النمذجة بطريقة العناصر المحدودة لسد بيتون مرصوص بالدحي (سد الموجب)

د.م. وسيم يوسف داؤود[1] كلية الهندسة المدنية – جامعة البعث

[1]دكتوراه في الهندسة الجيوتكنيكية، قسم الدراسات والشؤون الفنية، مديرية الموارد المائية بطرطوس، سوريا.

للمراسلة: الجوال: 00963969930452

البريد الإلكتروني: waseem.daoud@yahoo.com

الملخص:

يقدّم البيتون المرصوص بالدّحي مفهوماً مختلفاً في إنشاء الرصف والسدود، فهو بيتون جاف (هبوط أبرامز معدوم)، ذو محتوى مائي منخفض، ومزيج كثيف يتضمن حصويات متدرجة الخشونة، ومواد إسمنتية رابطة و ماء. مما يجعل من رصّه بسماكات كبيرة أمراً صعباً بدون استخدام الرجّاجات ذات الطّاقة الكبيرة. يُنقل هذا البيتون بالشاحنات، ويوضع ويُرصّ باستخدام معدّات الرّصف الإسفلتي. تكمن الفائدة الرئيسية لهذه التقنية في تخفيض زمن الإنجاز والتوفير في كُلَف العمل وامكانية الاستعاضة عن المواد التقليدية في الرّصف الطّرقي. كما يؤمّن سطحاً متيناً ومصقولا أملساً من شأنه تسهيل عمليات المرور المتوقعة في كلّ الظروف والعوامل المختلفة كالحمل المحوري و كذلك في كل الشروط البيئية. في هذا البحث تم استخدام برنامج SAP لتحليل الإجهادات في جسم السد و الأساسات في سد الموجب المبني من البيتون المرصوص بالدحي. و لقد قدّمت هذه الدّراسة منهج معدّل في تطوير نمذجة الإجهاد من خلال البرامج المتوفرة مثل برنامج العناصر المحدودة (SAP). و لقد أظهرت النتائج أنّ إجهاد الشدّ الأعظمي يكون أعظمياً في المنطقة المجاورة لقدم وجه السدِّ الرّطب. و حصلنا على عامل آمان الاستقرار من أجل الحمولات الستاتيكية بقيمة تزيد عن 1 من أجل إجهادات القص الأفقية و الإجهادات الأساسية. لكن من أجل الحمولات الديناميكية أظهرت الدراسة وجود منطقة واضحة بعامل آمان أقل من القيمة المطلوبة.

الكلمات المفتاحية: البيتون المرصوص بالدّحي، بوزولان، الحمولات الستاتيكية، الحمولات الديناميكية.

Finite element modeling method of roller compacted concrete dam (Mujib Dam).

Waseem Yousef Daoud[1]

[1] PhD of geotechnical engineering, Department of studies and technical affairs, water resource directorate in Tartous, Tartous, Syria.

Mob: +963 969930452, Email: waseem.daoud@yahoo.com (Waseem Daoud)

Abstract:

The Roller Compacted Concrete (RCC) offers a different concept in the creation of pavement and concrete dams, it's dry Beaton (Zero Abrams slump), with a low watercontent, and includes of dense mix consisting of graded coarse aggregate, andcementations materials, and water, this makes it so difficult to compact it in big thicknesses layers without using large energy rollers compactors. concrete conveys bytrucks, placed and compacted by using equipment asphalt pavement. The main advantageof this technique is in reducing the completion time and cost savings in labor and thepossibility of replacing traditional materials in road paving. It also provides a solid surfacesmooth and polished, and would facilitate the operations of traffic expected in allcircumstances and various factors such as axial loads and environmental conditions. In this research SAP program was used to analyze stresses in the body dam and foundation in RCC mujib dam. This study presents a modified step-by-step approach, which improved the stress modeling within the available commercial software (SAP finite element program). The results are shown that the greatest tension is developed in the rock adjacent to the toe of the battered slope. For static analyses it is shown the safety factor (SF) for stability was greater than 1 for both horizontal shear stresses and principal stresses. But for dynamic loads the analyses showed a significant zone were the SF was less than required value.

Key Words: roller compacted concrete, pozzolan, static load, dynamic loud.

1- Introduction:

Roller compacted concrete (RCC) dams emerged as a viable new type of dam during the 1980s. They have gained acceptance worldwide in a relatively short time due to their low cost, which is derived in part from their rapid method of construction [1]. The RCC method evolved not only from the effort of some influential concrete dam designers but also from the work of geotechnical engineers who have traditionally designed earth and rock-fill embankments. Their combined efforts have produced a concrete dam built by methods usually associated with earth dam construction. The product is a less costly dam with the same inherent safety as a conventionally placed concrete dam [2].

Roller Compacted Concrete - RCC - is a technique characterized mainly by its use of rollers for compaction. Roller compacted concrete (RCC) is a construction methodology, not a Design Criteria or technology, that use a concrete (and is a concrete as material) of no-slump consistency in its unhardened state that is transported, placed, and compacted using earth and rock fill construction equipment [3].

RCC is a concrete that differs from conventional concrete principally in that it has a consistency that will support a vibratory roller and an aggregate grading and fines content suitable for compaction by the roller or other external methods.

All materials used in a high RCC dam, including cement, pozzolanic material and fine and coarse aggregates, The objective of RCC proportioning is to provide a dense and stable mass that meets the strength, durability, and permeability requirements for its application. Materials used for RCC include cementitious materials, aggregates, water, and admixtures. A wide range of materials has been used successfully to produce RCC mixtures.

2- RCC technology:

In the development of RCC technology, two philosophies, or approaches, have emerged with respect to a RCC a mix design methods. They can be termed the soils, or geotechnical, philosophy, and the concrete philosophy, there is no distinct line separating the two philosophies. Basically, RCC mixtures produced using concrete design methods have a more fluid consistency as measured by Vebe or vibratory compaction (VC) test. these mixes may be described as being more workable than those developed using the soil approach, yet both philosophies will produce a concrete that is termed (zero slump) [4].

