Technium Vol. 2, pp. 56-65, (2020)
ISSN: 2668-778X
www.techniumscience.com

Evaluation of safety in arch dam using post analysis including inertia force and temperature variations of water

Alaa Jabbar Rahman[1] , Ali Majdi[1,2], Wissam Khlaf Obied[1]
[1]Technical University of Civil Engineering of Bucharest, [2] Al-Mustaqbal University College, Hilla / Iraq
alaajabbar2017@gmail.com,alimajdi@mustaqbal-college.edu.iq,
wissam.obiedko@gmail.com

Abstract. Dams considered as one if very important infrastructure, they are lifeline structures and have a vital role our economics and social life. A concrete gravity dam is one of wide used dam worldwide, it constructed from reinforced concrete and his typical cross section is triangular, the other type is arch section. A gravity dam can be combined with an arch dam into an arch-gravity dam for areas with massive amounts of water flow but less material available for a purely gravity dam. The inward compression of the dam by the water reduces the lateral (horizontal) force acting on the dam. Thus, the gravitation force required by the dam is lessened, i.e. the dam does not need to be so massive. The aim of this paper is to obtain a preliminary post analysis for an arch gravity dam by considering of typical applied loads that effects on it. In order to check and verify the dam and ensure the assumptions used during this process, the dam is analysed in different type of major effects such as own weight, water pressure, temperature and static load intertie generated from seismic load. These loads are presented in this paper in different cases, totally five cases combined between all these factors as explain in details in the section of methodology.To achieve the target of this study, modelling of an arch dam, reservoir and foundation provided by finite element using software ANSYS. An arch dam with height of 41.5 m is studied in this paper to simulate the reality of the future dam that will be erected as accurate as possible. The response of the dams is represented by the maximum displacement of it and also the stresses in each case. The results of all analysis were compared in the five cases mentioned above to determine the impact of each case as well as the worst case affecting the safety of the dam.

1. Introduction

An arch dam is a curved dam that carries a major part of its water load horizontally to the abutments by arch action. If the dam has moderate thickness and curvature, such that vertical cantilevers carry a significant part of the water load, the dam is called an arch-gravity dam. An arch dam obtains its stability by both the self-weight and, to a great extent, by transmitting the imposed loads by arch action into the valley walls. The geometry of the dam site is, therefore, the most basic consideration in the selection of an arch dam. As a general rule, an arch dam requires a site with abutments of sufficient strength to support the arch thrust. On special occasions, artificial abutments - thrust blocks - may be used in the absence of suitable abutment. [1]. the stability of arch dams depends so largely on the strongly nonlinear hydro-mechanical behavior of the weakest zones localized on the dam body and the foundation rock discontinuities. These critical regions are mainly the foundation faults zones, the dam concrete lift lines, the contact between concrete and foundation rock, and the contraction joints between the cantilevers of the dam [2]. Arch dams are constructed as vertical monolithic cantilever elements separated by contraction joints which are grouted with mortar. They are used to release the thermal stresses generated from concrete hydration during the construction phase, and thermal loads after use. They minimize the formation of tensile cracks due to shrinkage of concrete [3]. in this paper study the linear elastic behavior of concrete arch dams during Static analysis the monolithic structure by applying the associated static loads (excluding gravity) simultaneously or separately, and the equivalent static analysis, from the dynamic point of view the only complete result is the dynamic response of the structure at free vibrations shapes and periods, this means a modal analysis.

Water resources development in Iraq started long ago and by the present time has reached a high level. In the most populated areas of river basins the natural water resources had already been developed by the middle of the last century, which necessitated construction of large regulating reservoirs, such as Habbaniya, Tharthar, Dokan, Der-bandikhan, Mosul, Hdeetha, and Udhaim.

