

Figure 16. Channel connected to sensor of extensometer in Shahr-e-Bijar Dam

The fixed points are visible at the end of earth filling operations. These points are exposed to settlement or displacement due their position on the downstream slope. Therefore, fixed benchmarks are specified on these concrete boxes to determine their probable future displacements. The benchmarks are specified to measure the horizontal displacement of each channel. The channels spaced 25 m apart and interlocked in their surrounding materials are pushed to and fro on their axis (the excavated trench) due to soil lateral strain caused by overburden pressure. The movement of channels to and fro is the same as compression or tension, which is received by the sensor of vibration extensometer, transmitted outside the embankment by cables and then read. In each sensor, downward displacements are considered to be positive and upward displacements are considered to be negative, according to the agreement made with the instrumentation company. In the longitudinal section, the movements towards the spillway (on the right side - position of fixed points) are positive and vice versa.

7. MONITORING OF EXTENSOMETERS IN SHAHR-E-BIJAR DAM

In Shahr-e-Bijar Dam project, there are 73 extensometer sensors of which 72 are connected to the monitoring circuit. The 73 sensors consist of 10 extensometers of which 2 sets are located at levels of 175 and 200 m, 3 sets are located at levels of 151, 175 and 200 m in cross section 9-9, 2 sets are located at level of 175 and 200 m in another cross section and 3 sets are located along the longitudinal axis at levels of 151, 175 and 200 m. Like other electrical devices, the values of these instruments are regularly read on a weekly basis and the results of this study are addressed in the following.

8. EXTENSOMETERS INSTALLED IN CROSS SECTION 9-9

For cross section 9-9, three extensometer sets are considered at levels of 150, 175 and 200 m, all of which are installed. Extensometer EX 5 at level of 151 m with 11 benchmarks, extensometer EX 4 at level of 175 m with 7 benchmarks and extensometer EX 3 at level of 200 m with 3 benchmarks are installed. The sensors are numbered from upstream to downstream. According to approximate distance of 25 m between channels, it can be discussed that the EX 5, EX 4 and EX 3 cover an axis of about 250 m, 150 m and 50 m, respectively. At level of 151 m, the displacements fluctuate in different sensors from upstream to downstream. The displacements of benchmarks near the dam slopes represent compression, while the benchmarks near the axis (center) of dam show tensile displacements. At this level, the maximum displacement occurs in the benchmark 5, which amounts to 4.5 cm. It should be noted that the value is the result of displacements carried at this point, which eventually reaches about 4.5 cm to the downstream. The maximum compressive movements recorded in this extensometer (strain toward upstream) also occurs in sensor 1 (adjacent to the upstream apron), which amounts to 16 mm at the end of construction and 40 mm after the first impoundment. In the winter 2016, the value was recorded 41 mm after impoundment of the reservoir. It must be noted that the effect of impoundment on the upstream of rockfill dam is considerable, but the influence of reservoir pressure decreases toward the downstream; so that in the sensors in the downstream of dam axis, the effect of reservoir water level on tensions is not significant. Moreover, the results of numerical analysis are used to present allowable ranges of transverse displacement. However, the results show the ranges of expected changes for extensometers at this level of the longest cross section in order compare the cases. Comparison of these results with extensometer data shows that the measured values are within allowable range. At level of 175 m, the movements recorded by sensors amounts to 12.8 cm in form of tensile deformation and all channels are moved toward downstream. Hence, the total deformation is equivalent to a strain of 0.09%. In fact, the high volume of rockfill dam in cross section 9 increases the tension at level of 175 m. As stated above, an extensometer set (EX 3) is installed with three benchmarks in the longest cross section of rockfill dam at level of 200 m, similar to instrumentation of other cross sections. The chart of data recorded at each benchmark during construction and the comparison between the results of three benchmarks of this extensometer are presented. According to these charts, the benchmark located at a distance of 25 m from the dam axis experiences compression and the benchmark located on the dam axis is exposed to tension. The compression of off- axis benchmarks is reduced and the tension of on-axis benchmarks rises during impoundment. At the end of construction, compression is about 7.8 to 9.3 mm at both ends of the axis and the tension is about 4.2 mm at the center of the extensometer. In fact, this extensometer shows a total displacement of 12.6 mm to the upstream during impoundment. This displacement is equivalent to a strain of 0.03%. Total displacement of reservoir is reduced to about 7 mm during the first impoundment; in other words, the estimated strain is almost halved compared to the value for end of construction. As the level of dam reservoir increases, the total displacement drops to about 5 mm. Given the allowable ranges, it is worth mentioning that all lateral deformations are within the acceptable range.

9. COMPARISON OF SETTLEMENT METER VALUES WITH SOFTWARE VALUES DURING IMPOUNDMENT

Vertical displacements in the body of CFRDs are displayed during construction and operation by settlement meters. Settlement meters have different types. Their most common type is the hydraulic settlement meter which is used in Shahr-e-Bijar Dam. Settlement meters installed in cross section 9-9: 15 sets of electrical settlement meter are considered in cross section 9-9 (according to the instrumentation layout in cross section 9 within the rockfill dam); 3 settlement cells at the level of 200 m, 5 sets at the level of 175 m and 7 sets at the level of 150 m. The cumulative results recorded by the instruments are shown in the following figures (**Figure 17**, **Figure 18**, **Figure 19**, **Figure 20**, **Figure 21**, **Figure 22**, **Figure 23**, **Figure 24**, **Figure 25**, **Figure 26**, **Figure 27** and **Figure 28**).