The soil philosophy considered RCC as cement – enriched processed soil, or aggregate, whose mix design is based, is on moisture – density relationship. for a specified aggregate and cementations material content, the goal is to determine an optimum moisture content for a laboratory compactive effort that corresponds to the effort or density applied by the rollers in the field. In the soil approach, paste (cement, pozzolna and water) does not generally fill all the voids in the aggregate after compaction.

The principles of compaction developed by proctor in the early 1930s are applied in the soils approach to the proportioning of RCC mixtures. Proctor determined that for a given compactive effort there is an (optimum moisture) content that produced a maximum at dry density. Increasing the compactive effort results in a greater maximum dry density at lower optimum moisture content.

Based on these compaction principles, dry density is used as the design index in the soil approach. dry density is defined as the dry weight of solids per unit volume of material, independent of water content. it can be calculated from wet density, and vice versa, by the formula (1):

$$\rho_d = \frac{\rho_\omega}{1+\omega} \qquad (1)$$

Where ρ_d = dry density

ρ_ω= wet density

ω = moisture content of total mix expressed as a decimal.

if an optimum moisture content is used that corresponds to the compactive effort achieved by the rollers in the field, a material at maximum dry density will be produced.

Materials used for RCC include cementations materials (Portland cement and pozzolanas such as fly ash), aggregate, water, and admixtures. a wide range of material has been used successfully to produce RCC mixture. RCC can be made from any of the basic types of Portland cement or cement plus pozzolan, the cementations content is usually about 120 kg/m^3 and pozzolanic material (Fly Ash) in amounts from 20% to 30% by weight of the cementations material to reduce the heat of hydration [5].

Use of a pozzolanic material in RCC serves some purposes [6]:

a) As a partial replacement for cement to reduce heat generation;

b) To increase the compressive strength at large ages, if the material has large Pozzolanic Activity with cement.

c) To increase the durability.

d) To reduce cost.

Also for RCC, like conventionally placed concrete, aggregate quality and gradation are important factors influencing the final products.

Malkawi et al presented a thermal structural analysis using the ANSYS computer program to assess the effect of heat of hydration in RCC structural stresses [7].

3- Objective of this research:

This research presents a numerical modeling for AL-Mujib RCC dam, and static and dynamic analyses for dam. In this study presents a modified step-by-step approach, which improved the stress modeling within the available commercial software (SAP finite element program). Static, pseudo-static and dynamic structural stability analysis for AL-Mujib RCC Dam was carried out using finite element Method (FEM). The response spectrum of the 1995 Aquba earthquake and a representative elastic-spectrum with smooth plateau for both operating basis earthquake (OBE) was used in this study to carry out the dynamic stress analysis of AL-Mujib RCC Dam.

4- Description of the Dam:

The Mujib Canyon, about 60 km south of Amman, another hybrid dam was currently completed. Mujib Dam, also owned by the Jordan Valley Authority, as well was designed as a central RCC gravity dam with adjacent earth fill dams at the valley flanks. Its maximum height reaches approx 60 m, the total volume of the RCC structure will be 720,000 m^3.

It is a 47 m high roller compacted concrete gravity dam. Geometric configuration for this dam is shown in Figure (1) [7].

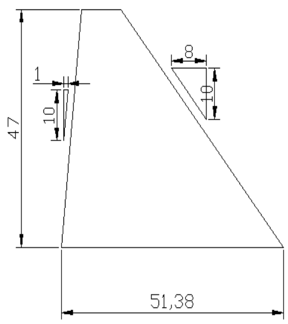

Figure (1): Geometric configuration for Mujib dam

5- Material properties:

The following static and dynamic material properties for (RCC and rock foundation) which the analysis process need to it were taken as shown in table (1).

Table (1): Static and dynamic material properties for (RCC and rock foundation).

condition	material	Modulus of elasticity E(Gpa)	Poisson,s ratio ν	Unit weight (KN/m^3)	Tensile strength (Mpa)	Compressive strength (Mpa)
Static	Dam material	15	0.2	24	1.05	14.6
	foundation	12	0.2	28		22
dynamic	Dam material	19.5	0.2	24	1.58	19
	foundation	16.8	0.2	28		22

The foundation rock conditions at the Mujib dam site, which is presented in the companying Geotechnical interpretative report, the foundation parameters use in the stability analysis are listed in table (2).

Table (2): Foundation parameters.

Rock location	Rack formation	Friction angle (ø)	Cohesion (c)	Compression strength (f_c)
Dam/foundation interface	Naure limestone	47^o	425 kpa	22Mpa

The boundaries of the foundation have been fixed for translation and rotation movement, as shown in Figure (2). In addition all out of plane DOF were restrained for all nodes.

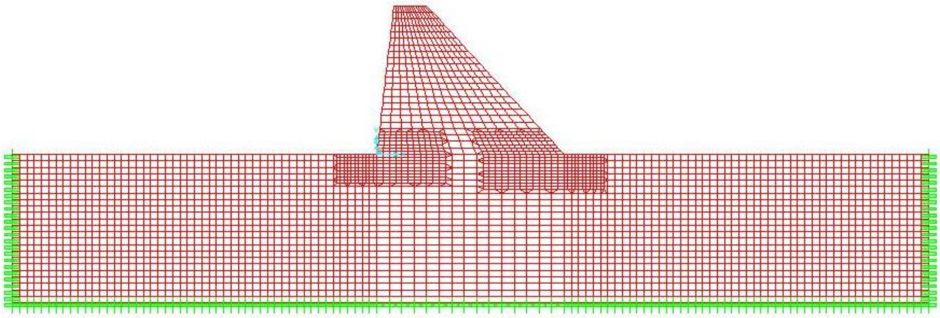

Figure (2): The boundaries of the foundation for Mujib dam.

