

DYNAMIC ANALYSES OF THE AUGUSTUS TEMPLE

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ABSTRACT

DYNAMIC ANALYSES OF THE AUGUSTUS TEMPLE

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In this thesis, the dynamic analyses of Augustus Temple was carried out. Three software packages (FLAC3D, 3DEC, SAP2000) were used in this study. The results were discussed and compared.

Keywords: Dynamic analyses, Augustus Temple, FLAC3D, SAP 2000, 3DEC

ÖZ

AUGUSTUS TAPINAĞININ DİNAMİK ANALİZİ

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Bu tez çalışmasında Augustus Tapınağının dinamik analizi gerçekleştirildi. Bu çalışmada FLAC3D, 3DEC ve SAP2000 yazılım paketleri kullanıldı. Sonuçlar tartışıldı ve karşılaştırıldı.

Anahtar Kelimeler: Dinamik Analiz, Augustus Tapınağı, FLAC3D, SAP 2000, 3DEC

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CHAPTER 1

INTRODUCTION

1.1. Research Statement

The purpose of this study comprises the dynamic analysis of a simplified historical building, Augustus Temple, for the assessment of soil-rock-structure interactions under seismic loads. With this concern, three dimensional, numerical, soil-rock-structure interaction analyses were performed to simulate both static and seismic stress state and performance.

Located in Ankara, Turkey, Augustus Temple is influenced by environmental changes since the year 1500. For many years prior to this day in this structure, the seismicity of the region, determine the behavior of soil-structure interaction and the structure against earthquakes, the structure is of great importance to protect the future.

The main aim lying behind the analysis of the remaining parts of the Augustus Temple for 1500 years, to identify the characteristics of these features can be determined according to the cause of survival for many years. Evaluating the results of this type of analysis as a researcher, various studies should be made to minimize the displacement of the earthquake.

“SAP 2000 finite element program”, “Itasca FLAC^{3D}” and “Itasca 3DEC” software packages were used to analyze the east side of the Augustus Temple. Wall on the east side was selected and the condition of the wall was better than the west side wall. Also, the foundation excavation was done close to the east side wall and this gives more important information about the wall’s overall structure.

1.2. Scope of The Study

Following this introduction,

In Chapter 2 general information will be given and some examples will be made about the temples. Then,

Chapter 3 includes the properties of Augustus Temple.

Chapter 4 mentions about the placement, mooring equipments with elements.

Chapter 5 includes the numerical methods about the dynamic analysis of the Augustus Temple.

Chapter 6 shows the information about the modelling of Augustus Temple.

The results of analysis and their discussions were given in Chapter 7. Finally, conclusion and further recommendations are given in Chapter 8.

CHAPTER 2

CONSTRUCTION TECHNIQUES IN ROMAN PERIOD

2.1. Overview

Roman temples were rectangular and circular. Rectangular temples were built in the style of the Greeks with a podium and portico. While the Greek temples were normally twice as long as they were wide, Roman temples were shorter in proportion. Most rectangular Roman temples were simple structures compared to theaters, amphitheaters, and baths, but temples are good evidence of how Roman construction could cover large spans without the aid of supports (15 to 18 meter) [1].

The composition of a temple is based on symmetry, a notion whose principles architects should take the greatest care in order to master. Symmetry derives from proportion, which is called analogia in Greek. Proportion is the mutual calibration of each element of the work and of the whole. And as a result of this calibration proportional system is achieved. Without symmetry and proportion no temple can have any compositional system, unless, as it were, it has an exact system of correspondence to the likeness of a well formed human being [1].

In fact, the temples of Rome provide an especially powerful expression of empire. Temples were monuments for the religious gods and also monuments for the Emperors themselves, who each desired his own temple. Between the first century BC and that latter part of the second century AD majority of temples were constructed and that was the most influential period of Rome (See Figure 1).

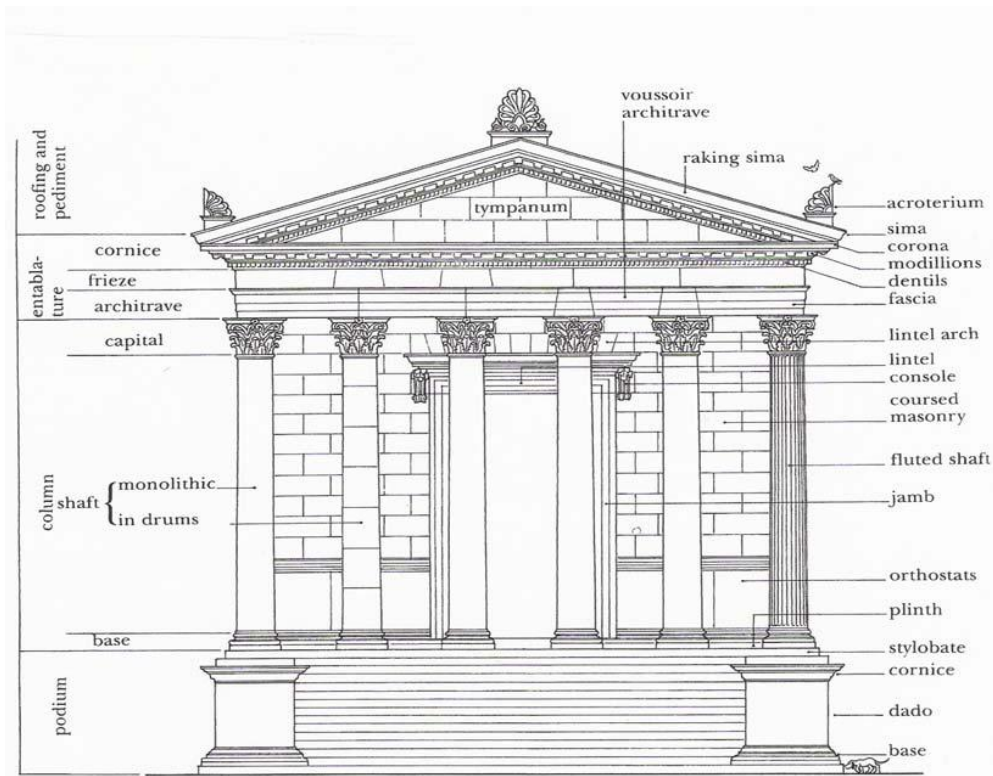


Figure 1 – Architectural Features and Proportion on a Temple Façade.

In addition, as a repository of civic documents, and as a place for recording public events temples served as a means of communication. The temple then was a vital component in providing organization to the empire, and then its expansion and maintenance were necessity. The most impressive of these temples is the Pantheon, which eighteen centuries after its completion still stands today as an expression of Rome’s power.

Some of the roman temples are given in the following sections but the Augustus temple is given in Chapter 3 in detail.

2.2. Roman Temple Examples

2.2.1. Temple of Baalbek

Baalbek, which is also called as Heliopolis, is a spectacular archaeological site in northeastern Lebanon. The Romans built three temples here from the 1st century BC and over a period of two centuries: Jupiter, Bacchus and Venus. The temple of Jupiter which was constructed to be the largest temple in the Roman Empire was lined by 54 massive granite columns each of which were 21 meters (70 feet) tall. Only 6 of these titanic columns remain standing but they are still incredibly impressive. The best preserved temple at the site is the Temple of Bacchus which was built in 150 AD. Also known also as Dionysus, the ancient Roman temple was dedicated to Bacchus the Roman god of wine. (See Figure 2) [2].



Figure 2 – Temple of Baalbek [2].

2.2.2. Temple of Pantheon

The Pantheon, which is one of the best preserved Roman buildings, was built in 126 AD as a temple for all the Roman gods. Since the 7th the temple has served as a Roman Catholic Church. The Pantheon consists of a large circular portico with three ranks of huge granite Corinthian columns. Topped with a concrete dome with a central opening the portico opens into a rotunda: the oculus. When it's raining in Rome, it's a great time to visit the Pantheon and you can see the rain pouring into the building through the oculus (See Figure 3) [2].



Figure 3 - Temple of Pantheon [2].

2.2.3. Temple of Palmyra

Palmyra, which is situated in an oasis 130 miles north of Damascus, is one of Syria's most popular tourist attractions. Palmyra was an important and wealthy city for centuries, located along the caravan routes linking Persia with the Mediterranean

ports of Roman Syria. Including the huge Temple of Bel, the monumental arch and the colonnade that once consisted of 1500 Corinthian columns today there is much to see at the site (See Figure 4) [2].



Figure 4 - Temple of Palmyra [2].

2.2.4. Temple of Maison Carrée

Located in Nimes, France, Maison Carrée was built in 16 BC by the Roman General Marcus Vipanius Agrippa, and it was dedicated to his two sons who both died young. It is one of the best preserved Roman temples in the world. The Maison Carrée owes its exceptional state of preservation to the fact that it was transformed to a Christian church in the 4th century, saving it from destruction. It has also been used as a town hall, a stable, a storehouse, and finally a museum (See Figure 5) [2].



Figure 5 - Temple of Maison Carrée [2].

