Numerical Modelling of Dynamic Stability of RCC Dam

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Objective of the Study

Stability and stress analyses are the most important elements that require rigorous consideration in design of a dam structure. Stability of dams against sliding is crucial due to the substantial horizontal load that require sufficient and safe resistance to develop by mobilization of adequate shearing forces along the base of the dam foundation. In the current research, the static and dynamic sliding stability of a roller-compacted-concrete (RCC) dam was modelled using finite elemnt method to invistigate the stability against sliding. A commerically available finite element software (SAP 2000) was used to analyze stresses in the body of the dam and foundation.

Mujib Dam Description and Location

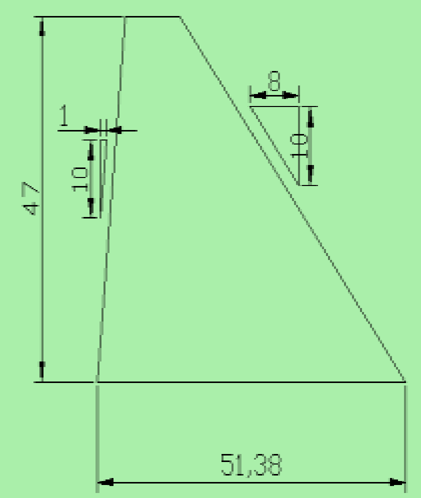
Location

- In the Mujib Canyon, some 60 km south of Amman, Jordan.
- The dam is located in south of Jordan in the Wadi Al Mujib, south of Madaba and north of Al Karak as shown in Figure below. The Al Mujib drains toward the Dead Sea.

Description

The dam (Mujib Dam) is owned by the Jordan Valley Authority.

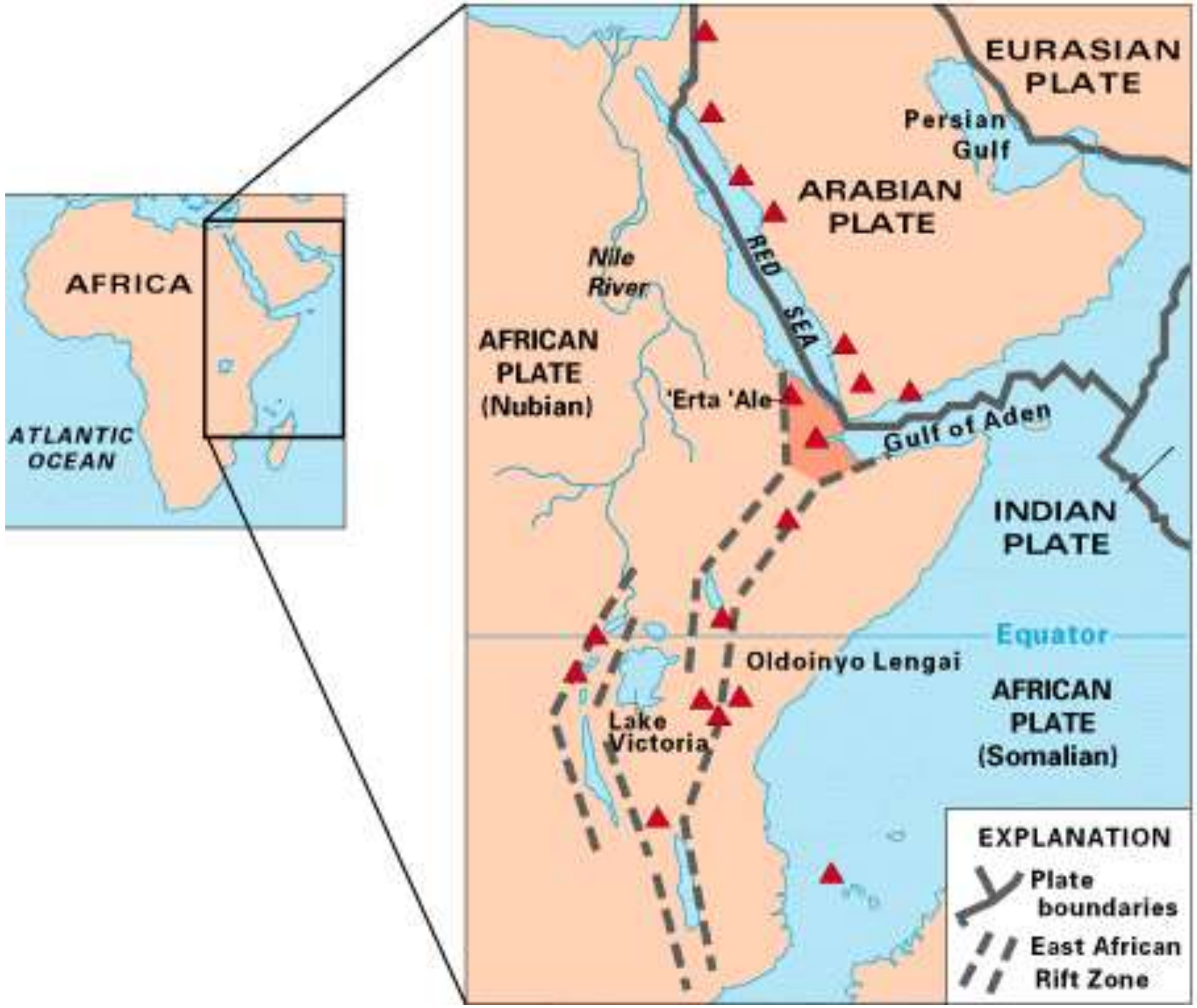
- Designed as a central roller-compacted-concrete (RCC) gravity dam with adjacent earth fill dams at the valley flanks.
- Its maximum height reaches approximately 47 m and the total volume of the RCC structure is 720,000 m^3.
- The reservoir will be mainly used for irrigation purposes.
- The catchment area is 4380 km^2 and the reservoir capacity is $35x10^6$ m^3.
- The geometric configuration of the dam is shown in Figure below.