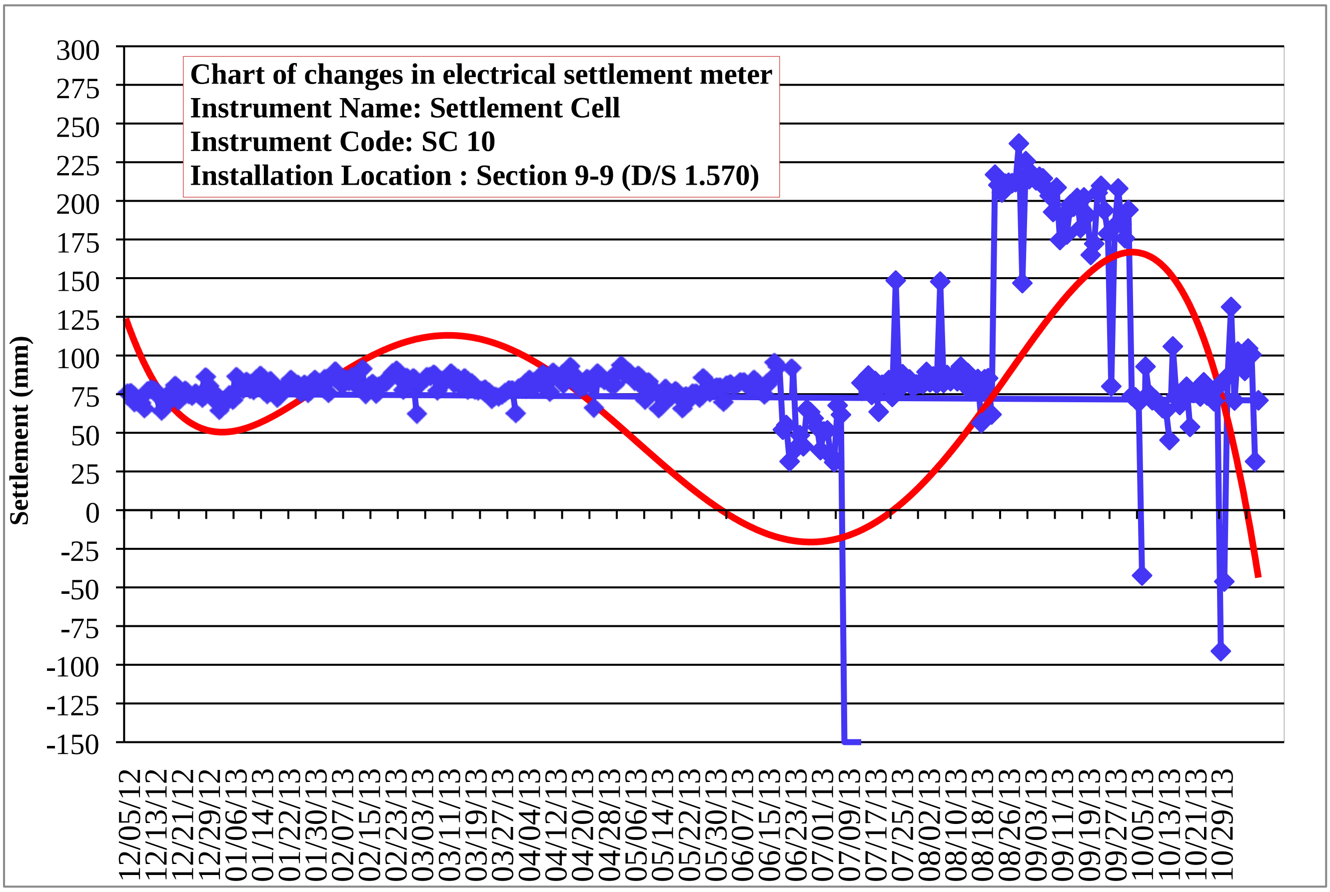


Figure 17. Changes in electrical settlement meter for instrumentation SC10

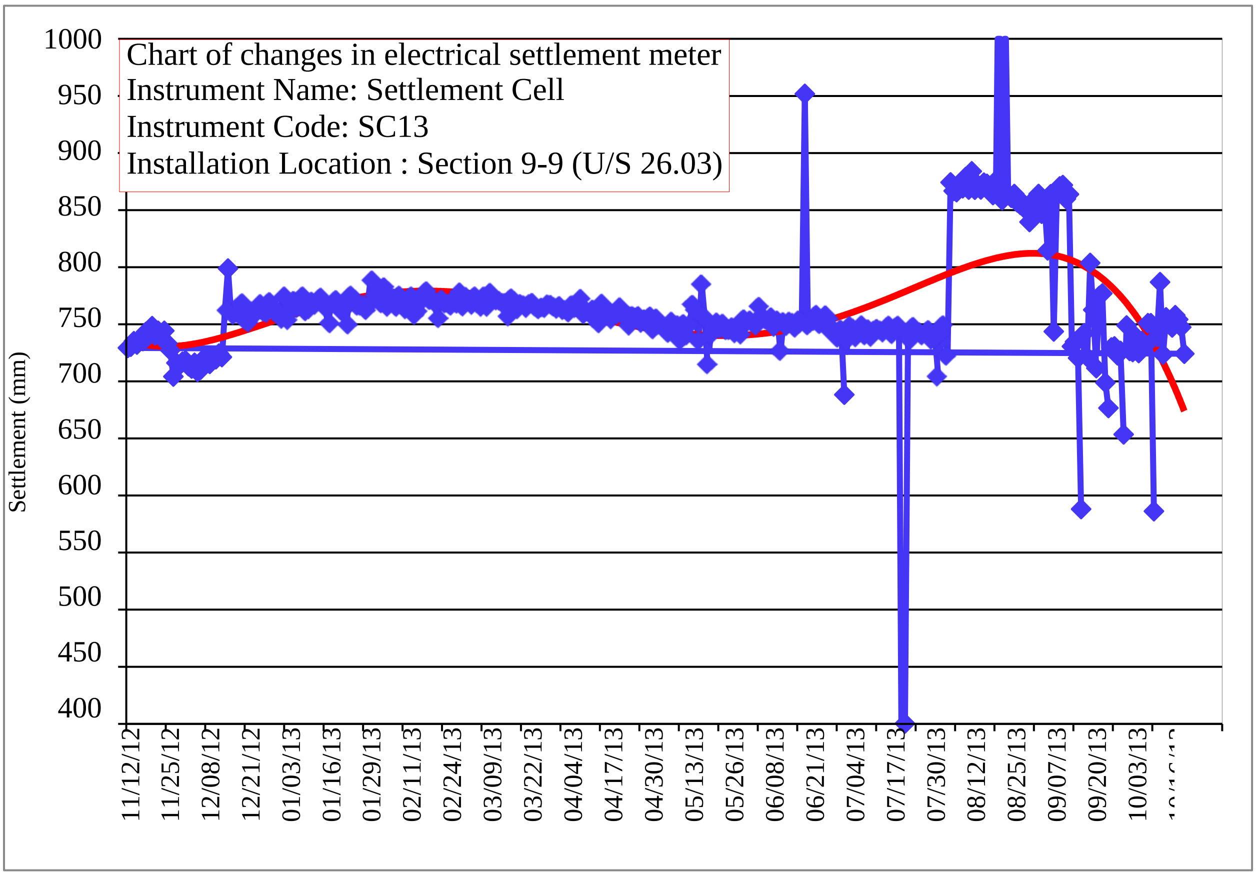


Figure 18. Changes in electrical settlement meter for instrumentation SC13

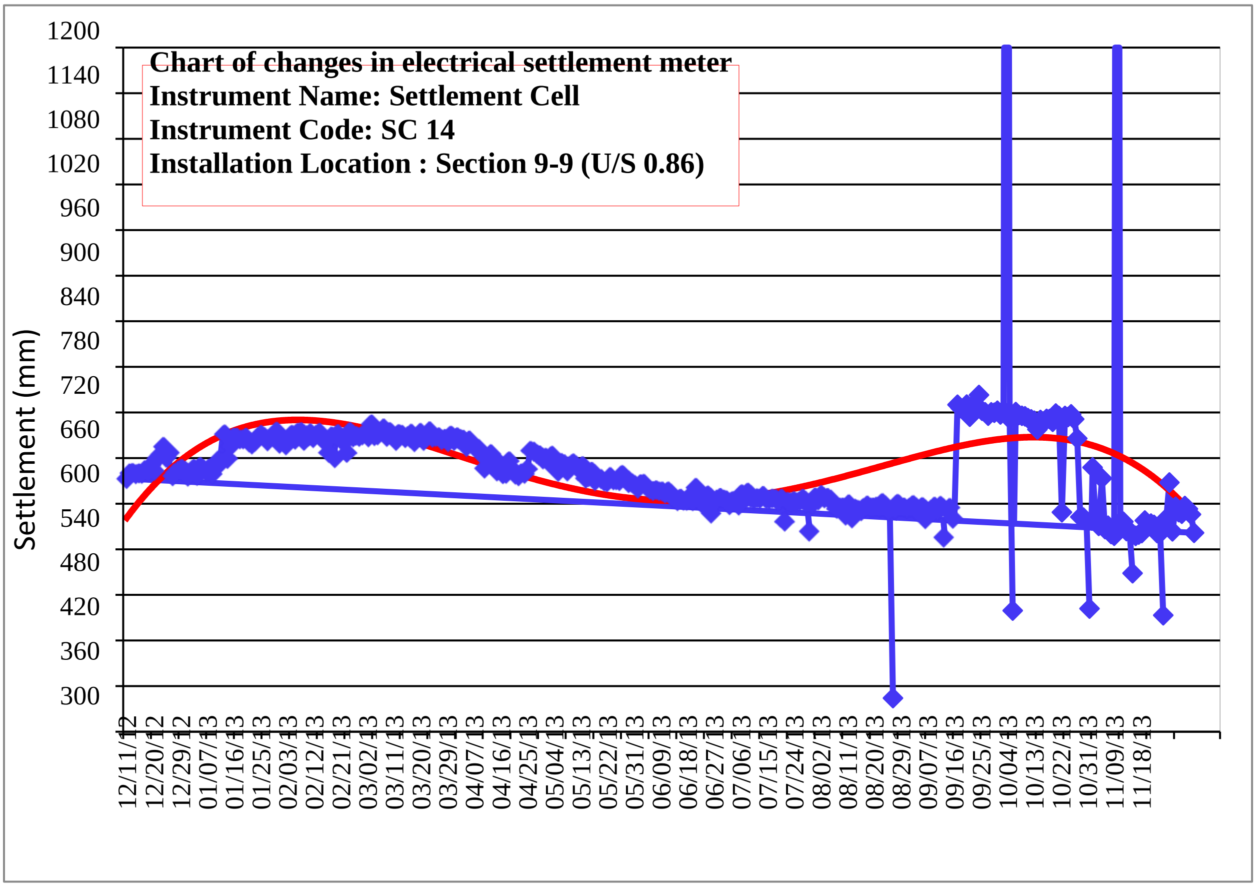