2.2.5. Temple of Sbeitla Forum

Sbeitla (or Sufetula) is a substantially well preserved Roman city in the mid-west of Tunisia. Paved with stone slabs and surrounded by a wall. The forum has a gateway on one side and three Roman temples on the opposite side; the city contains a vast almost square forum. The inhabitants of Sbeitla built separate temples for each god instead of creating only one temple dedicated to the three most important Roman gods, Jupiter, Juno, and Minerva. A similar arrangement is only found at Baelo Claudia, in Spain (See Figure 6) [2].



Figure 6 - Temple of Sbeitla Forum [2].

2.2.6. Temple of Augustus in Pula

The Temple of Augustus remains to be the only structure from the original Roman forum in Pula, Croatia. It was dedicated to the first Roman emperor, Augustus and it was probably built during the emperor's lifetime at some time between 2 BC and his death in AD 14. The temple was converted into a church under Byzantine rule and was later used as a granary. During WWII it suffered considerable damage when the temple was hit by a bomb. Later, much of the structure was rebuilt since that time (See Figure 7) [2].



Figure 7 - Temple of Augustus in Pula [2].

2.2.7. Temple of Garni

The Garni temple was built by the Armenian King Trdates I in the 1st century AD and it was dedicated to Helios, the Roman god of the sun. The construction was probably funded with money the king received from the Roman Emperor Nero in return for military support against the Parthian empire. Resting on an elevated podium the Garni Temple contains 24 Ionic columns and it is made of basalt unlike other Greco-Roman temples. The ancient Roman temple was completely destroyed by an earthquake in 1679 and it remained in ruins until its reconstruction in the 1970s (See Figure 8) [2].



Figure 8 - Temple of Garni [2].

2.2.8. Temple of Dougga Capitol

Temple of Dougga Capitol is located in northern Tunisia. It is sometimes called “the best-preserved Roman small town in North Africa”. Punic-Libyan mausoleum, the theatre and the capitol are amongst the most famous monuments at the site . From the 2nd century CE the capitol has been a Roman temple and it is principally dedicated to the three most important Roman gods: Jupiter, Juno and Minerva. It has a secondary dedication to the well-being of the emperors Lucius Verus and Marcus Aurelius (See Figure 9) [2].



Figure 9 - Temple of Dougga Capitol [2].

2.2.9. Temple of Zeus at Aizanoi

Aizanoi, has been inhabited since 3000 BC, and through the production of wool, grain, and wine it grew wealthy under the Roman Empire. Aizanoi's most impressive structure, the Temple of Zeus is the best-preserved Roman temple in all of Anatolia and was built in the 2nd century AD. By renting the land around the temple, the money needed for the temple's construction was met. Yet, the boundaries of the temple lands were unclear, and those who worked them refused to pay the taxes. Emperor Hadrian settled the dispute and copies of the letters which were very significant for the city were later inscribed on the temple walls (See Figure 10) [2].



Figure 10 - Temple of Zeus at Aizanoi [2].

2.2.10. Temple of Augustus and Livia

Built at the end of the 1st century BC, the Temple of Augustus and Livia survives today basically intact in the city of Vienne, France. The temple in Vienne which is closely similar to the famous Roman temple Maison Carrée in Nîmes, was originally dedicated to Augustus. In 41 AD the ancient Roman temple was rededicated to his wife Livia in by her grandson Claudius who was the Roman emperor born in nearby Lyon (See Figure 11) [2].

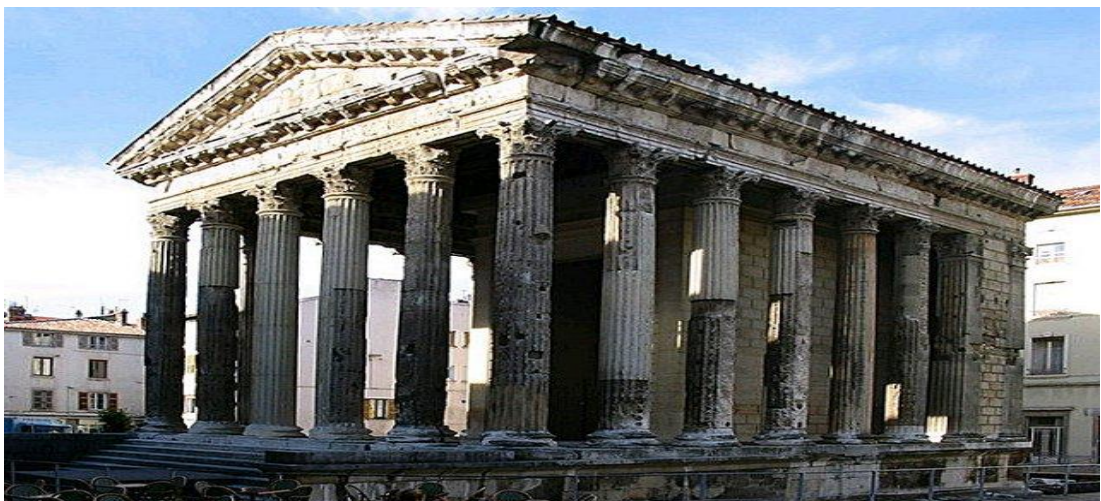


Figure 11 - Temple of Augustus and Livia [2].

2.3. Roman Temple Construction Techniques

2.3.1. Deployment and Connection Elements

2.3.1.1. Displacement, Bending Elements

Considering deployment lines, an operation to deploy the elements exactly in place has been implemented by crowbars engaged into slots we call “bending slots”. That’s why these blocks had to be displaced carefully and accurately for them to approach other ones so that there shall be never any opening between them and set exactly in place. These operations have been implemented by forcing and displacing these blocks by wooden or metal crowbars engaged into the slots been drilled only for these purposes on upper surfaces of the blocks or the slots placed on lower edges of their side surfaces and it is ensured that the blocks set exactly in place and approach to a block placed previously. As for a block to be set on such placed block, same slots are also drilled on its upper surface according to its size. Orientation of the slots indicates in which direction the block shall be pushed. It is stated above that the spurs placed in front and behind the blocks to be laid may have been used to displace the blocks forward and backward (Shown in Figures 12 and 13) [3].

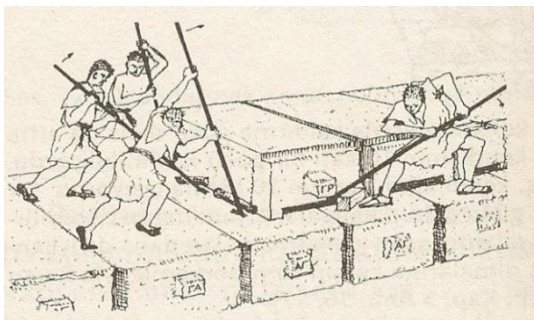


Figure 12 - Bending and deployment by means of crowbars Arrows shows deployment direction [3].

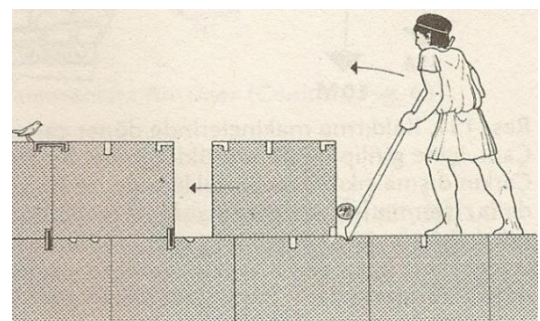


Figure 13 - It shows forward deployment of the stones by forcing the crowbar inserting into the bending hole forward [3].

Furthermore, we also stated herein any problems on uses of the spurts in lifting operation. Maybe the spurs obtain power upon leaning of the crowbars against the spurs on their sides, and also rupture of the block is prevented. The bending slots take place at opposite side to repulsion direction of the block and distance from the line to be reached as far as a spur may run. But, it is seen that there is one bending slot at each side of the blocks to be deployed. That's why, according to Hansen, they relate to deployment of the blocks. According to this opinion, it is impossible to displace and set the corner blocks exactly in place without the bending slots. Therefore, construction of a wall consisting of blocks may never be started from corner blocks. A wall may be built only as a result of implementation of the following operations:

- 1) For instance, first other blocks except third one from left are laid in a wall line consisting of 7 blocks. In this operation, among two blocks at left side, firstly first block and then second block is displaced leftwards, and for blocks at right, i.e. 7th, 6th, 5th and 4th blocks are displaced respectively and are deployed in their place (use of 4 left, 3 left and 3 right slots).
- 2) To put 3rd block in its place and approach 2nd block, 4th block is dislocated. But, a line is drawn showing the setting position of the block before removing.
- 3) 3rd block is set and approached to 2nd block (use of 4 left slots).
- 4) To set 4th block, 5th block is removed and 4th is replaced and approached by using 5th left slot and considering the previously specified line.
- 5) Finally, 5th block is sandwiched between them. Curved cut edges of this block facilitate its deployment.

As seen, Hansen's solution suggestion on double bending slots increases the workload considerably. It should be noted that the corner blocks were deployed by hitting with great boards to set them in their place. In this case, any other suggestion should be required for double bending slots (Shown in Figure 14) [3].

