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Nonlinear dynamic analysis of Moshampa Dam Spillway structure and modelling it in finite element software, taking structure soil interaction in to account

Hadi Asgarzade[1] and Arman Memarian[2*]
[1]Iran, Tehran, Tehran University, Iran
[2]Iran, Zanjan, Zanjan University, Iran
arman.memariann@gmail.com

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Abstract

The region subjected to this study is Qezelozan river basin up where Moshampa dam is located, near Moshampa-ye-Sharqi village. The structure of the spillway is currently placed on the right axis abutment of Moshampa dam. By changing the spillway dimensions and adding to the size of the plunge pool, this study focuses on a new alternative in which the concrete structure of the flip bucket has been shortened and a concave projectile has been added to its end. After hydraulically investigating the idea of remodeling the drain system of Moshampa reservoir applying value engineering, the hydraulic function mechanism of the spillway was changed from flip bucket + stilling bas in model to projectile bucket + plunge pool one. The climatological and geotechnical characteristics of the region including the river basin, its climate, its surface geology, the resistivity and the geotechnical factors of the different kinds of soils or the alluviums existing under and around the spillway structure, the stilling basin and also the concave projectile were studied and the characteristics of the stone wall necessary for the analysis of the soil resistivity under and around the spillway were processed in a computer software .At the first step of this research, the resistivity of the soil existing around and under the spillway and the pool has been analyzed by Praxis software in both static and quasi static modes considering the loads. Next, the model has been given to Finite element analytical software, so that the structure soil interaction could be analyzed in terms of the rules and regulations and its nonlinear dynamic design would be revealed.

Keywords: Spillway, nonlinear analysis, plunge pool , dam, dynamic.

Introduction

In article, a new design of Ski-jump-step Spillway, a new kind of ski-jump-step spillway was reported. By means of the effects of the aeration basin, it supplies the sufficient aeration flow from the first step for stepped chutes, especially for large unit discharge, the physical model experiments demonstrated that, this spillway makes a far better hydraulic performance as regards energy dissipation and cavitation damage protection than the current and conventional stepped spillways[1]. In article, a new design of Ski-jump-step Spillway, The physical model experiments demonstrated that this spillway makes a far better hydraulic performance as regards energy dissipation and cavitation damage protection than the current and conventional stepped spillways, and the unit discharge can be enlarged from about 50 m^3/s-60 $m^3/s\cdot m$ to 118 $m^3/s\cdot m$ in order to significantly reduce the width of the spillways[2]. In article, Hydraulics of crest spillway with large unit discharge and low Froud number, existing spillway is considered as the Ogee type. Six kinds of LSCS have been used in the research. The experiments were performed in the laboratory by using an open flume. Ogee prototype was made of wood and LSCS was made of acrylic. During the experiment, water was flowed into the flume with varying discharge. At any change of water thickness above spillway, the water discharge was measured. Observation has been done both on the Ogee and LSCS[3]. In article, Seismic Behavior Analysis of Spillway Weir Section Based on ANSYS, The response spectrum method was applied to calculate the seismic behavior analysis of a spillway weir gate. Based on the analysis of the structure performance, special attentions were paid to the stress state of the key parts on the surface and root of the pier. The results showed that the displacement and stress of the whole structure were related to the direction of earthquake excitation; large principal tensile stress and principal tensile stress area appeared in steep change points of geometry shape, special attention should be paid when calculating anti-seismic checking and reinforcement arrangement; the displacement and stress of the weir section met the standard requirements[4]. In article, Seismic analysis of concrete arch dam based on ANSYS, an approximately incremental dynamic analysis (IDA) is presented for seismic performance assessment of arch dams. The nonlinear seismic analysis of arch dams involves the effects of contraction joint opening, cracking of concrete and foundation radiation damping. Three damage measures, i.e. the maximum joint opening, the cracking depth on the dam–foundation interface and the extent of cracking in the upper portion of the dam, associated with the IDA curves are suggested to identify the performance levels of arch dams. The Dagangshan arch dam (210m high) under construction in China is used as the case study[5]. In article, Cantilever mode response spectrum method for seismic analysis of sluice structures, Fundamental principles from structural dynamics, theory of random processes and perturbation techniques are used to develop a new method for seismic analysis of multiply supported secondary subsystems[6]. In article, developing a model for analysis of uncertainties in prediction of floods, unsteady non-uniform flow computations were incorporated. Using this model, flooding flow–sediments were simulated and compared to earlier research including hydrologic engineering centre (HEC-series) computer models[7]. In article, Cavitation in chutes and spillway, water resources technical publication, the purpose of this monograph is to give the designer of hydraulic structures both an understanding of cavitation and the design tools necessary to eliminate or reduce the damaging effects of cavitation in hydraulic chute and spillway structures[8]. In article, free surface air entrainment on spillways. In Air Entrainment in Free Surface Flows, Small physical models operating under a Froude similitude systematically underestimate the air entrainment rate and air-water interfacial properties[9]. In article, Evaluation of earthquake ground motions to predict cracking response of gravity dams, Computers and Structures, 1595-1606: i. historical records scaled to the smooth spectrum intensity; ii. spectrum-compatible accelerograms generated by random vibration theory; and iii. spectrum-compatible accelerograms obtained from the modification of the Fourier spectrum coefficients of historical records while preserving the original phase angles[10].In article, Seismic fracture analysis of concrete gravity dams including dam-reservoir interaction the seismic fracture response of concrete gravity dams is investigated with considering the effects of dam–reservoir interaction. A co-axial rotating crack model (CRCM), which includes the strain softening behavior, is selected for concrete material. The dynamic equilibrium equations of motion for the dam–reservoir system are solved by using the improved form of the HHT-α time integration algorithm[11]. In article, Seismic analysis of concrete arch dams by combined discrete crack and non-orthogonal smeared crack technique, a special finite element program is developed based on the combined discrete crack and non-orthogonal smeared crack (DC–NOSC) technique.

The basic concepts of the method are explained initially. Overall, DC–NOSC model is found to be a more rigorous, consistent and realistic approach from different aspects in comparison with both DC and NOSC models alone[12]. In article, Plastic-damage model for cyclic loading of concrete structures, the strength function for the effective stress is used to control the evolution of the yield surface, so that calibration with experimental results is convenient. A simple and thermodynamically consistent scalar degradation model is introduced to simulate the effect of damage on elastic stiffness and its recovery during crack opening and closing[13].

The spillway structure of Moshampa dam is placed on its right axis abutment. Based on this design, the concrete structure of the flip bucket has been shortened and a concave projectile has been added to its end, approximately at its 181st kilometer. In this new option, the lengths of the concrete spillway and stilling basin are 184.18 and 252 meters respectively. The region subjected to this study is Qezelozan river basin up where Moshampa dam is located, near Moshampa village, somewhere between the latitude of 35° 01' and 36° 57' north and longitude of 46° 35' and 48° 53' east. In this research, the dynamic analysis of the spillway has been done after investigating the soil resistivity under and around the spillway and stilling basin and finding the factors of safety in both static and quasi static mode; with regards to the structure soil interaction and using Finite element software.

Methodology

The spillway structure of Moshampa dam is placed on its right axis abutment. By changing the spillway dimensions and adding to the size of the plunge pool, this study introduces a new alternative. The geological reports reveal that the bedrock of the spillway consists of units of tuff, Qom formation limestone and upper red formation lichen. The stone mass found downstream at the end of the spillway includes sand containing red marls. According to Moshampa geological reports presented by the consultant, this area contains red sand marlstones, marl, conglomerate, gypsum and sandstone.

Cross Sectional Geometry and Characteristics of the Materials: Moshampa spillway structure consists of three parts; the stilling basin, the concave projectile and the main part of the spillway. All three parts have a concrete crusting illustrated in the image below.

