International Journal of Innovative Engineering Applications

Journal homepage: https://dergipark.org.tr/ijiea

SEISMIC SOIL-STRUCTURE INTERACTION OF A MASONRY STRUCTURE: SUNGURBEY MOSQUE

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Abstract

Original scientific paper

In existing buildings, it may be necessary to repair, adapt, renew, relocate or demolish buildings and building parts that have come to the end of their usage period due to spatial, functional, technical and economic obsolescence. After the necessary applications to extend the service life of buildings, it is of great importance to analyze the dynamic behavior of buildings under soil-structure interaction and earthquake loads and to obtain accurate results. In this study, the seismic soil-structure interaction of the historical Sungur Bey Mosque, which was first built in 1577 but was disassembled, moved and rebuilt in another area (relocated) in order to preserve its historical and cultural values and extend its service life, was examined. The analysis of the masonry structure that survived after the Sivrice (2020) earthquake, where the great loss of life and property occurred, was carried out with the PLAXIS 3D software program. The real record of the Sivrice NS (2020) earthquake was used in dynamic analysis. Local soil properties obtained as a result of field investigation studies were utilized in numerical modeling. Depending on the result of the analyzes, the effects of soil-structure interaction on a reconstructed historical masonry structure were examined. The results obtained from the analysis showed that the local soil conditions have an amplification effect on seismic waves that may induce structural damages in prospective seismic events.

Keywords: *Relocation, masonry structure, earthquake, soil-structure interaction, PLAXIS 3D.*

1 Introduction

Functional, technical and economic obsolescence occurs when certain performance characteristics of the building and its parts remain below a certain level of service value during their lifetime. In such a case, the building and its parts cannot meet the expectations and requirements in the face of changes and developments in technological, intellectual, visual, social, cultural, aesthetic, environmental and economic conditions. In order to create more sustainable environments, various recovery possibilities have been arranged for buildings and building parts that have reached the end of their lifetime.

Relocation within the established hierarchy of recovery possibilities enables the building system to be reused. At the same time, especially when relocation is applied in historical buildings, it helps to keep social and cultural values alive and transfer them to the future. The relocation of historical buildings takes place in line with social and environmental needs such as changes in building owners and user needs, climate changes and natural disasters, the ground structure they are located in, public investments (road, dam, etc. construction decisions), legal regulations.

Relocation is accomplished by removing existing or historical buildings from their current locations and transporting them to their new predetermined locations. Relocation is done in three different ways:

- Relocation as a whole/ intact move
- Complete disassembly
- Partial disassembly

Factors such as the distance from the place where the building is located and the area to be moved, construction technique, mass weight, plan scheme and transportation cost are effective in the selection of the method to be used for relocation. Regardless of the method to be applied, the relationship between soil-structure and earthquake loads after displacement is important for the long-term durability of structures. The relationship between soil-structure and earthquake loads should be examined by making detailed analyzes for the assessment of the long-term performance of historical buildings, especially before they are moved to their new location.

In this context, the soil-structure relationship of Sungur Bey Mosque, a historical building with masonry structure, which was relocated in another area, was examined in this study. Since the first day it was built, it has been exposed to many large and destructive earthquakes. Finally, on January 24, 2020, the structure experienced an earthquake with a magnitude of Mw 6.8, the epicenter of which was Sivrice, Elazığ. The main reasons for considering the historical Sungur Bey Mosque within the scope of the study are that;

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Received 05 October 2021; Received in revised form 26 December 2021; Accepted 27 December 2021

 Doi: https://doi.org/10.46460/ijiea.1004627

- It represents an important historical and cultural richness with its four centuries of history,
- It is a transported structure and its structural performance on local soil conditions is worth examining,
- Except for some structural deflections observed, it has not lost its structural performance under static and dynamic loads throughout its life.

Within the scope of the study, information about the period when the Sungur Bey Mosque was first built, the reason for moving, the process of moving and the interventions after the move was obtained as a result of a comprehensive literature search. In order to determine the structural and spatial characteristics of the current state of the building, first observational and then technical fieldwork was carried out. The general structural problems of the building were determined in the observational field study. As a result of the study, it was thought that the visible deviation, especially in the mosque minaret, would cause an important structural problem.

In the technical field study, a simple survey of the building was prepared in order to determine its spatial and structural dimensions. The deviation determined in the minaret section was measured using the total-station device. By using the structural and the soil investigation data the model of the mosque was developed using PLAXIS 3D software program and the soil-structure interaction was analyzed.

2 Case Study (Sungur Bey Mosque)

After the construction of the Keban dam, archaeological excavations, surveys and restoration work, ethnography, folklore and music researches were carried out between 1965 and 1975 in cooperation with universities and official institutions in the settlements that were flooded by the dam. During the works carried out before the construction of the dam, the Sungur Bey Mosque (Baysungur Mosque), which is the subject of the article, was included among the historical structures that needed to be preserved. Afterward, the survey and determination works of the mosque were carried out on 03.07.1969 and 15.08.1969 by the survey teams of the Restoration Department of the Middle East Technical University and the General Directorate of Foundations. As a result of detailed research, it was decided to protect the Sungur Bey Mosque by moving it to another place [1]. With the transfer of the mosque to its present location in 1971-1973, it was the first time a building of this size was relocated in Turkey with the cooperation of universities and official institutions.

In the light of these developments, it was decided to move the building using the dismantling technique with the help of numbers. Before dismantling, the survey of the building and its surroundings was performed, and all the building components were numbered. During dismantling, simple hand tools such as picks, hammers and crowbars were used. The use of lime mortar in the stone masonry provided great convenience in removing them one by one.

It is stated on the inscription in the Harput museum that the mosque was built by Sungur Bey between 1572-1577. The mosque was originally built on slightly sloping land on the northeastern skirts of the Pertek castle on the edge of the Murat River. (Figure 1) [2]. With the relocation decision, the mosque was rebuilt in Pertek District, at the exit of Elazig highway, on a sloping land descending from north to south. (Figure 2). There is an elevation difference of 2.83 m between the north and south points of the land where the mosque is newly located.

Figure 1. Before relocation of Sungur Bey [3].

Figure 2. Current location of Sungur Bey [4].

In the center of the mosque, there is a single domed, square planned prayer hall with dimensions of 10.50 x 10.50 m. In the prayer hall, there are plastered rubble masonry walls with a height of 3.50 m from the ground and a thickness of 0.9 – 1.10 m. The strums carried by the masonry stone walls bordering the prayer hall are limited by a pointed arch. An octagonal surface was used in the transition to the dome. The width of the dome in the prayer hall is 9.80 m and its height is 11.40 m from the ground. There are many windows on each facade, two on the lower part, one on the upper part (except for the north facade), and one on each facade of the octagonal drum. [5].

In the northern part of the building, there is a narthex with a width of 12 m and a depth of 4.50 m. The east and west facades of the narthex are closed, and there are three domes with pendentive passages on them. There is a 29.00 m high minaret, which rises on a pedestal measuring 3.00 x 1.80 m, located in the north-west of the mosque. The east, west and south façades of the mosque are symmetrical and were formed with lime mortar between the rough rubble stone walls. The walls of the northern façade were built with cut stone.