The main function of these reservoirs is annual flow control, admitting surplus water in the winter-spring period and releasing it in the low water period of summer and autumn (seasonal regulation). Besides, large reservoirs are designed to have an extra capacity for reserve supplies allowing accumulation of some of the river flow in years with abundance of water and its use in dry years (many-year regulation) [4].Due to dams built in neighbouring countries, and a lack of common management practices, peak flows in Iraq do not coincide with the country's water needs. This problem will become worse with time as demand increases due to the increasing population, the unpredictable effects of climate change and extreme weather events. Therefore, the Iraqi government decided to build several dams to increase water storage capacity. We suggest that this dam be one of the dams on the Khabour River in Iraq."[5].

2. Literature

Many references studied the evaluation of safety in the arch-gravity dam, whether relevant to FE applications or experimental tests. Dawlatzai and Dominic [6] studied two dimensional stability analysis of a non-overflow section of the Koyna dam with maximum height of 103 m by using two methods, first using the Gravity method of analysis which is a rational analysis and 2D finite element model of the dam is simulated using ANSYS to obtain the stresses.In 2002, the literature studied the Statistical models are based on correlations between environmental factors (reservoir water level, ambient temperatures, wind) and dam responses (displacements, pressures, stresses). These correlations are estimated by performing a statistical analysis of historical data [7]. Another research studied presented the results of the collected data, namely inclination, temperature and reservoir level. The inclination measurements were taken in connection with a test on a fully automated geodetic system for continuous monitoring of displacements. Using regression models, a good correlation was observed between the variations in the inclination with temperature and with changes in the reservoir level of Cabril dam. Inclination J Civil Structural Health Monitoring measurements were conducted for two days during which temperature was also measured on the downstream of the face of the dam. The study showed that temperature and water levels influenced the structural behavior of the dam. The authors noted that there were some variations in the components of the inclination, which cannot be explained by the regression models used. Demirkaya and Balcilar [8]. The literature [9] studied the dynamic monitoring approach, structural responses in form of accelerations due to vibrations are measured. Accelerations are obtained using either forced vibration tests or ambient vibration tests.

3. Methodology

Three-dimensional FEA is preferred for the static and dynamic analysis of arch dams. The trial load method is deemed outdated, but may still be used for preliminary static stress analysis only if the dam has uniform material parameters and a simple geometry can be considered for the foundation rock and the concrete in a low hazard area. Other mathematical approaches and formulations can also be employed, but the accuracy of such methods should be verified by comparison with the FEA. With the development of the FEM, the advances in dynamic analysis procedures and the availability of high capacity computers, the older traditional methods of analysis have been abandoned. The use of the FEA technique, with its versatility and capability to deal with structural, geotechnical and fluid aspects, allowing a higher realistic analysis of virtually any type of dam, has become the standard practice for dam design and analysis. Different elements have been used in the past to model arch dams, including solid elements and shell elements. Shell elements (with five or six degrees of freedom) are consistent with the behavior of the dams; however, they are unable to accurately model stress distribution through the dam thickness. Therefore, three-dimensional brick/solid elements (with three degrees of freedom) are now routinely used for the analysis.The performed different solutions for these combinations of loads, actual, performed Own-weight first considered only Own-weight, then only Pressure and only inertia force then combined them, because every solution was considered and saved as a different load case.These load cases are loaded again in the model and combined, because we can be combined the load cases having in mind effect the state of materials, all the materials of our model in the rock masses and in the dam are always in linear elastic state, so this is why we can apply this procedure of adding the effects, it is a possible only in linear elastic state of the materials if the loads, for example, are creating a state of stress which is above elastic limit of the materials, then, that's mean we have also post-elastic regions in the model cannot combined the effects, because the effects of the solution will depend on the load path, it is more complicated, but it is allow to do it because the materials are in linear elastic state. By switching (solid 70) to thermal field analysis. SOLID70 has a 3-D thermal conduction capability. the fact that we consider the constant temperature in the reservoir, so the upstream face is subjected to constant temperature and the downstream and the crest temperature in contact with the air are available temperature.Extreme values of air temperature are considering as well as a constant temperature in the reservoir, so the upstream face is subjected to constant temperature with 4 degrees Celsius and the downstream and the crest temperature in contact with the air are vary dramatically of 25degreesCelsius in summer and -15 degrees Celsius in winter.