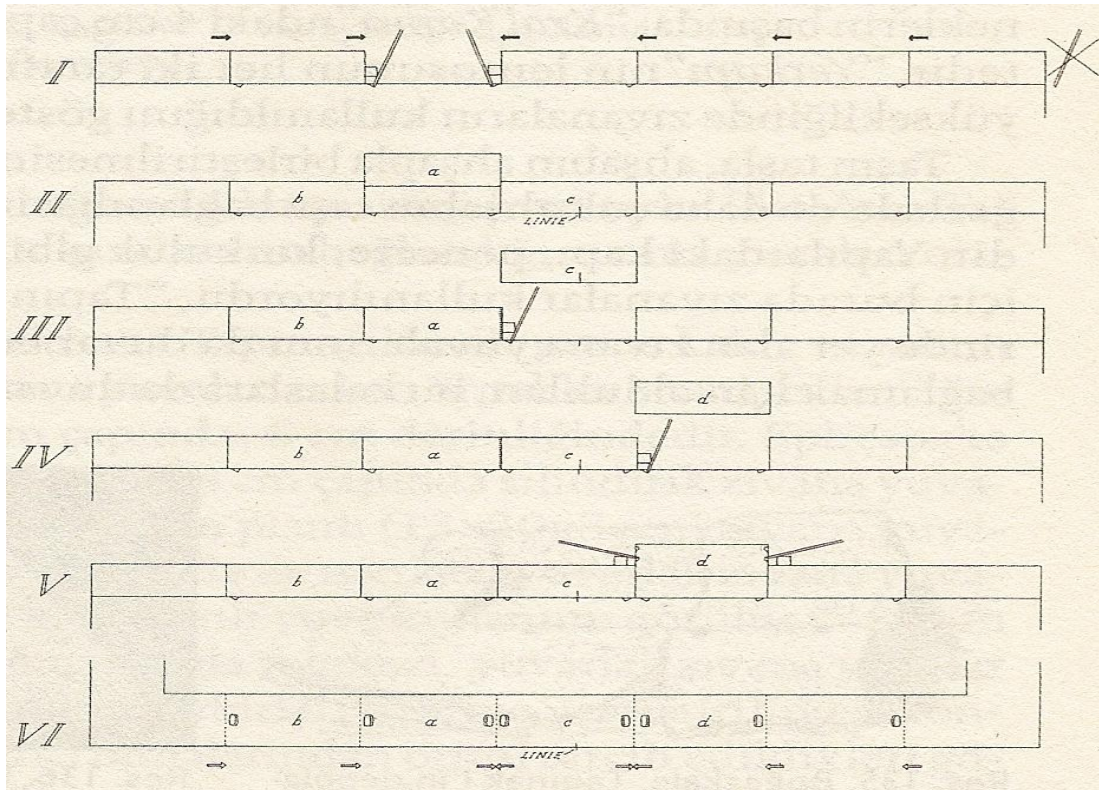


Figure 14 - According to Hansen, a method to deploy blocks aligned on a wall consisting of 7 blocks [3].

2.3.2. Connection Elements

2.3.2.1. Vertical Connection Elements (Bush Slots and Bushes)

Each block set in place should be connected first to one under it and then to one near it or in case of elements belonging to an independent and vertical carrying group such as column drums, it should be connected only to ones under it. Inherently, if these elements are free for instance such as column drums, i.e. should be connected to ones under and above them only, but not to ones near them, they are not approached, displaced or bended. But, except exemptions, all elements should be connected to ones under and above almost all of them whether these elements are side non-connection type such as column drums or side connection type such wall blocks. We call any media used for this purpose as bushes and slots drilled on their bottom and top surfaces to place them as bush slots.

While only one example in a W construction and in size of 4x4x7.5 cm is identified in Troia among early examples, it is understood from the bush slots that the bushes were used so commonly in the Hittites as well as in Egypt. We should assume that a reason of using cylindrical bush slots is maybe a facility provided by a tubular drill. One of major examples in hand is a bush slot of 4 cm in diameter at “the King Door”. The slots are identifying showing that the bushes of 5.5 in diameter and 7 m in height at both sides of the lintel of "Yerkapi" [3].

It is seen that the bushes used to fix a wooden material to another wooden one and a stone to another one are used mostly to fix a wooden material to a stone in Bogazkale. The bushes were used to fix wooden components such as doors, windows, handrails, etc. to a stone in buildings. It is assumed that the bush slots placed on the ortho-stats of “Temple 1” were used to connect the boards laid cross the wall and the vertical placed boards of wooden coatings of the walls were connected to these boards. Furthermore, the stone sills at Temple 1 were utilized as bush slots, to which the door frames were fixed (See Figures 15 and 16)

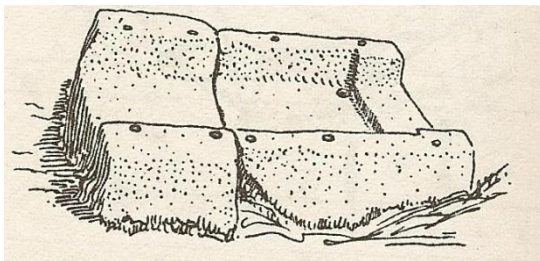


Figure 15 - It shows the bush slots at stone sills at storehouses (72-75) of Temple 1 in Bogazkoy [3].



Figure 16 - Bush slots at a sill in Bogazkale. [3].

Among early examples, there are the bush slots at center of porous plinth and column drums of the Bayrakli Athena Temple built in 600s. These cylindrical bush slots are 7 cm in diameter and 6 cm in depth. It is seen that, while square or rectangular bush slots (13x20x8cm) used were as well as central cylindrical bush

slots of 8 cm in diameter on Archaic column drums, and central circular bush slots were used under and above Ion heads, square bush slots were used at top side in Ephesus. The opinion that, since use of central circular bush slots on the circular elements such as column drums facilitates turn the drum while overlapping the drums, they may have been chosen is suggested. The wooden bushes used on the columns were highly greater. For instance, the bushes at the Artemis Temple in Korfu are about 50 cm in length and 15x17cm in size. I know that wooden ones are mostly made of olive, cedar and pine trees. Use of bushes became widespread in 5th century B.C. (Shown in Figures 17, 18, 19 and 20) [3].

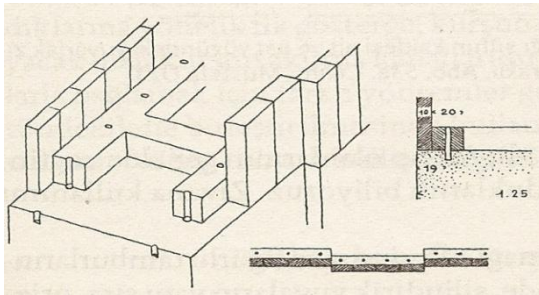


Figure 17 - A presumptive figure showing connection of wooden materials used to connect the ortho-stats of Temple 1 to the lower adobe wall by bushes in Bogazkale [3].

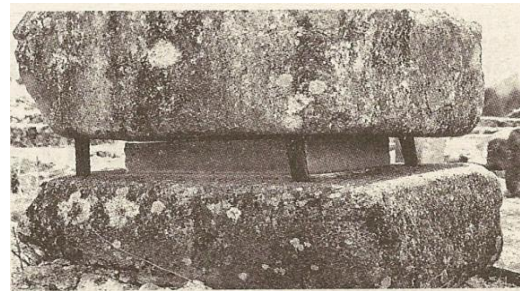


Figure 18 - An application proving that the bushes in Alacahoyuk were used in vertical connection of the blocks [3].

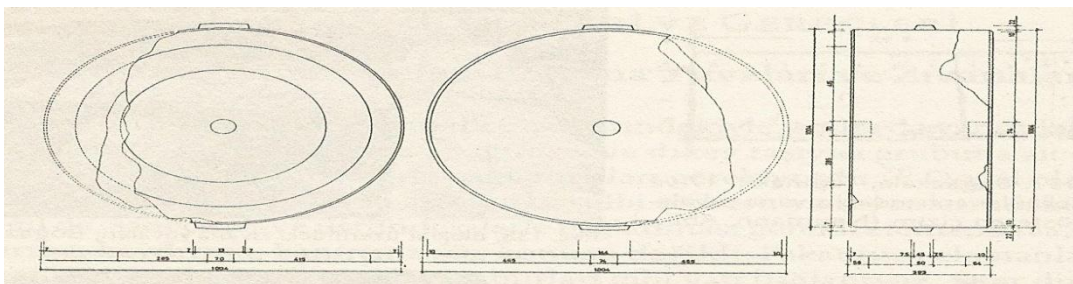


Figure 19 - A Circular bush and a circle drawn by a compass on bottom and top surfaces of column plinth at the Athena Temple in Bayrakli, Former Izmir [3].