Various maintenance and repairs were carried out by the General Directorate of Foundations in 1977, 1978, 1981, 1987-1988 in order to eliminate the damages caused by environmental and structural effects after the relocation process. Within the scope of the study, it was determined that there were some assembly and structural problems in the mosque.

Assembly Problems: The decorations on the crown door of the mosque also showed defects in application and workmanship (Figure 3). In addition, some gaps were found in the joint fillings between the decorations. Especially as a result of the repetitive temperature changes of the settlement area, regional defects may occur in the decorations. In addition, significant manufacturing defects were detected at the stone joints in the interior (Figure 4).

Structural Problems: In the interior of the building, there are deficiencies in the joint filling in a significant part of the arch elements. In addition, insulation problems and plaster spills were detected in certain areas on the walls, under the windows and inside the dome (Figure 5). If preventive measures are not taken, this may lead to significant structural problems in the future. There are cracks in the lintel above the window that is suitable for capillary and development (Figure 6).

Significant deflections were detected on the basis of the single-story WC structures, which were built separately in the mosque yard. It is thought that this situation occurred as a result of differential settlements on the ground. In the body of the mosque minaret, a visible deviation from the vertical axis is observed at the exit level of the roof of the prayer hall. It is thought that this deviation will cause an important structural problem in the future. However, there is no clear information about whether this deviation occurred after the earthquake. (Figure 7).

Figure 3. Assembly problems of the crown door


Figure 4. Stone wall joints problem in the interior.


Figure 5. An example for Insulation problem.


Figure 6. Cracks in the lintel above the window.

Structural damage to the architectural heritage is often caused by the displacement of the earth's soil, its differential settlement, rotation of the structure or any other effect of the interaction between the structure and the soil [6]. Many analytical and experimental studies have been carried out to determine the structural behavior of historical buildings [7-19]. The most crucial part of the studies be performed in this area is to evaluate the soil and building behavior together. Otherwise, performing these analyzes independent of the soil conditions may cause possible soil amplification effects to be neglected especially for dynamic cases.

The behavior of the structure under the earthquake is affected by factors namely; source effect, path effect, local soil conditions, and soil-structure interaction. The source effect is generally considered to be the fracture mechanism, the distance to the fault, and the earthquake magnitude. Earthquake waves, on the other hand, reach the soil surface by passing through different rock formations, and in some cases are changed by soil layers. With this change, seismic waves may amplify or deamplify up to 4-5 times. As a result of these effects, upper structures will be exposed to extreme earthquake forces. Therefore, soil-structure interaction (SSI) analyzes are of great importance in simulating the real behavior of structures under earthquake motions. In general, the SSI analysis has been performed under two categories namely; substructure and direct method. Both of these methods aim to overcome nonlinearity problems. According to Menglin and Jingning [20], this interaction may become evident in three ways; **i.** In particular, the fundamental period will lengthen and the rigid body motion of the structure will change, **ii.** The overall damping of the soil-structure system increases, **iii.** It will change free-field ground motion.

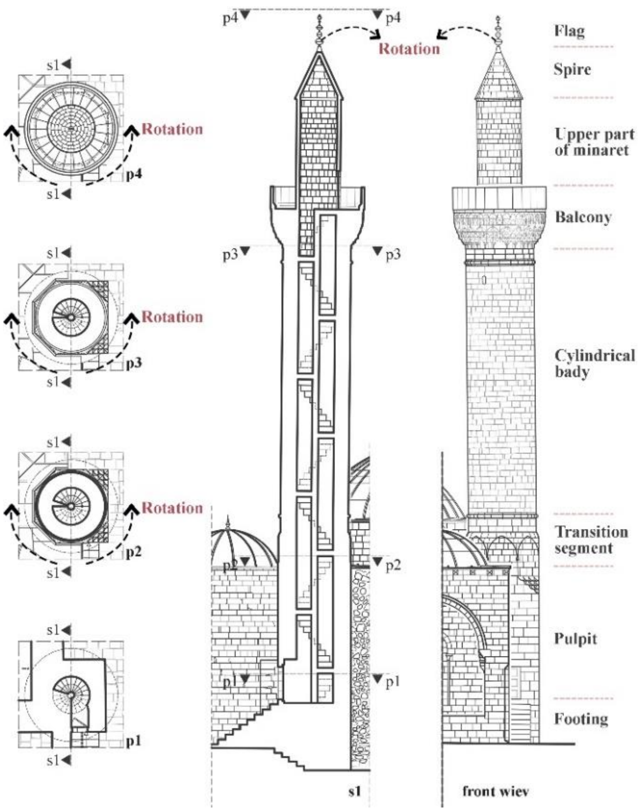


Figure 7. Deviation observed in the minaret.

Studies on soil-structure interaction were conducted by several researchers [21-27]. Ivanovic [23] performed 3D finite element analysis of a seven-story reinforced concrete building supported by the piled foundation on loose soil. Effect of the load magnitude and length/diameter ratio on pile response and pile head displacement subjected to harmonic loads revealed as a result of finite-difference numerical analyses performed by researchers [24]. Torabi and Rayhani [25] utilized FEM models to investigate the effect of site response and seismic soil-structure interaction on the performance of structures. It was demonstrated that the greater values of aspect ratio and structure-foundation relative stiffness ratios may lead structure vulnerable to the inertial soil–structure interaction. A set of factors depending on the structural abrasion of masonry foundations were proposed utilizing 2D FEM models [26]. Gouasmia et al. [27] developed analytical models of a 5 story reinforced concrete building to investigate soil-structure interaction. Allowing the structure to slide or uplift has not changed on measured acceleration or displacement whereas the base shear and overturning moments reduced 74%. Kavitha et al. [29]. investigated the dynamic behavior of a pile embedded in various types of soil using PLAXIS 3D finite element software. It has been revealed that the dynamic response is dependent on the frequency and stiffness ratio. As a result of a set of FEM analyses of a historical masonry church performed using the PLAXIS 3D software program, the humidity problems are attributed to subsurface water rise, and the damages on brick walls are explained with the consolidation settlement of the soil occurred after earthquakes [6]. Bovolenta and Bianchi [30] developed a 3D model of a village subjected to slope movements and a historical church. The soil movement that caused damages to a historical church is validated by FEM analysis. The dynamic soil-structure interaction of a railway bridge was investigated and it has been revealed that the adjacency of the fundamental frequencies of the structure and soil strongly influences soil-structure interaction [31].

The purpose of the current study is to develop 3D FEM model of the historical masonry Sungurbey Mosque, to investigate dynamic soil-structure interaction considering local soil conditions. The main motivation for the analysis is to simulate the seismic soil-structure interaction under local soil conditions of a reconstructed masonry structure in an area with high seismic activity intensity with the same structural elements after being moved. The analysis is accomplished by the HS small soil model which is a refined version of the hardening soil model for modeling soil behavior within the small strain ranges. The soil profile was modeled using site investigation data. In the dynamic analysis, the Sivrice (2020) earthquake record was used, the epicenter of which is very close to the location of the mosque (**i.e.** 60 km). The response of the building was evaluated in terms of accelerations and lateral displacements.