The effect of the earthquake -dynamic analysis- is represented in this study as an equivalent static analysis by inertia load, this load is derived from equilibrium equation of motion for the entire structure in dynamic case according to Newton's laws of motion. Inertia force is a result of the product of the ass of the dam and the acceleration due to gravity (g) with considering of the effect of the seismic load (α). This force is act in a direction opposite to the acceleration caused by earthquake forces.
To simulate a realistic situation in the north of Iraq where the designed dam is expected to construct, the value for the peak ground acceleration 0.24g is selected.

To summarize the major effects on the dam, the load combinations are selected according to field experience. The most interesting cases and give results through which examine the body of the dam and the risk that maybe exposed. [10]. These cases are:

- Case I: Combination of Own weight + Pressure of water is used in static analysis
- Case II: Load case combination of own weight + pressure + inertia in upstream-downstream direction when reservoir is full
- Case III: Load case combination of own weight + pressure + inertia in left bank-right bank direction when reservoir is full
- Case IV: Load combination of own weight + pressure + summer temperature
- Case V: Load combination of own weight + pressure + winter temperature)

4. Description of the arch dam
The arch dam modelled in this study has main characterises shown in table 1.

Table 1: Main characteristics of the dam

Parameter	Dimension (m)
Height of the dam	41.5
Length of the crest	110
Span of the crest	96.3
Thickness of crest	2
Thickness of the bottom	5

And the specifications of the materials used are shown in table 2.

Table 2: material properties of the arch dam

Type	Material	Modulus of Elasticity (Kpa)	Density t/m^3	Poisson ratio
Dam structure	Concrete	2.4×10^6	2.4	0.18
Plinth	Concrete	2×10^6	2.4	0.2
Left rock	Rock	3.5×10^6	2.65	0.25
Right rock	Rock	5.5×10^6	2.65	0.25

5. Modelling of the arch dam by ANSYS software

The modelling the dam in ANSYS software performed by more steps, the main steps that highlighted here is the boundary conditions and additional mass from water pressure. For the boundary conditions, the displacement along the lateral limits of the model along X and Y directions (Ux and Uy) while for the vertical displacement I assigned on Z direction simple support U as shown in figure 1.

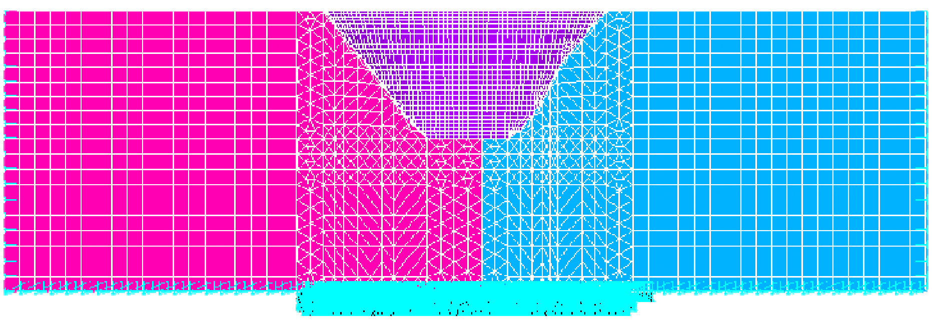

Figure 1: Boundary conditions

As illustrated in figure 2, water pressure presented by divided the water pressure into six strips with different masses from the height of it, then computed the volume of these masses for each node

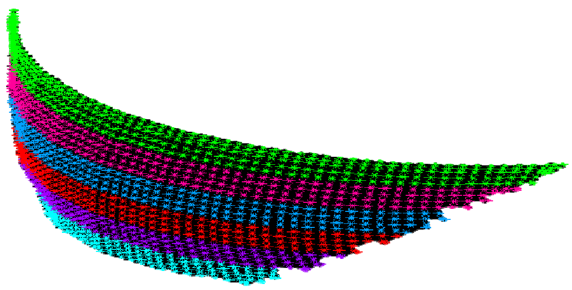

Figure 2: Additional masses of water pressure

The final model of the arch dam is shown in figure 3. Solid45 element and the Type Mass 21 for additional masses are used for concrete to structural analysis were calculated first; then, the distributions of thermal were performed by switching solid70.