Figure 19. Changes in electrical settlement meter for instrumentation SC14

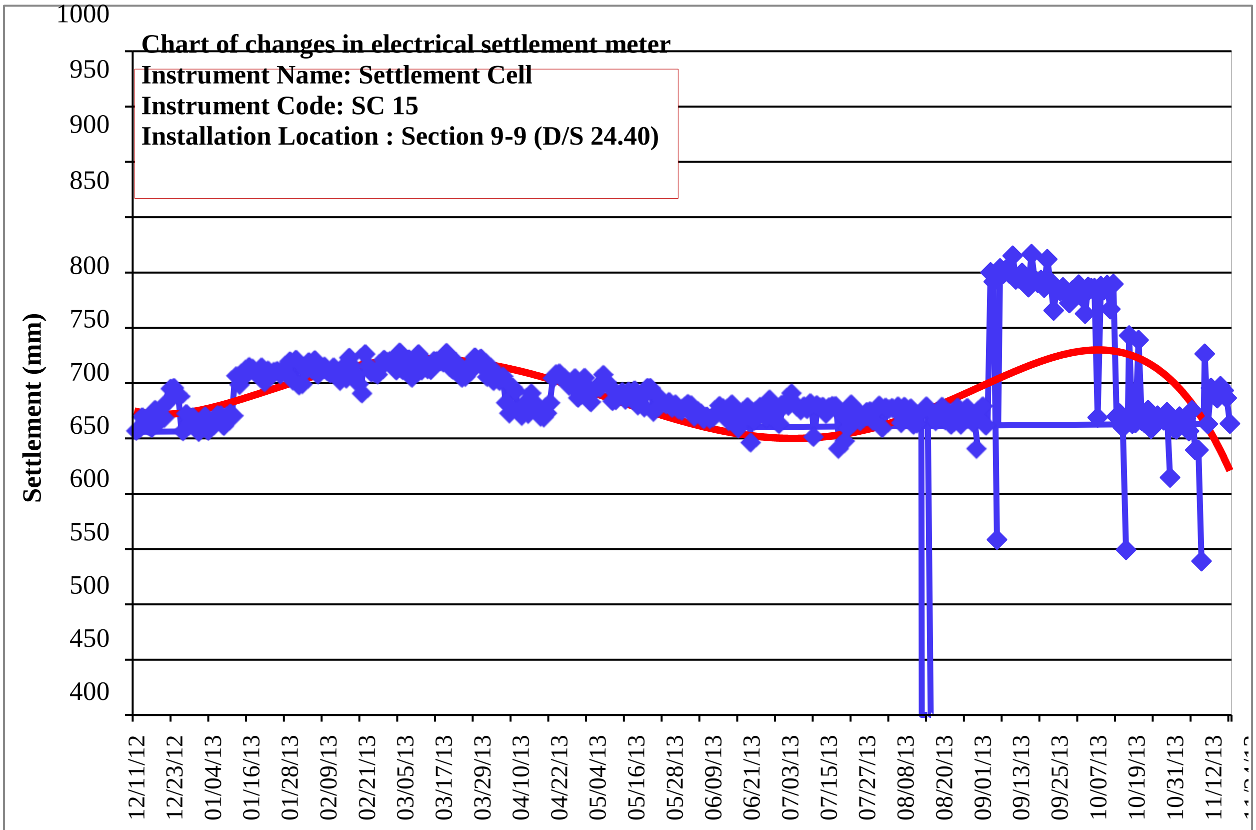


Figure 20. Changes in electrical settlement meter for instrumentation SC15

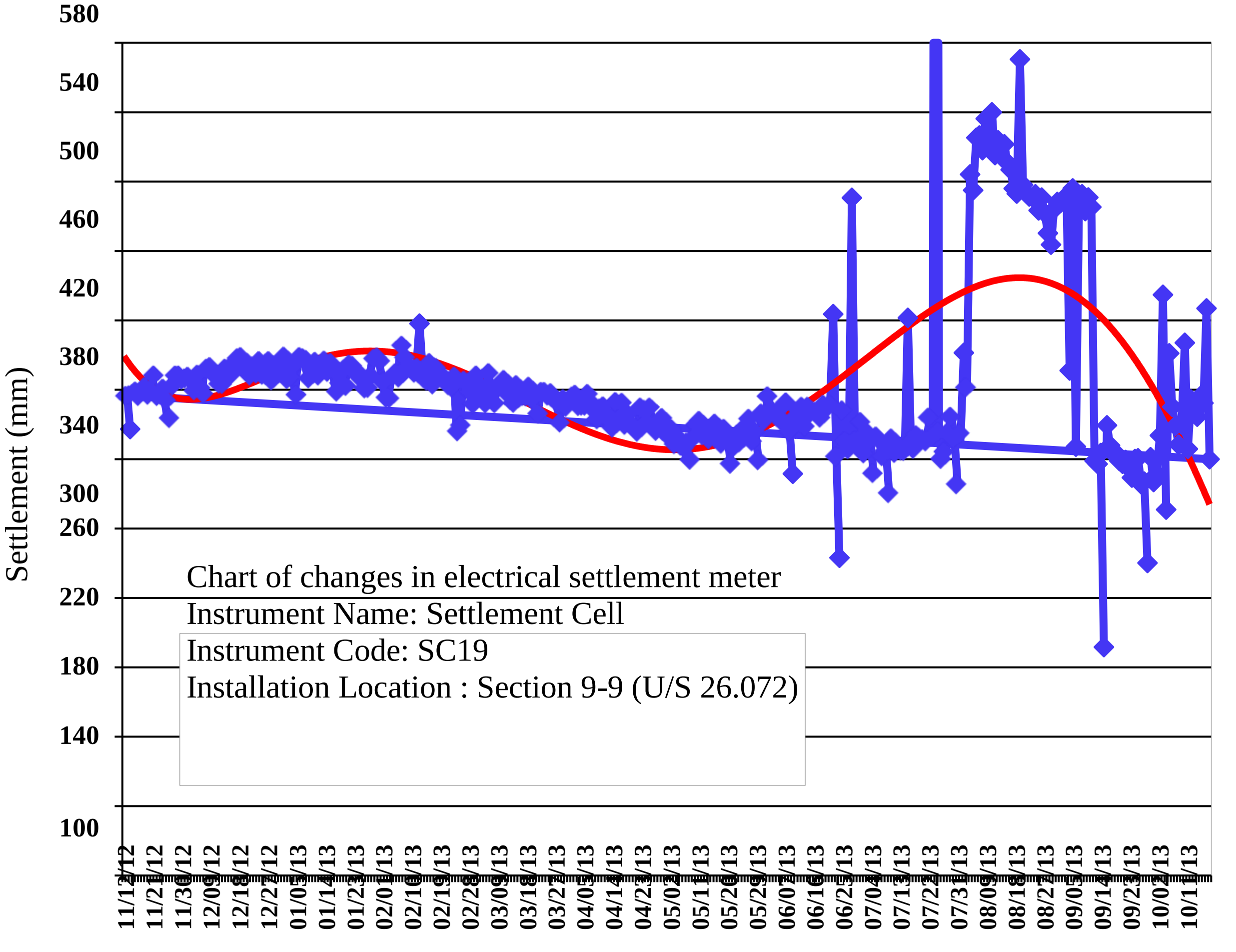