Modelling and Analysis of the Spillway in Plaxis Software: Plaxis, a software for finite element analysis of soil and stone, was to analyze the soil resistivity of the soil around the spillway. First, the model of the spillway was built and different kinds of soil _ marl, alluvial, TP and TF layers, their characteristics, that is their C factors, angle of expansion, saturated and unsaturated specific weight, deformation modules and also the characteristics of the concrete layer, such as the resistivity factor have all been introduced to the software. Next, as shown in the image below, was to specify the interfaces and to mesh[7].

After that, the rock bolts were sketched and applied on the model. Finally, after loading the model in the three stages of excavation, it was time to analyze the structure in static and quasi static mode and by Phi-c reduction analytical method. The results of this analysis have been explained in the related part.

Doing the Project in Finite element Analytical Software: Continuing the procedure, in Finite element, which is a software for finite element[14], was used to analyze the spillway structure. After sketching the cross sections in Part module, the next step was to introduce all the following factors to the software: first, the characteristic of the materials, such as density, elastic and plastic characteristics of the concrete and the soil in Property module; next, the contiguity between the concrete part of the spillway and the soil; then, the loads pressing on spillway in different parts from the plunge pool to the concave projectile.

Pressing Hydraulic Loads on the Spillway Structure: At this step, the way the hydraulic loads are pressed on the spillway structure is explained. The hydraulic loads pressed on the spillway structure with regards to the pressure counter presented in the feasibility report of Moshampa dam spillway hydraulic design. Load Module has been used to apply the loads in Finite Element software[14].

The hydraulic loads applied are listed: i. The hydraulic load on the main part of the spillway (50000 Pascal), ii. The hydraulic load on the upper part of the spillway (100000 Pascal), iii. The hydraulic load on the flip bucket part (200000Pascal), iv. The hydraulic load on berms (200000 Pascal), v. The hydraulic load on the bottom part of the Plunge pool (450000 Pascal)

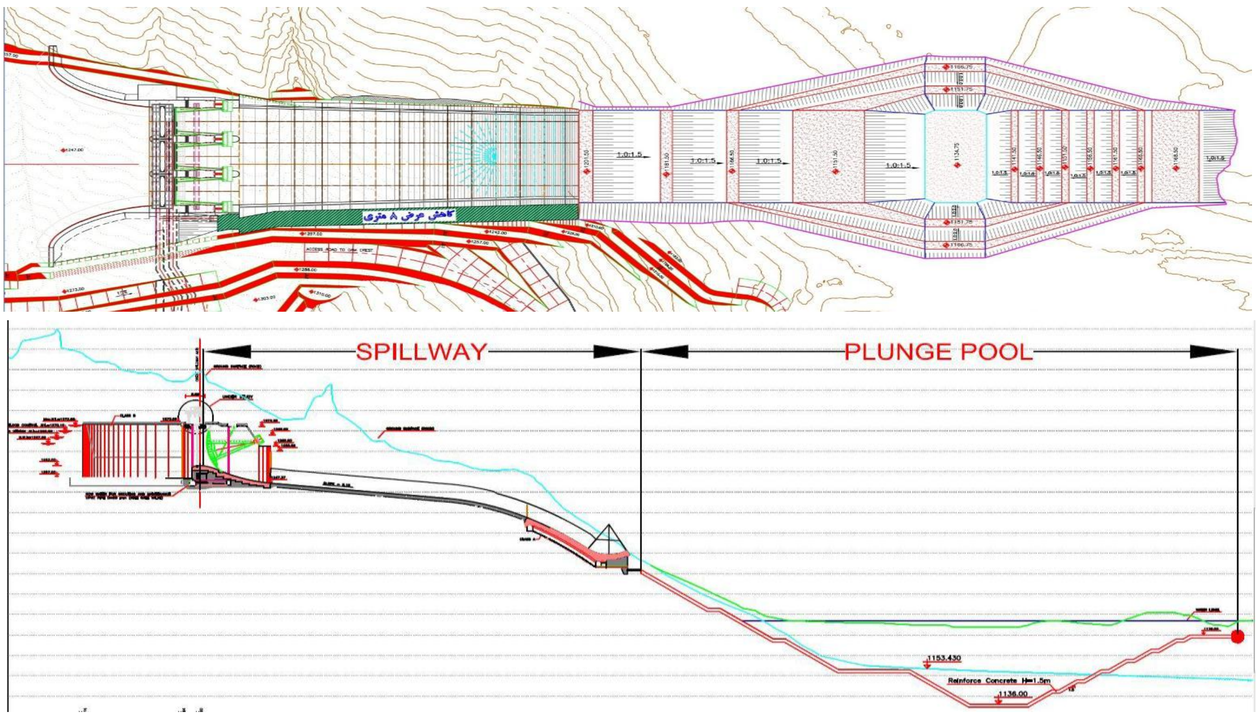

Figure-1: the Spillway Cross Sectional Geometry.

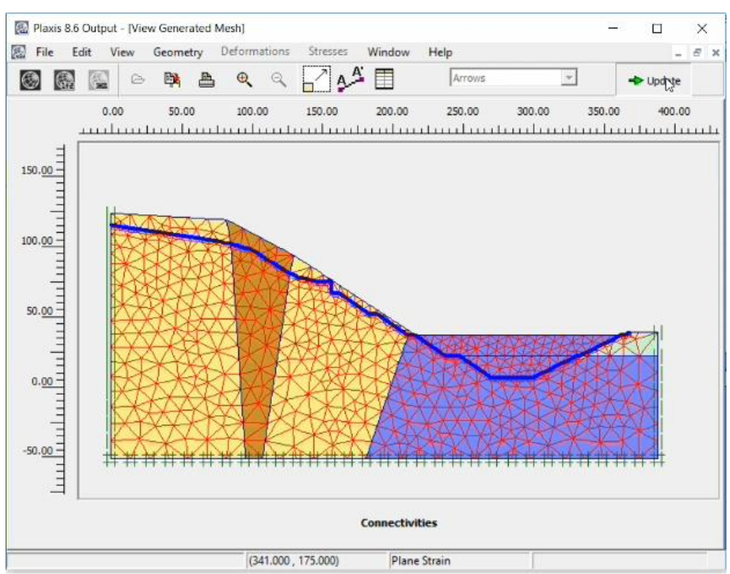

Figure-2: Specifying the interface.

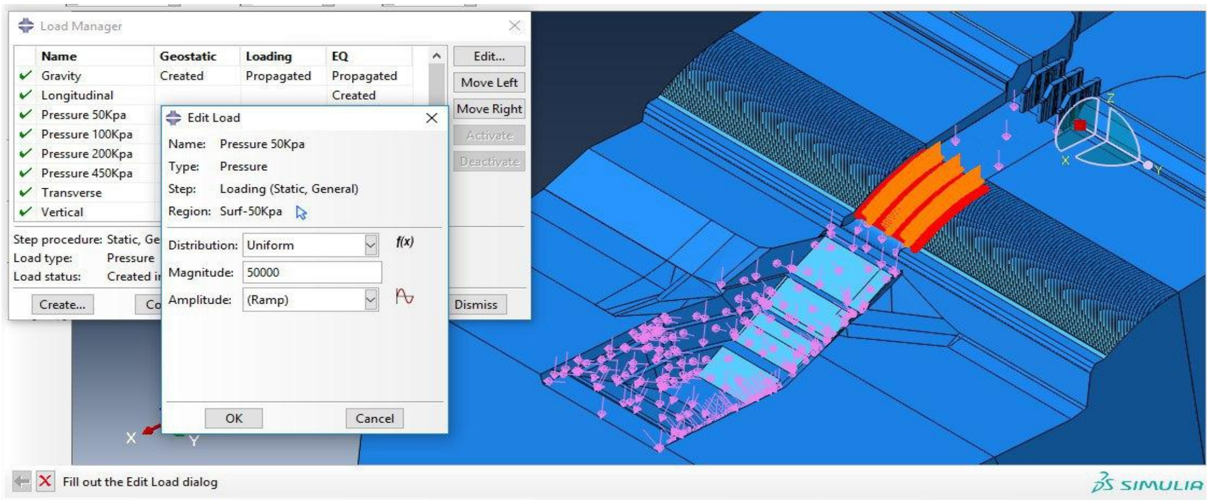

Figure-3: the hydraulic load on the main part of the spillway.