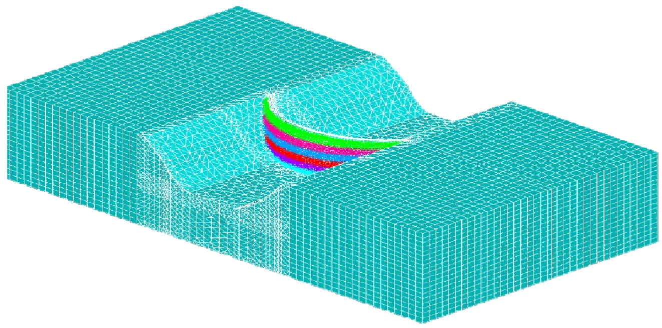

Figure 3: 3D Model of the arch dam

6. Results

The following subsections from 6.1. to 6.5. shows the results in graphical presentations of the horizontal and vertical displacements as well as the stresses results from the analysis in each case of loads.The maximum values obtained from these results are listed in table 3 and as well as in charts in figures 9 and 10.

6.1. Case I: Combination of Own weight + Pressure of water

The results obtained from case I are shown in figure 4, where a) is the Horizontal displacement in upstream-downstream direction (Ux) measured in meter, b) is the vertical displacement (Uz) measured in meter, c) is the horizontal displacement in leftbank - rightbank direction (Uy) measured in meter, d) is the vertical stresses distribution on upstream and downstream faces (Sz) measured in Kpa, e) is the principal tension stresses distribution on upstream and downstream faces (S1) measured in Kpa and f) is the principal compression stresses distribution on upstream and downstream faces (S3) measured in Kpa.

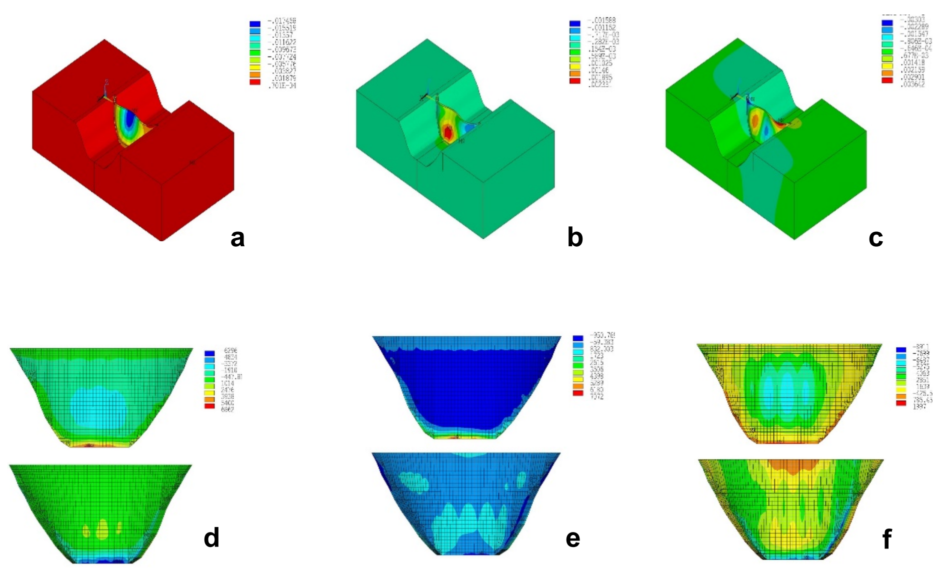

Figure 4: Displacement and stresses results from case I

6.2. Case II: Load case combination of own weight + pressure + inertia in upstream-downstream direction when reservoir is full

Figure 5 illustrates the results that caused by load combination in case II, where a) is the Horizontal displacement in upstream-downstream direction (Ux), b) is the vertical displacement (Uz) measured in meter, c) is the Horizontal displacement in leftbank-rightbank direction (Uy) measured in meter, d) is the vertical stresses distribution on upstream and downstream faces (Sz) measured in Kpa, e) is the principal tension stresses distribution on upstream and downstream faces (S1) measured in Kpa and f) is the principal compression stresses distribution on upstream and downstream faces (S3) measured in Kpa.