6- Design loads:

Several basic load cases are defined for inclusion in the structural load conditions for the mujib dam: Dead load (D), Reservoir water load, Uplift load, Silt load and Earthquake load.

Hydrostatic uplift pressure: Uplift at the concrete/rock interface assumed to vary as a straight line from full headwater pressure at the heel to zero water pressure at the toe, over 100% of the base area,

Hydrostatic pressure: The weight of fresh water should be taken at 9.81 kN/m^3. A linear distribution of thestatic water pressure acting normal to the surface of the dam should be applied varies from 0at the water face to (W * h) at the dam base.

Earthquake load: The seismic loading has been input as response spectra for the Operating Basis Earthquake (OBE) at 0.2 PGA (peak ground acceleration) and the Maximum Credible Earthquake (MCE) at 0.5 PGA. A response spectrum is a plot of the peak response of a Spectra Damping (SD) of system to an earthquake motion against the natural period of oscillation for that system at a given level of damping. The transverse component acceleration time history recorded at Aquaba Hotel Station of the 1995 Aqaba Earthquake was used in this study in figure (3), this earthquake record was used to generate response spectra for OBE loading which are shown on figure (4) [7]. The seismic loading is applied horizontally only.

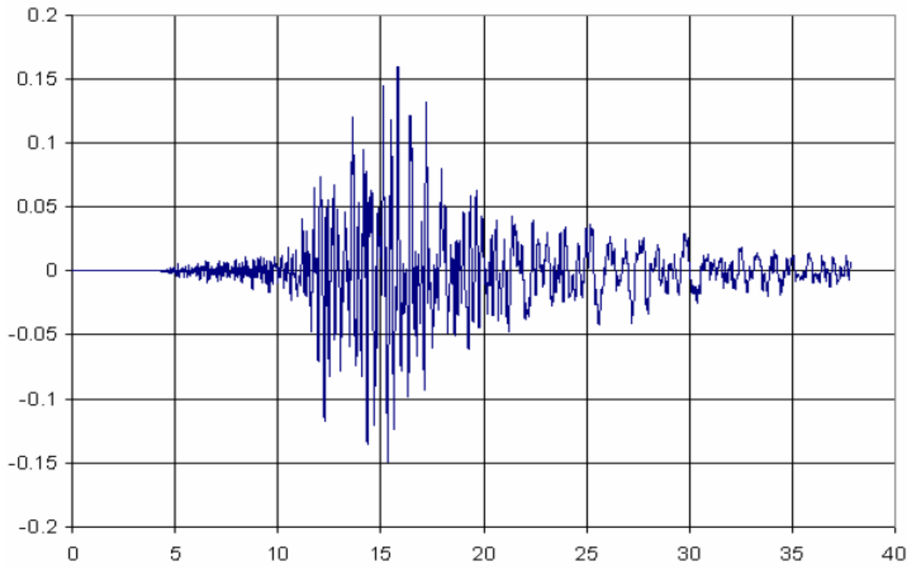

Figure (3): The Transverse component acceleration time history at Aqaba Hotel station of the 1995 Aqaba Earthquake [7].

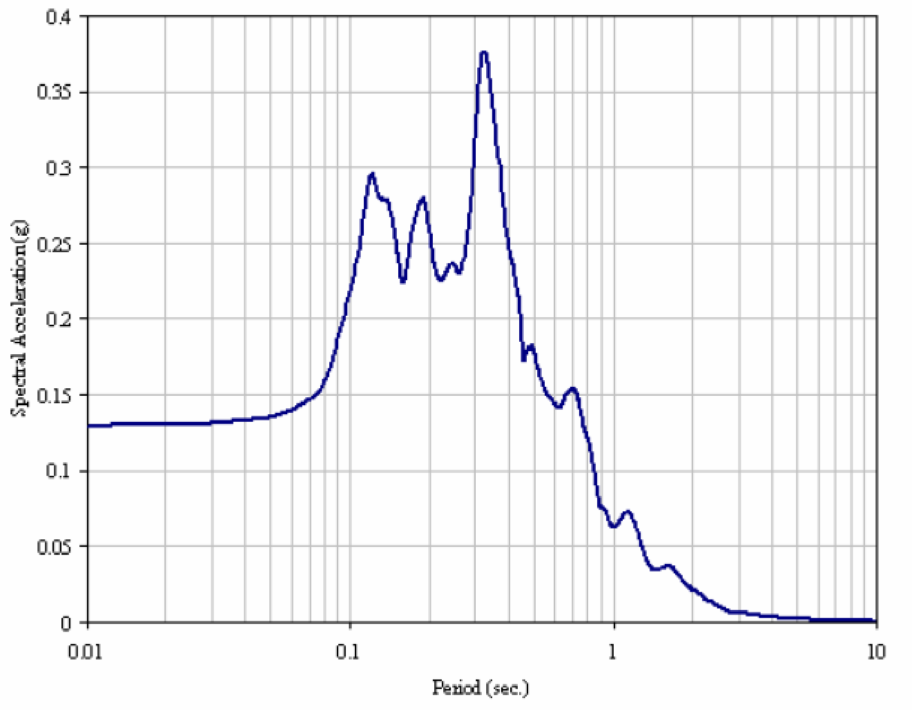

Figure (4): OBE Response Spectra for 10% Damping

The parameters are considered in this study to evaluate their effects on stresses in the dam. Figure (5) show the considered dam geometry with the associated finite element. The results are taken in the section at the dam base.