Seismicity of The Dam Site

The dam site, latitude 32.7 N longitude 35.822, is situated about 26 Km east of the Jordan Rift Valley, the boundary between the Arabian and African and African–Sinai plates. The primary seismic sources contributing to the hazard at the AL Mujib dam site is active Jordan Valley fault which extends from the dead sea of Galilee (from 30.90̊ N to 32.93̊ N at a longitude of 35.5̊ E), with an expected maximum earthquake magnitude of 7.5 and greater.

Map of the Great Rift Valley



■A map of East Africa showing some of the historically active volcanoes (red triangles) and the Afar Triangle (shaded, center)—a triple junction where three plates are pulling away from one another: the Arabian Plate, and the two parts of the African Plate (the Nubian and the Somali) splitting along the East African Rift Zone (USGS).

Material_Properties

Properties of the Dam and Foundation Material

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 (Naur limestone)	12	0.2	28		22
dynamic	Dam material	19.5	0.2	24	1.58	19
	Foundation (Naur limestone)	16.8	0.2	28		22

Parameters of Foundation

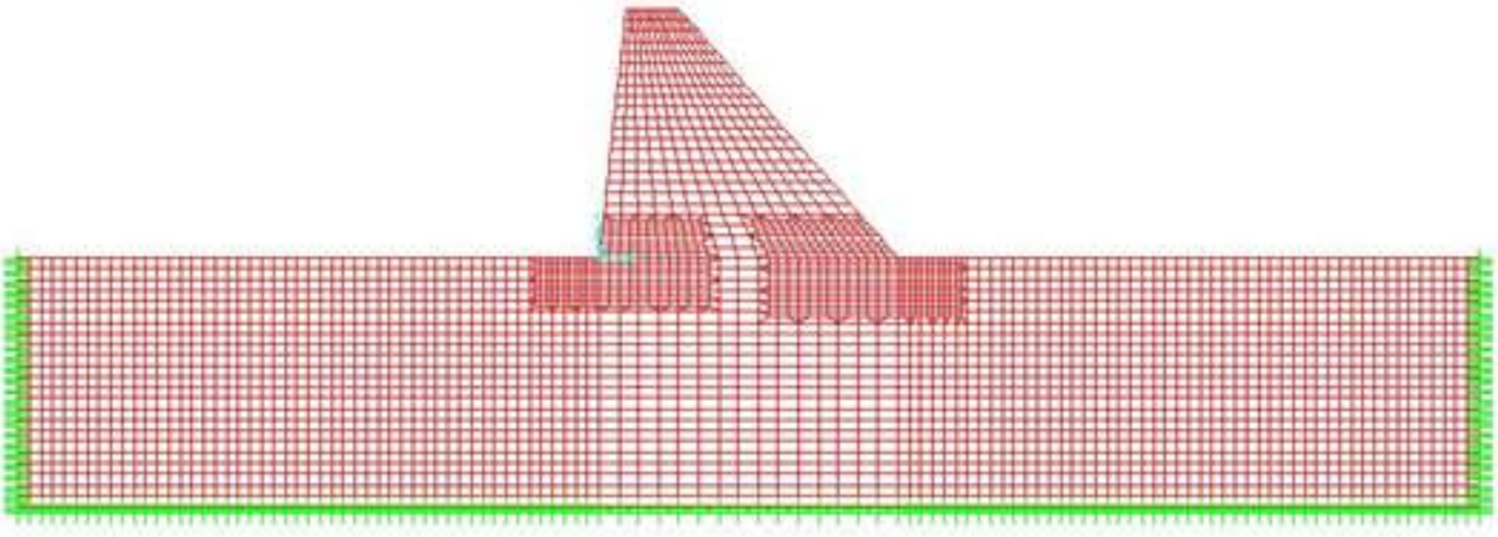
Rock location	Rock formation	Friction angle (ø)	Cohesion (c)	Compression strength
Dam/foundation interface	Naure limestone	47^{o}	425 kpa	22MPa

Structural Idealizations

- The dam was modeled using 2-D plain strain isoperimetric elements.

- The FE analysis was performed based on the following assumptions:

• Plain strain linear elastic behavior.
• Simplified soil-structure interaction entailing massless elastic foundation.
• A uniform and homogeneous foundation.
• The boundaries of the foundation were fixed against translation and rotation movement.