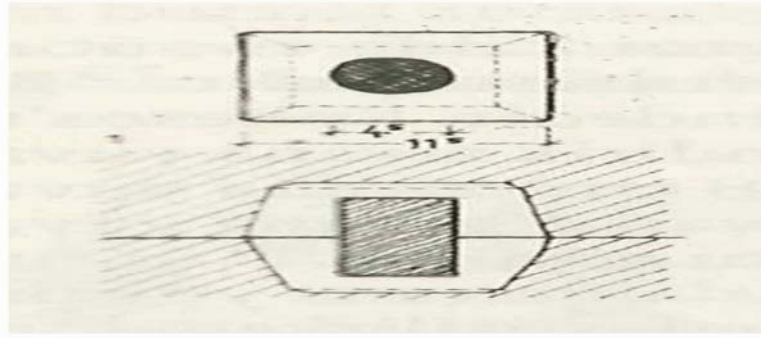


Figure 20 - Bronze bushes within the wooden bush used at the Parthenon Temple in Athena [3].

We see that two types were used side by side although prismatic bushes were used as well as cylindrical bushes on column and figured drums, heads and cubic plinths at Late Classic Ephesus Artemis Temple. Thus, the bushes took their place definitely in structural technology upon appearance of slots in a form of cubic and rectangular prism as well as cylindrical slots. Prismatic ones were used on same type of elements since they were used for listing and handling operations rather than use of these elements as bush slots or as well as use of them as bush slots. All of them indicate that use of iron downsized cylindrical and prismatic bushes had become widespread increasingly as well as bronze ones other than “wedge” bushes and “hook” or “T-form” bushes used curvedly and encountered rarely in examples [3].

As we shall discuss later, it may not had been required to use a connector such as lead to be able to rivet the bushes belonging to the Archaic era in their slots at the beginning whether they are made of wooden, iron or bronze. Or, it may be assumed that such an application was not known yet in that time. It is apparent that if the bushes were wooden, such application was unnecessary. However, we know that metal bushes were stored in a wooden envelope such as at the Parthenon Temple. Any new applications were initialized to fix the bushes into the slots, disconnect them from atmosphere and prevent them from corrosion. Another reason of this application that metal bushes installed thoroughly into the slot without any buffer may cause ruptures and cracks of the elements during this operation or any minor movement of the structure. A connector found to prevent them was made of lead. First indication that the bushes are coated by lead includes lead flowing ducts, which

shall cause lead to flow into the bush slots. Different methods were developed to connect the elements to be overlapped to the bushes. Principal one of the methods used in connection of the elements to ones under and above them includes a method, where such ducts were used vertically.

2.3.2.1.1. Lead Flowing Method by Vertical Duct

Although the bushes used in this method are greatly high and long, they include incomparable thin masses. The upper bush slot takes place on at center of top surface of the lower block. Since they are open on top edge and covered on for side and at bottom, it shall be convenient to call them "covered slots". The covered slots are used together with a slot with open sides to set on these covered slots. In the method applied on such slots, the bush is inserted first into center of the lower block. The bush under the block to be overlapped does not a slot to cover the bush completely. (Shown in Figures 21, 22 and 23)

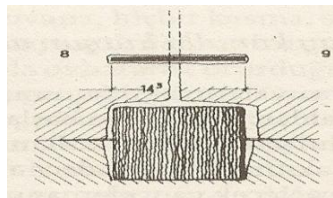


Figure 21 - A wide, narrow and high bush used in two bushing systems open on one site Magnesia [3].

Figure 22 - It shows two bushing systems with one covered side at the bottom and with one open side at the top [3].

Figure 23 - A vertical lead flowing duct and a slot with one open side under the duct. Magnesia [3].

In this application, two blocks, which combine exactly at the center of the lower bush, are placed at the top. The slots on these blocks are located on lower edge of joining surfaces. Thus, surfaces of the bushes are open in joining edges (a slot

with one open side). When two blocks are overlapped and combined exactly on the bush, two slots with one open side combine and form a complete slot on both blocks. Therefore, the bush is deployed into two bush slots to form a complete slot at the bottom and a complete slot at the top as wide as the lower bush when the combine. Then, it is necessary to rivet the bust to the housing in the slot. For this, a groove is drilled from upwards to inside of the slot one joining surface of one of upper blocks. Once two blocks combine, this groove converts to a duct. The melted lead flown through this downstream duct flows into the slot and ensures that the bush is riveted into the slot. Heads of the Magnesia Artemis Temple were connected by architraves set on them by using this method.

In another application, while there is a slow with one open side on one of the blocks to be overlapped, the open edge is covered upon approach of the covered surface of the other block (a one-sided bush with one open side). The lead is poured by a conic-shaped template into the bearing in these bushes, and it is ensured that this bush is riveted without approaching the other block. The other block is approached later. (See Figure 24)

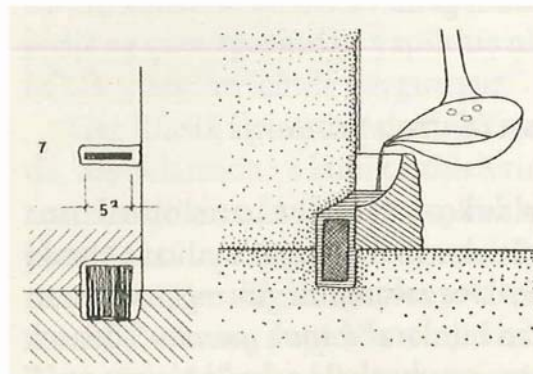


Figure 24 - It shows an application with one open side and flowing of the lead [3].

2.3.2.1.2. Lead Flowing Method by a Horizontal Duct

Seen that the lead began to be flown through a duct on a surface, where the lower bush slot is located, that is, the lead flowing ducts began to be used in 3rd century. In this method, the lead flowing duct is located only on the lower structural element.

One feature of the bush slots to be used in these applications is that two slots to be overlapped are in different size. The slot on an element is always larger than the slot under that element. That's why it ensures a facility in the application. In this application, firstly the block to be overlapped is turned upside down and the bush is inserted into a narrow and small slot under the block. The lead is poured into the bush slot and it is ensured that the bush is riveted into slot, or squeezed without lead. It is not necessary that there is no lead duct on these surfaces. Thus, when the bush riveted on the lower side is corrected to replace the block, it never goes out and falls and remains fixed at the lower side of the block. The element, on where the bush is riveted, is turned upside down and corrected. Then, it is aligned on the slot, on which the block shall set. Since the slot, on which the block shall set, made larger, the slot under the element may be placed and set so easier on a larger lower slot without clamping, friction and compression. It is so easier to reset edges of the bush by the element by playing the element right and left. Immediately before it is set, the lead is flown and poured through horizontal ducts into the lower slot as it shall not overflow. Finally, the block shall be replaced and thus this operation shall be completed. (Shown in Figures 25 and 26) [3].

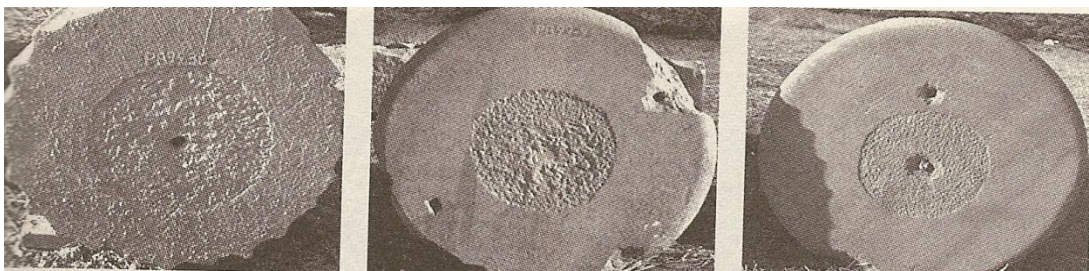


Figure 25 - Bush slots on the lower surfaces of the column drums, Magnesia, Propylene [3].

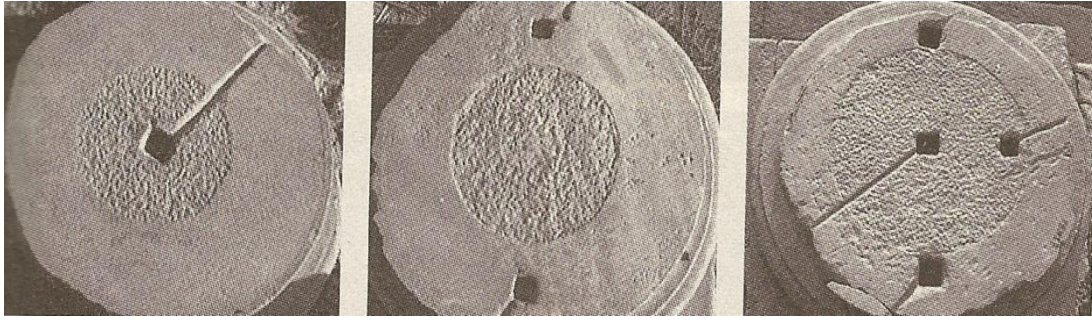


Figure 26 - Bush slots on the upper surfaces of the column drums, Magnesia, Propylene [3].