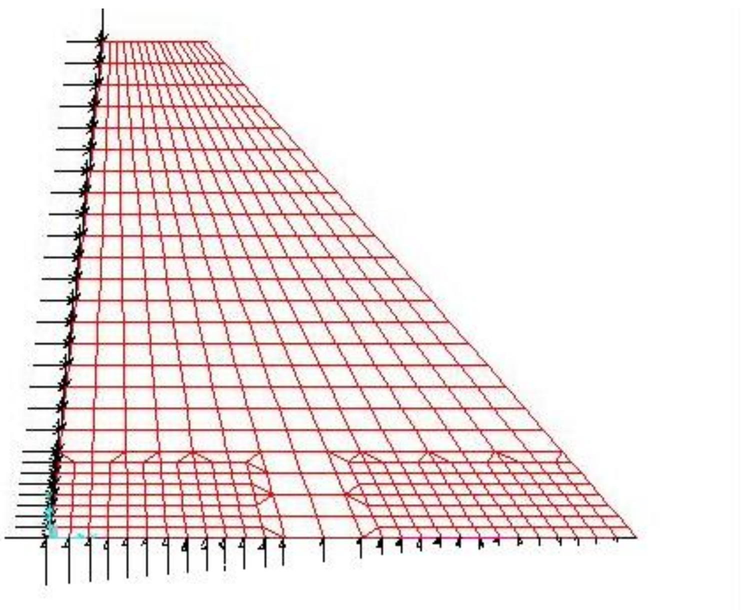

Figure (5): Dam geometry with the associated finite element.

7- Static results:

Figure (6) show the deformation shape of Mujib Dam due to the static loads and figure (7) show the envelope of Maximum stress (S11) due to static loading, Figures (8) show the peak stress distributions and the peak stress across base of dam due to static loads. It should be noted that the greatest tension is developed in the rock adjacent to the toe of the slope and figure (9) show the minimum stress across base of dam due to static loads and figures (10), (11), (12) show the stress in X-direction and Y-direction and shear stress on the bass of the Dam due to the static loads. It is noted that almost all the types of stresses decreased across the bass of dam, it is due to the uplift water and increasing the distance from water pressure, but some times the stresses increase at the end of the bass of dam, it is depended on the geometric configuration for this dam (in static load), and seismic loading (in dynamic load).

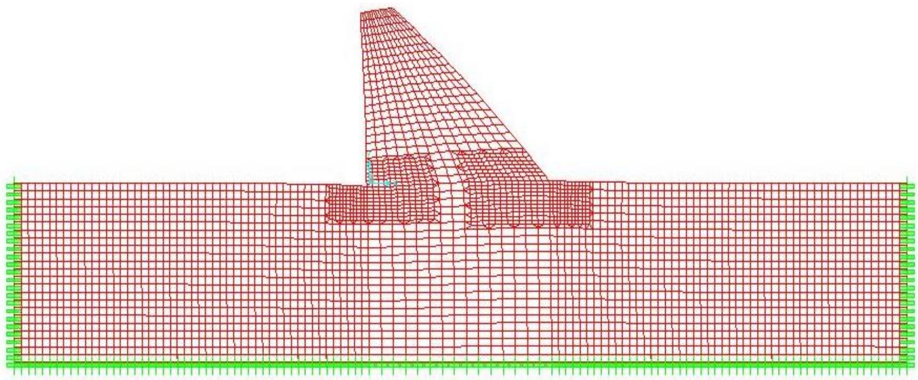

Figure (6) deformation shape of Mujib Dam (static loading condition)

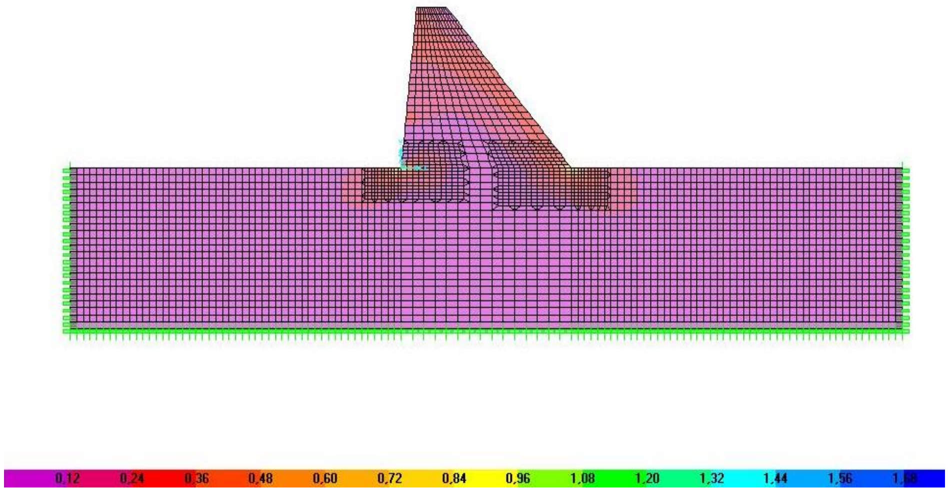

Figure (7) Envelope Maximum Stress (S11) (static loads condition).

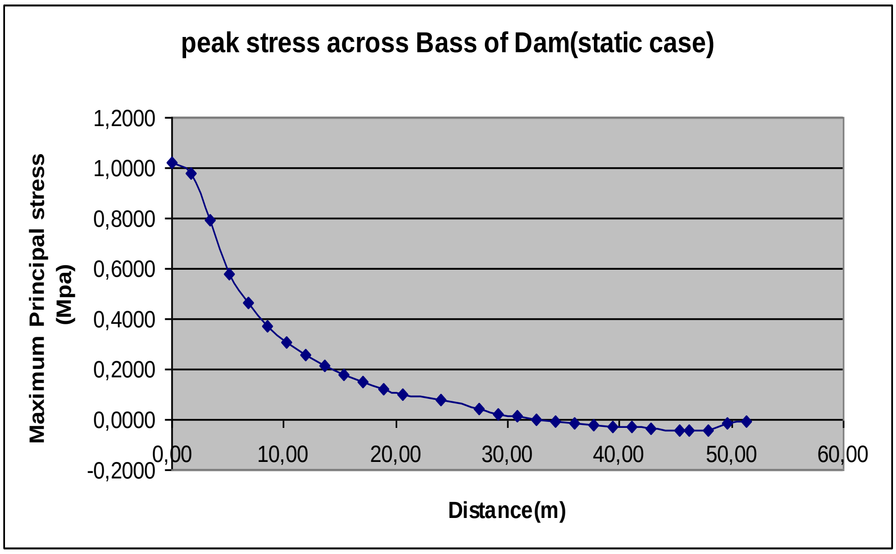

Figure (8): Peak Stress across Bass of Dam (Static Case).

