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The Behavior of the Al-Kadhim Minaret during Earthquakes, A Virtual Study

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ABSTRACT

The study focuses on the causes of minaret tilting as well as possible solutions. The major aims of this study are to improve knowledge of historical tall structure stability and rehabilitation operations using the finite element approach to model the soil and minaret (PLAXIS 3D 2020), a platform for computational soil investigation and modeling. The numerical analysis aims to identify stresses, settlement, and deformation of the soil and minaret in various scenarios like Earthquakes, explosions, and winds. The simulation of the problem by the PLAXIS 3D revealed that the greatest lateral displacement computed at the Top Minaret is 5.5 cm, and the greatest vertical movement is calculated to be 3 cm. Seismic settlement is the effect of earthquake shaking, causing densification of soil with lower relative density.

Keywords: Minaret, earthquakes, PLAXIS 3D.

سلوك المئذنة أثناء الزلازل. دراسة افتراضية

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الخلاصة

تركز الدراسة على أسباب إمالة المئذنة بالإضافة إلى الحلول الممكنة. تتمثل الأهداف الرئيسية لهذه الدراسة في تحسين المعرفة باستقرار الهيكل الطويل التاريخي وعمليات إعادة التأهيل باستخدام نهج العناصر المحدودة لنمذجة التربة والمئذنة (PLAXIS 3D 2020) وهي منصة للتحقيق في التربة والنمذجة الحسابية. يهدف التحليل العددي إلى تحديد ضغوط واستيطان وتشوه التربة والمئذنة في سيناريوهات مختلفة مثل الزلازل والانفجارات والرياح. كشفت محاكاة المشكلة بواسطة PLAXIS 3D أن أكبر إزاحة جانبية محسوبة في أعلى المئذنة هي 5.5 سم وأن أكبر حركة رأسية محسوبة على 3 سم. التسوية الزلزالية هي تأثير اهتزاز الزلزال الذي يتسبب في تكثيف التربة بكثافة نسبية أقل.

الكلمات الرئيسية: المئذنة , الزلازل , PLAXIS 3D.

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1. INTRODUCTION

Studying the impact of earthquakes on buildings and facilities has become very necessary, especially the proximity of our region (the Middle East region) to the seismic line and the impact of earthquakes that have become present in recent years. The need to take measures to protect it, especially the historical buildings. It focuses on the interaction of soil and structure, where soil plays a major role in stabilizing the foundations of structures.

According to the earthquake study, displacements grow along the height of the minaret, and the highest and minimum primary stresses occur at the transition segment and the cylindrical body. The majority of minaret failures happened above the structure's base **(Türker, 2011)**.

As is commonly known, masonry has a reasonably high compressive strength but poor tensile strength. In addition to gravity stresses, masonry constructions may be subjected to lateral loads and other forces. The buildings' own weight can withstand small lateral loads. However, under greater lateral stresses, these structures typically demonstrate unsatisfactory structural performance, this is especially true for thin masonry buildings such as minarets, tall chimneys, and towers located in seismically active areas and/or subjected to severe winds **Fig. 1** displays some instances. When **Fig. 1** is examined, it is observed that the collapse or damage of masonry minarets occurs at different buildings in the occurrence of seismic events **(Mammadov, 2013)**.

The release of energy waves known as seismic waves in the earth's crust causes a natural calamity known as an earthquake. An earthquake is defined as a sudden, violent shaking of the ground produced by the shattering and shifting of rocks under the earth's surface. Stresses accumulate under the earth's surface throughout time. Stress is occasionally released, resulting in unexpected and sometimes disastrous shaking. As a result, the performance of erected structures must be carefully established in the design process while taking earthquakes into account, and it must be regulated throughout their life; tall structures, by definition, need a lot of processing power to examine. Minarets are engineering constructions that are both thin and tall **(Bayraktar1a, 2014).**

Figure 1. Collapsed masonry minarets **(Mammadov, 2013)**

2. EARTHQUAKE LOAD

Many minarets are partially or fully destroyed in earthquake-prone or high-wind zones. One of the reasons for building minarets' failure is related to the misunderstanding of their dynamic behavior. In particular, the damage pattern, conservation, and structural safety evaluation of tall and thin structures like minarets and towers have become more important in the recent decade. The study of earthquakes aims to know the performance to design logical elements that can be studied and solved to give a description, such as an earthquake intensity scale. So the main feature is the definition of performance measures for decision-making to mitigate the risks of earthquakes to be a methodology to know the important seismic risks and engineering aspects of the problem, as these problems are depicted in **Fig. 2** Visualizing the structure as being loaded with lateral forces resulting from the earthquake that leads to damage **(Moehle, 2004).**