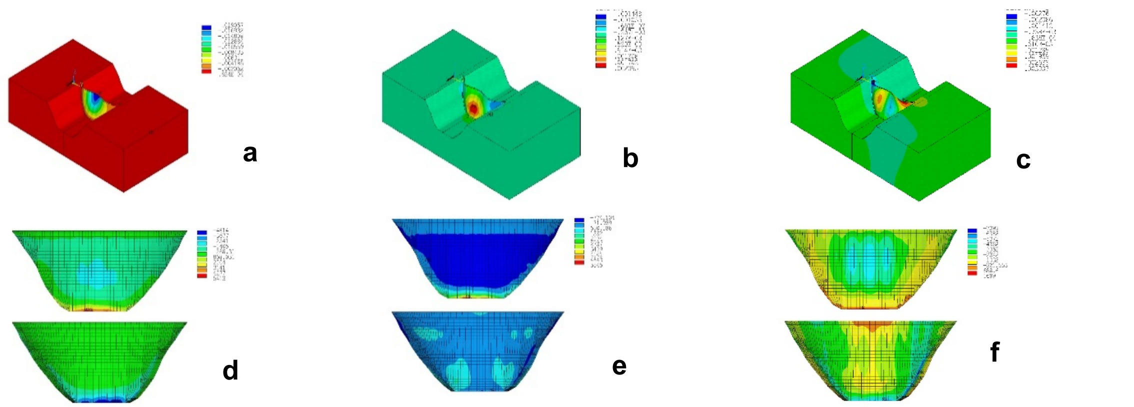

Figure 5: Displacement and stresses results from case II

6.3. Load case III: combination of own weight + pressure + inertia in left bank-right bank direction when reservoir is full

The results of the load case III are shown in figure 6, the a), b), c), d), e) and f) are represent the same values like results in case II. That is also applied for cases IV and V.