3 Seismicity and Local Soil Conditions

Pertek is located between the two most important seismic belts of Turkey, the East Anatolian Fault Zone (EAFZ) and the North Anatolian Fault Zone (NAFZ). Among these belts, the East Anatolian Fault Zone (EAFZ) is a 580 km long left-lateral strike-slip fault zone extending in NE-SW direction between Karlıova and İskenderun Bay in eastern Turkey. It lies along the border between the Anatolian Plate and the Arabian Plate. The Eastern Anatolian Fault starts from the Maraş Triple Junction at the northern end of the Dead Sea Fault Zone (DSFZ) and runs in the Northeast direction and ends at the Karlıova Triple Junction. Another important fault system is the NAFZ, which runs east-west. The NAFZ is an 1100 km long right-sided and strike-slip active fault line, starting from Karlıova in the east and extending to the Biga Peninsula and Saros Bay in the west, with a length of approximately 1200 km and intersecting the north of Turkey. [31-34]

As a result of the researches carried out in recent years, a fault with a lateral continuity in the topography has been mapped around Pertek [35]. The findings suggest that the Pertek fault is located in the compression zone between Erzincan, Karlıova, and Elazığ, bounded by the NAFZ to the north and the EAFZ to the east. The fault extends south-east and north-west direction and is approximately 40 km long. The southeast extension of the fault is under the Keban Dam Lake, while the northwest extension is damped along the Kinzir creek in the northwest of the Gökçe district (Figure 8). The seismic hazard map of Turkey is presented in Figure 9

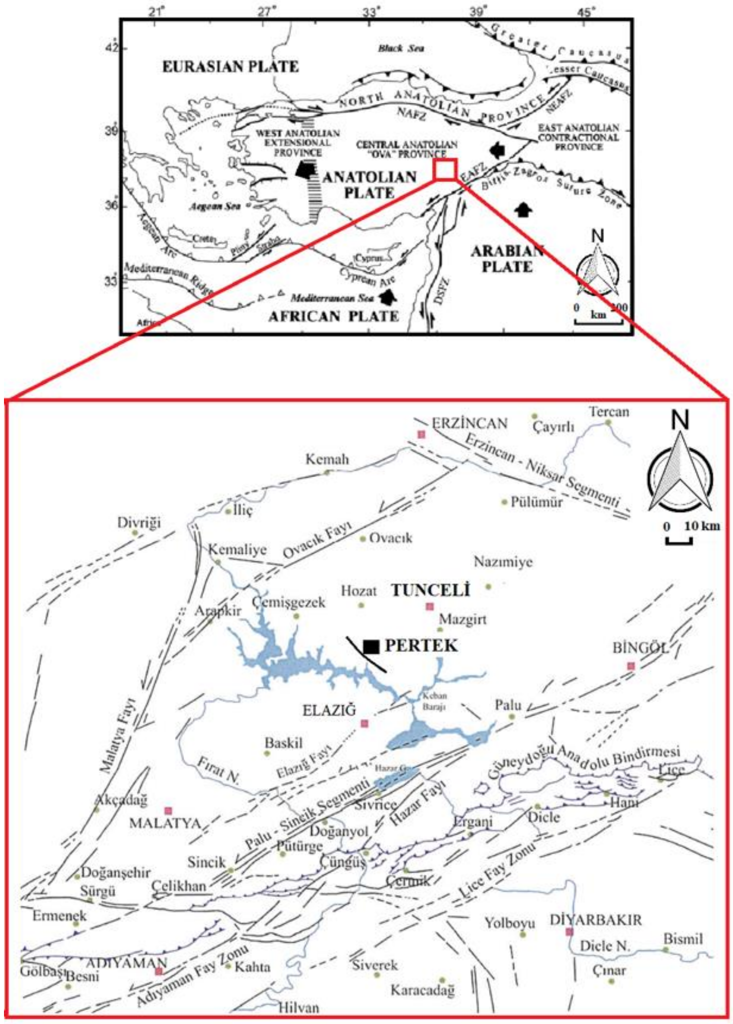


Figure 8. Simplified tectonic map of eastern Turkey showing major structures and neotectonic provinces (DSFZ – Dead Sea Fault Zone, EAFZ – East Anatolian Fault Zone, NAFZ – North Anatolian Fault Zone, NEAFZ – Northeast Anatolian Fault Zone) [32-34].

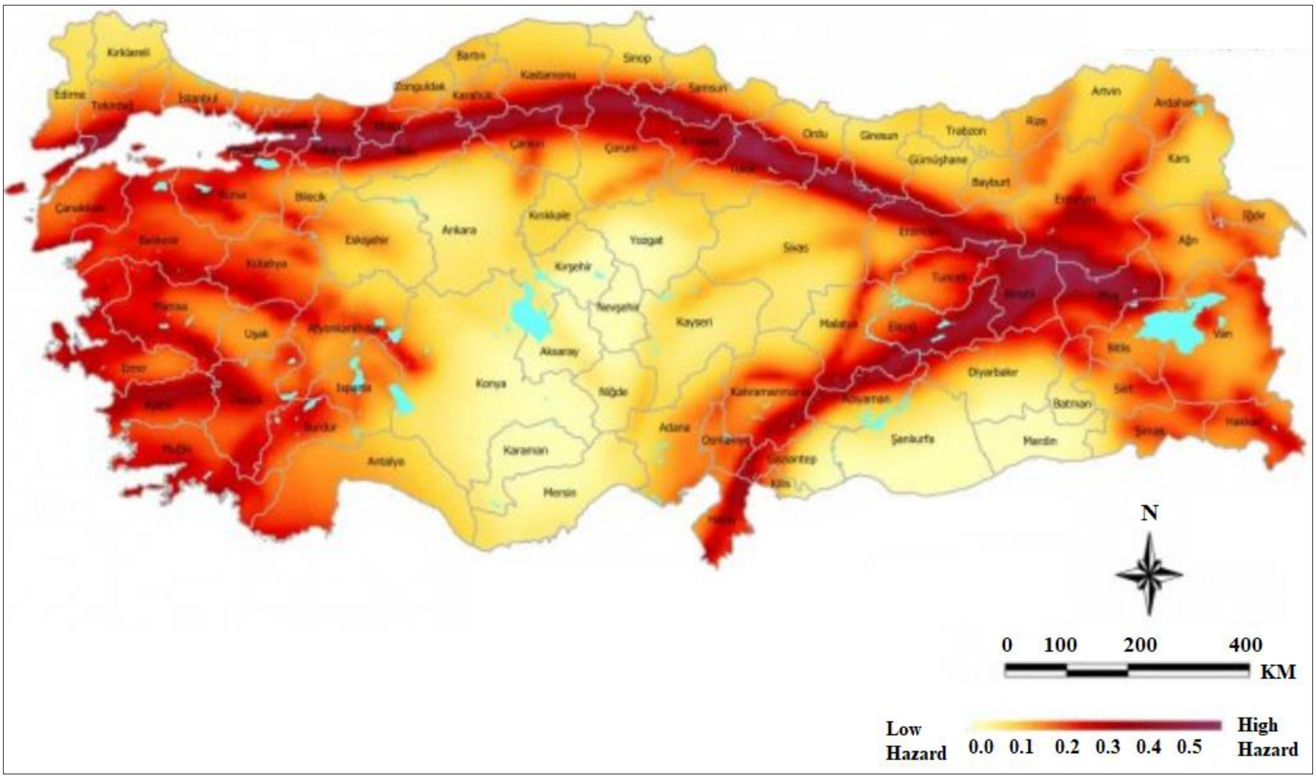


Figure 9. The Seismic Hazard Map of Turkey [38]