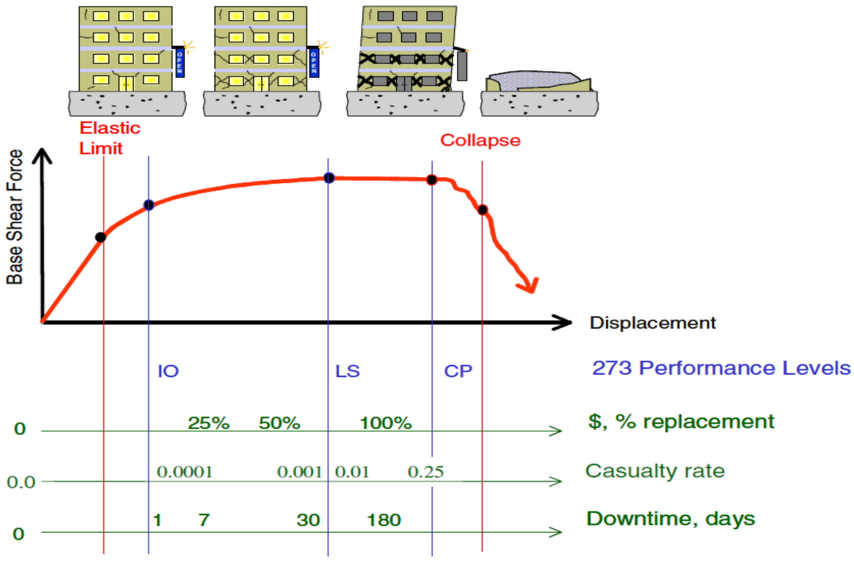


Figure 2. visualization of performance-based earthquake engineering **(Moehle, 2004)**

3. CASE STUDY and DESCRIPTION

The mosque is on the site of the Qureish cemetery, which was erected in 762 AD alongside Baghdad's old Round City. Imam Musa al-Kaim was buried there in 799 AD, and his grandson, Imam Muhammad al-Jawad, was also buried in 834 AD. The current structure stems from Shah Ismail Is restoration work, which took place between 1502 and 1524. Suleiman the Magnificent, the Ottoman Sultan who captured Baghdad in 1534, in this paper, the Al-Kadhim minaret is chosen to be a case study for research proposes. The minaret is approximately 41.5 m tall and made of bricks and plaster. The superstructure of the minaret is split into three sections, the first of which marks the height of the minaret from the ground to the slab floor, roughly 11.2 m. The second section is 18.8 m. The highest point is 11.5 m. The subterranean minaret is approximately 3.6 m in diameter. The foundations of the minaret consist of 3 steps. The dimensions of the first step are 3.6m × 3.6m and a depth of 2.5 m, and the dimensions of the second are 6m × 6m meters and at a depth of 1.5 m, and finally, the last step is 8m × 8m at a depth of 1.5 m. As seen in the illustration Fig 3&4,