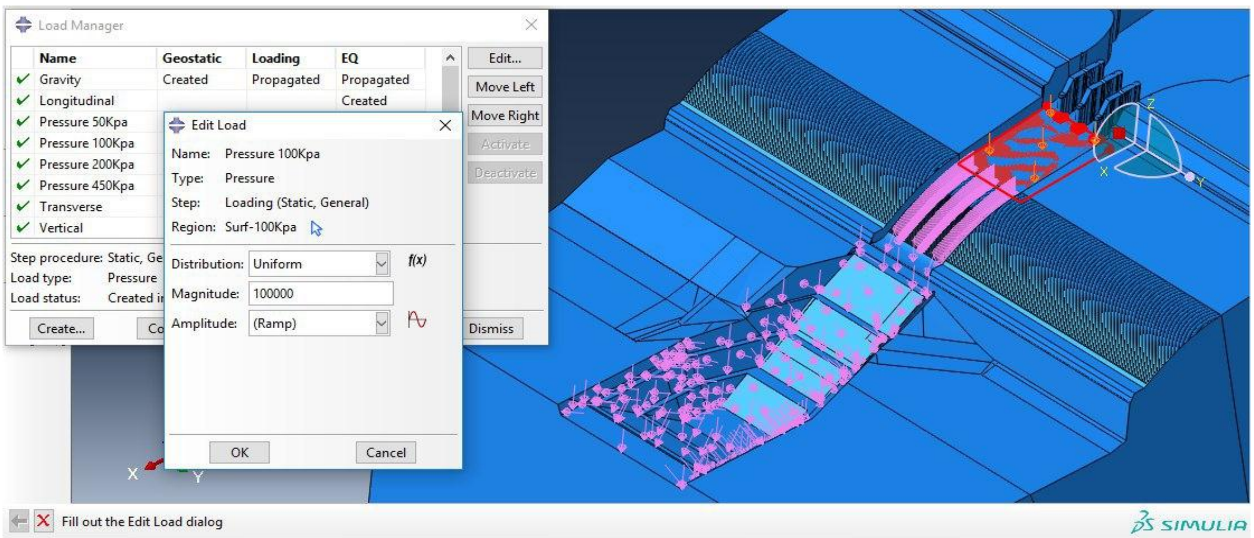

Figure-4: The hydraulic load on the upper part of the spillway.

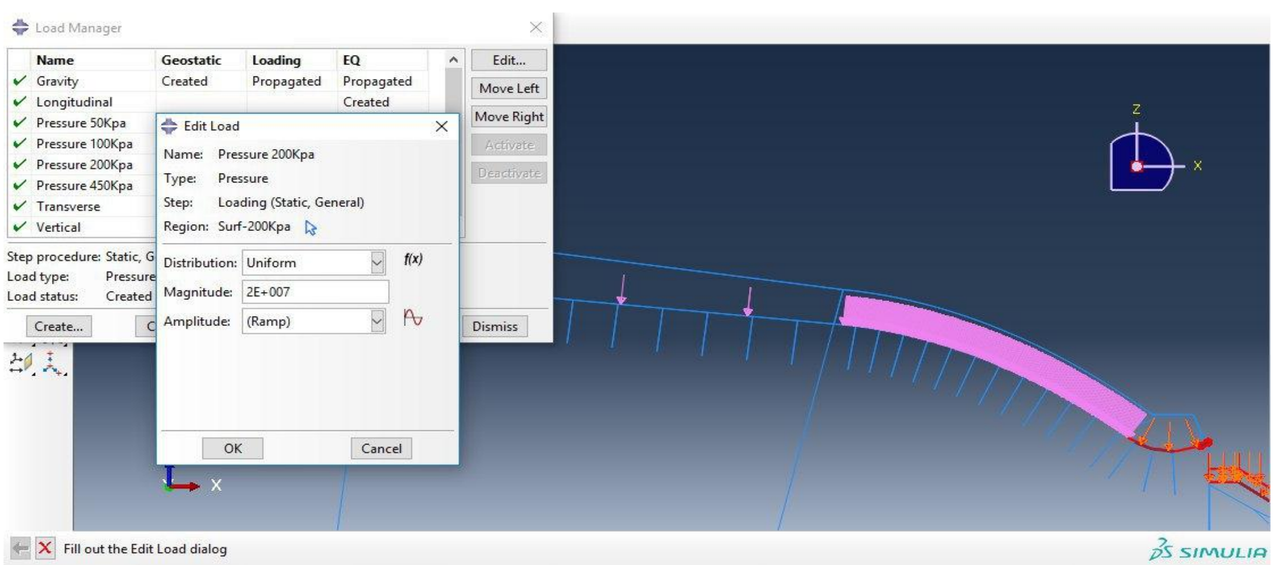

Figure-5: The hydraulic load on the flip bucket part.

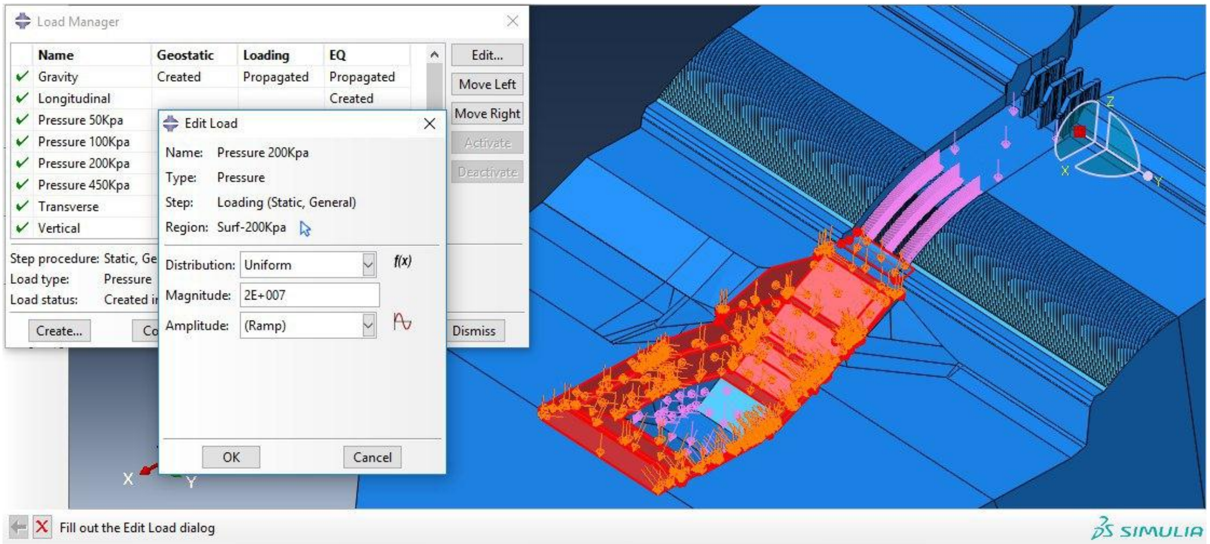

Figure-6: The hydraulic load on berms.