In the investigation area, 4 boreholes with a depth of 20 m and 3 Multi Analysis Surface Wave (MASW) tests were carried out. As a result of the field investigations, artificial fill layers up to 0.50 m depth from the ground level and clayey gravel and clayey sand units at different levels up to 40 m depth were encountered. Gravel and sand contents differ in lateral and vertical directions. The groundwater level is below the bottom of the borehole. The Vs_{30} wave velocities of the Quaternary units in the study area were measured as low in the upper layers and high in the deeper layers. When V_s wave velocities are measured as 430 m/sec on average, soil class is defined as C according to the NEHRP soil classification system. The soil parameters are summarised in Table 1. The idealized soil profile with the SPT and MASW test results is depicted in Figure 10.

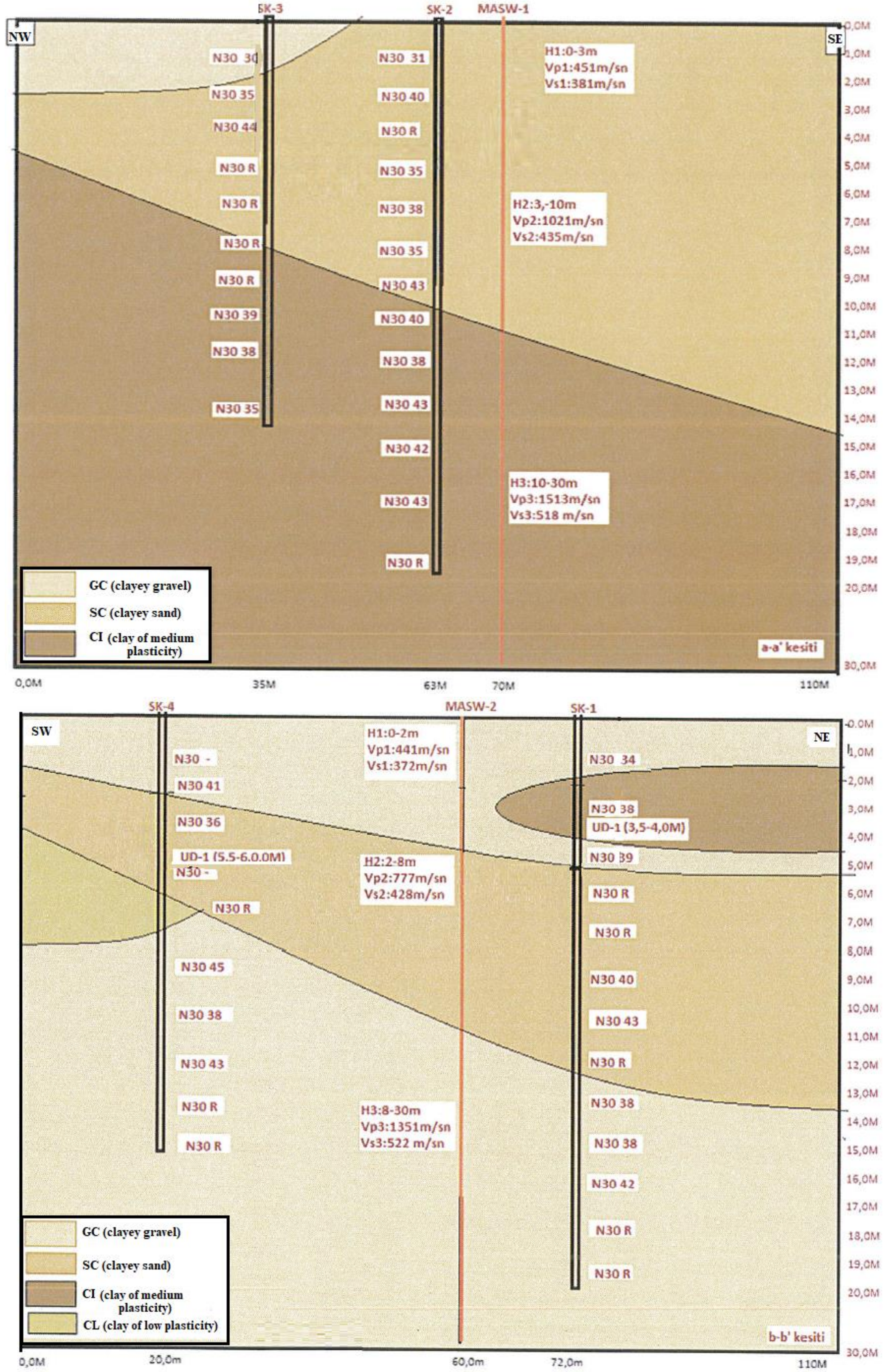


Figure 10. Idealized soil profile

4 Numerical Model and Analysis

The effects of local soil conditions on structural performance have been observed once again in recent earthquakes. Therefore, PLAXIS 3D finite element program, which is software with a high ability to analyze dynamic soil behavior, was used for soil-structure interaction analysis. The hardening soil model is an advanced model for simulating soil behavior. It assumes the elastic material behavior during unloading and reloading. However the strain range of the elastic soil is very small, therefore, the HS small soil model in which the very small-strain soil stiffness and its non-linear dependency on strain amplitude are taken into consideration is adopted as a soil behavior model. The HS small model requires defining reference stiffness modulus for first loading ($E_{50,\ ref}$), reference Young's modulus for unloading ($E_{ur,\ ref}$), and oedometer modulus ($E_{oed,\ ref}$). However, these parameters were numerically calculated by assuming the power for stress level dependency of stiffness, m as 0.70 since there is a lack of laboratory tests. The reference shear strain ($\gamma_{0.7}$) and shear modulus (G_{ref}) were used as 15.10^{-5} and 300.000 kN/m^2, respectively. The area of the model has been determined as 60*60 m wide in order not to be affected by the limited zone of the soil as stated by researchers that may capture non-linearity problems related to soft soil conditions [40]. Standard fixities were adopted at the boundary to fix the bottom in all directions. The geometry of the model is divided into volume elements and compatible structural elements. The element distribution was set to medium in the mesh generation menu. Since the total area of the model is enough large, the finer mesh size was not preferred to avoid very long calculation times (Figure 11). The calculation process consists of the initial conditions, simulation of the construction of mosque, loading, free vibration, and earthquake analysis phases, respectively. The earthquake record with a magnitude of M_w 6.8, which happened at a depth of 8.06 km in Sivrice (EW), Elazig on January 24, 2020, was used as input motion in the analysis. The details of the earthquake are given in Table 2. The record has measured by the TK2308 Sivrice station. To get rid of the noise contamination portion of the record, high pass and low pass filters were applied as 0.1 Hz and 25 Hz low and high cut-off frequencies, respectively. In this way, the signal-to-noise ratio (SNR) remained above 3. This evaluation regarding the determination of cut-off frequencies was carried out on the FAS belonging to the earthquake record. The acceleration-time history of the record is given in Figure 12. The partition and load-bearing walls of the mosque, except for the dome, are designed as limestone, which