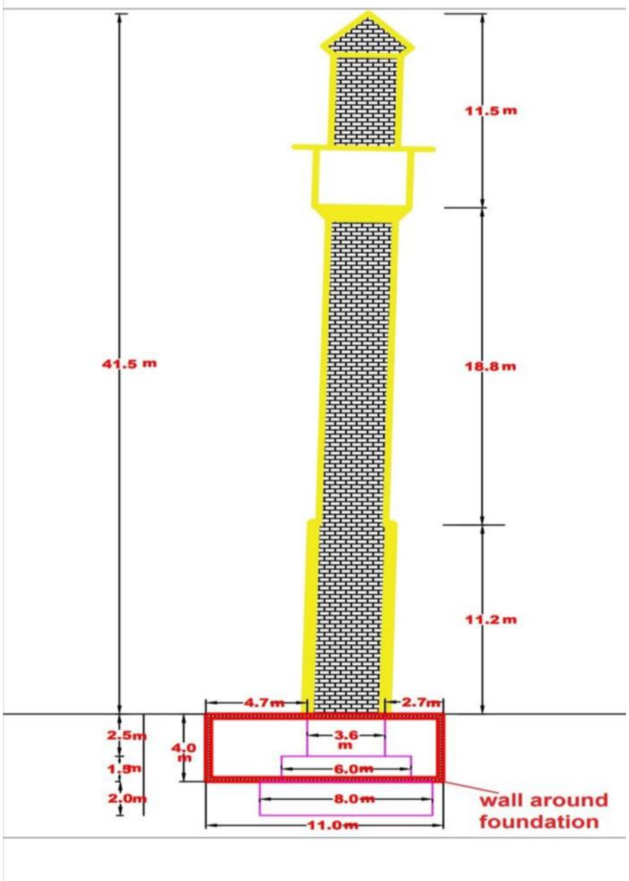


Figure 3. Al-Kadhim Tilted Minaret

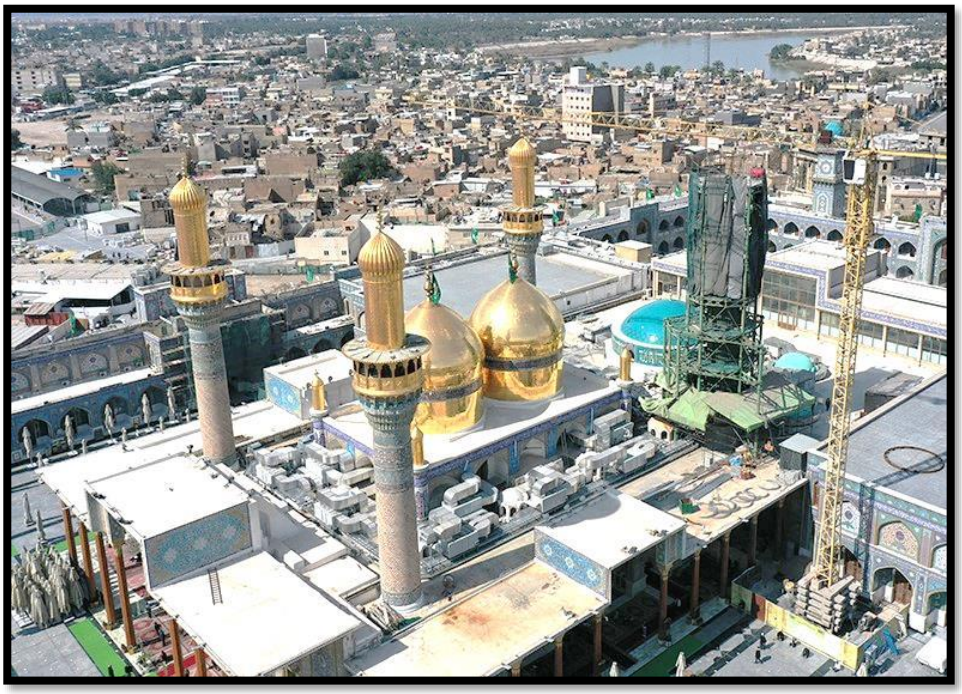


Figure 4. Al-Kadhim minaret **(Engineering Affairs Unit)**

4. SOIL PROFILE

The stratification of soil layers under the ground surface at the (NEM) site is depicted in **Fig. 5**. The site's most plentiful soil is a cohesive brown to grey clay soil. The USCS classifies cohesive soil as Fat Clay (CH) or Lean Clay (LC) (CL). Then there was poorly graded sand (SP) mixed in with well graded sand (SW). The soil parameters beneath the minaret are depicted in **Table1**.

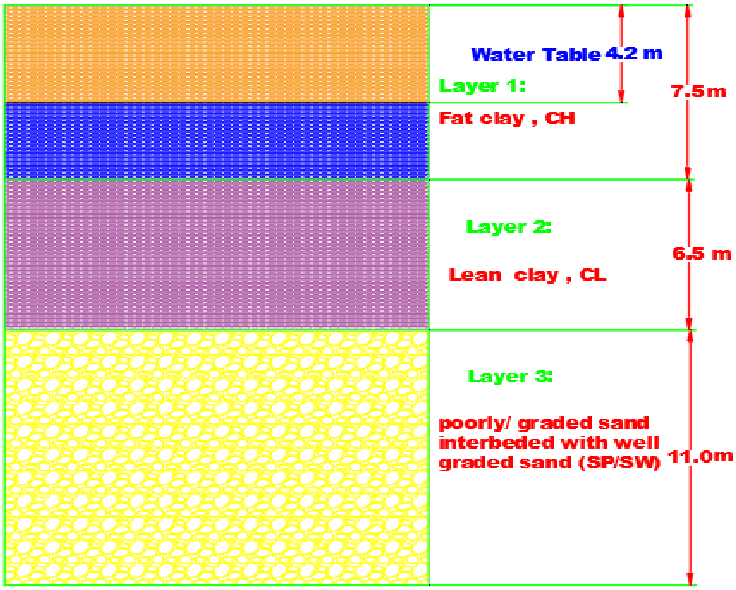


Figure 5: Soil Profile

The water table level in the shrine's courtyard is 4.20 m below the earth. Low seismic wave velocities (low stiffness modulus) describe the soil to a depth of (9-10 m), suggesting weak zones beneath the foundation and the surrounding wall of the Al-Kadhim shrine. The flaw was located between 3.0 and 5.0 meters below ground level (i.e., based on the site investigation report).