Figure 21. Changes in electrical settlement meter for instrumentation SC15

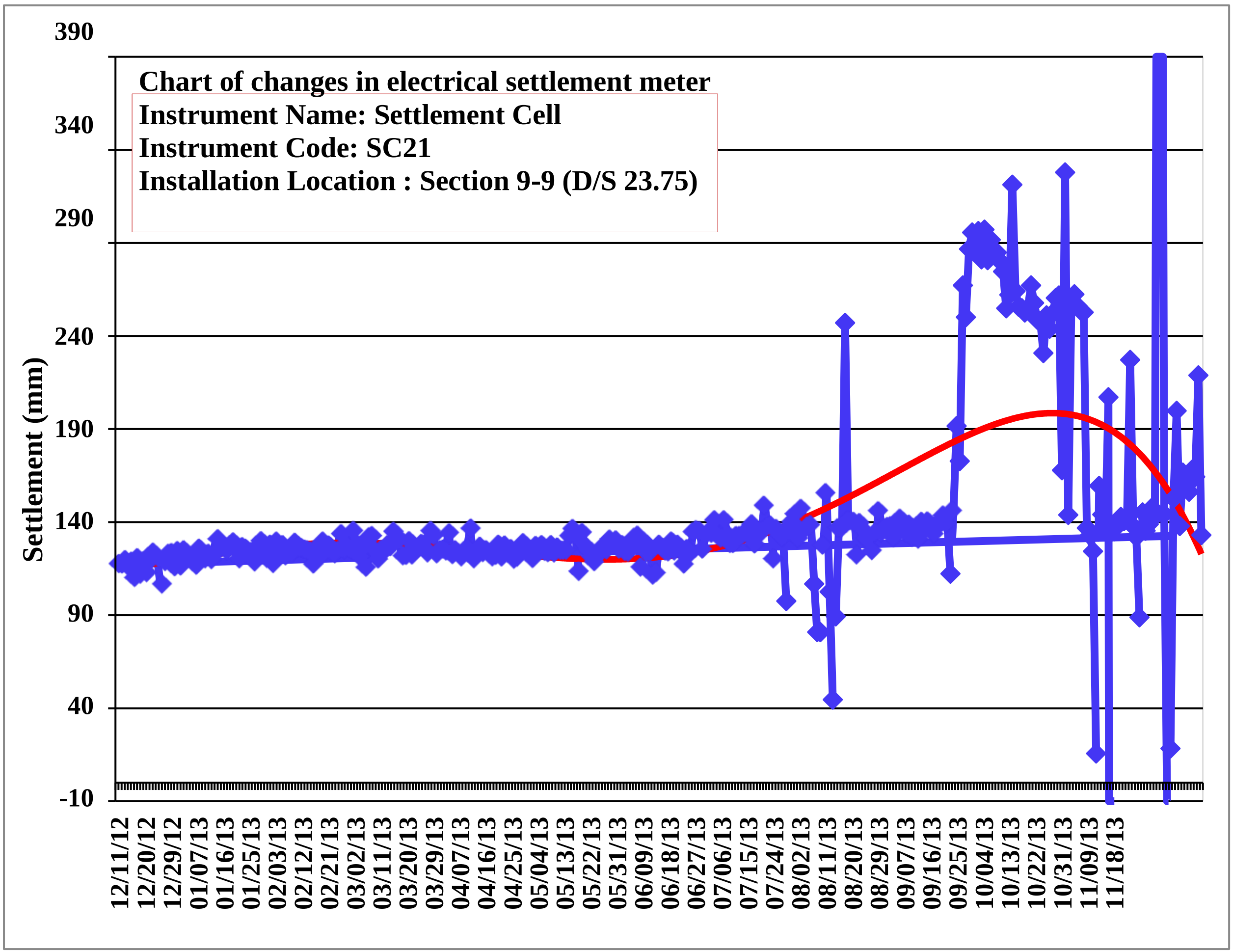


Figure 22. Changes in electrical settlement meter for instrumentation SC21

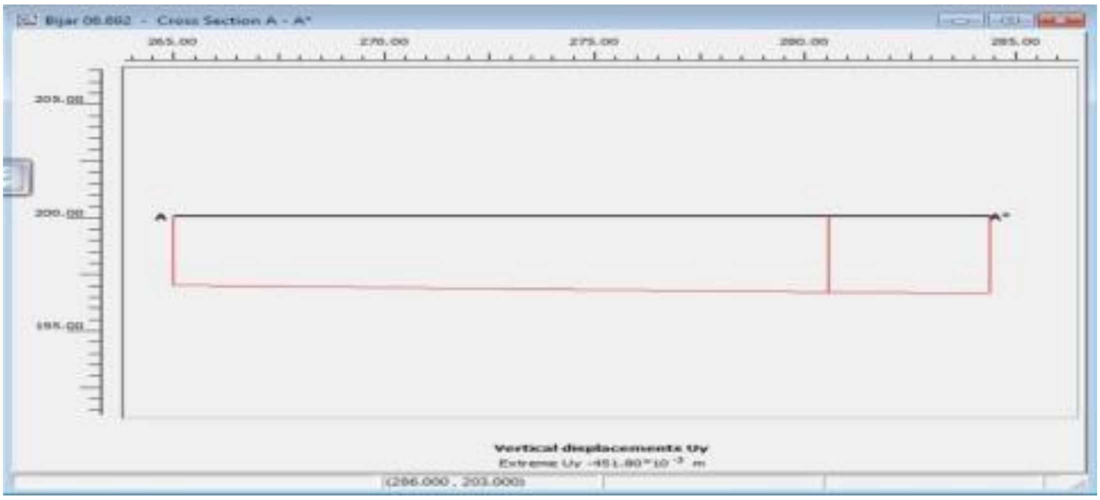
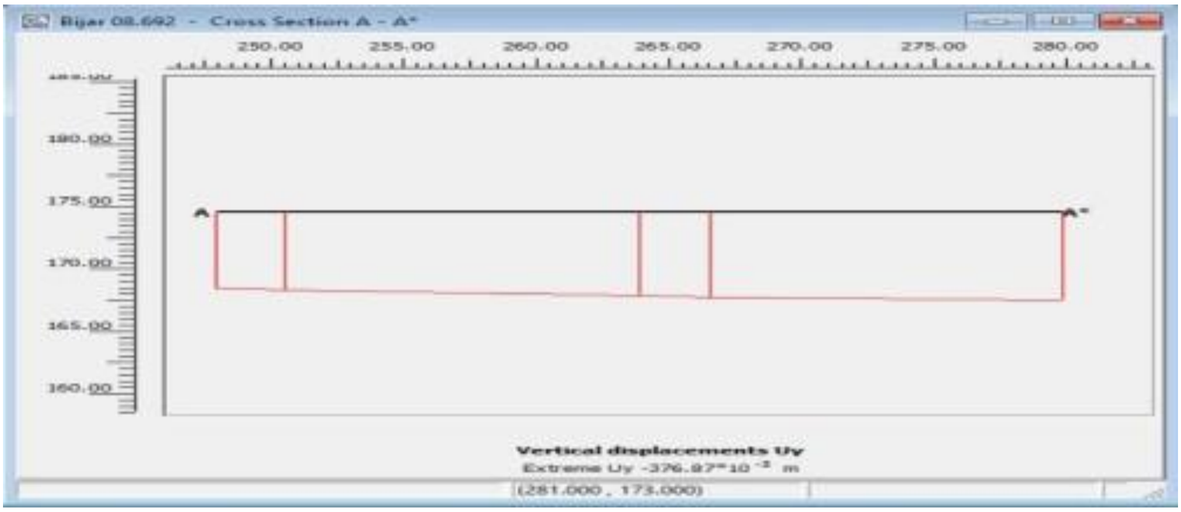
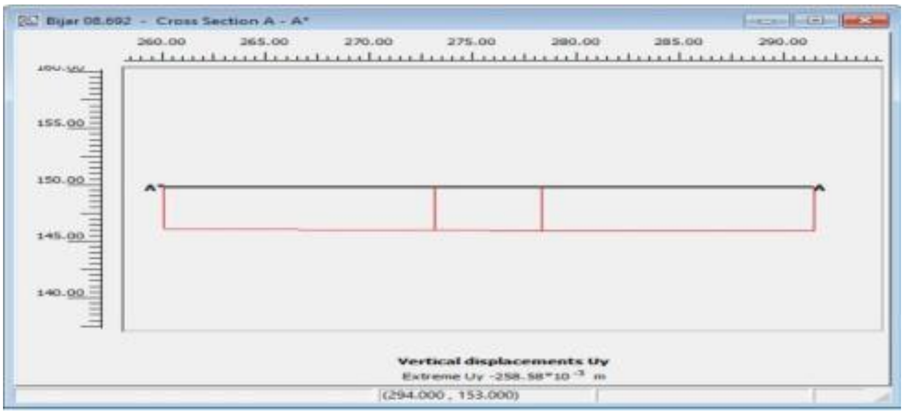