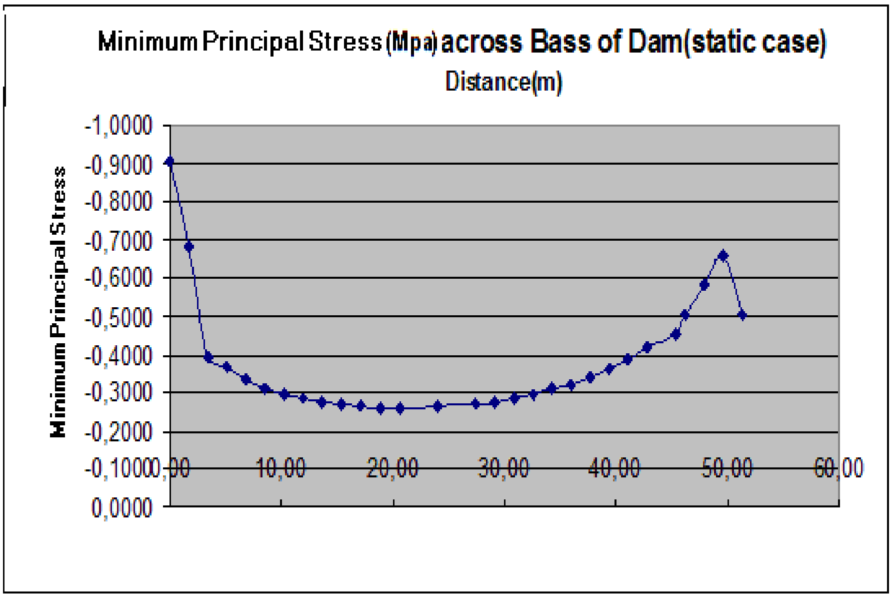

Figure (9): Minimum Principal Stress across Bass of Dam (Static Case).

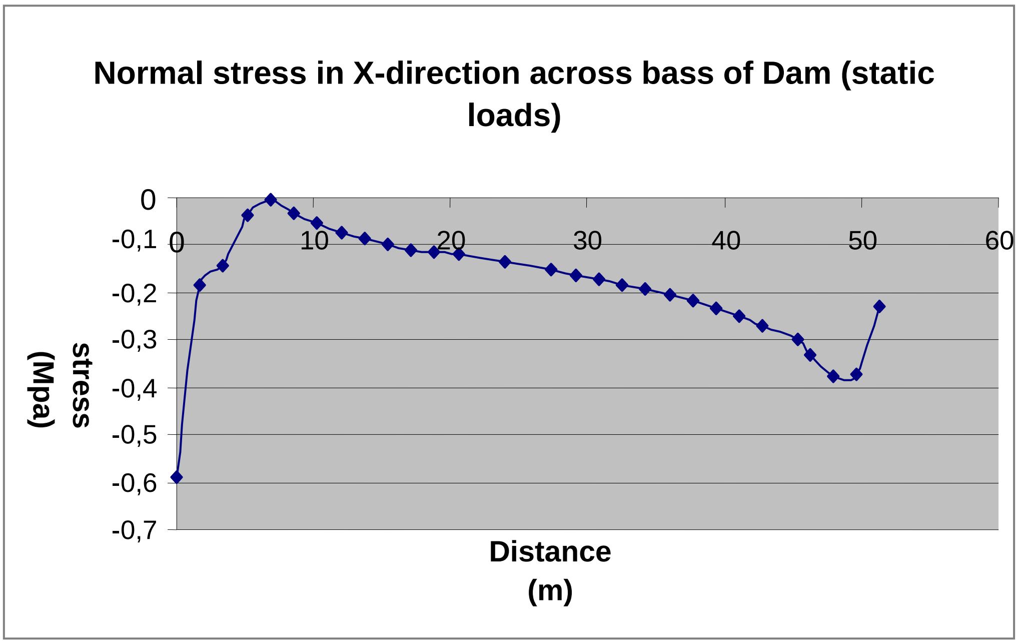

Figure (10): Normal stress in X−direction across Bass of Dam (Static Case).

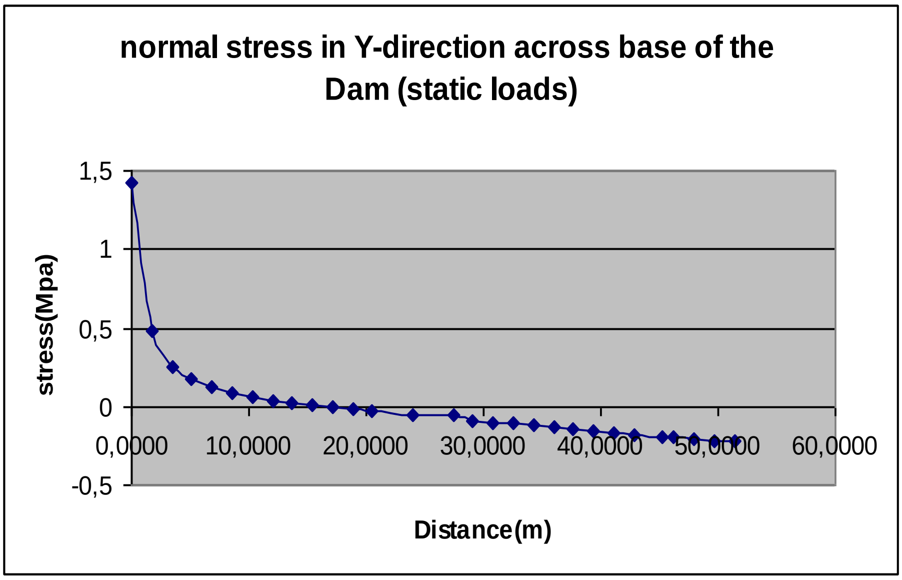

Figure (11): Normal stress in Y-direction across Bass of Dam (Static Case).