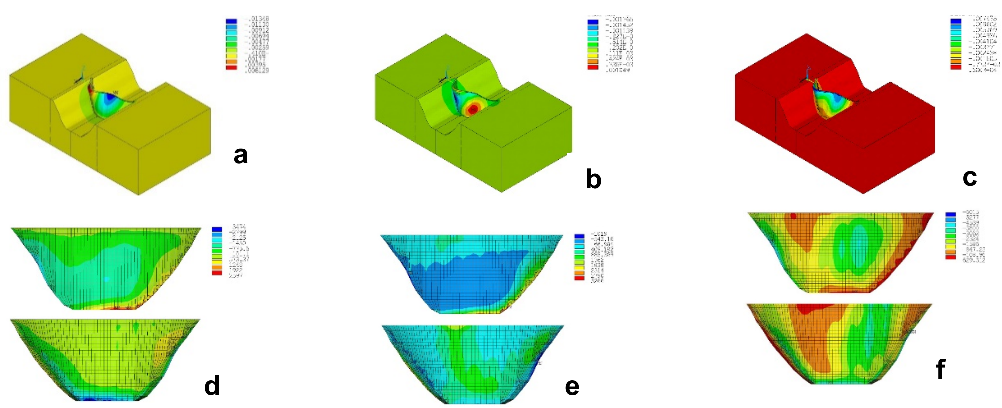

Figure 6: Displacement and stresses results from case III

6.4. Load case IV: LOAD COMBINATION of OWN WEIGHT + PRESSURE OF WATER + THERMAL FIELD EFFECT IN SUMMER

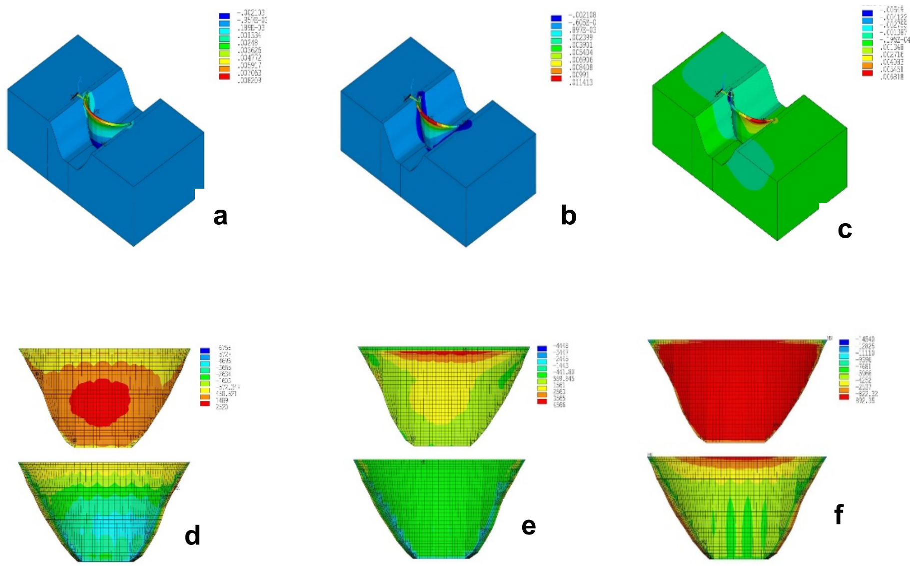

Figure 8: Displacement and stresses results from case IV

6.5. Load case IV: LOAD COMBINATION of OWN WEIGHT + PRESSURE OF WATER + THERMAL FIELD EFFECT IN WINTER

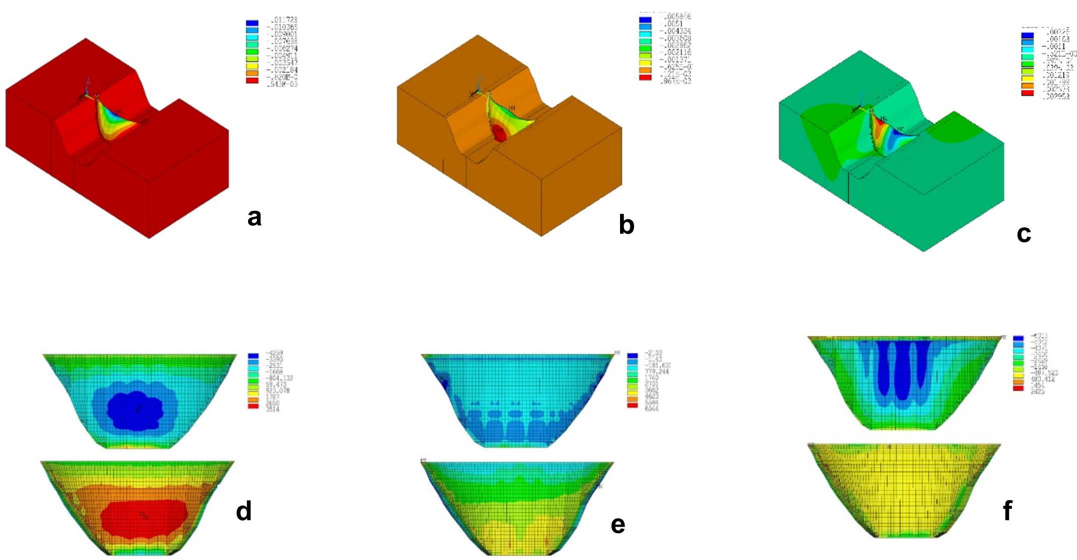

Figure 7: Displacement and stresses results from case V

6.6. Comparison of the results

The maximum values of displacement and stresses are shown in table 3 and in the charts illustrates in figures 9 and 10 respectively.