5. GEOMETRY of the 3-D MODEL

The PLAXIS 3D tool was utilized to do the analysis around the minaret foundation. The model's dimensions were 80 m in length and 8m in width, and the depth of the soil in the model was 25 m, representing the depth of the borehole from the site investigation. The model's boundary condition was applied in the same way as in earlier investigations **(Acharyya and Dey 2018), and (Chavda and Dodagoudar 2018)**, where the bottom border was set against the movement, whereas the right and left sides could only move vertically The interface element was utilized to show the interaction between the earth and the brick foundation. The mesh size was fine-tuned based on the convergence study performed for various scenarios to guarantee that the obtained results are independent of the mesh size, as shown in **Fig. 6**.

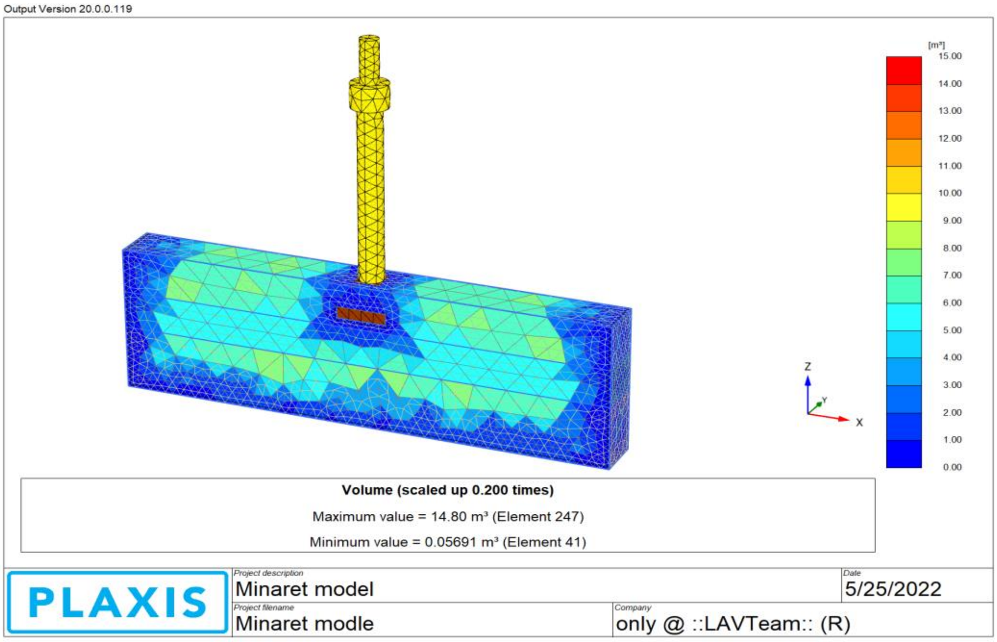


Figure 6: Meshed view of the model

They were modeled using linear elastic with brick properties. Soil properties that were used in numerical analysis are shown in **Table 1**. The properties of the bricks as shown in **Table 2**.

Table 1. Soil properties

Description	**Fat Clay,CH**	**Lean Clay, CL**	**Poorly /Well Graded Sand, SW/SP**
Unit weight (kN/m^3)	20	20	20
Modules of elasticity (kN/m^2)	4000	6000	10000
Poison ratio%	0.3	0.3	0.3
Cohesion (kN/m^2)	50	60	10
Internal angle($\emptyset^{\circ}$)	8	10	35

Table 2. Micropile and Brick properties

Properties	***Brick***
Unit weight γ	17 kN/m^3
Elastic modulus of the grout of micropile, Eg	5.6*10^6 kPa
Poisson's ratio, μ	0.2

The Virtual earthquake record was used as input motion in the analysis. The acceleration-time history of the record is given in **Fig. 7**.