Boundaries of the Foundation

Static Loading Components

Static loading components comprises of:

a) self-weight of the dam.

b) hydrostatic uplift pressure: uplift at the concrete/rock interface assumed to vary as a straight line from full headwater pressure at the heel to 0 water pressure at the toe, over 100% of the base area, and these values are applied at the nodes in the finite element model to get the nodal uplift forces.

c) hydrostatic pressure: a linear distribution of the static water pressure acting normal to the surface of the dam was applied varies from 0 at the water face to (W * h) at the dam base, then the values of hydrostatic nodal force were calculated and used in the analysis.

d) silt pressure: weight of accumulated silt resting up to 10 m on the upstream face.

Design Criteria for Earthquake Load

Design Criteria:

ICOLD (Bulletin – 72, 1989) and USACE (2007) proposes two different earthquake levels to consider in the earthquake design of dams. These are named as the operating basis earthquake, OBE and the maximum design earthquake, MDE (or safety evaluation earthquake, SEE as suggested by ICOLD Bulletin – 72,2010).

Operating Basis Earthquake, (OBE)

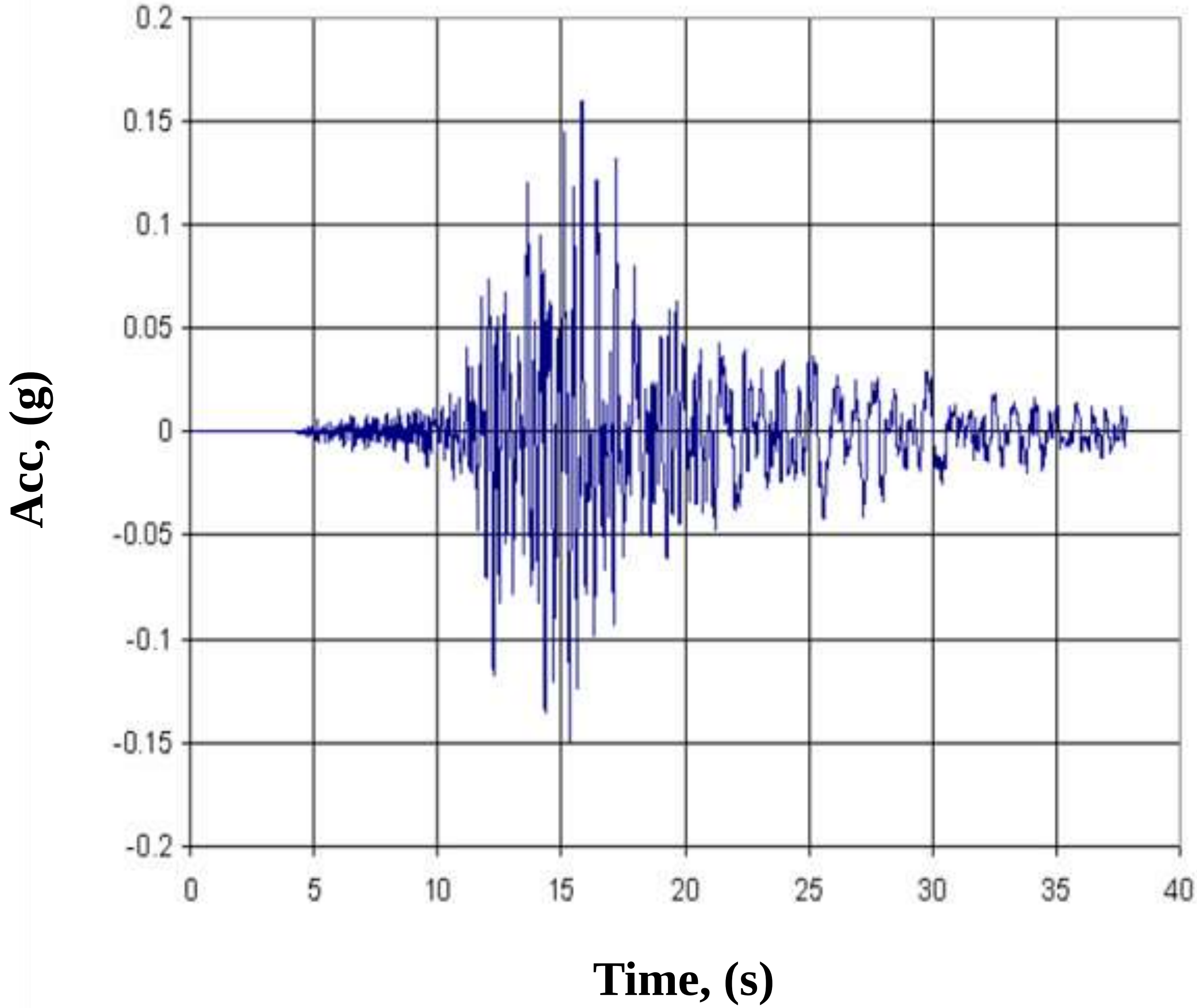
OBE has been defined as the earthquake with a return period of 144 years by ICOLD (1989). After an earthquake of this level, the dam, appurtenant structures and equipment need to remain functional and the damage need to be easily repairable. USACE (1995), finds it necessary for
the stress levels in the concrete gravity dams to remain within the elastic region in case of OBE.