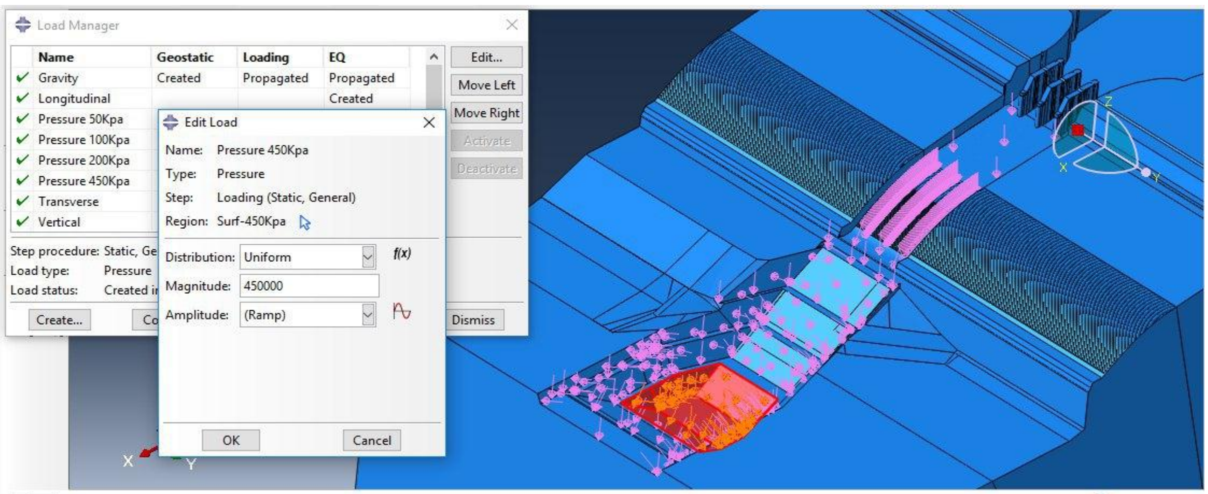

Figure-7: The hydraulic load on the bottom part of the Plunge pool.

Applying the Earthquake Records: The analysis chosen for this project is the dynamic analysis of the time history. At this step, the corrected accelerographs should be introduced to Finite Element software.

There are two kinds of analysis used at this phase; implicit and explicit. Explicit analysis has a very short time step and can be used to model blast pulse. In implicit analysis, however, the time steps are longer, so they can be used in this design.

In this phase, the input earthquake should be entered and so should be the strong motion duration in Significant Duration part (the middle 90% of the graph) Also the amount of the increment Size determined according to the ΔT of the input earthquake should be entered in the incrimination part.

The first accelerographs should be filtered in Seism signal software before being corrected so that their frequency dimension could be increased. The two figures of 0.1 and 9 Hertz have been selected for the low and the high dimensions of the frequencies respectively.

The earthquake accelerograph should begin at movement 0 and end at movement 0. At this phase, integration constant is added and it wouldn't allow the spectrum to reach 0. Therefore to stop it, the Apply Base Correction option in the Base line correction part should be activated with a tick mark.

After that, the dynamic analytical modes of time history was introduce and considering the strength motion based on the seismological data from the studied area (step: 13.52 in general, increment size: 1352), the earthquake accelerations were applied to the model after scaling it in three directions. Then the boundary conditions, the partitions and meshing were introduced and applied. What to do next was to study the results achieved after the analysis of the model.

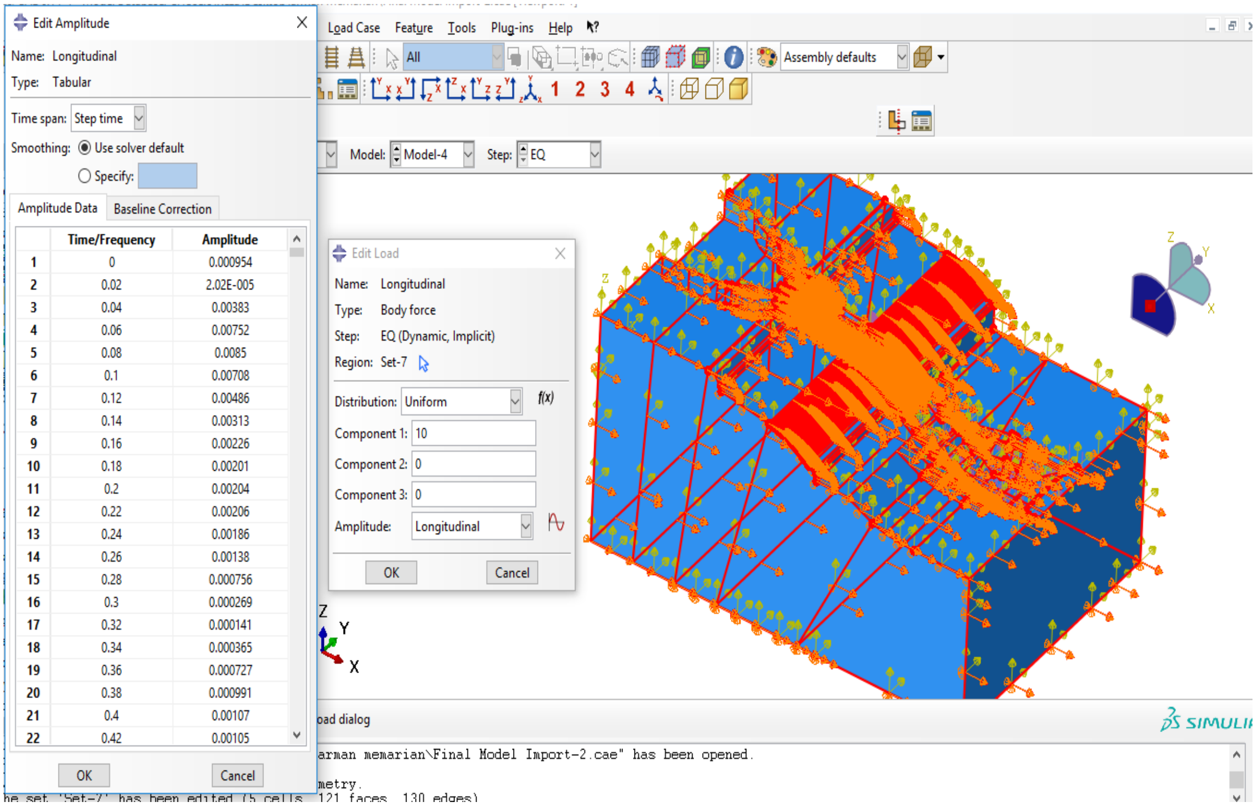

Figure-8: applying the records in X direction to the model.