Technium Vol. 2, pp. 56-65, (2020)
ISSN: 2668-778X
www.techniumscience.com

Table 3: Maximum values of displacements and stresses in each load case

Case	Load Combination	horizontal dis. (m)	vertical dis.(m)	vertical stress (Kpa)	Principal Stress (tension) (Kpa)	Principal stress (compression) (Kpa)
Case I	COMBINATION OF OWN WEIGHT + PRESSURE OF WATER	0.017	0.0023	6862	7072	8911
Case II	OWN WEIGHT + PRESSURE + INERTIA IN UPSTREAM-DOWNSTREAM DIRECTION WHEN RESERVOIR IS FULL	0.019	0.002	5413	5545	7393
Case III	LOAD CASE COMBINATION (OWN WEIGHT + PRESSURE + INERTIA IN LEFT BANK-RIGHT BANK DIRECTION WHEN RESERVOIR IS FULL)	0.013	0.0017	3474	3266	6015
Case VI	LOAD COMBINATION (OWN WEIGHT + PRESSURE OF WATER + THERMAL FIELD EFFECT IN SUMMER)	0.0114	0.008	6758	4566	14540
Case V	LOAD COMBINATION (OWN WEIGHT + PRESSURE OF WATER + THERMAL FIELD EFFECT IN WINTER)	0.0117	0.0058	4259	6544	6313