is used as a natural building stone in a significant part of the historical buildings in Turkey. Stone samples have been collected from different locations in the structure of Sungurbey Mosque and the physical and mechanical testing have been achieved in the Ar Alçı Laboratory in Elazig by authors. The engineering properties of the stone are determined by laboratory tests and summarised in Table 3. Considering the laboratory test results, the self-weight of the structural elements was considered in the analysis during the construction phase. The masonry structure of the mosque was modeled using a solid element module. The mosque was modeled using frame elements for stone columns and shell elements for the ceilings. The domes are modeled as shell elements. The foundation is designed as a continuous with a thickness of 1 m. The material properties of the model is summarises in Table 4. All the graphical demonstrations were made for selected nodal points from different heights of the model and soil profile. The origin of local coordinates for the developed model is defined as front-left corner point as Node 0. Each of the selected nodal points and their local coordinates were summarised in Table 5 with a schematical demonstration of the mosque.

Table 1. Soil parameters used in numerical modelling

Layer	Depth (m)	γ (kN/m^3)	$E_{50\ ref}$ kN/m^2)	C_{ref} (kN/m^2)	ϕ (°)	ν_{ur}	V_s (m/s)
Topsoil	0-0.50	16	10000	40	5	0.2	430
Brownish clayey gravel	0.50-2.0	16	15000	44	5		
Medium plasticity dark brown clay	2.0-4.0	17	15000	47	5		
Clayey gravel I	4.0-5.0	17	20000	44	5		
Dark brown clayey sand	5.0-13.5	17	20000	55	7		
Clayey gravel II	13.5-20.0	18	30000	55	7		

Table 2. Details of the applied earthquake motions

Earthquake	Date	Station Name	Magnitude	Component	PGA (cm/sec^2)
Sivrice, Elazığ	24.01.2020-17:55 (GMT)	Sivrice (2308)	6.8 (M_w)	E-W	292.80 (0.30 g)
				N-S	235.79 (0.24 g)
				U-D	178.58 (0.19 g)

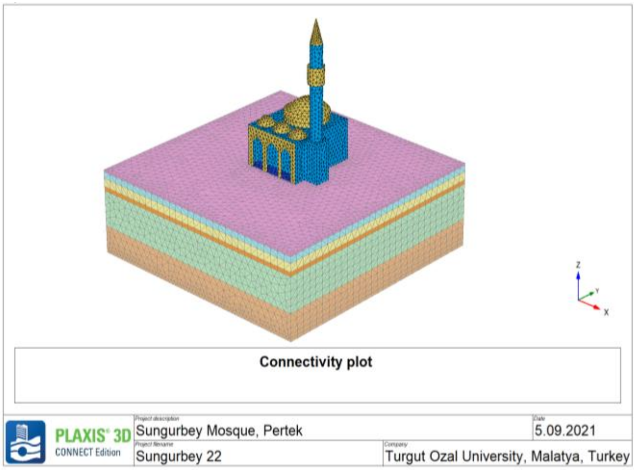


Figure 11. Meshed view of the model

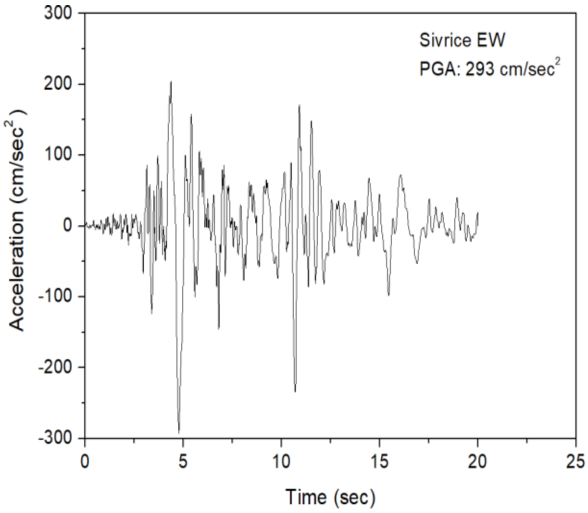


Figure 12. The acceleration time history of Sivrice EW (2020) earthquake

Table 3. Average material properties of limestone

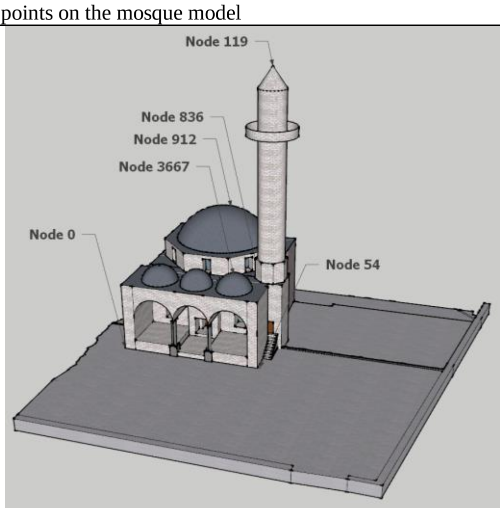
Sample	G_s (g/cm³)	W_a (%)	n (%)	σ_c (MPa)	σ_t (MPa)	E (GPa)
Limestone	2,68	2,93	0,11	94	11,45	30

Table 4. Material properties of the structure

Parameter	Foundation	Structure
EA (kN/M)	13.000.000	850.000
EI (kNm²/m)	2.000.000	70.000
w (kN/m/m)	20	15
ν	0.0	0.0
α	0.23	0.23
β	0.008	0.008

Table 5. The local coordinates selected nodal points on the mosque model

Nodal Points	x (m)	Y (m)	Z (m)
0	0	0	0
836	14.90	4.40	5.30
3667	11.40	2.60	6.74
912	7.45	11.20	10.40
119	14.10	6.20	26.4
54	42	28	0



5 Results and Discussion

Acceleration spectra were obtained as a result of analyzes for the base of the soil profile (**i.e.** Node 131), ground surface (i.e. Node 54), the top level of the main dome (**i.e.** Node 912), and minaret flag level (**i.e.** Node 119) defined for 5% damping ratio is given in Figure 13. While the spectral acceleration values at the level of the soil profile defined at a depth of 40 meters from the ground level were in the order of 0.50 g, this value was calculated as 0.55 g with an increase of 10% at the ground level. If the investigation area is located on the bedrock or if the stiff soil layers are close to the surface, the effect of the local soil conditions is much smaller than the source effects. However, in such soft soil layers, earthquake waves are significantly affected by the properties of soil environment and significant increases in amplitudes may occur. The amplification effect observed here on earthquake waves is attributed to clay units with lower density and stiffness at different depths.