Figure 23. Changes in settlement at the end of construction by Plaxis at level of 200 m



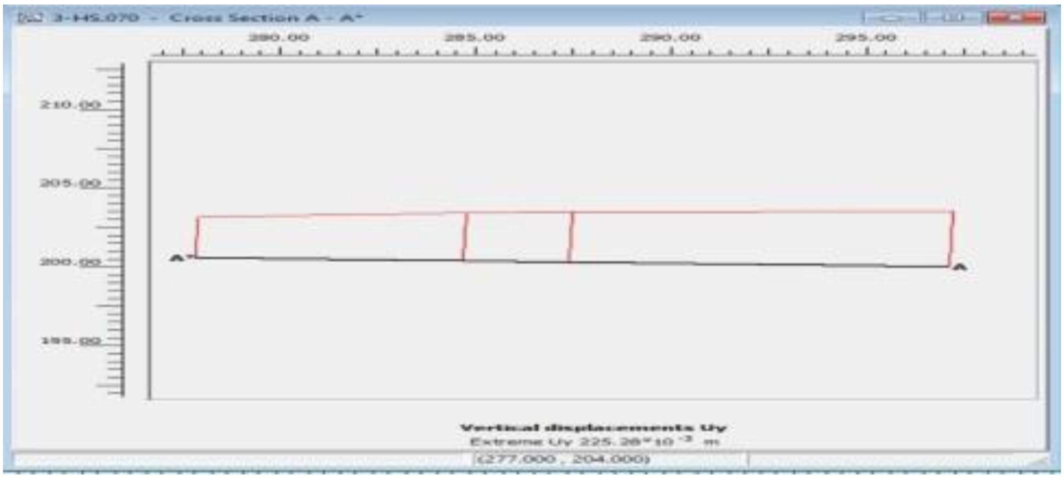
Vertical displacements Uy
Extreme Uy -376.87*10 $^{-3}$ m
(281.000 , 173.000)

Figure 24. Changes in settlement at the end of construction by Plaxis at level of 175 m



Vertical displacements Uy
Extreme Uy -258.58*10 $^{-3}$ m
(294.000 , 153.000)

Figure 25. Changes in settlement at the end of construction by Plaxis at level of 150 m



Vertical displacements Uy
Extreme Uy 225.28*10 $^{-3}$ m
(277.000 , 204.000)