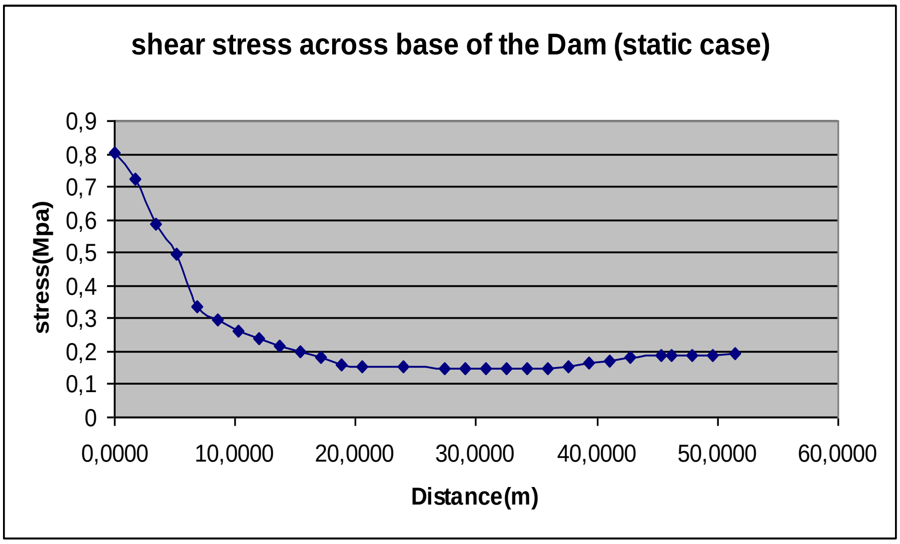

Figure (12): Shear Stress across bass of Dam (Static Case).

8- Dynamic results:

Figure (13) show the envelope of Maximum stress (S11) due to dynamic loading, Figures (14),(15), (16) show the normal stress in X direction, in Y direction distributions and the shear stress across base of dam due to dynamic loads.

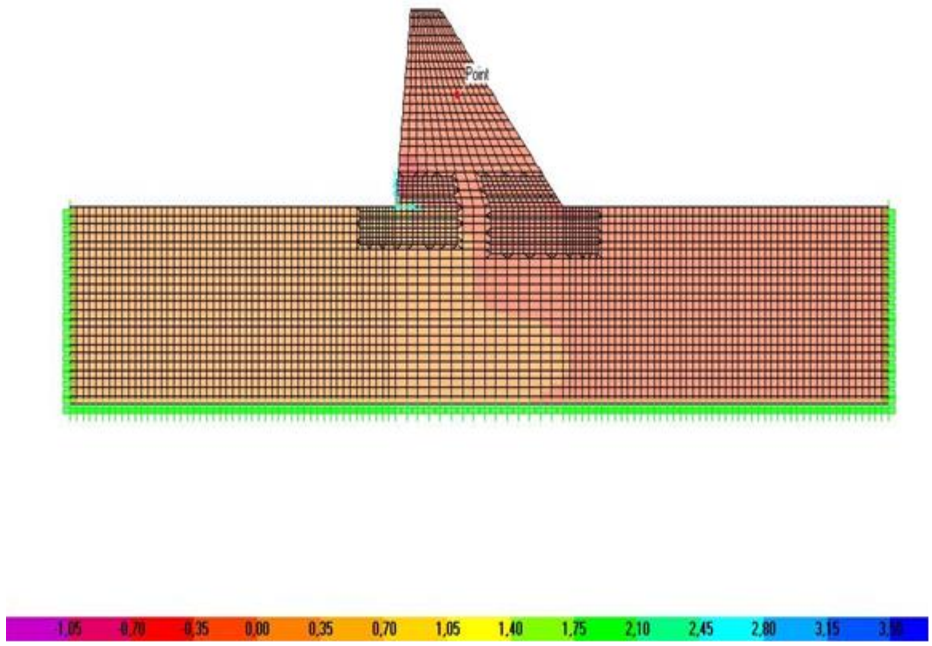

Figure (13): Envelope Maximum Stress (s_{11})