Maximum Design, (MDE) Earthquake

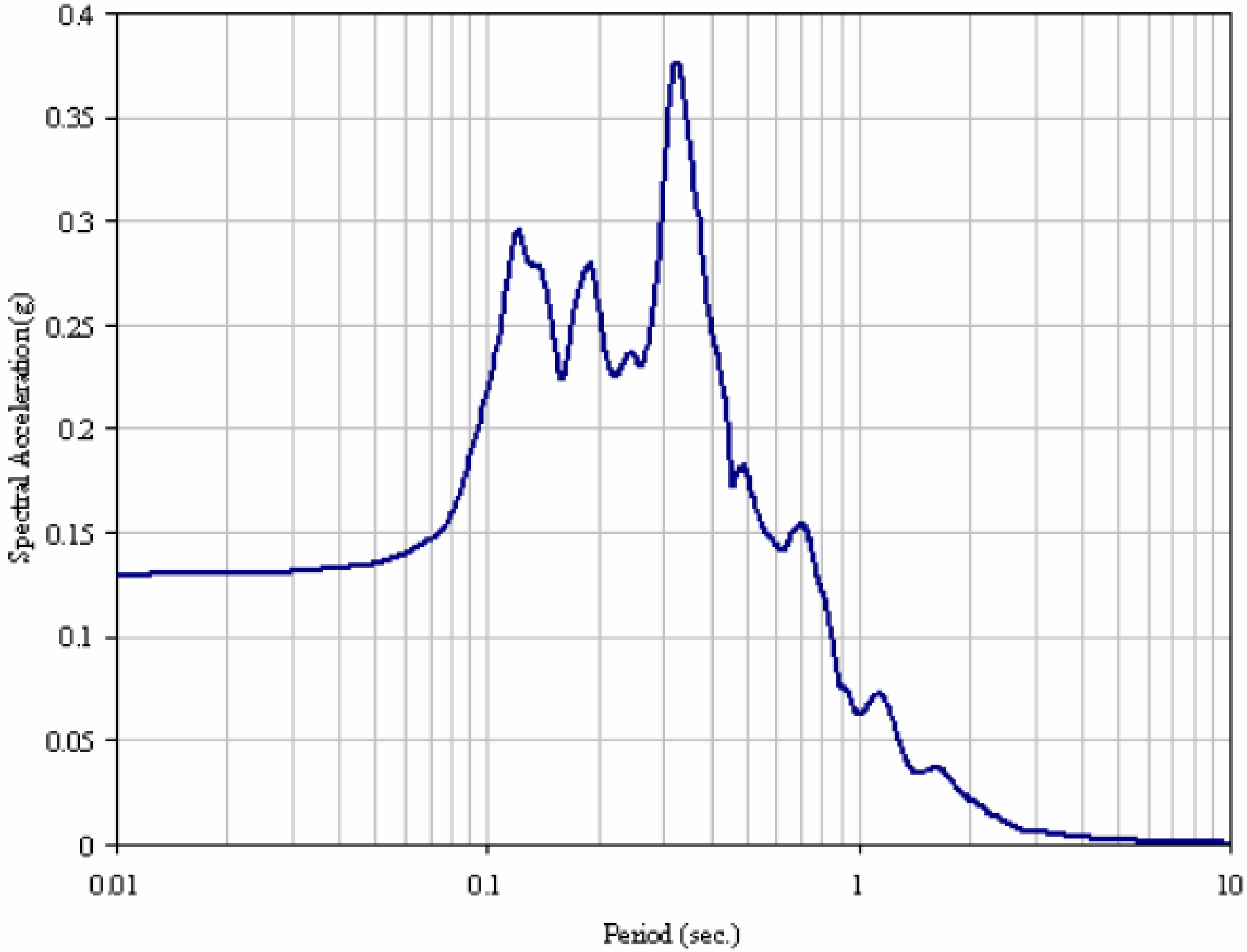
The MDE (or SEE) defined as the earthquake that generates the maximum ground motion level according to the assumed tectonics, seismic activity of the region to be used in the design. After an earthquake of MDE level, reaching of the elastic limits in the dam body and appurtenant structures, and the related damage are considered as acceptable (USACE, 1995). However, a catastrophic failure which may lead to an uncontrolled release of reservoir water or life loss should not occur