Figure 26. Changes in settlement during impoundment by Plaxis at level of 200 m

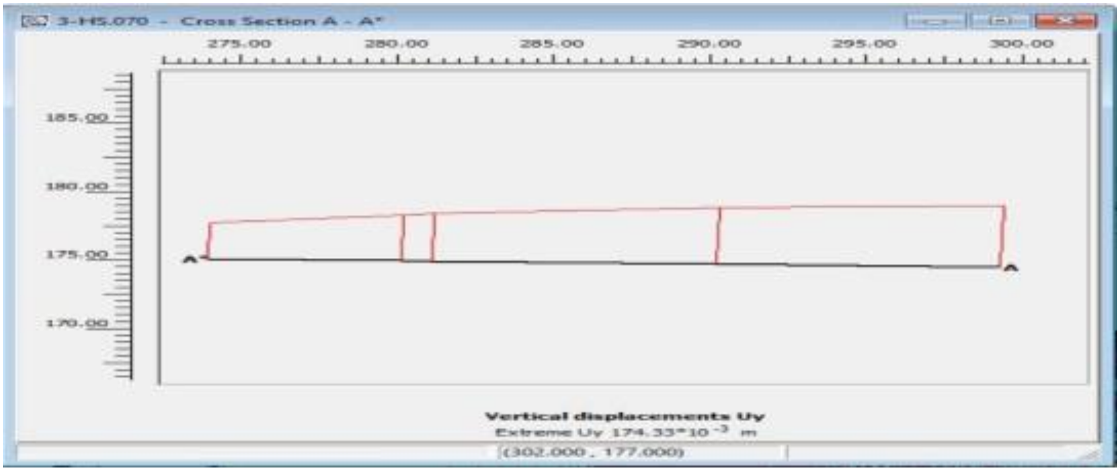


Figure 27. Changes in settlement during impoundment by Plaxis at level of 175 m

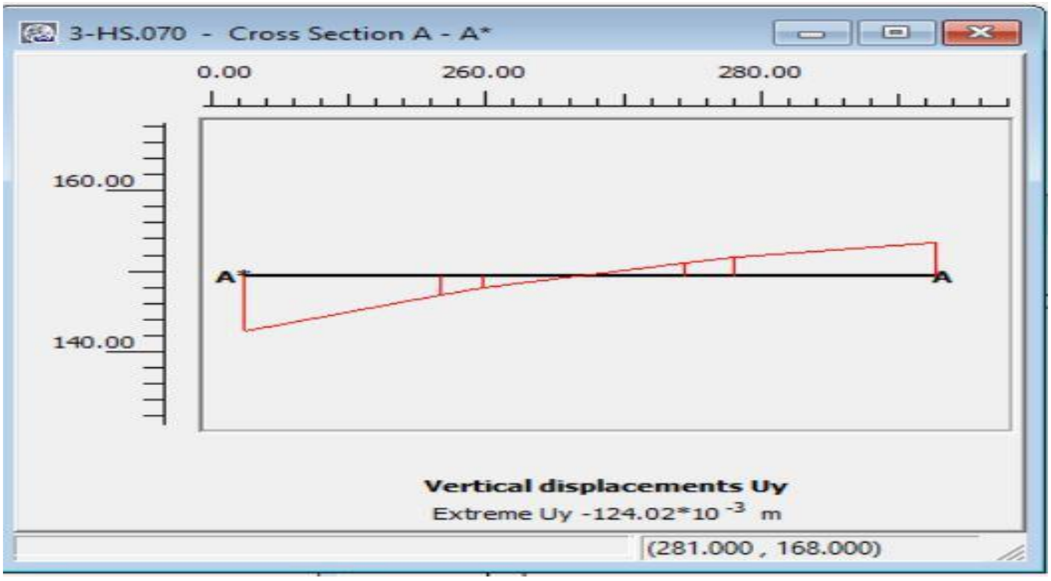


Figure 28. Changes in settlement during impoundment by Plaxis at level of 150 m

Some results of comparison between the changes in electrical settlement values obtained by instrumentation and the software values are presented in the Table 5:

Table 5. Comparison of settlement obtained from instrument and software

Impoundment (mm)	*End of construction (mm)*	*Y*	*X*	
71	86	4096244.523	383852.764	Sc10
724	768	4096259.467	383872.126	sc13
562	621	4096243.907	383852.330	sc14
663	678	4096228.834	383832.066	sc15
340	354	4096259.06	383872.488	sc19
432.91	440.12	4096242.397	383847.662	sc21
120-250	250-500	Numerical analysis (Plaxis)		

10. INVESTIGATION INTO SETTLEMENT METERS AT LEVEL OF 200 M

At level of 200 m in cross section 9-9 (the longest cross section of the dam), 3 settlement cells including SC9 to SC11 are installed. These 3 instruments are respectively located from the upstream to the downstream according to the details of instrumentation layout in this cross section. The results recorded by some of these instruments are presented in the charts. There are two hydraulic settlement meters near the slopes of rockfill dam that do not have reasonable data. So their recorded changes practically require further research based on more information. However, the settlement of 70 to 90 mm is recorded in the cell installed on the dam axis, which shows the cumulative settlement of about 9 cm at the center of this level during construction. Actually, the modest incremental changes recorded in the data of cell SC10 are the same as what is expected and have relative compatibility with the height of embankment on the settlement cell. The settlement increases in this location by impoundment, so that it reached 110 mm in the winter 2016. However, quantitative reliability of the data is questionable due to great fluctuations of the information, which involves attention to the design elements. Two-dimensional finite element analyses are conducted in order to control the allowable deformation ranges in this cross section of the rockfill dam. As can be seen, there is not good agreement between the information and changes in monitoring data and the results of analyses. Therefore, it is necessary to notice the assessment of proper performance of instrumentation in terms of weather conditions in the area and the application of instrumentation results in the future of project through behavioral stability of the rockfill dam.