The spectral accelerations of varied damping ratios for nodal points selected from different heights of the mosque are given in Figure 14. The natural period of the considered nodes is around 0.5 sec. As the height of the selected nodes increases, the amplitude of the calculated spectral acceleration gets higher values at each damping level. The spectral acceleration for the Node 119 which represents the flag level of the minaret is calculated as 2.3g. Considering the whole masonry structure, it is likely that the acceleration values calculated at these levels at the end of the analyzes may normally cause destruction, especially for the minaret, which is vulnerable to damage in seismic conditions due to its height and structural features. According to the literature studies, minarets are at the limit of collapse in terms of tensile stresses. The main reason for this is that the tensile stresses are concentrated in the transition region of the minaret. Because in this region, the cross-sectional area is considerably reduced in the transition from square section to circular section [40]. In addition to these structural features of the minarets, the amplification effects due to soft soil conditions compel these structural elements to damage in seismic conditions. In this case, it is assumed that the acceleration value calculated at the bottom of the soil profile is amplified as a result of soft clay layers.

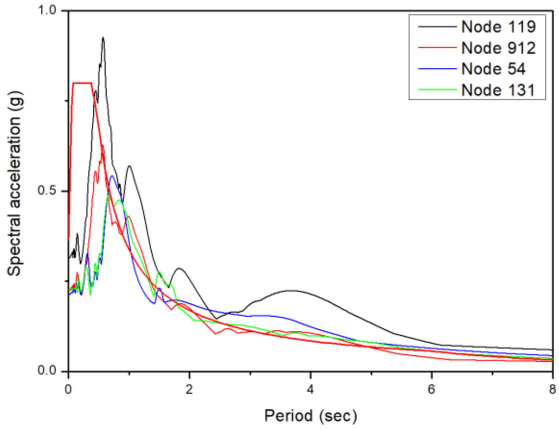


Figure 13. Response spectrum of various nodal points of structure and soil profile

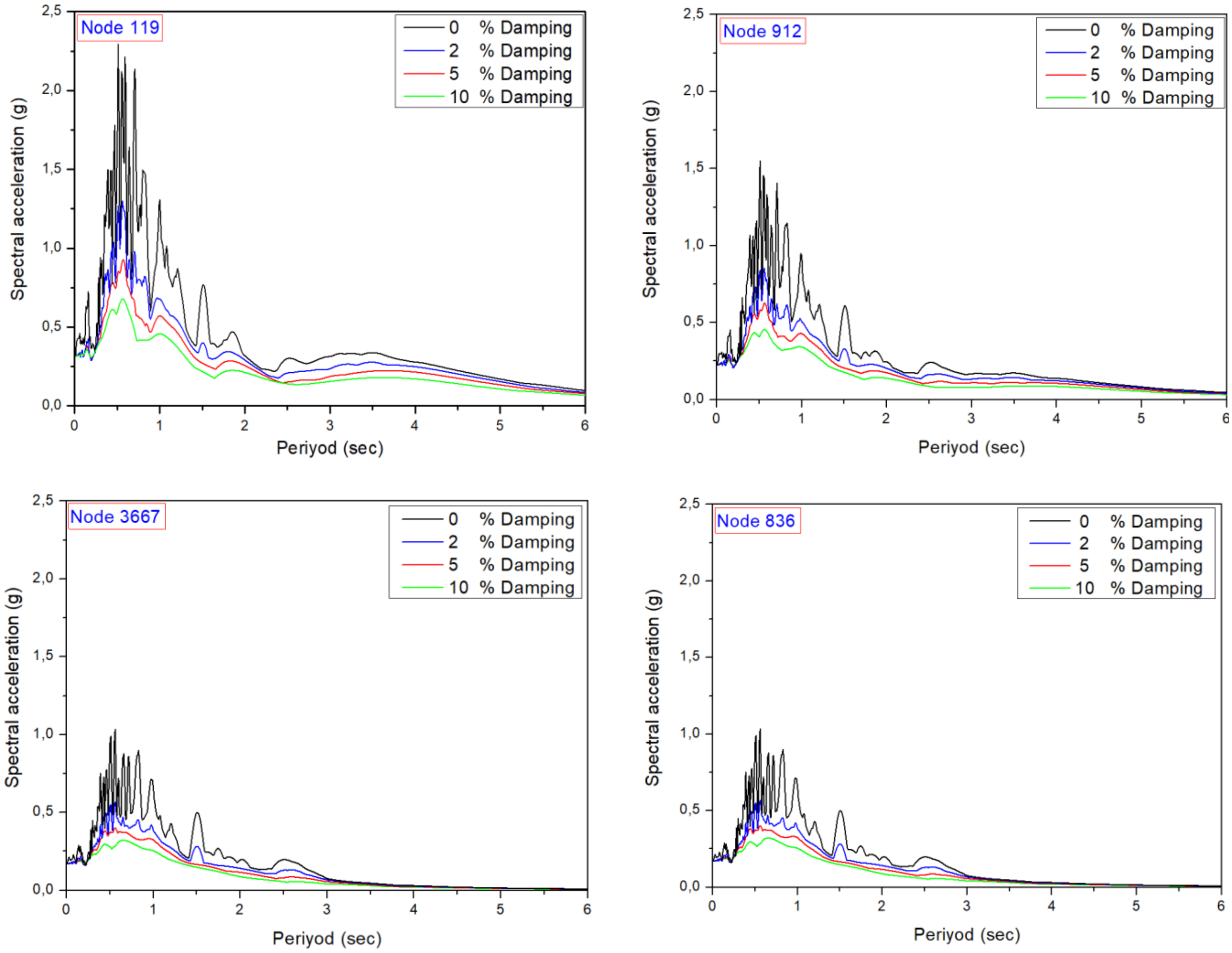


Figure 14. Response spectrum of selected nodal points on mosque model

The numerical model of the structure is subjected to Sivrice 2020 earthquake and the measured acceleration time history for selected nodal points is presented in Figure 15. The nodal points were selected from different heights of the numerical model in order to measure the effect that occurs at different heights of the structure. The PGA value of the applied earthquake motion is 0,29 g (293 cm/sec^2). The nodal points of 836 and 3667 represent the center of the semi-dome and the pulpit of the minaret, respectively. The PGA measured by the specified those two nodal points was measured as 0.22 g. Besides that, the PGA value of the central dome was measured as 0,24 g. The PGA value of the flag which is the highest level of the minaret was measured as 0,36 g. It is seen that the acceleration values increase as the considered nodal points get higher in terms of their elevation with respect to the base of the structure. The deflection observed on the minaret are attributed to the amplified accelerations along the cross-section.