Number of the bush slots and therefore of the bushes in a structural element may be one two or more depending on size of the element. These different two applications in the structural elements belonging to the Magnesia Propylene are seen in the figures. At the upper line, the bush slots in small size are seen under the elements to set o the upper side. At the lower line, large slots and lead flowing ducts on large slots and lead flowing ducts are seen on the lower elements. Since a difference in numbers and places may depend on the element connected to the slots as well as it may be caused by their secondary use. For instance, the column drums combined to the plinths and heads may have more bushes. Additional bushes may be required in the element damaged for any reasons, e.g. cracked elements (See Figure 27)

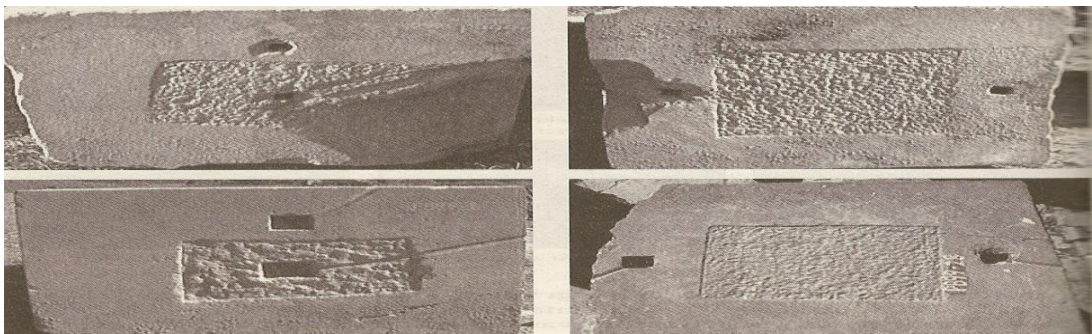


Figure 27 - Examples of the bush slots on the upper surfaces of the elephant-foot plinths and the bush slots under the blocks to be set on the slots through the lead flowing ducts [3].

The fact that the bush slots are in different size and are available only on the upper surfaces of the horizontal lead flowing ducts ensure a facility in identifying lower and upper surfaces of the structural elements. Earliest examples, on which the horizontal lead ducts, include the Ptolemaios Altar Columns in Olympia between 276 and 270 B.C. and heads of the Belevian Grave Monument in Anatolia (See Figure 28) [3].

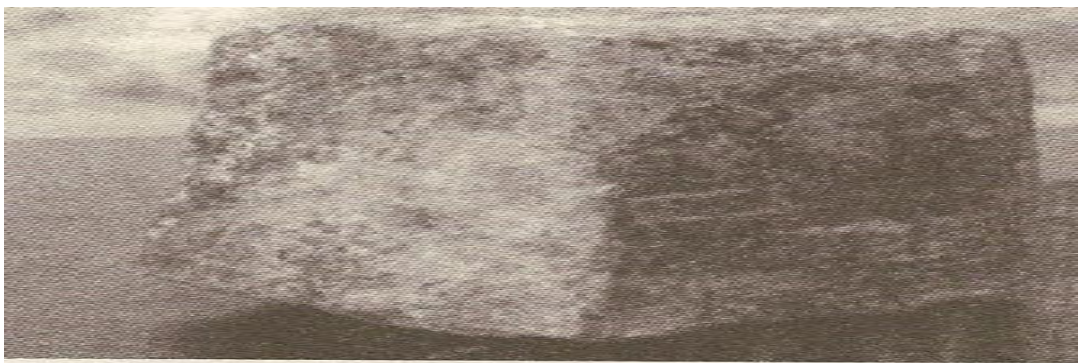


Figure 28 - Bronze bush in the form of rectangular prism. Magnesia [3].

Undoubtedly, the bushes include most significant details in the structures considered for "infinite". As we shall see below, care was taken to sizes and ratios of alloys.

This care to be able to be proven by archeological examples was taken in different applications from general bush slot examples stated above. One of them is an application seen at the Bodrum theatre building. There, two female bushes poured so carefully and called as an “envelope” are connected by a male bush. The envelopes riveted by pouring lead into them are in a form of rectangular prism. It is seen that sizes of the bushes and envelopes are compatible completely. It is clear that no doubt is necessary to make the upper slot larger in this application as stated above (Shown in Figures 29 and 30)

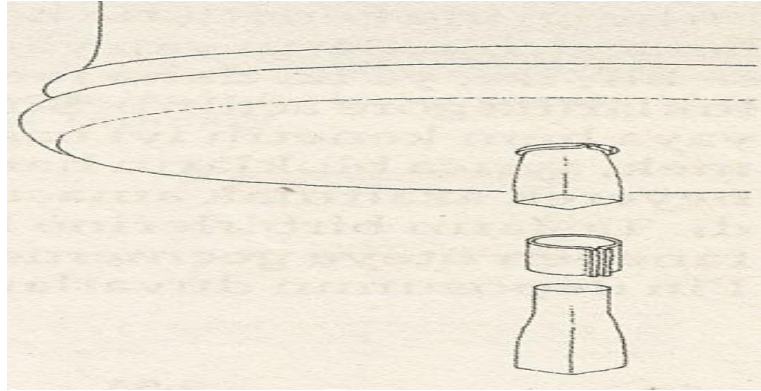


Figure 29 - Application of a system with envelope [3].

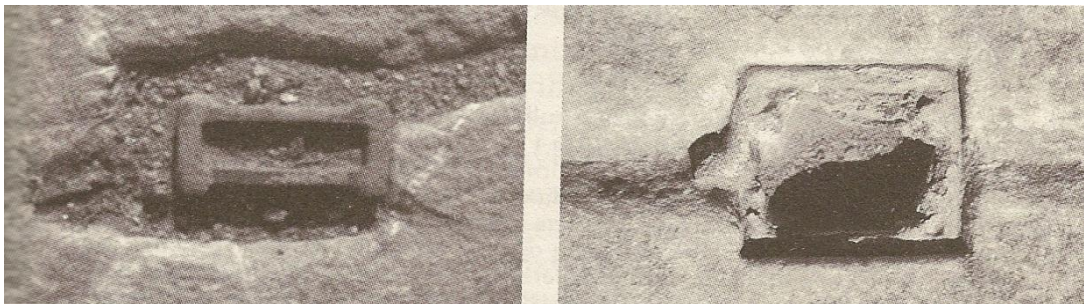


Figure 30 - An example of female bush, Bodrum Theatre [3].

A further application should be described as well as female and male bush system. Any examples, on which a different method is used instead of pouring lead and riveting the bush, are known. In this application assumed to constitute an alternative to ruptures and cracks in applications, on where the bust was riveted and set especially without pouring lead, the above-mentioned envelope is used complete with a female and male bush. A female bush includes a tubular envelope, which may expand sufficiently on one side and is remained open. A male bush includes one with one end rounded to insert into the envelope. It is clear that the envelope shall expand and cause the bush to be squeezed as the bush is riveted. Undoubtedly, this operation was carried out quickly and cost-effectively by an envelope, which serves as a buffer preventing a stone from being ruptured and cracked. An example in below figure shows how this application was implemented.

2.3.2.2. Horizontal Connection Elements (Clamp Slots and Clamps)

If top surfaces of the bushes to be set exactly in their place were aligned with top surfaces of the blocks, each one of which connected to the lower under it and approached completely to the block near it, should have been connected by clamps. One or two or more clamp slots were drilled according to length of the blocks and form and length of the clamps on adjacent edges of the blocks to be connected by the clamps. Then, after the clamps were inserted, lead was poured and filled into the clamps to connect the clamp thoroughly into the slot, to prevent iron from being rusted and when the blocks played, to stretch and reduce any probable friction. In a little bit examples belonging to 2000 year, the stones were interconnected by clamps. As one of these examples, we encountered two blocks forming walls of the storehouse of Temple 1 in Bogazkale (Shown in Figures 31 and 32) [3].

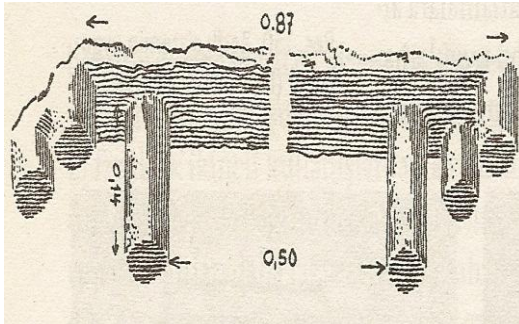


Figure 31 - A metal clamp. Bogazkale. To use this clamp, a slot in remarkable length such as 88 cm, of 11 cm in width and of 6 cm in depth was drilled, and meanwhile, the corners were scoured 4.5 cm in depth by a drill. Moreover, a slot of 22 cm in depth was scoured by a drill at center of each slot. It is assumed that the operation was carried out by pouring the bronze clamp into this slot [3].