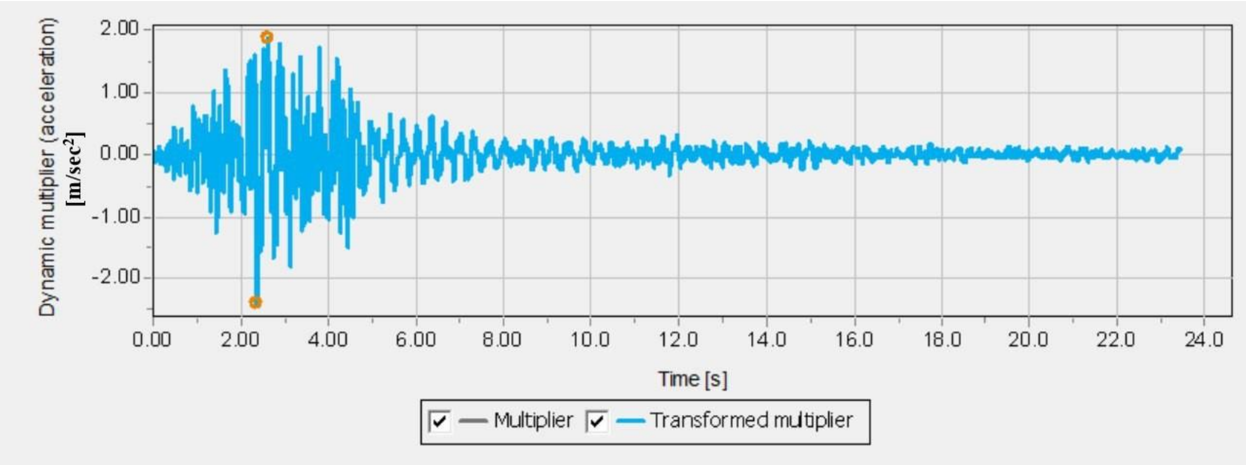
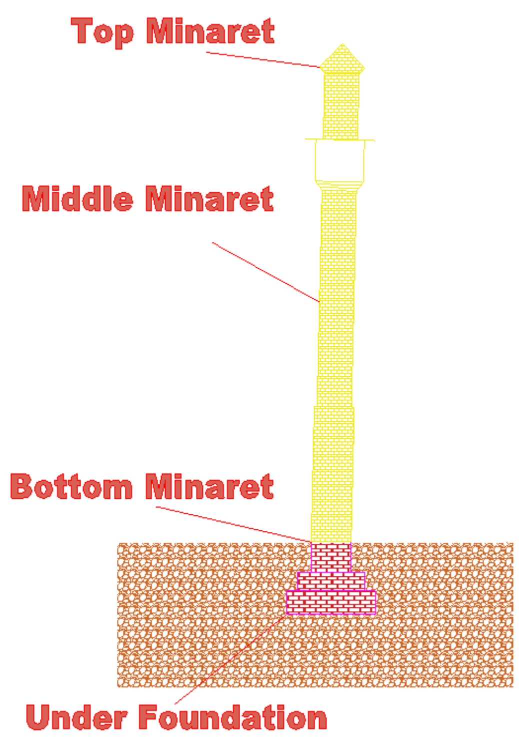


Figure 7. The acceleration time history of earthquake

Selected nodal points were from different heights of the model and soil profile. Each of the selected nodal points and their local coordinates was summarized in **Table 3.** with a schematic demonstration of the minaret.

Table 3. The local coordinates selected nodal points on the minaret model

Name Node	X	Y	Z
Top Minaret	*38.5*	*4*	*41.5*
Middle Minaret	*38*	*4*	*20*
Bottom Minaret	*38*	*4*	*5*
Under Foundation	*37*	*0*	*-6*



6. NUMERICAL ANALYSIS RESULTS

The acceleration spectra produced from analyses of the soil profile's base shows **Fig. 8** (i.e., node under foundation), ground surface (i.e., Node bottom minaret), the middle level of the minaret (i.e., node middle minaret), and minaret flag level (i.e., node top minaret) determined for a 5% damping ratio.

The spectral acceleration values at the level of the soil profile established at a depth of 25 meters below ground level were on the order of 0.18 g. If the research region is located on bedrock or near to the surface, the influence of local soil conditions is substantially lower than the effect of source effects. However, earthquake waves are substantially impacted by the features of the soil environment in such soft soil layers, and considerable increases in amplitudes may occur. The amplification impact on seismic waves recorded here is ascribed to clay units with lower density and stiffness at varying depths.