Earthquake Load

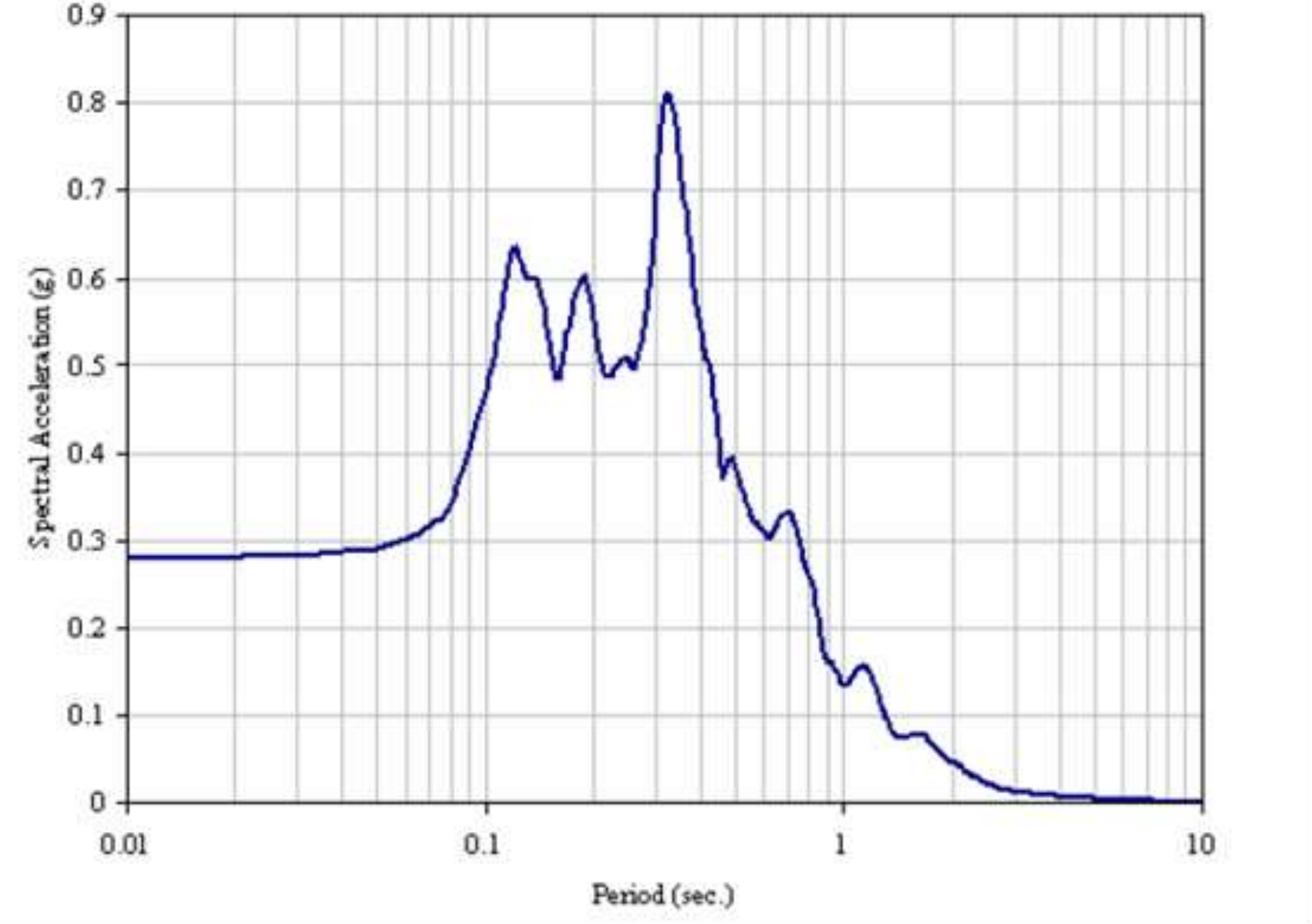
The response spectrum of the 1995 Aqaba earthquake and a representative elastic-spectrum with smooth plateau for both Operating Basis Earthquake (OBE) and Maximum Credible Earthquake (MCE) were used in this study to carry out the dynamic stress analysis of AL-Mujib RCC Dam. The peak ground accelerations (PGA) corresponding to operating basis earthquake (OBE) and maximum design earthquake (MDE) have been determined as 0.2 g and 0.5 g respectively. The evaluation of the peak ground acceleration (PGA).



The1995 Aqaba Earthquake Record



OBE Response Spectra



MCE Response Spectra

Results of Analysis and Discussion

Factor of safety against sliding was calculated as the ratio of the shear strength of the rock determined from Mohr-Coulomb criterion and the applied shear stress at each node along the entire base of the dam. The shear stregth of rock is given by Eq. below.

$\tau_f = c' + \sigma_n' \tan\phi'$

Where:

τ_f is the shear strength of foundation

c' and ϕ' are the shear strength parameters of the foundation

σ_n' is the effective normal stress along the base of the dam.