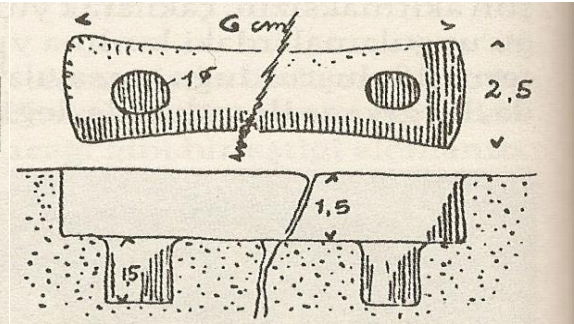


Figure 32 – A dovetail clamp. Zincirli. While clamps of a dovetail type known as they were used at middle 14th century in Ras Shamra are seen in structures in Zincirli, they were used in repair of a cracked plinth [3].

Although there are metal types of clamps, any wooden clamps called as “dovetail” were usually used in examples of Minoan and Mycenaean civilizations at the beginning in Egypt. When clamps were used on soft stones, they were made of wood not to cause the stone in frictions caused by the stone during any movement of the earth (Korfu Artemis Temple; Aegina Aphaia Temple; Delphi Siphnos Treasure). We see in a Bogazkale example that iron clamps were used for instance in Delos instead of this type of clamps used for long years and know that they had studs. Stud type ones were forged in a U form. The slot should be separated from the clamps obtaining a dovetail form and seen in Didyma, Ephesus and Labraunda from Late Archaic Era. Z clamps were seen as well as dovetail clamps especially in Greece in 6th B.C. Double T clamps were seen as well as ancient types toward late 6th century B.C. Double T clamps were used commonly instead of them in 5th or 4th century B.C. Z clamps of 12 to 25 in length and made mostly of iron an double T clamps of 20 to 40 cm in length were used especially in structures belonging to Classic Era in Greece. Double T clamps were formed by bending the ends of two long straps of 2 to 6 cm in height in a "u" form and combining them side by side or in same way, by bending the ends of a strap to both sides. There are bronze cast ones or ones formed by soldering three pieces. Among double T clamps, ones up to 59 cm in length are known (e.g. Olympia Zeus Temple and Parthenon). After U clamps appeared and became widespread in 4th B.C., T clamps disappeared. U clamps are iron type one of 12 to 25 cm in length and, hooks of which are mostly 1 to 2 cm in a square section. In these clamps, a method to pour lead and rivet are used to prevent corrosion (Shown in Figures 33, 34 and 35) [3].

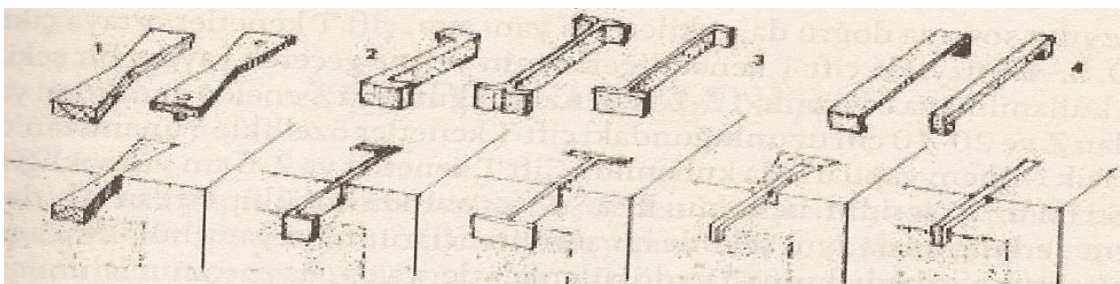


Figure 33 - Types of clamp: 1) Dovetail; 2) “Z”; 3) Double; 4) Narrow and wide U [3].

Four examples selected from Labraunda include bushes and bush slots used at the Zeus Temple (355-350 B.C.). Only dovetail slots were identified on first two ones. Although there is a dovetail in third slot, the clamp is U type. In this case, it is apparent that any detailed studies are required to ensure that any typological differences of the clamps give any information about buildings and may be used in dating them. Use of bronze astragals as clamps at the Apollo Temple in Claros is associated with cult. (See Figure 37) [3].

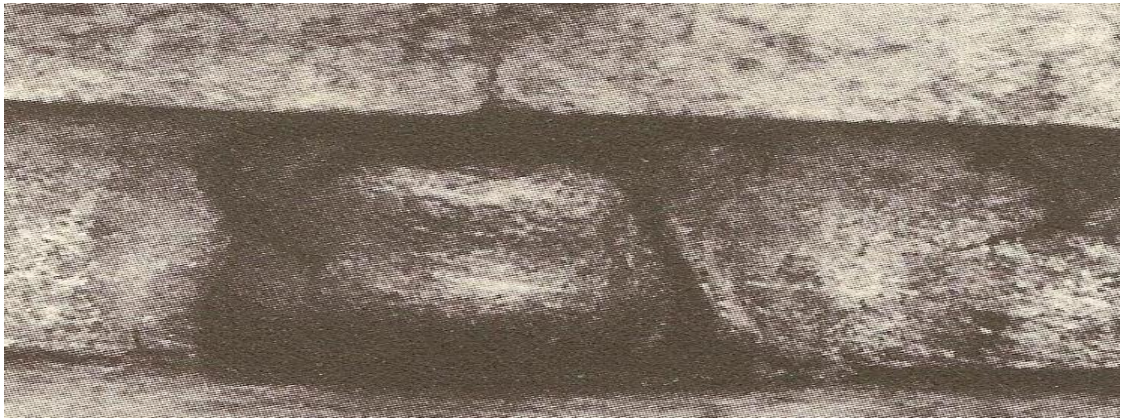


Figure 37 - A bronze astragal, Claros [3].

Assuming that 2 to 3 kg lead per a bush was used, cavities seen on ancient walls are most clear indications of where lead, which used commonly after invention of gun, was supplied the easiest although these cavities were covered. [3].

CHAPTER 3

THE AUGUSTUS TEMPLE

3.1. General Information

Temple of Augustus was built in Ankara in BC 25. This monument to Roman hegemony celebrated the glory of the first roman Emperor Augustus, after his death the temple was adorned with colored engraved letters which was the most famous epigraph of the roman world. The importance of the Augustus temple in Ankara derives from the epigraph engraved of the wall, the so-called Res Restae, the most important and famous of the roman world (See Figures 38, 39 and 40) [4].

The temple was changed into a basilica and three windows were opened on the south wall of the inner part of the temple (Cella) with vaulted place (Cryptos) beyond the internal complexes (Naos). In Figure 40 the inside of the Cella is shown.

The plan of the temple is a rectangular shape; the axis of the temple is directed north-west. It is about 12 meters high and 32 meters long.

In Figure 39, a scaled prototype of original Augustus Temple is given.



Figure 38 - Standing wall with foundation of Augustus Temple



Figure 39 - A scaled prototype of Original Augustus Temple [3].



Figure 40 – Inside of cella of Augustus Temple

3.2. Restoration Works

The General Directorate of Cultural Heritage and Museums conducted restitution and restoration in 2008. (See Figures 41, 42 and 43)

The implemented works are as the following:

- Implementation of a drilling at the foundation of the temple to understand the structure of the ground (See Figure 41 and 42).
- The geophysical investigation by ground penetration radar method of the Cella and part of the Temple.
- Analysis of the source of the stones used in the temple during the Byzantine period and the properties of the mortar.



Figure 41 - Excavation for foundation investigation



Figure 42 - The foundation investigation in front of the east wall of cella [3].



Figure 43 - A scaled foundation detail of the standing east cella wall [3].

3.3. Seismicity of the Site

The Augustus Temple walls which are located at the center between active fault lines, experience frequent ground movements from various plates. Figure 18 illustrates the extent of Ankara's seismic area and shows the highly active region surrounding the Central Anatolian plateau. The Augustus Temple is in 4th degree region of Earthquake (See Figure 44).