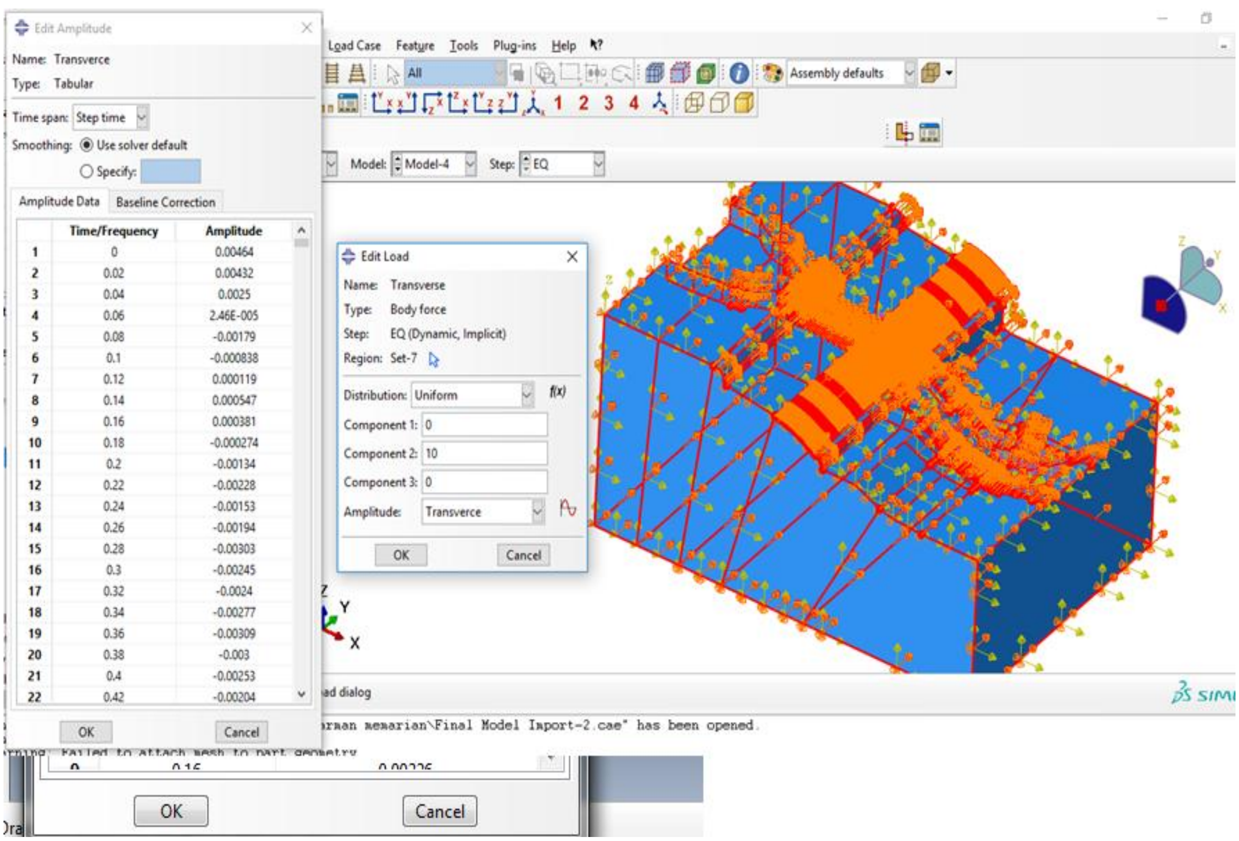

Figure-9: applying the records in Y direction to the model.

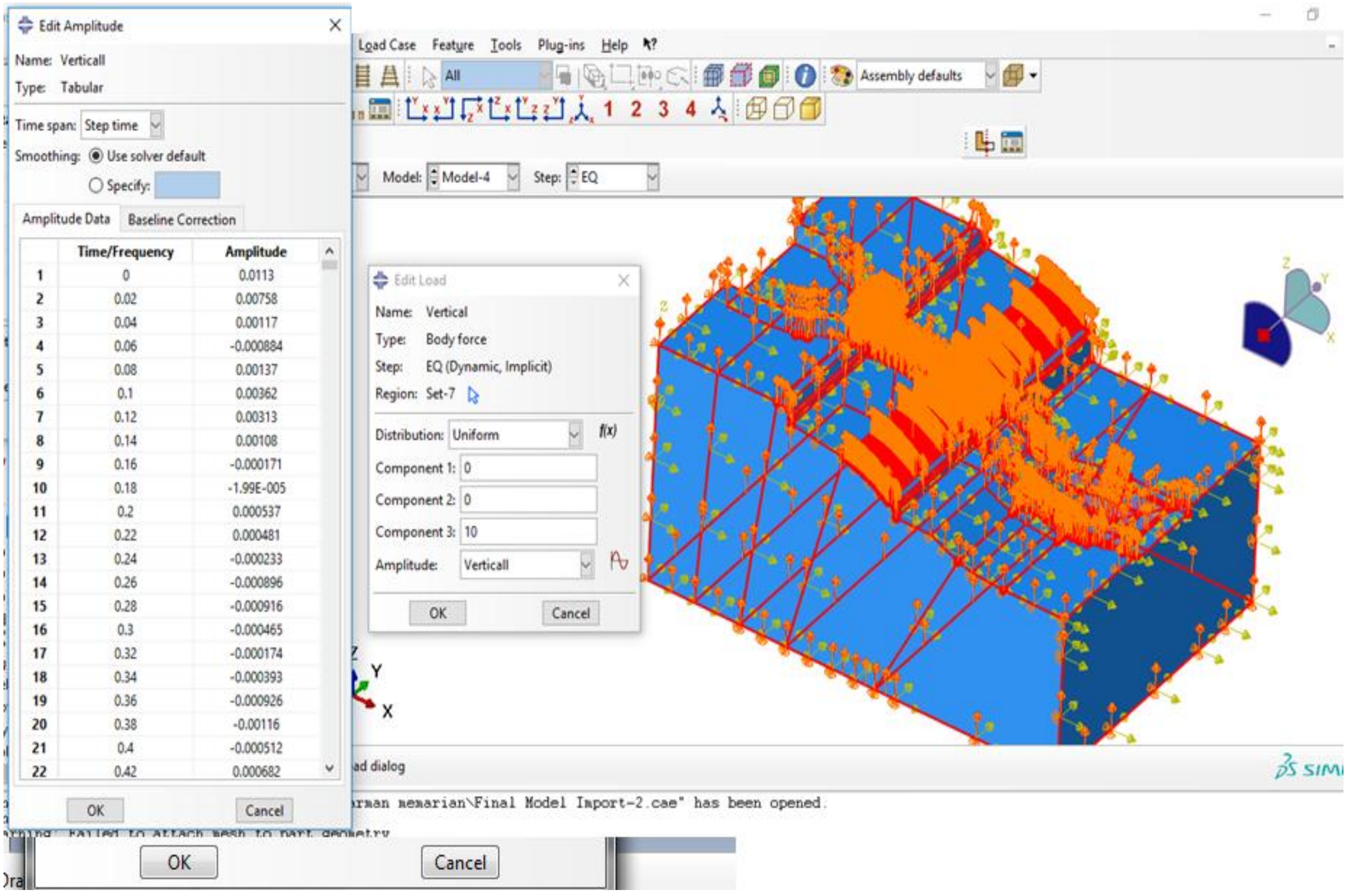

Figure-10: applying records in Z direction to the model.

Results and discussion

The deformation results of longitudinal section analysis in Plaxis software.

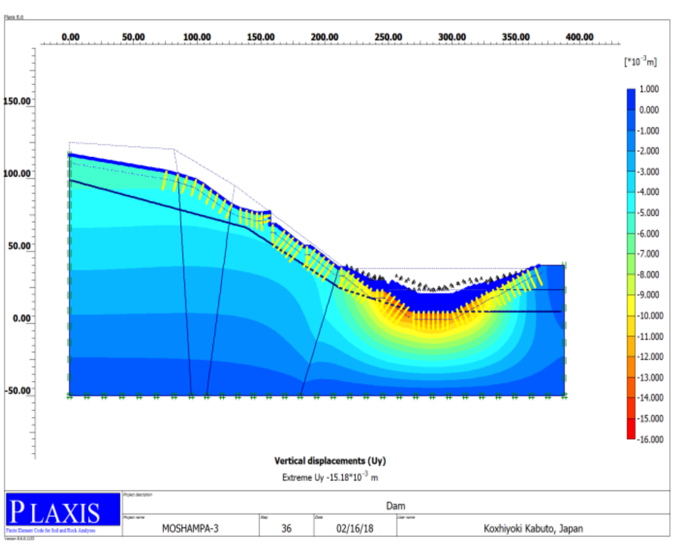

Figure-11: Vertical deformation (subsidence) of the pool and the surrounding soil (maximum subsidence at the floor of the pool being 16mm).