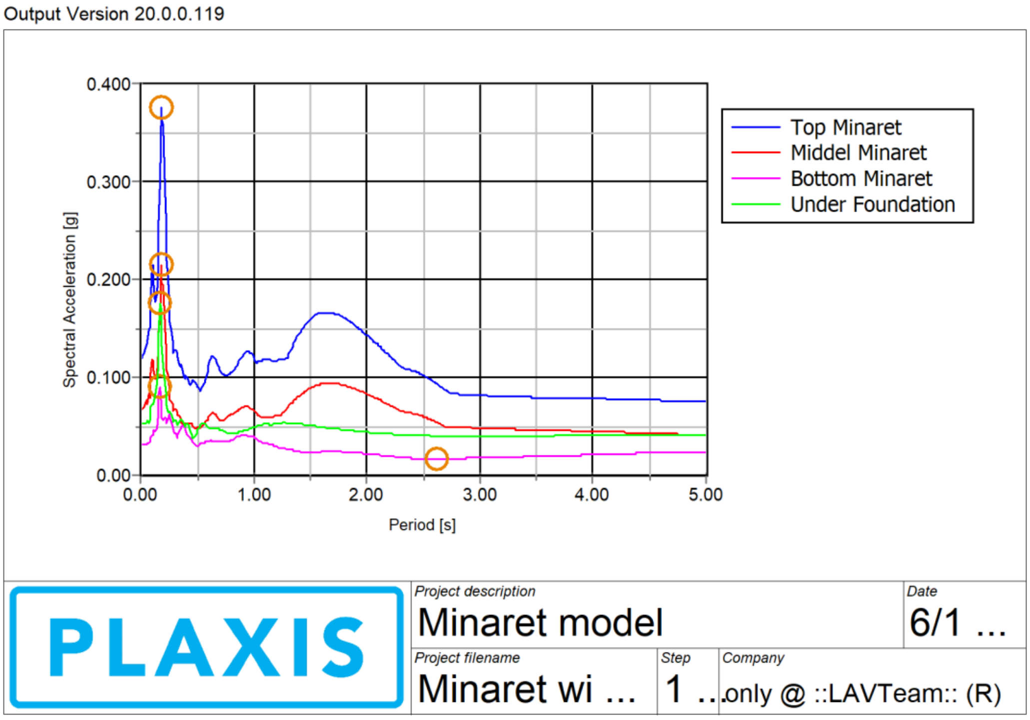


Figure 8. The response spectrum of various nodal points of structure and soil profile

Fig. 9 depicts the acceleration time history for chosen nodal sites. The nodal points were chosen from various heights of the numerical model to measure the influence at various heights of the structure. The applied seismic motion has a PGA value of 0.24 g (240 cm/sec^2). The PGA value of the flag, the highest level of the minaret, was measured as 0.117 g, and The PGA value of the ground surface (i.e., minaret bottom Node) was measured as 0.029 g.

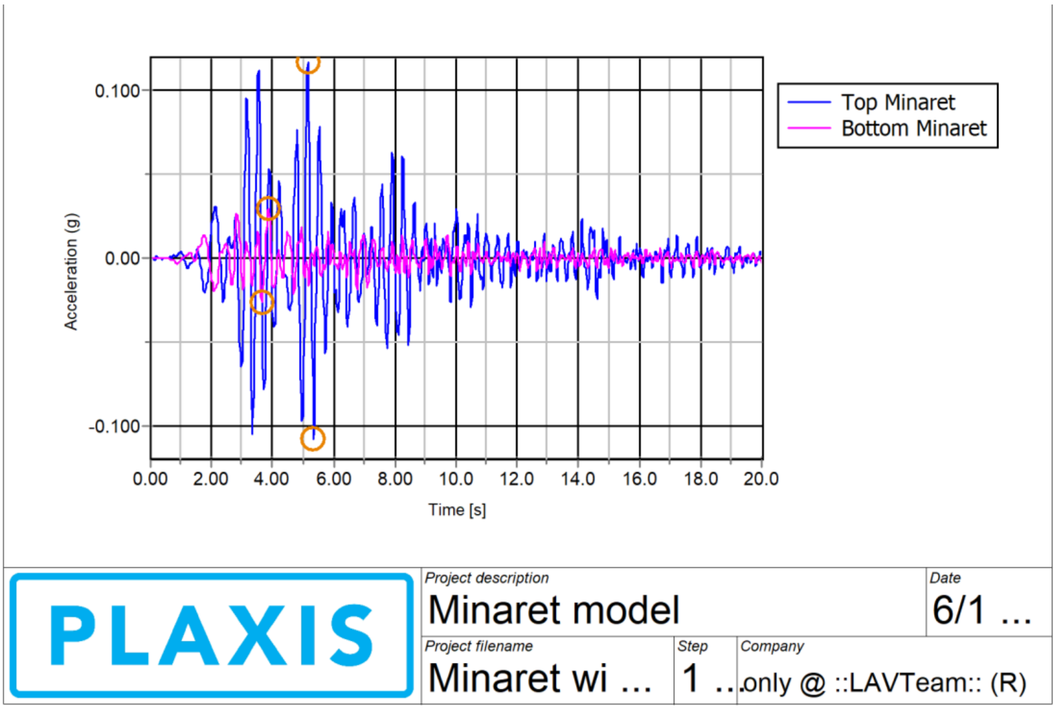


Figure 9. Acceleration time history of the selected nodal point

6.1 Lateral Displacement of the Minaret

The displacement time history of the chosen nodal sites is shown in **Fig.10**. The greatest lateral displacement computed for Middle Minaret Node, Bottom Minaret Node, and Under Foundation Node are 4.5cm, 3.5cm, and 3.4 cm. The greatest lateral displacement computed at the Top Minaret is 5.5 cm, and the model's deformed lateral displacement of the minaret mesh in **Fig. 11**.