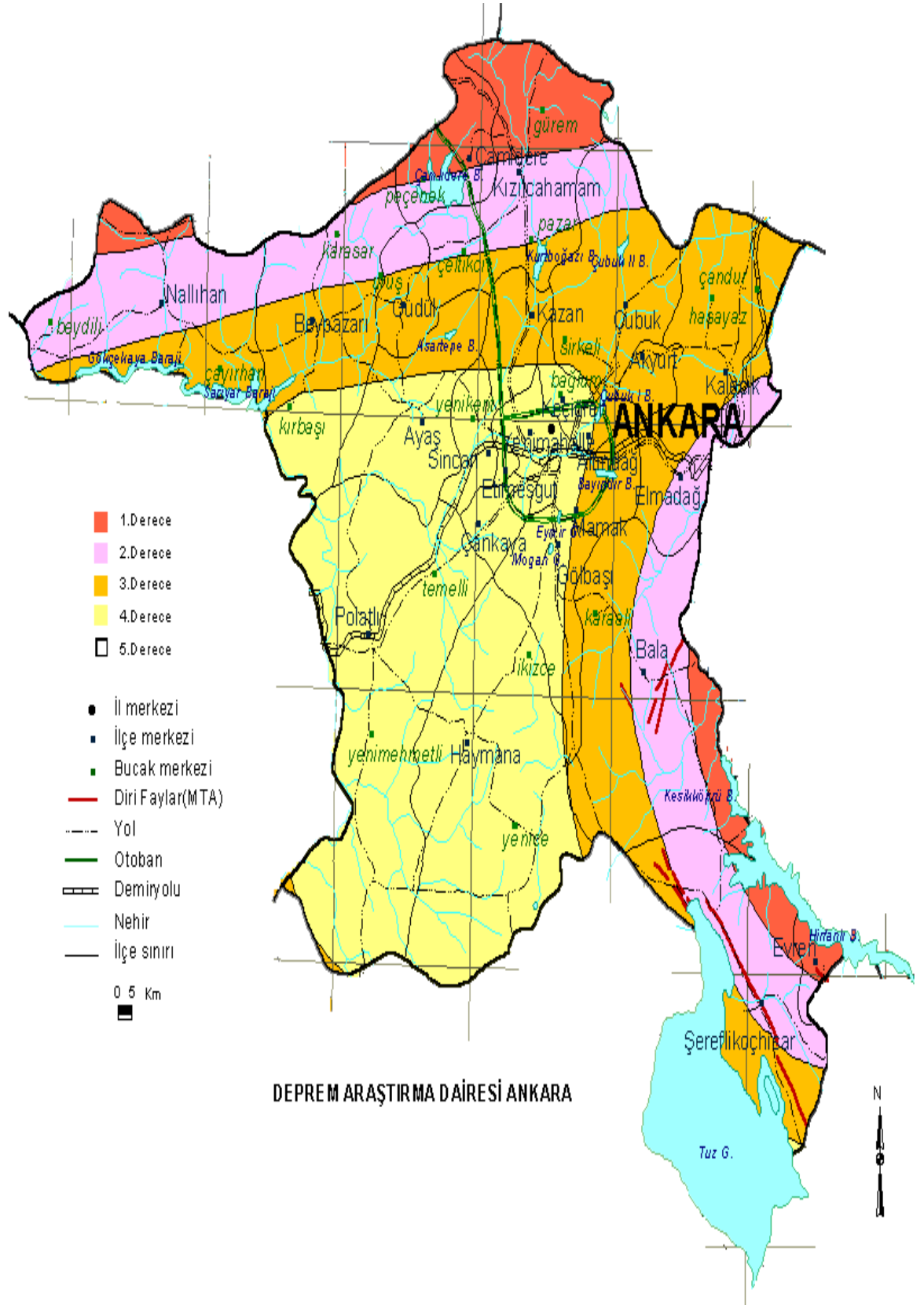


Figure 44 - Map of the fault lines surround Ankara [5]

CHAPTER 4

NUMERICAL METHODS

4.1. Introduction

4.1.1. FLAC^{3D}

FLAC^{3D} is a three-dimensional distinct finite-difference program used for engineering mechanics computation. The principle for this program is the well-established numerical formulation used by two-dimensional program, FLAC. By simulating the behavior of three-dimensional structures made of soil, rock or other materials that undergo plastic flow when their yield limits are reached, FLAC^{3D} extends the analysis capability of FLAC to three dimensions.

Materials are represented by polyhedral elements within a three-dimensional grid that is adjusted by the user to fit the shape of the object to be modeled. Responding to the applied forces or boundary restraints, each element behaves accordingly with a prescribed linear or non-linear stress/strain law. The material can yield and flow, and the grid can deform (in large-strain mode) and move with the material that is represented. The mixed-discretization zoning technique used in FLAC^{3D} and the explicit, Lagrangian, calculation scheme ensure that plastic collapse and flow are modeled in a very accurate manner. Large three-dimensional calculations can be made without excessive memory requirements as no matrices are formed [6].

The disadvantages of the explicit formulation (i.e., small time step limitation and the question of required damping) are met by automatic inertia scaling and automatic damping that does not influence the mode of failure. FLAC^{3D} offers an

ideal analysis tool for solution of three-dimensional problems in geotechnical engineering.

The number of calculation steps required to reach a solution condition with the explicit-calculation scheme can vary, but a solution typically can be reached within 3000 to 5000 steps for models containing up to 10,000 elements, regardless of material type [6].

FLAC^{3D} can be operated from either a command-driven mode or graphics menu-driven mode. The default command-driven mode is very similar to that used by other Itasca software products. A prototype for a menu-driven, graphical user interface is available in this version of FLAC^{3D}. This is the basis for a fully interactive interface that will ultimately make model generation and solution more user-friendly.

To get a better view, the model can be translated, rotated and magnified on the screen. Color-rendered plots of surfaces showing vectors or contours can be made in 3D, and a two-dimensional plane can be placed at any orientation and location in the model for the purpose of viewing vector or contour output on the plane. All output can be directed to a black-and-white or color hardcopy device. FLAC^{3D} is written in ANSI C++, which was found to provide several benefits over Fortran-based programming.

4.1.2. SAP 2000

The SAP name has been synonymous with state-of-the-art analytical methods since its introduction over 30 years ago. Featuring a very sophisticated, intuitive and versatile user interface powered by an unmatched analysis engine and design tools for engineers working on transportation, industrial, public works, sports, and other facilities, SAP2000 follows in the same tradition [7].

From its 3D object based graphical modeling environment to the wide variety of analysis and design options completely integrated across one powerful user interface, SAP2000 has proven to be the most integrated, productive and practical general purpose structural program on the market today.

This intuitive interface allows you to create structural models rapidly and intuitively without long learning curve delays. Now you can harness the power of SAP2000 for all of your analysis and design tasks, including small day-to-day problems. Complex Models can be generated and meshed with powerful Templates built into the interface [7].

The Advanced Analytical Techniques allow for Step-by-Step Large Deformation Analysis, Multiple P-Delta, Eigen and Ritz Analyses, Cable Analysis, Tension or Compression Only Analysis, Buckling Analysis, Blast Analysis, Fast Nonlinear Analysis for Dampers, Base Isolators and Support Plasticity, Energy Methods for Drift Control and Segmental Construction Analysis.

4.1.3. 3DEC

3DEC is a three-dimensional numerical program based on the distinct element method for discontinuum modeling. 3DEC simulates the response of discontinuous media (such as a jointed rock mass) subjected to either static or dynamic loading. The discontinuous medium is represented as an assemblage of discrete blocks. The discontinuities are treated as boundary conditions between blocks; large displacements along discontinuities and rotations of blocks are allowed. Individual blocks behave as either rigid or deformable material. Deformable blocks are subdivided into a mesh of finite difference elements, and each element responds according to a prescribed linear or non-linear stress-strain law.

For the movement in both the normal and shear directions, the relative motion of the discontinuities is also governed by linear or non-linear force-displacement relations. 3DEC has several built-in material behavior models, for both the intact blocks and the discontinuities that permit the simulation of response representative of discontinuous geologic or similar, materials. 3DEC is based on a “Lagrangian” calculation scheme that is well-suited to model the large movements and deformations of a blocky system. The distinguishing features of 3DEC are summarized below [8].

- The rock mass is modeled as a 3-D assemblage of rigid or deformable blocks.

- Discontinuities are regarded as distinct boundary interactions between these blocks; joint behavior is prescribed for these interactions.
- Continuous and discontinuous joint patterns can be generated on a statistical basis. A joint structure can be built into the model directly from the geologic mapping.
- 3DEC employs an explicit-in-time solution algorithm that accommodates both large displacement and rotation and permits time domain calculations.
- The graphics facility permits interactive manipulation of 3-D objects. In the graphics screen mode, the user can “move” into the model and make regions invisible for better viewing purposes. This allows the user to build the model for a geotechnical analysis and instantly view the 3-D representation. This greatly facilitates the generation of 3-D models and interpretation of results [8].

3DEC also contains the powerful built-in programming language FISH (short for FLAC); FISH was originally developed for our two-dimensional, finite-difference, continuum program (FLAC). You can write your own functions to extend 3DEC’s usefulness with FISH. FISH offers a unique capability to 3DEC users who wish to tailor analyses to suit specific needs.

With the exception of the graphics mode, 3DEC is a command-driven (rather than menu-driven) computer program. Even though a menu-driven program is easier to learn for the first time, when applied in engineering studies the command-driven structure in 3DEC offers several advantages.

1. The input “language” is based upon recognizable word commands that allow you to identify the application of each command easily and in a logical fashion (e.g., the BOUNDARY command applies boundary conditions to the model).
2. Engineering simulations usually consist of a lengthy sequence of operations
 - e.g., establish in-situ stress, apply loads, excavate tunnel, install support and so on. A series of input commands (from a file or from the keyboard) corresponds closely with the physical sequence that it represents.
3. A 3DEC data file can easily be modified with a text editor. Several data files can be linked to run a number of 3DEC analyses in sequence. This is ideal for performing parameter sensitivity studies.
4. In order to keep a documented record of the analyses performed for an engineering study, the word-oriented input files provide an excellent means. Often, it

is convenient to include these files as an appendix to the engineering report for the purpose of quality assurance.