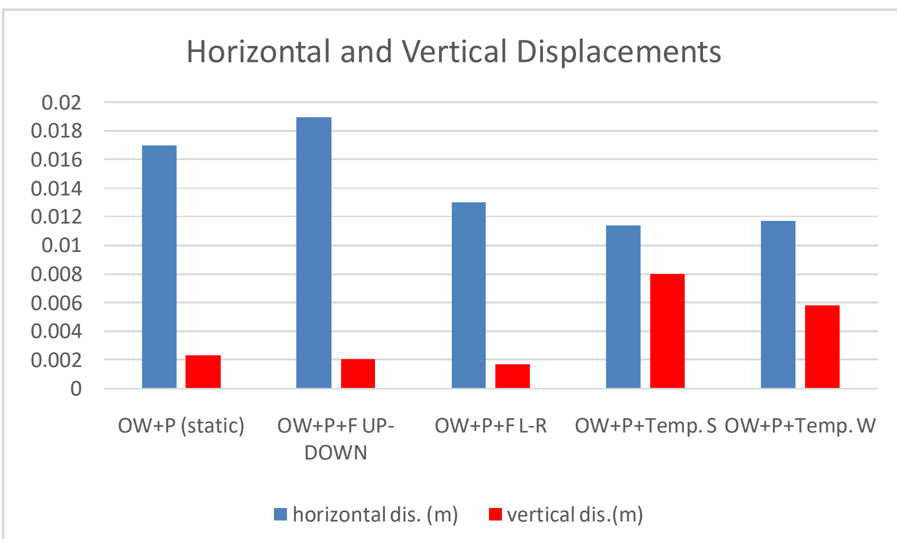

Figure 9: Comparison between the Horizontal and Vertical Displacements

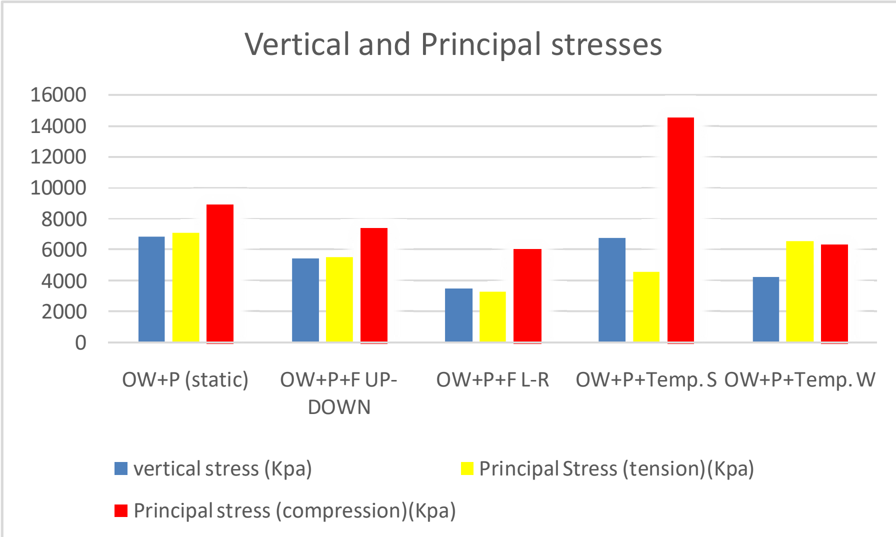

Figure 10: Comparison between the Vertical and Principal stresses

7. Conclusion

In this paper, the expected impact of the main forces on a hypothetical gravity arch dam that was modelled by the ANSYS softwarethat exposed after its erection. These forces included own weightof dam, water pressure, maximum external temperature of water in summer and winter and also seismic force effect, which was represented by inertia force. A small arch dam has been designed to simulate the future plans of the Iraqi authorities as accurate as possible. The amount of horizontal and vertical displacement as well as the vertical as well as principle tension and compression stresses were analysed by the effect of these forces on the dam. Five cases were examined, including the worst-case scenario the dam could be exposed to during its operation as described in the previous sections of this paper.

It was found from the results obtained that the effect of the combination of the forces in the second case, which represents the weight of the dam, the pressure of water and the inertia force in the vertical direction caused the largest horizontal displacement of the in compare with other cases, which has the value the horizontal displacement is 0.019 meter, that`s mean the drift ratio is less than 0.05% which indicate an acceptable ratio and does not caused majorcracks or other significant damages. The resulting of vertical displacement is very small and ineffective in all cases where the maximum value is 8 mm which caused in case four for combination between own weight, water pressure and temperature in summer. The results of the stress analysis show that the largest vertical stress as well as the largest basic tensile stress result from the first case under effects of the body weight of the dam and water pressure, which amounts to 6862 and 7072 respectively. The largest pressure effort occurs in the third case by the impact of the body weight of the dam and the pressure of water and the impact of temperature during the summer.Furthermore, the uplift pressure is neglected in this study because thebase arch dam is thin and the uplift pressure only effects on the base.

Finally, this study, along with other similar studies, is used to give a preliminary indication of which forces and factors are most affecting the safety of the dam, it is useful for the engineering staffwho responsible for the operation and maintenance of the dam to have a preliminary knowledge of the impact of these forces and will to take appropriate actions in the due timeforsafety of the dam. It is recommended that the engineering and technical authorities to perform this kind of analysis each time in case ofsignificantchangesin seismic data or external temperatures of water.

References

[1] Kronberg, R. J. 2011. Stability analysis of the hydropower arch dam Jinping I in China. Department of Applied Physics Chalmers University of Technology, 22-25.

[2] Clough, R. W., Raphael, J. M. &Mojtahedi, S. 1973. Adap- a computer program for static and dynamic analysis of arch dams. Technical Report EERC 73-14. University of California: Berkeley.

[3] Chopra, A. K. 2008. Earthquake analysis of arch dams: Factors to be considered: The 14th World Conference on Earthquake Engineering, October 12–17, 2008, Beijing, China.

[4] Kliot, Nurit1994. Water Resources and Conflict in the Middle East. Milton Park: Routledge. ISBN 0-415-09752-5.

[5] Carlyle, Bill 2008. "The Binnie heritage in dam engineering". Dams and Reservoirs. 18: 121–134.

[6] Dawlatzaiand Dominic2018, Structural Stability And 2d Finite Element Analysis of Concrete Gravity Dam. International Journal of Engineering Science Invention (IJESI) ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726 www.ijesi.org ||Volume 7 Issue 1|| January 2018 || PP.09-20

[7] Behrouz AN 2002 Multivariate statistical analysis of monitoring data for concrete dams. Dissertation. McGill University, Montreal

[8] Demirkaya S, Balcilar B 2012 The contribution of soft computing techniques for the interpretation of dam deformation. In: Proceedings of the FIG working week 2012, Rome

[9] Danielle WE, Taylor CA 1999 Effective ambient vibration testing for validating numerical models of concrete dams. EarthqEngStructDynam 28:1327–1344

[10] EN 1992-1-2, European Committee for Standardization, Eurocode 2: Design of concrete structures – Part 1-2: General rules – Structural fire design (2004)