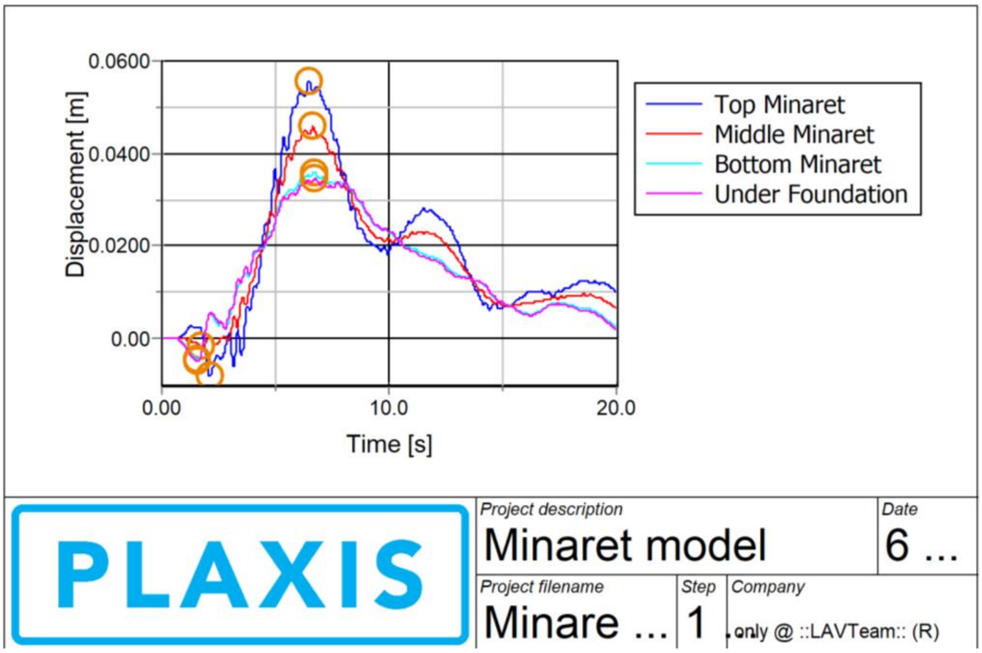


Figure 10. Displacement time history of selected nodal points

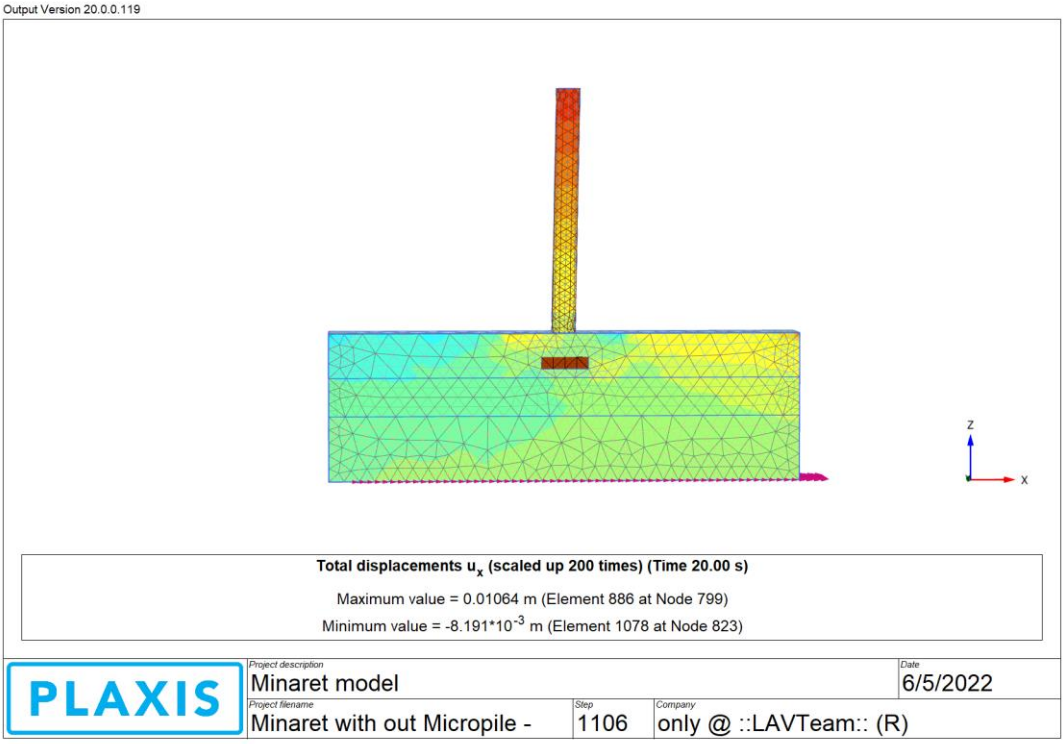


Figure 11. Displacement distribution of the numerical model

6.2 Deformation of Soil and Vertical Displacement (Settlement)

The geometry and FE discretization of the 3D model and the studied model's deformed mesh are shown in **Fig.12**. The greatest vertical movement is 2 cm. Vertical fractures produced on structural parts and their propagation over service life can be attributed to the predicted vertical displacement. The minaret's subsurface soil characteristics are multilayers of soft clay mixed with sand. The lesser stiffness of soil strata is linked to the vertical displacement during seismic force. The rising stiffness and shear strength of soil due to seismic shaking are referred to as seismic settlement influencing variables. Seismic settlement is the effect of earthquake shaking, causing soil densification with lower relative density**.**