11. INVESTIGATION INTO SETTLEMENT METERS AT LEVEL OF 175 M

At level of 175 m in cross section 9.9 (the longest cross section of the dam), 5 settlement cells including SC12 to SC16 are installed. These 5 instruments are respectively located from the upstream to the downstream according to the details of instrumentation layout in this cross section. The results recorded by these instruments are presented in the charts. The hydrostatic settlement meters at level of 175 m of this cross section also show lower settlements in its both sides (30 to 39 mm) and higher settlements at its center (about 65 to 77 mm) during construction. However, the settlements increase due to reservoir impoundment; so that the reservoir pressure has a minor impact on the middle settlement meters, but the increasing effect of settlement on side settlement meters is significant (especially for instruments in the upstream of rockfill dam, near the concrete face). For instance, the side settlement increased to about 50 to 60 mm through full impoundment of dam reservoir in the winter of 2016. In this cross section, the settlement begins from 34 cm on the sides and reaches 71 cm at the center. It is worth mentioning that the values recorded by hydraulic instrument during and after construction at the level of 175 m in the longest cross section of dam are in good agreement with the data of magnetic plates. Settlement values increase during impounding process, so the stabilization of this increasing trend in 2016 should be considered.

12. INVESTIGATION INTO SETTLEMENT METERS AT LEVEL OF 150 M

The sensor of settlement meter 17 is installed at level of 150 m, about 12 m far from the upstream slope. The effective direct height of rockfill above this sensor is about 7 m. Therefore, the settlement measured at this point is not expected to be significant during construction. It is worth mentioning that a significant increase of settlement occurs at this point after the beginning of settlement process, so that the settlement of project has increased from 5 cm to 32 cm for three years of impoundment and the increasing trend is also expected for it. Since this settlement meter is practically installed at a very short distance from the concrete face behind the perimeter joint, its large deformation can affect the sealing performance of perimeter joint in the long run. Therefore, it is necessary to control the stability of settlements in future years. Sensor 20 shows a small settlement (about 9 cm) like Sensor 17, while the sensor is at the center of cross section and it is expected to have the highest settlement among all sensors installed at this level. This value is not consistent with the data recorded by magnetic settlement plates. Thus the sensor data is virtually unverifiable and cannot be referred to, although further studies and spending more time in the future may lead to a more comprehensive conclusion. The significant growth of settlement in the cell may be considerable during impoundment in 2016. The data measured by sensor 21 is expected to be geometrically the same as that of sensor 19. However, the dramatic difference between the data of these two sensors indicates a considerable error in installation of instruments or readouts. Although a slight difference in data may be due to engineering properties of materials and asymmetric earth fillings, the difference in data of these two sensors is about triple the value and virtually inconsistent with other data. Totally, the settlement changes at the level of 150 m in this cross section have a variable procedure during construction. Therefore, the results curves of settlement cells at this level are not properly consistent with each other in terms of form, intensity or fluctuations. Since the data fluctuations dramatically decline during construction process, it seems that the operational error also affects the recorded fluctuations. Like other hydraulic settlement meters, the data of these sensors cannot be interpreted and analyzed during impoundment. Therefore, it is necessary to check and control the results of central readout unit, probable errors, readout method and the applied fluid.

13. RESULTS

The monitoring of dams by installing instruments at critical points and measuring various parameters, such as pore pressure and deformations, including Settlement and displacement, are possible. In this research, the reservoir characterization of Shahr-e-bijar Dam has been investigated using instrumental data and numerical analysis. A numerical analysis of the plaxis bundle, a program based on finite element, has been used. According to the results of the analyzes carried out by the program that are in good agreement with the observations and data obtained from the instrumentation, it can be concluded that the use of these programs will be very useful for analyzing and predicting the behavior of soil dams. It is important to note that the effect of impounding on the upper part of the dam body is tangible, but by moving downward, the amount of pressure effect of the reservoir is reduced, so that in the lateral sensors of the dam axis, the effect of reservoir water level on the elongations is not considered. Meanwhile, numerical analysis has been used in order to provide the permeability intervals in the transverse direction. However, in order to compare the case, the intervals of expected changes for the extensometers of this level from the maximum dam section are depicted in the figures (**Figure 17**, **Figure 18**, **Figure 19**, **Figure 20**, **Figure 21**, **Figure 22**, **Figure 23**, **Figure 24**, **Figure 25**, **Figure 26**, **Figure 27** and **Figure 28**). Comparison of these results with extensometer data shows that they are within the range of the measured values. At the end of construction, the amount of shrinkage on the sides of the axis is about 7.8 to 9.3 mm and the center of the extensometer is about 4.2 mm. In fact, this extensometer shows a total displacement of 12.6 mm upstream during impounding. This displacement is equivalent to a strain of 0.03%. The initial impounding of the total displacement tank has been reduced to about 7 mm, in other words, the estimated strain has almost halved compared to the period ending. With increasing the dam reservoir, the total displacement dropped to about 5 mm. It is noteworthy that due to the permissible intervals, all peripheral deformations can be accepted within the permitted range. The comparison of settlement cells and numerical simulation shows that there is not a good match between the information and the way in which the data is changed and the results of the analyses are not. The moisture of dam site effects on the fluid viscosity of the settlement cell's fluid. Therefore, evaluation of the performance of this instrument in terms of weather conditions in the region and the extent of using the results of this tool in the future of the project should be considered with the stabilization of the body of the dam. In this research, different types of tools used in the body of dams are introduced and common methods and tools for measuring various geotechnical quantities have been studied. With the help of data from tools such as Settlement cells and Extensometeres that were measured over a relatively long time period, as well as the results of modeling the dam with finite element plans and the location of the Shahr-e-bijar Dam including deformation and leakage has been analyzed. One of the most important dam construction steps after designing and constructing them is managing the operation and maintenance of such projects. For this purpose, the results of dash instrumentation and subsequent return analysis are used. One of the main goals of this research is to express the importance of this stage and also, by examining the results of the instrumentation of an earth dam, as a practical part of the management process of exploitation and the dam has been maintained. In total: after the behavioral testing of the Shahr-e-bijar dam, based on the information recorded by the system of project tooling, two-dimensional numerical modeling of the Dam with the help of plaxis software version 8.2 and the results of numerical modeling with the behavioral will be compared and interpreted. It is required to use the behavioral model of Mohr–Coulomb in this research.

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CONFLICT OF INTEREST

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