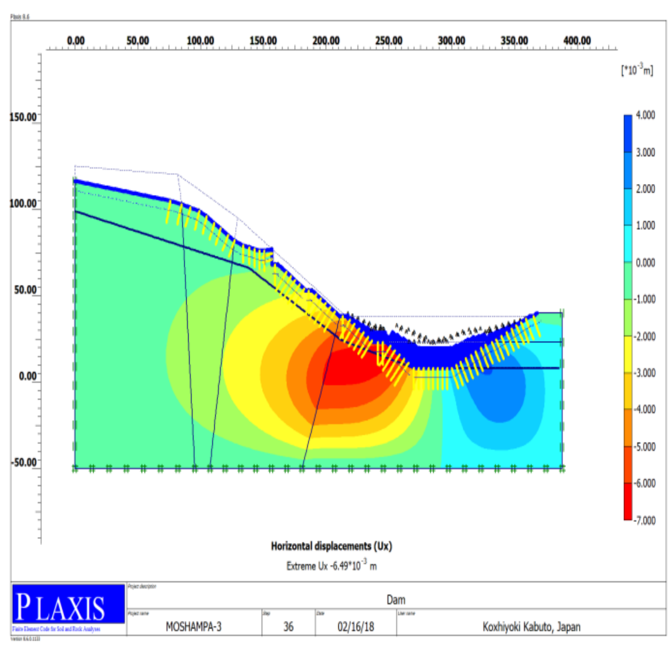

Figure-12: Horizontal deformation of the pool and the surrounding soil (maximum deformation at the bottom of the pool being 7mm).

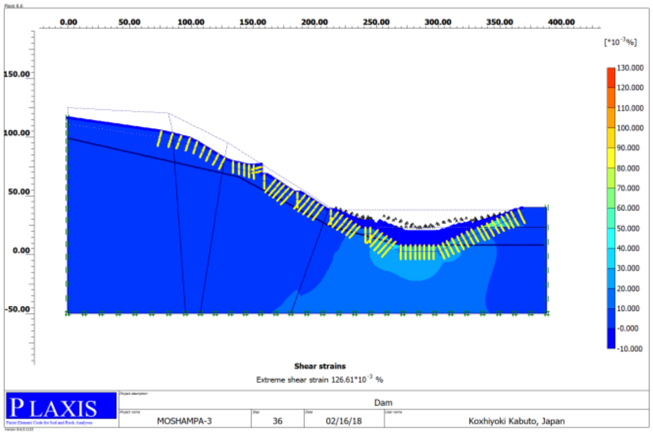

Figure-13: Relative shear strain formed.

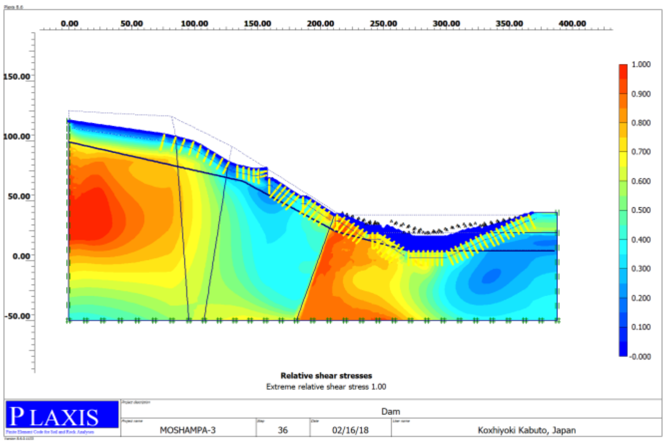

Figure-14: Relative shear stress formed.

As the images illustrate, the maximum horizontal displacement, subsidence of the wall and the floor of the pool have been limited to 7 and 6 mm respectively, that are within the acceptable range.

The Results of the Analysis Performed on the Spillway Model in Finite element Software.

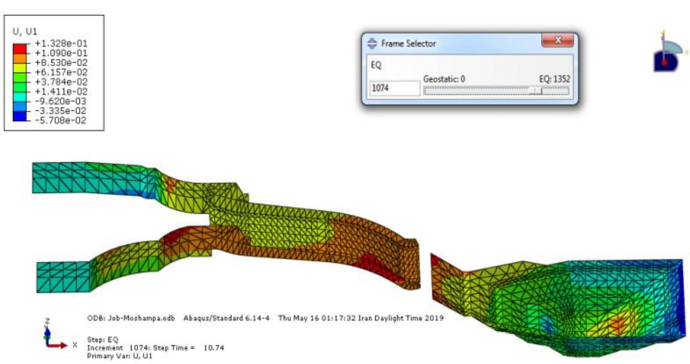

Figure-15: The amount of U1 displacement in the structural part of the spillway, time step: 10.74.

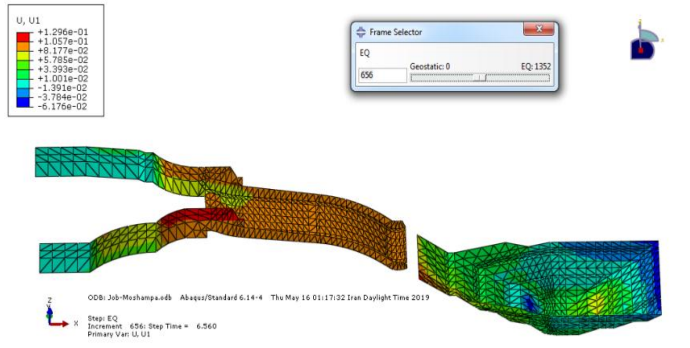

Figure-16: The amount of U1 displacement in the structural part of the spillway, time step: 6. 56.

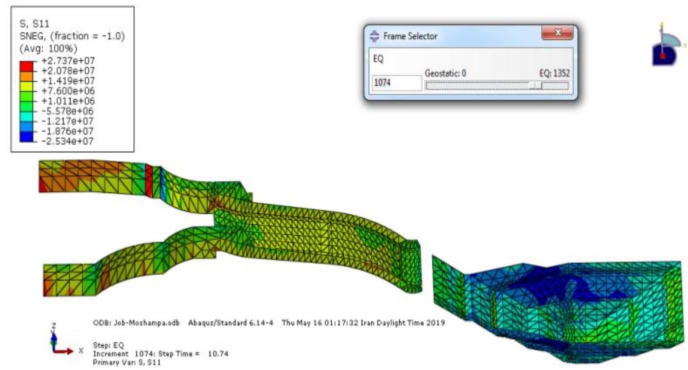

Figure-17: The amount of S11 stress in the structural part of the spillway, time step: 10.74.

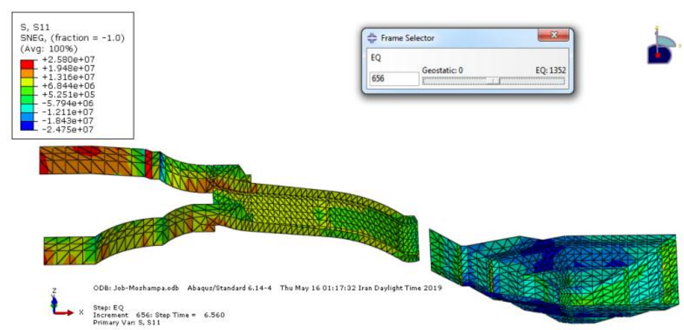

Figure-18: The amount of S11 stress in the structural part of the spillway, time step: 6.56.