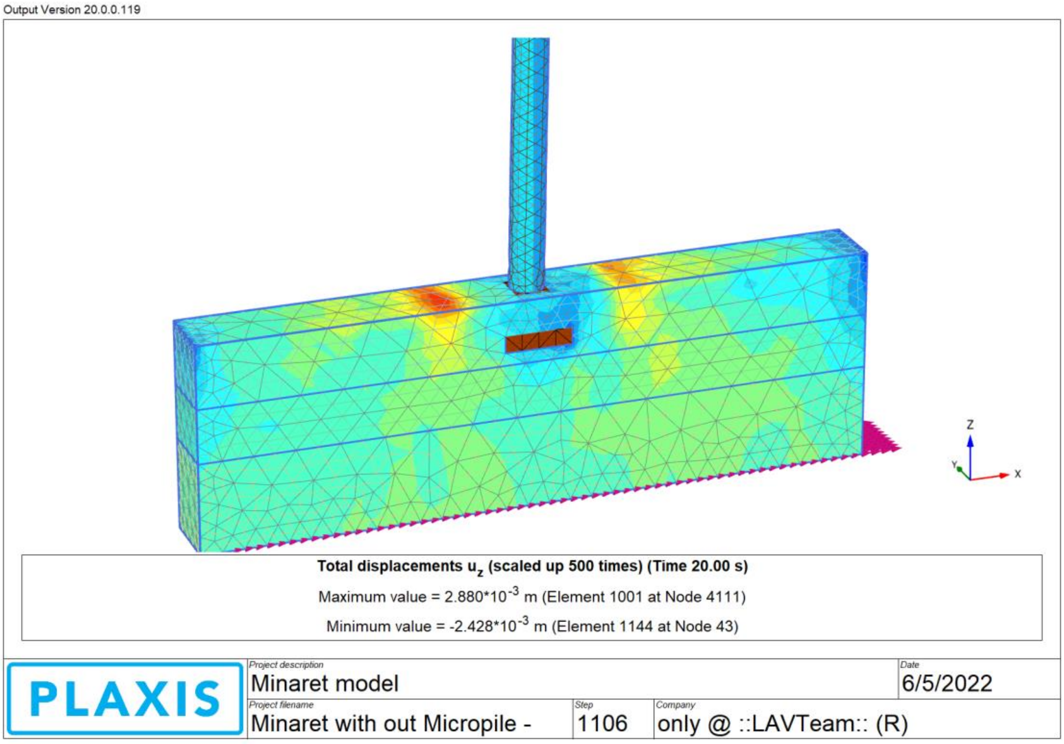


Figure 12. Total vertical displacement distribution of the numerical model

7- CONCLUSIONS

The seismic soil-structure interaction of the old Al-Kadhim shrine was investigated in this study. PLAXIS 3D finite element software was employed, commonly used by researchers in modeling and analyzing earth structures, as well as for soil-structure interaction issues in its 3D form. In the analysis, a fictitious earthquake record was employed, and the findings were evaluated in terms of acceleration and displacement. The following are the findings:

1. The local soil characteristics, which were largely made up of soft clay units, had an amplifying impact on seismic waves.
2. Spectral acceleration values obtained at various building heights reveal considerable increases, particularly at the minaret top level.
3. A horizontal displacement of 5.5 cm was observed at the top level of the minaret.

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