The displacement time history of the selected nodal points is demonstrated in Figure 16. The maximum lateral displacement for Nodes 836, 3667 and 912 is calculated lower than 1 cm. However, the maximum lateral displacement calculated at the flag level is measured as 13 cm. Indeed, total station measurements made in the field also confirm the lateral displacement (**i.e.** 11 cm) from the vertical axis at the flag level of the minaret, which was obtained from the numerical analysis. However, there is no clear information about whether the displacement immediately occurred after the Sivrice 2020 earthquake. What is clearly known about this is that the horizontal displacement in the minaret does not progress over time with the measurements made at intervals. Figure 17 demonstrates the geometry and FE discretization of the 3D model and the deformed mesh of the analyzed model. The maximum vertical displacement is obtained as 10 cm. The calculated vertical displacement can be considered as a cause of vertical cracks formed on the structural elements and their progression throughout its service life. The subsurface soil conditions of the mosque consist of multilayers of soft clay mixed with sand and gravel. The vertical displacement under seismic loading is attributed to the lower stiffness of soil layers. The increasing stiffness and shear strength of soil as a result of seismic shaking are referred to as influencing factors on seismic settlement. The earthquake shaking caused densification of soil having less relative density results as seismic settlement. The HS model, precisely because of this reason, is utilized for the investigation of soil behavior for small strain ranges.