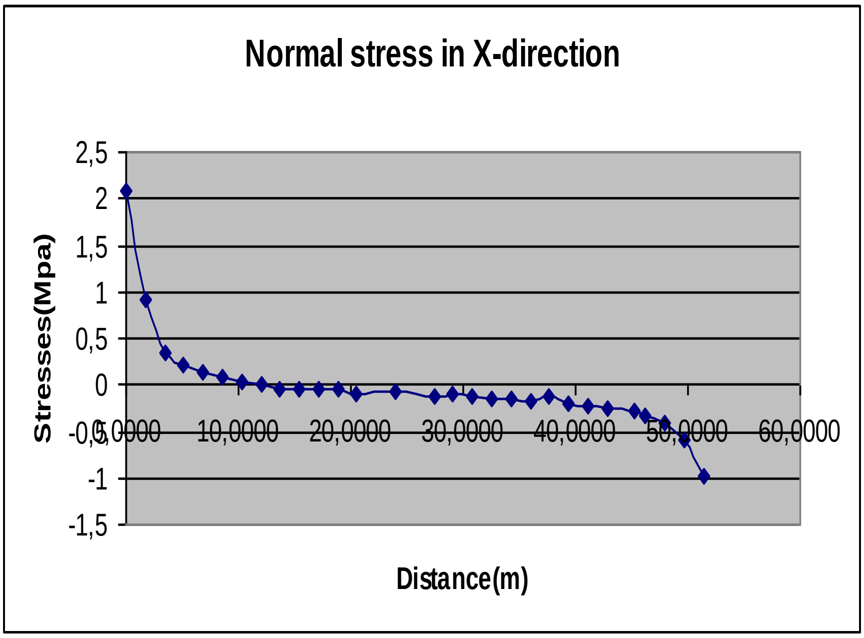

Figure (14): Normal stress in X–direction across Bass of Dam (Dynamic Case).

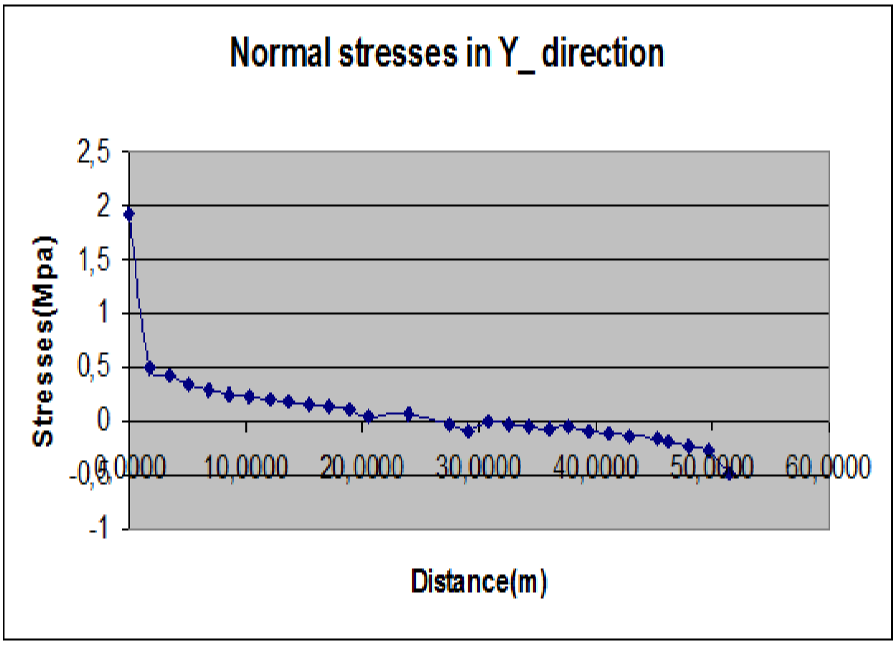

Figure (15): Normal stress in Y−direction across Bass of Dam (Dynamic Case).

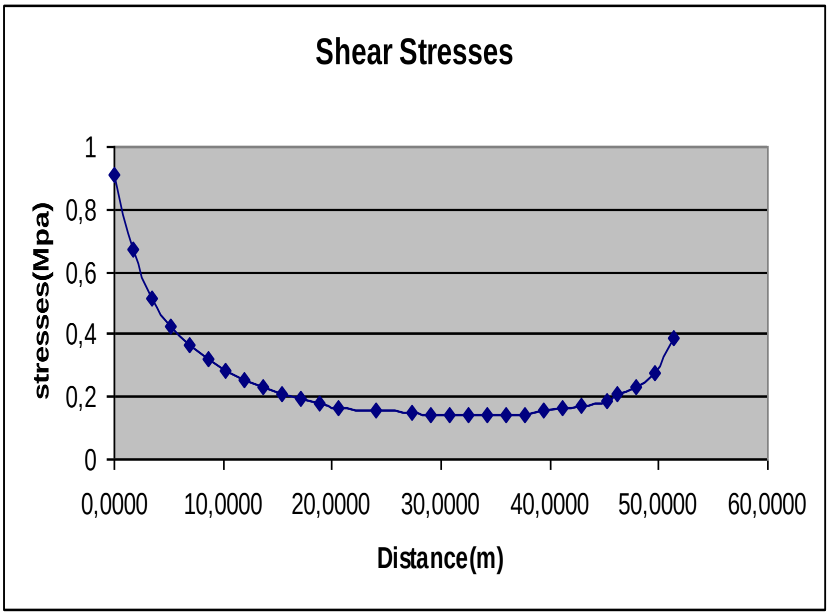

Figure (16): Shear stress across Bass of Dam (Dynamic Case).

9- Factor of safety:

The calculated stress levels were compared with the rock mass strength, as defined by cohesion and friction angle. In table (3) it shown how determines a factor of safety for each element.

Table (3): Formula for determine the factor of safety.

Cohesion,C,(Mpa)	Friction(Degree) (ø)	Normal stress σ_n,(Mpa)	τ	F.S
0,425	47^o	S_{22}	C+ σ_n tan(Ø)	τ/S_{12}

The analyses showed the significant zone where the factor of safety was less than required value 1. Factor of safety along the base of the dam was determined for various loading cases (static, OBE), for static analyses it is shown the safe factor for stability was greater than 1 for both horizontal shear stresses figure (17) and principal stresses figure (18), indicating thus that the strength available between the RCC layer is enough to ensure stability .

For OBE loading case the factor of safety for principal stresses also shown in figure (19). All the changes in the SF are depended on the changes of the stresses along the base of dam.