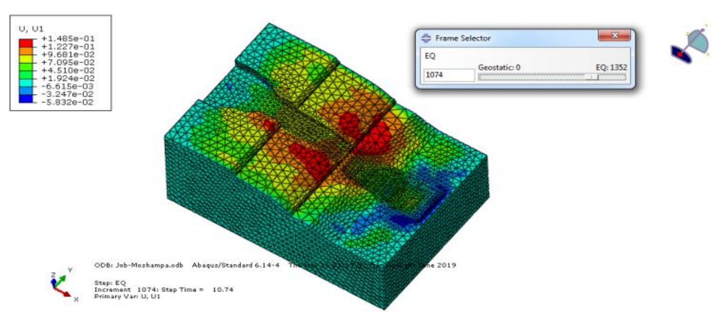

Figure-19: The amount of U1 displacement in the general model, time step: 10.74.

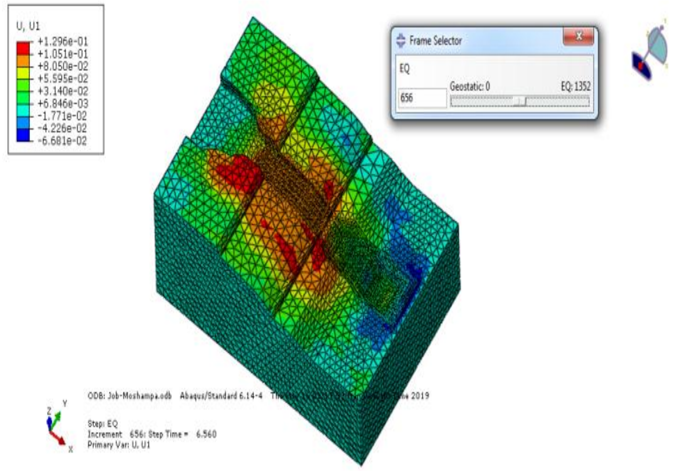

Figure-20: The amount of U1 displacement in the general model, time step: 6.56.

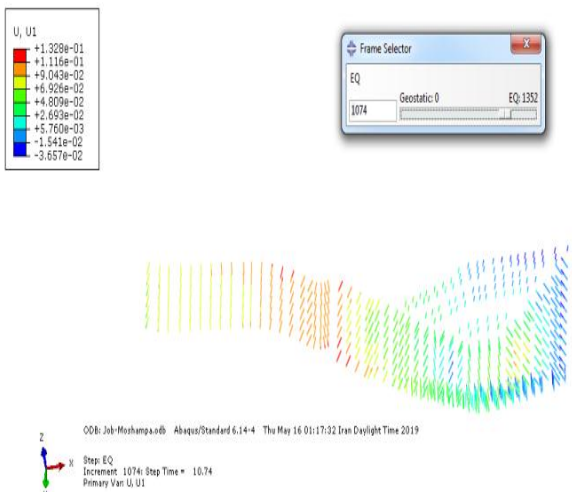

Figure-21: The amount of U1 displacement in the rock bolts, time step: 10.74.

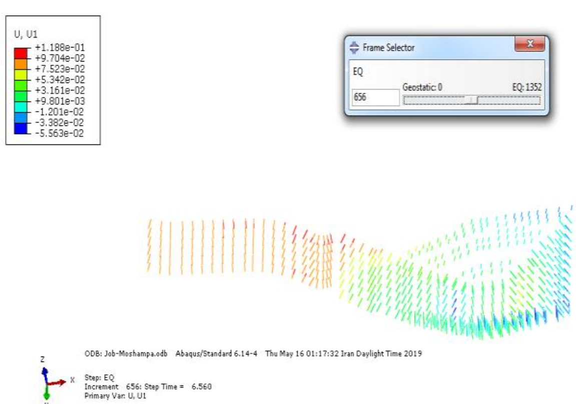

Figure-22: The amount of U1 displacement in the rock bolts, time step: 6.56.

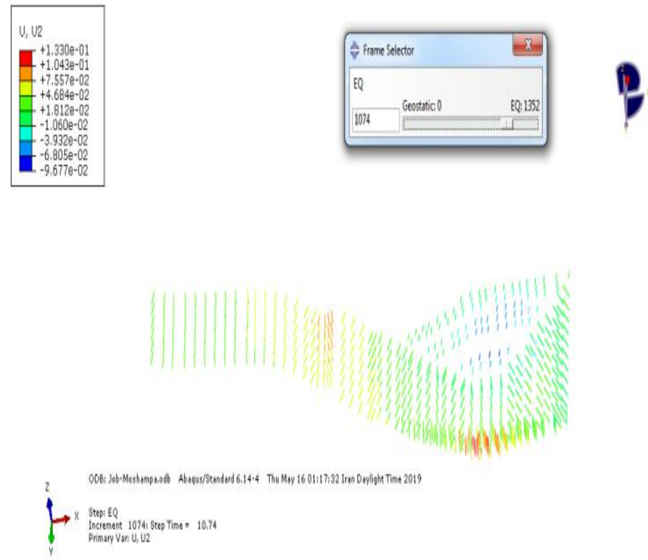

Figure-23: The amount of U2 displacement in the rock bolts, time step: 10.74.

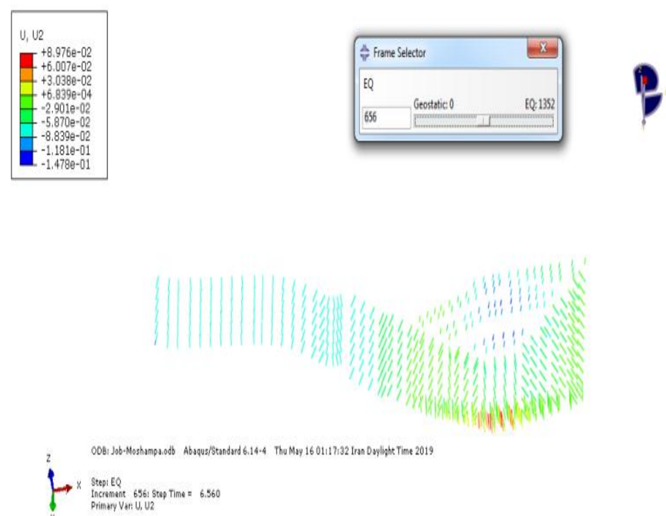

Figure-24: The amount of U2 displacement in the rock bolts, time step: 6.56.

Take note that all the outputs mentioned above have been illustrated at the two time steps of 6.56 and 10.74 that showed the highest amount on the accelerograph of that area.

The results from the design of the Spillway and Plunge pool: After analyzing the spillway and the plunge pool model in finite element software, it's time to design a model. The model is designed by considering a two way slab for the spillway and the basin berms. The first step was to extract all the moment forces from both directions out of the finite element output to design a way slab. The shear were extracted to be designed. The density of the slabs was considered 10*10 with regarded to the resistibility of the concrete in all the seams of the model and the slabs were designed based on the most moments.