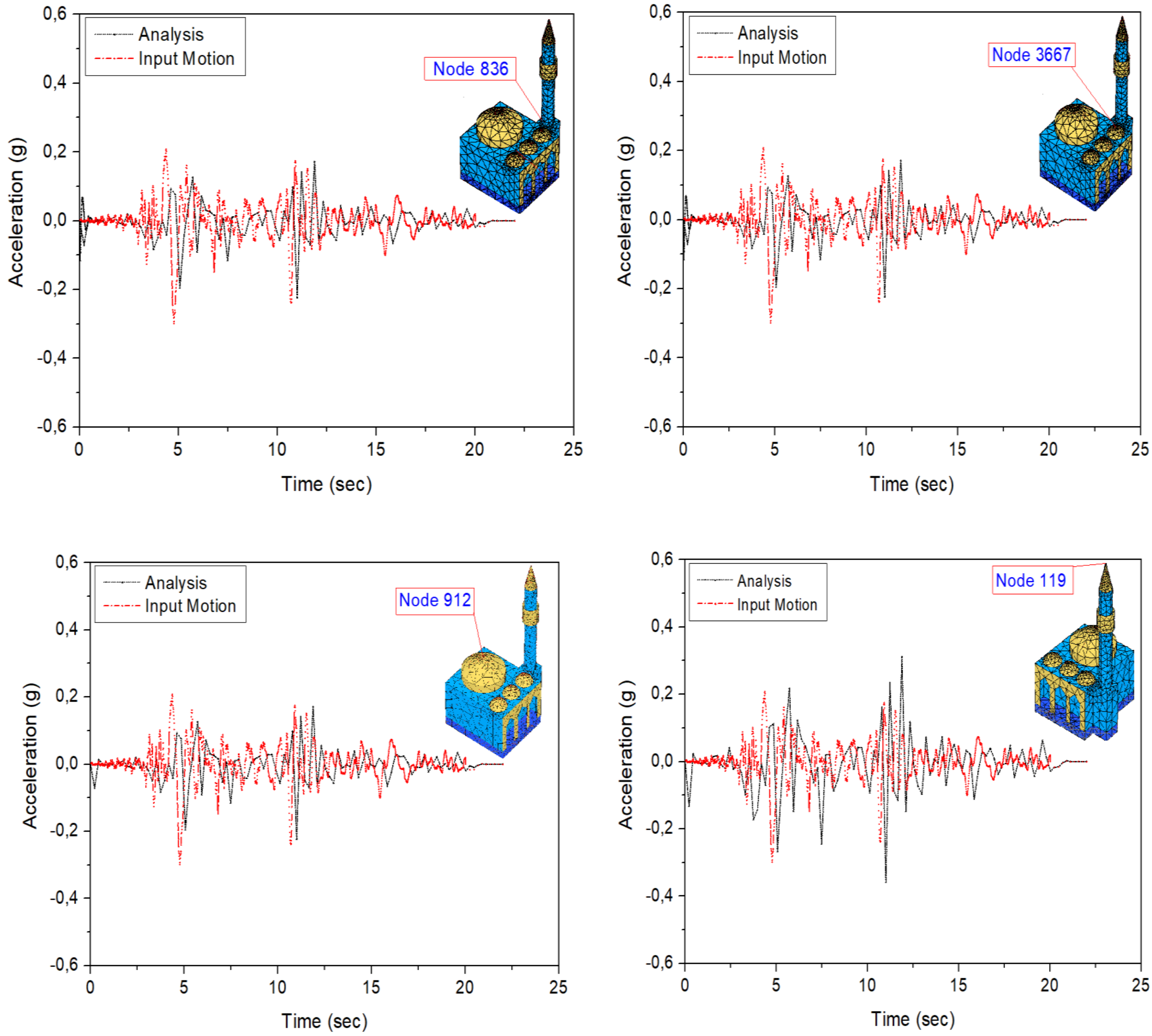


Figure 15. Acceleration time history of the selected nodal points

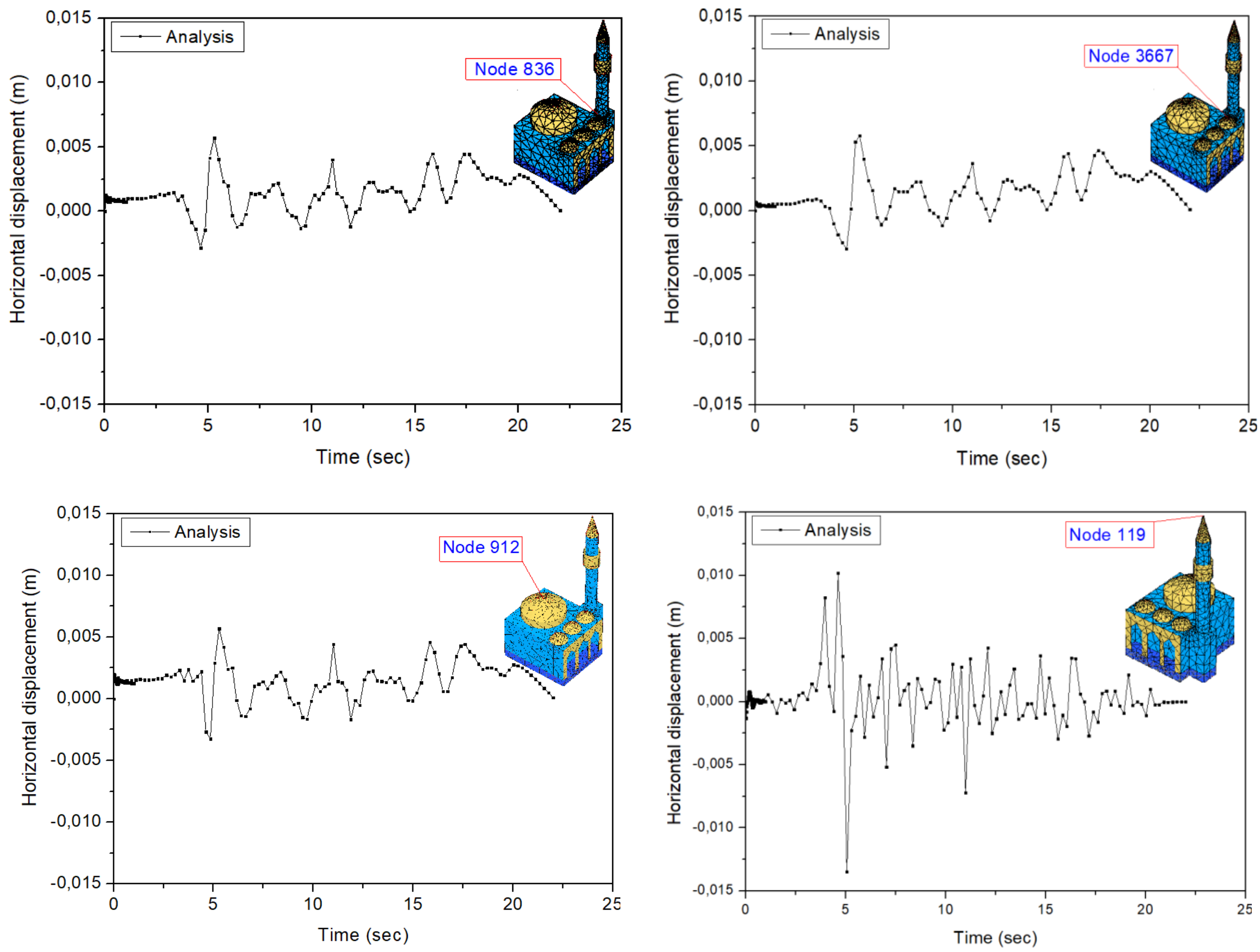


Figure 16. Displacement time history of selected nodal points

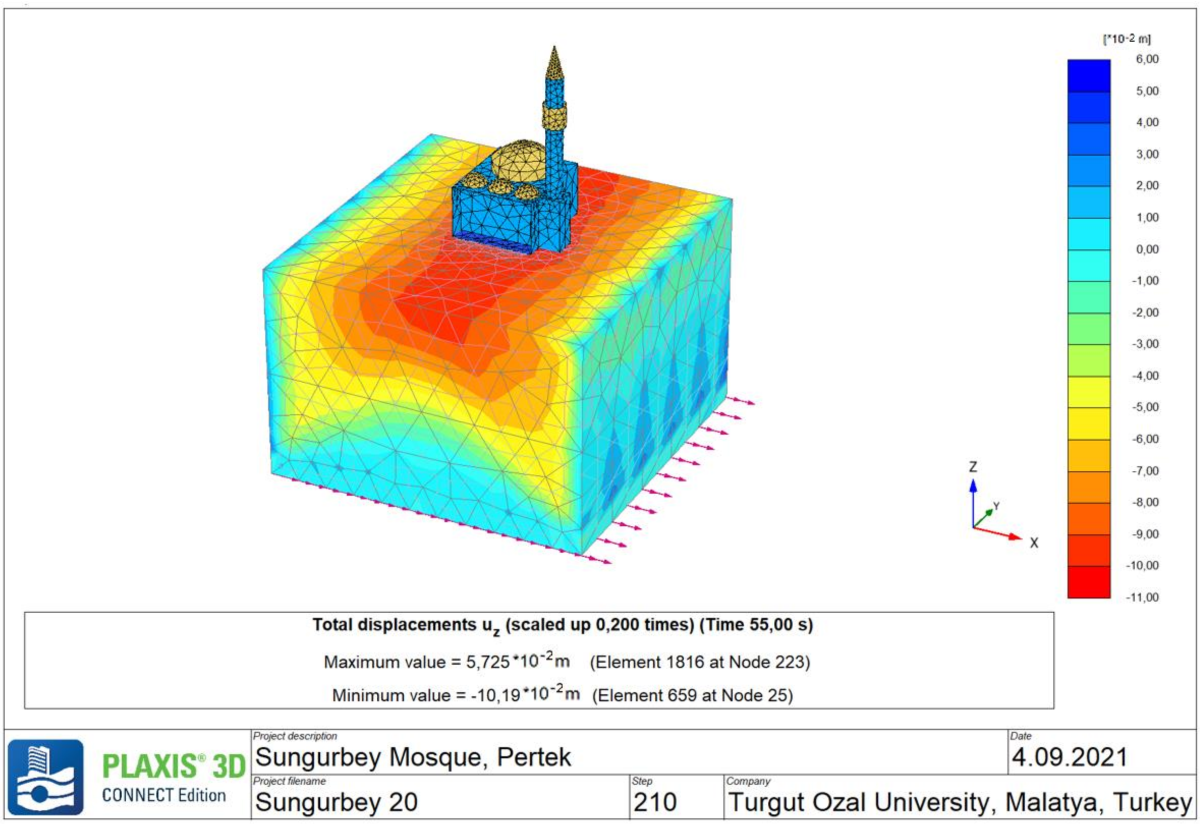


Figure 17. Total vertical displacement distribution of the numerical model

6 Conclusion

Historical monuments serve as a part of the cultural heritage of societies. The measures and activities to protect them are in the public interest. In this study, the seismic soil-structure interaction of the historical Sungur Bey Mosque, which was first built in 1577 and dismantled, moved, and rebuilt in another area, was investigated. In this context, firstly, the survey and architectural drawings of the historical mosque were examined, and the geological investigation of the area was evaluated. PLAXIS 3D finite element software, which is frequently used by researchers in the modeling and analysis of earth structures, and for soil-structure interaction problems with its 3D version, was adopted. Sivrice 2020 real earthquake record was used in the analysis and the results were evaluated in terms of acceleration and displacement. The findings obtained are as follows;

- Local soil conditions, mostly composed of soft clay units, showed amplification effect on seismic waves.
- The earthquake waves propagating from the bottom level of the soil profile to the ground level, amplified by 10%.
- Spectral acceleration values measured at different heights of the building show significant increases especially at the minaret flag level.
- As a result of the analyzes, the horizontal displacement of 13 cm measured at the flag level of the minaret is in significant agreement with the site measurements.
- When the structural defects observed in the masonry Sungurbey Mosque, which was moved from its original location and rebuilt with the same materials, are evaluated together with the amplification potential of the local soil conditions, it has revealed that there is a potential to cause significant damage in the future, especially under seismic effects.

Acknowledgements

The authors would like to acknowledge Bentley Systems and Geogrup A.Ş. for providing usage license of PLAXIS3D software program.

Decleration

This study does not require ethics committee approval.

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