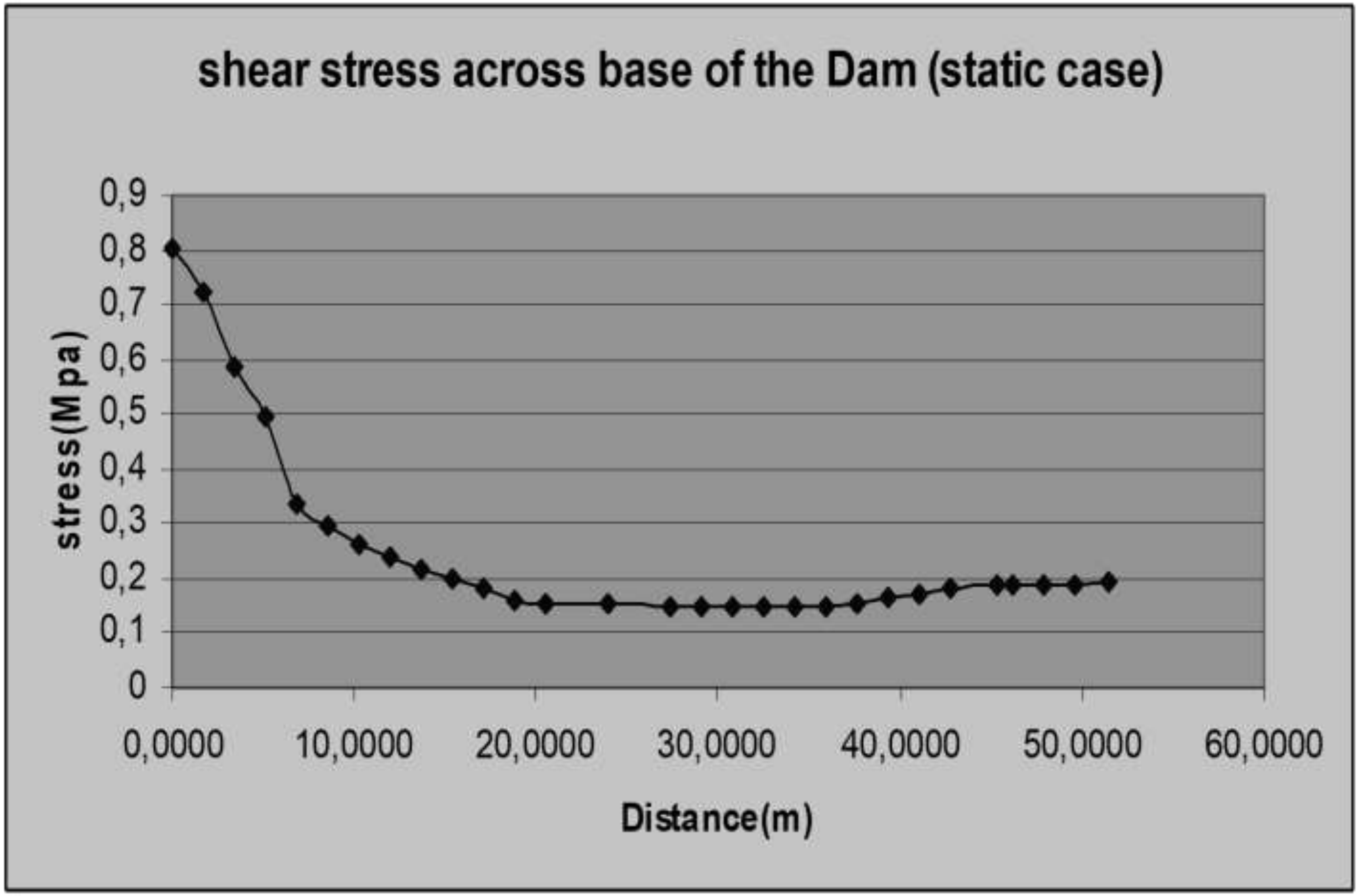
The factor of safety against sliding is given by Eq. below