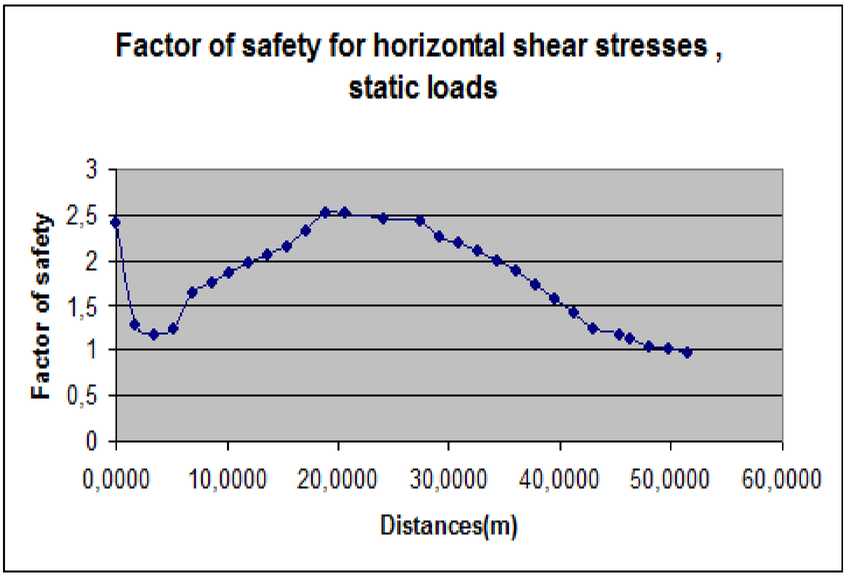

Figure (17): Factor of Safety for horizontal shear stresses (Static case).

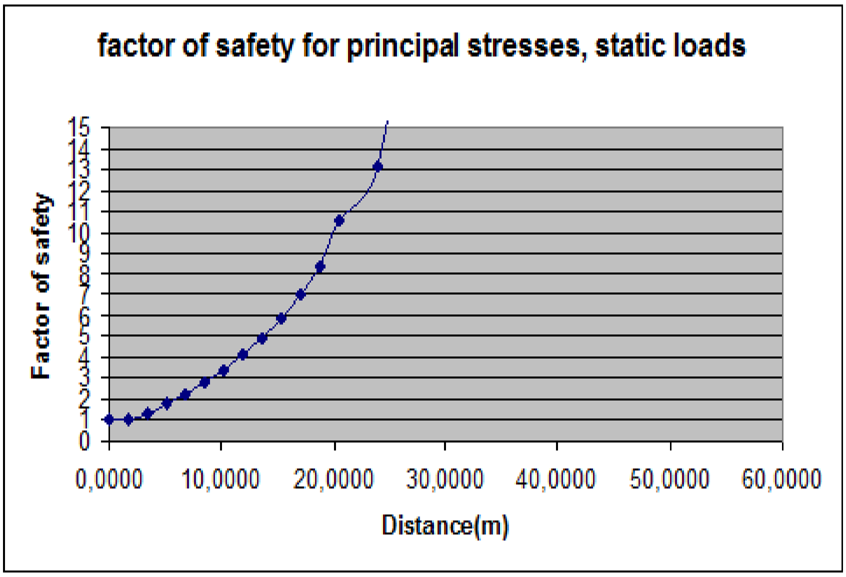

Figure (18): Factor of Safety for principal stresses (Static case).

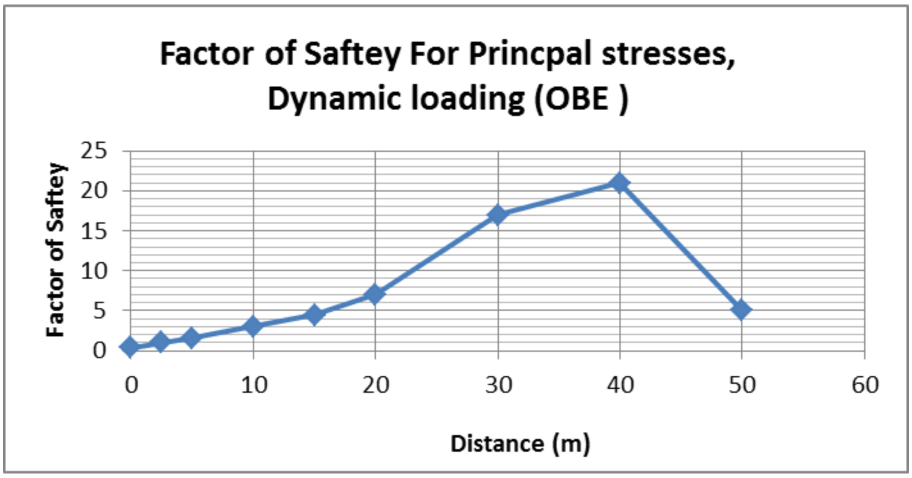

Figure (19): Factor of Safety for principal stresses (Dynamic case OBE).

10- Conclusion:

In this research it was discussed the numerical modeling for AL-Mujib RCC dam, and static and dynamic analyses were done for dam. This study presents a modified step-by-step approach, which improved the stress modeling within the available commercial software (SAP finite element program). Static, pseudo-static and dynamic structural stability analysis for AL-Mujib RCC Dam was carried out using finite element Method (FEM). The response spectrum of the 1995 Aquba earthquake and a representative elastic-spectrum with smooth plateau for both operating basis earthquake (OBE) was used in this study to carry out the dynamic stress analysis of AL-Mujib RCC Dam. It is shown that the greatest tension is developed in the rock adjacent to the toe of the battered slope. The safety factor (SF) was calculated against shear and principal stresses at different sections across the dam for all the loading conditions.

For static analyses it is shown the safety factor (SF) for stability was greater than 1 for both horizontal shear stresses and principal stresses, indicating that the strength available between the RCC layers is enough to ensure stability. But for dynamic analysis the analyses showed a significant zone were the SF was less than required value, so it should be modify the geometric configuration for this dam to reach to SF greater than required value.

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