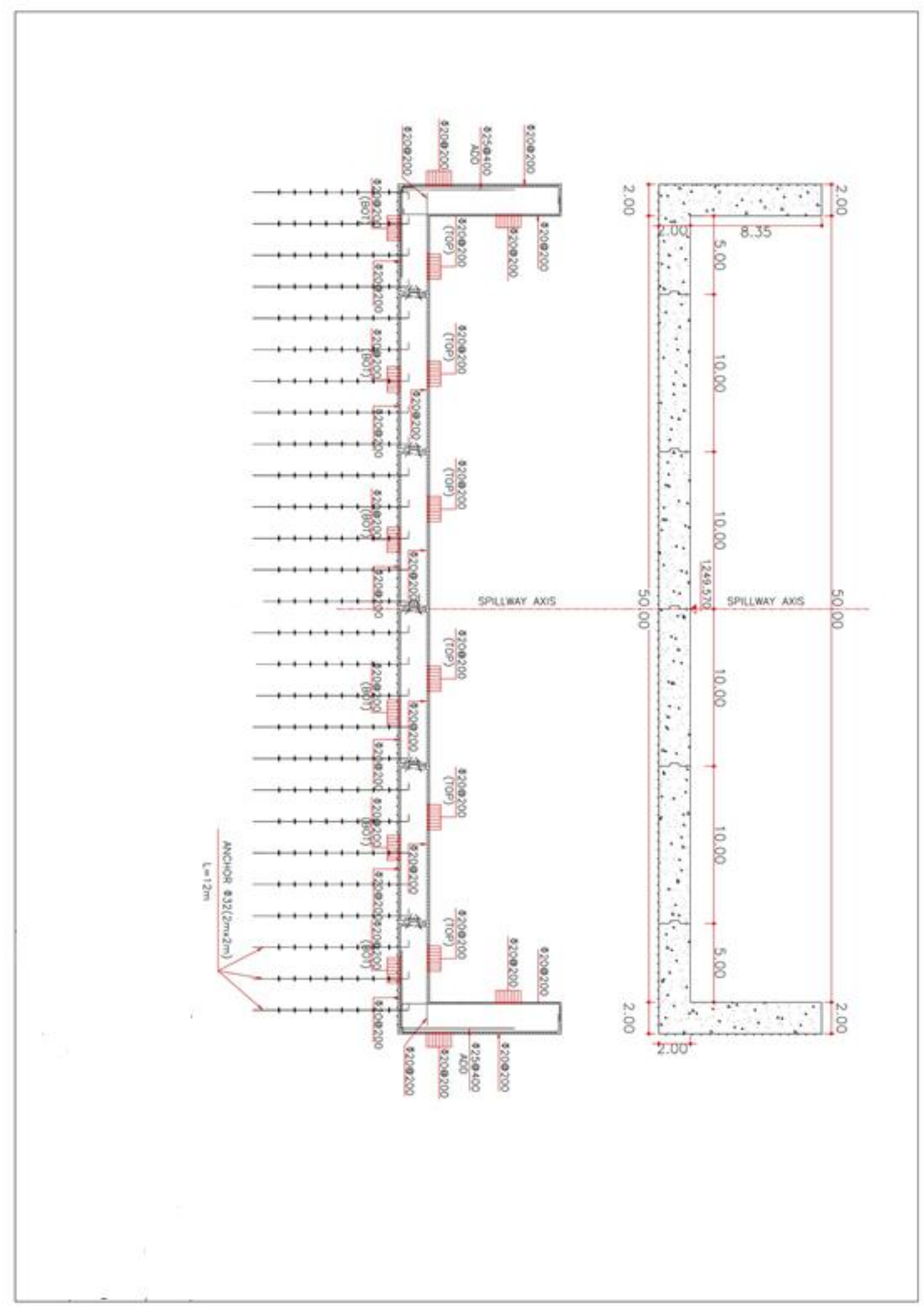

Figure-25: Reinforced Section of Spillway.

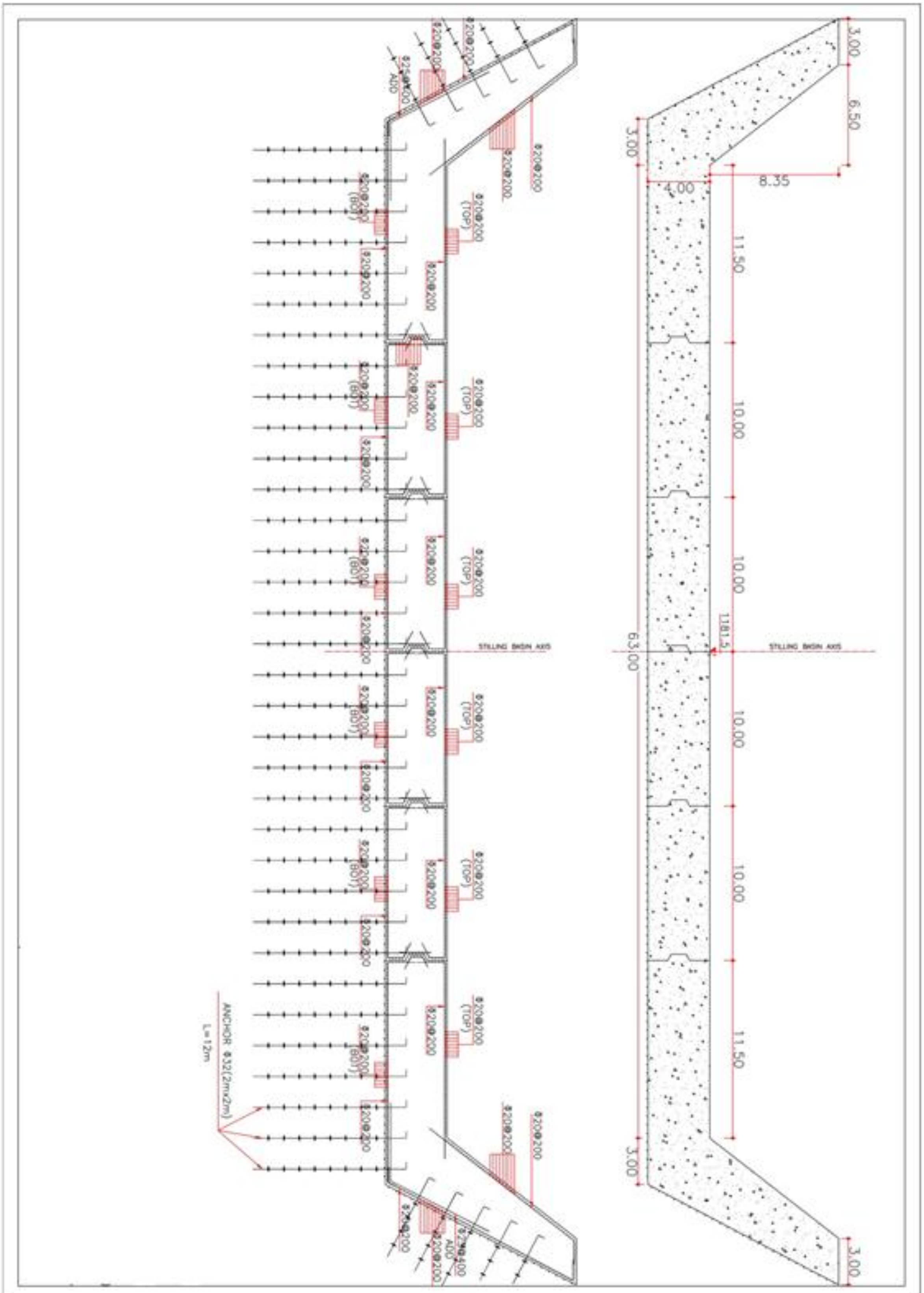

Figure-26: Reinforced Section of Berms.

Conclusion

According to the achieved results: i. The maximum horizontal displacement, subsidence of the wall and the floor of the pool have been limited to 7 and 6 mm respectively, that are within the acceptable range. ii. Also considering the results of the dynamic analysis of the pool and the spillway, it is made clear that the above mentioned pool is resistant to excavation and water force and the amount of subsidence and horizontal displacement is within the acceptable range. iii. By analyzing the model in in Finite element software, it is concluded that the outputs of displacement U, stress S, velocity V and SM are within the acceptable range and taking the structure soil interaction into account and with the ascribed density, the structure can tolerate the hydraulic load and the earthquake force (time history analysis).

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