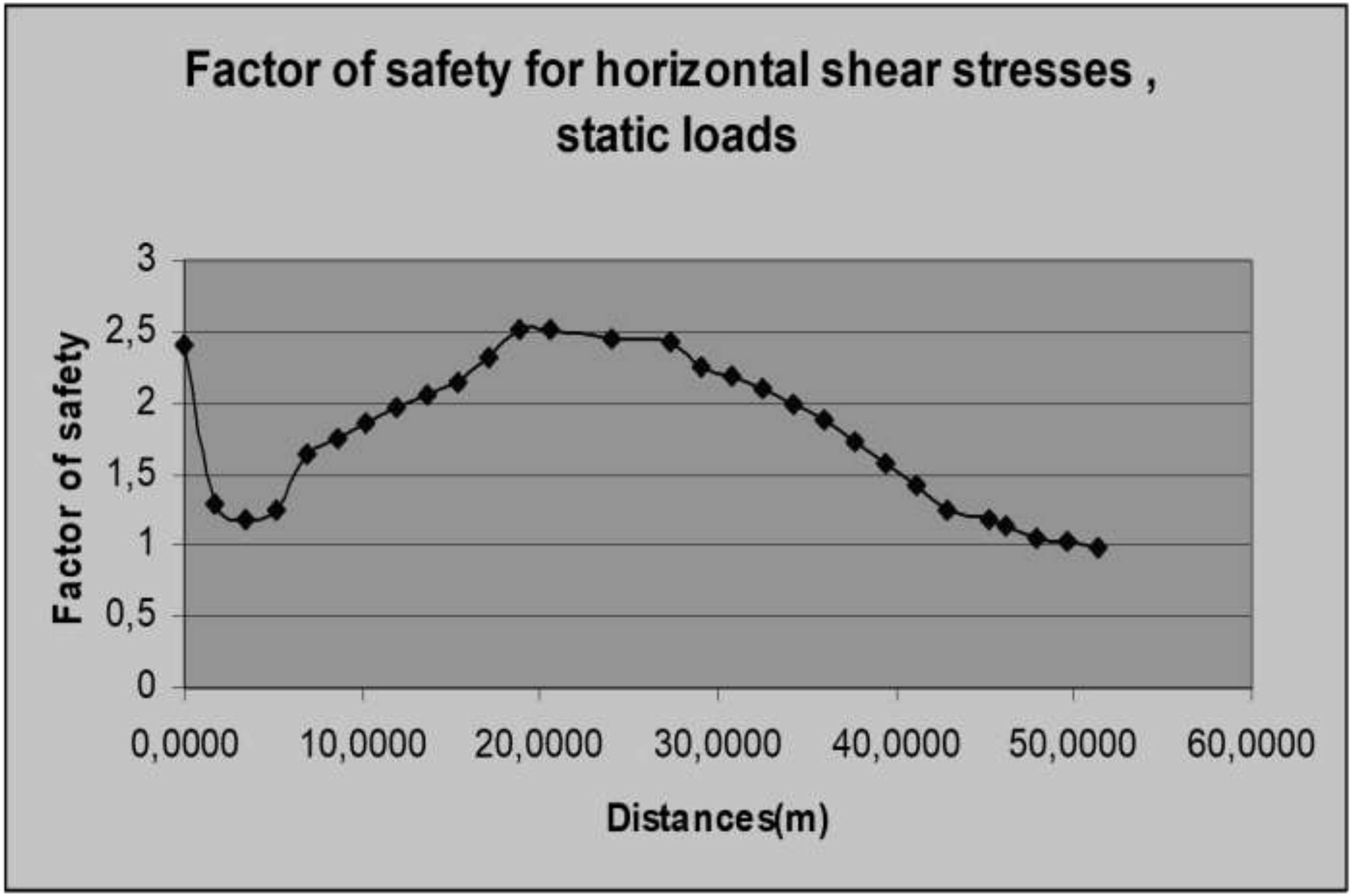
$$FS(Sliding) = \frac{\tau_f}{S_{12}}$$

Where:

S_{12} is the applied shear stress along the base of the dam

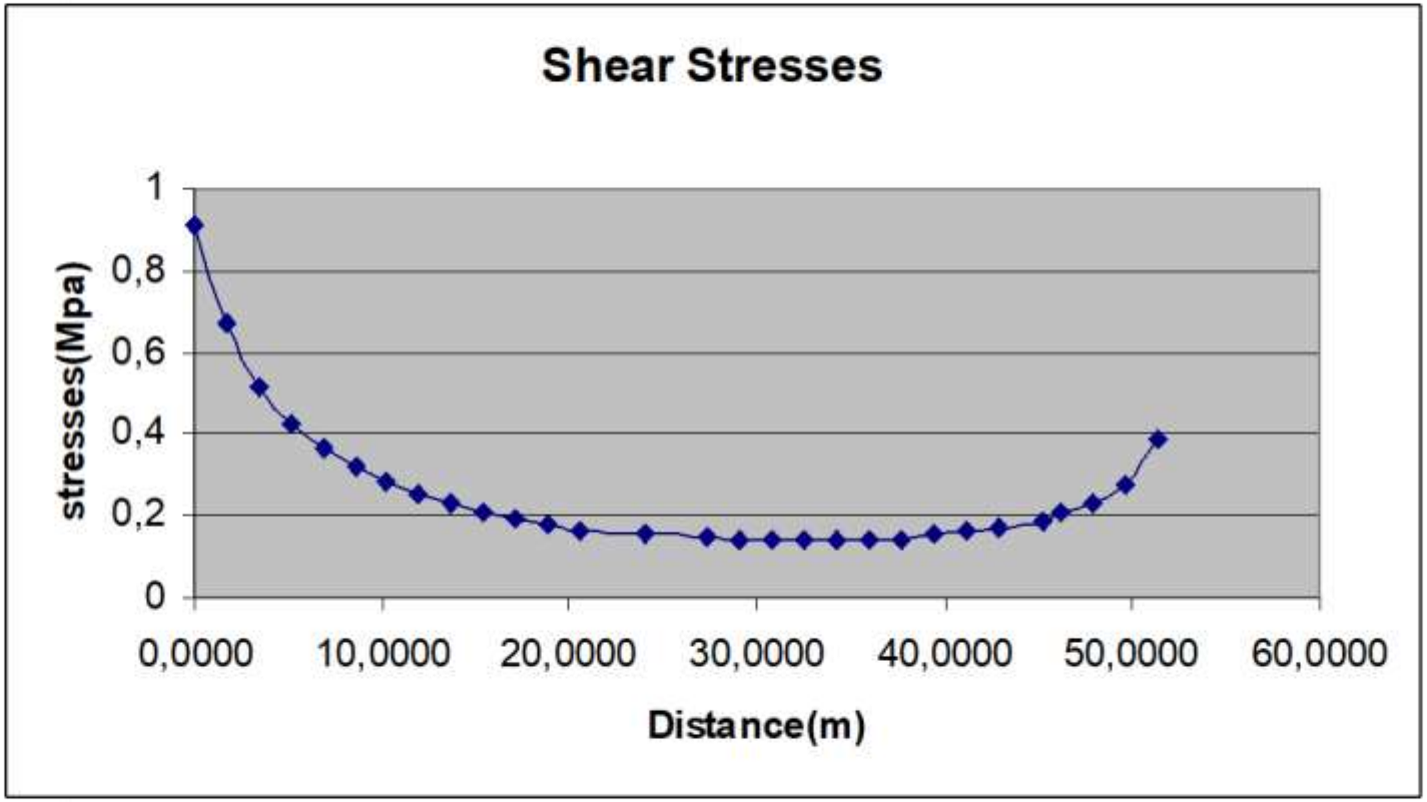
Static Analysis Results



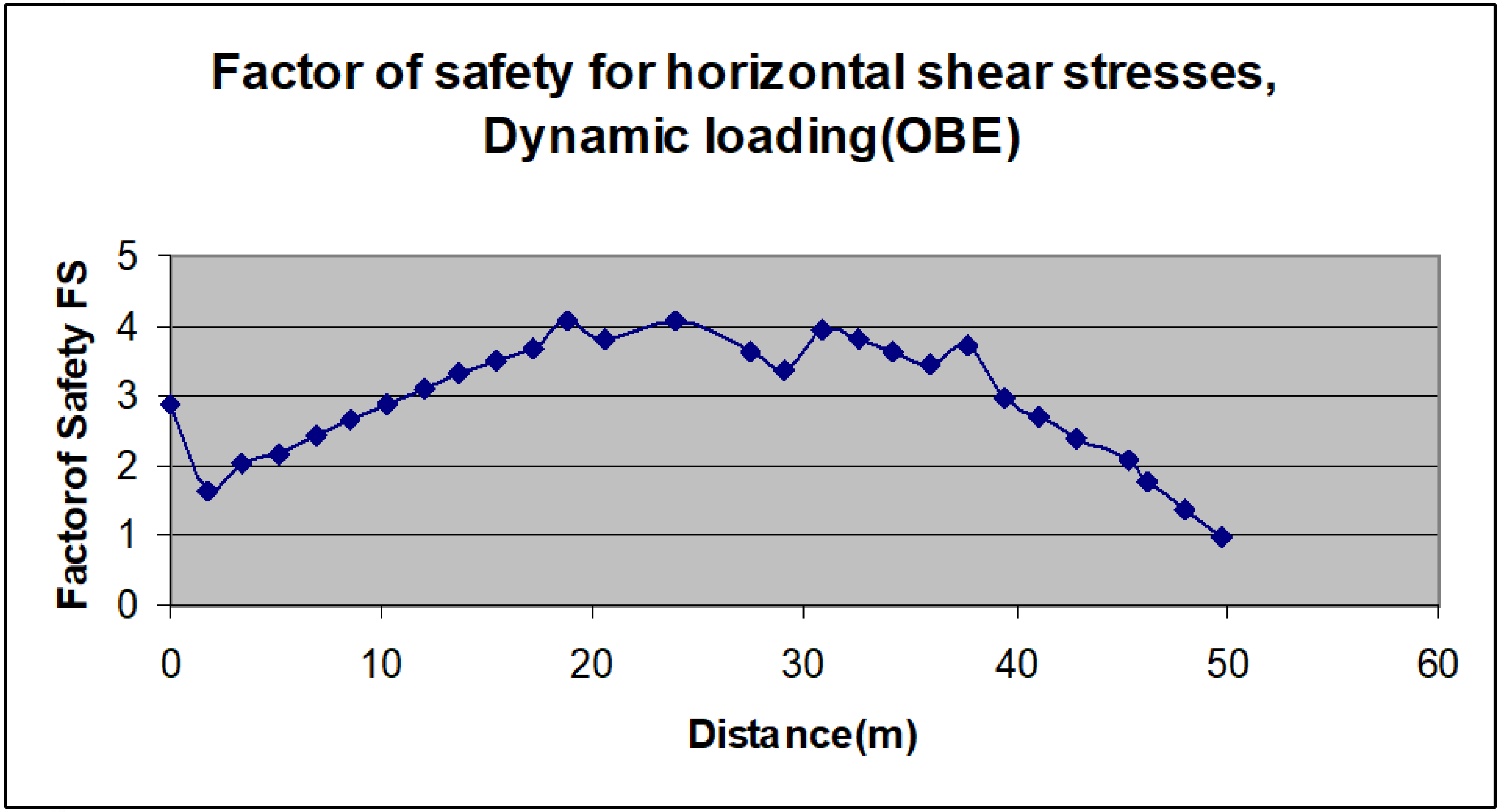

Factor of safety for horizontal shear stresses ,
static loads
Factor of safety
3
2,5
2
1,5
1
0,5
0
0,0000
10,0000
20,0000
30,0000
40,0000
50,0000
60,0000
Distances(m)

Dynamic Analysis Results

OBE



OBE



Factor of safety for horizontal shear stresses, Dynamic loading(OBE)
Factorof Safety FS
5
4
3
2
1
0
0
10
20
30
40
50
60
Distance(m)

Conclusion

The Satbility of Mujib dam against sliding was carried out using 2D-FEM.

The factor of safety against sliding along the base of the dam was determined for various loading cases (static, OBE, MCE). The calculated stress levels were compared with the strength of RCC and rock foundation. Also, the factor of safety against sliding was analysed and it was found that under static and dynamic loading conditions, all values of FS along the base of the dam exceeded 1.

Thank You