5. The command-driven structure allows you to develop pre- and post-processing programs to manipulate 3DEC input / output as desired. For instance, to create a special joint structure for a series of 3DEC simulations you may wish to write a joint-generation function. This can readily be accomplished with the FISH programming language and incorporated directly in the input data file [8].

The software is designed for high-speed computation of models containing several thousand blocks. With the advancements in floating-point operation speed and the ability to install additional RAM at low cost, increasingly larger problems can be solved with 3DEC.

For typical models, consisting of roughly 2000 rigid blocks (or 1000 deformable blocks) or less, the explicit solution scheme in 3DEC requires approximately 2000 to 4000 steps to reach a solved state. For instance, a 1000 deformable block model run on the Pentium computer described above would require roughly 32 minutes to perform 4000 calculation steps. Thus, typical engineering problems involving several hundred blocks and multiple solution stages can be solved with 3DEC on a microcomputer in a matter of minutes or a few hours.

4.2 Comparison of FLAC^{3D}, 3DEC and SAP 2000

All softwares are making analysis in three dimensions. In Itasca FLAC3D and Itasca 3DEC are numerical modeling code for advanced geotechnical analysis of soil, rock, and structural support in three dimensions; the SAP 2000 is used for the finite element analysis method.

How does FLAC3D compare the more common method of finite elements for numerical modeling? Both methods translate a set of differential equations into matrix equations for each element, relating forces at nodes to displacements at nodes.

Even though FLAC3D's equations are derived by the finite difference method, the resulting element matrices, for an elastic material, are identical to those of the finite element method (for constant strain tetrahedra). Yet, FLAC3D differs in the following respects.

1. The "mixed discretization" scheme is used for accurate modeling of plastic collapse loads and plastic flow. This scheme is believed to be physically more

justifiable than the “reduced integration” scheme commonly used with finite elements.

2. The full dynamic equations of motion are used, even with modeling systems that are essentially static. This enables FLAC^{3D} to follow physically unstable processes without numerical distress.

3. An “explicit” solution scheme is used (in contrast to the more usual implicit methods). Explicit schemes can follow arbitrary non-linearity in stress/strain laws in almost the same computer time as linear laws, while implicit solutions can take significantly longer to solve non-linear problems. Moreover, it is not necessary to store any matrices, which means that (a) a large number of elements may be modeled with a modest memory requirement, and (b) a large-strain simulation is hardly more time-consuming than a small-strain run, because there is no stiffness matrix to be updated. These differences are mainly in FLAC^{3D}’s favor, but there are two disadvantages.

1. Linear simulations run slower with FLAC^{3D} than with equivalent finite element programs; FLAC^{3D} is most effective when applied to non-linear or large-strain problems, or to situations in which physical instability may occur.

2. The solution time with FLAC^{3D} is determined by the ratio of the longest natural period to the shortest natural period in the system being modeled. Certain problems are very inefficient to model (e.g., beams, represented by solid elements rather than structural elements, or problems that contain large disparities in elastic moduli or element sizes).

Common questions asked about 3DEC are: “Is 3DEC a distinct element or discrete element program? What is the difference, and what is 3DEC’s relation to other programs?”.

Many finite element, boundary element and Lagrangian finite difference programs have interface elements or “slide lines” that enable them to model a discontinuous material to some extent. But their formulation is usually restricted in one or more of the following ways. First, the logic may break down when many intersecting interfaces are used; second, there may not be an automatic scheme for recognizing new contacts; and third, the formulation may be limited to small displacements and / or rotation. Such programs are usually adapted from existing continuum programs.

The name “discrete element method” applies to a computer program only if it:

(a) allows finite displacements and rotations of discrete bodies, including complete detachment; and

(b) recognizes new contacts automatically as the calculation progresses.

Without the first attribute, a program cannot reproduce some important mechanisms in a discontinuous medium; without the second, the program is limited to small numbers of bodies for which the interactions are known in advance.

There are four main classes of computer programs that conform to the proposed definition of a discrete element method.

1. *Distinct Element Programs* — These programs use explicit time-marching to solve the equations of motion directly. Bodies may be rigid or deformable (by subdivision into elements); contacts are deformable. 3DEC falls in this category.

2. *Modal Methods*—The method is similar to the distinct element method in the case of rigid bodies but, for deformable bodies, modal superposition is used.

3. *Discontinuous Deformation Analysis* — Contacts are rigid, and bodies may be rigid or deformable. The condition of no-interpenetration is achieved by an iteration scheme; the body deformability comes from superposition of strain modes.

4. *Momentum-Exchange Methods*—Both the contacts and the bodies are rigid: momentum is exchanged between two contacting bodies during an instantaneous collision. Frictional sliding can be represented.

In contrast with classical methods like Finite Element and Boundary Element Methods that treat the medium as a continuum, the Distinct Element Method treats the medium as a discontinuous. Therefore, reproducing the mechanics of contacts and impacts between distinct blocks is the emphasis of Distinct Element Method. The method is well suited to analyze diverse problems at various scales in civil engineering.

Discontinuities are treated as boundary conditions between blocks. Large displacement on the discontinuities such as slip and opening is simulated in a discontinuous medium. Relative motion along discontinuities is governed by linear and non-linear force-displacement relations for movement in both the normal and shear directions. The program uses an explicit solution scheme, which gives a stable solution to unstable physical processes.

CHAPTER 5

MODELING

5.1. Model Statement

Reached here about 2000 years ago until today, have been subjected to wear and tear of various earthquakes and nature of climatic modeling and analysis of a historic temple is the Temple of Augustus (See Figure 45).

The purpose of these studies, taking into account the current state of this historic structure and the region, may be exposed to possible displacements of a structure against earthquake loads, forces and moments in the future may be exposed by examining the structure is to be aware of situations. The structure is composed of many blocks. Figure 45 shows the full model.

5.2. Modeling Procedure

The $FLAC^{3D}$, SAP2000 and 3DEC software packages were used to model the historical structure shown in Figure 45. In order to reduce the computation time some simplifications are made.

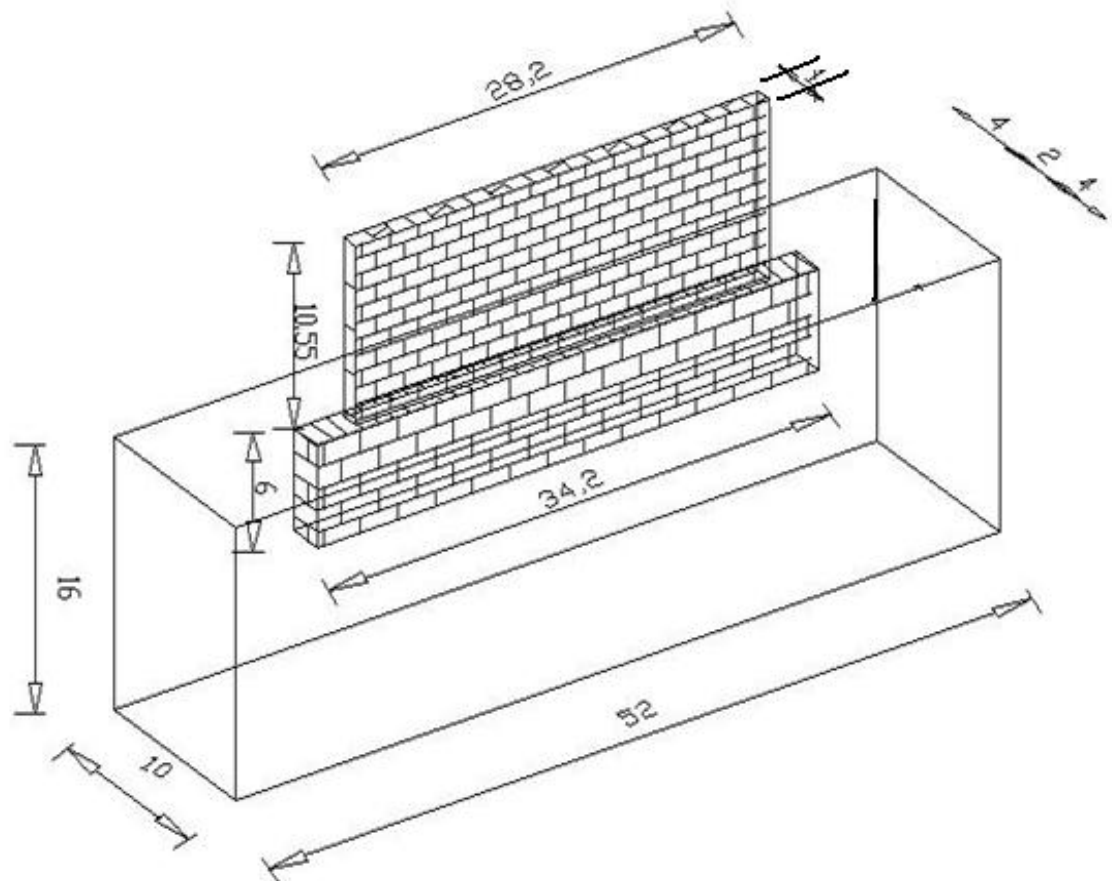


Figure 45 - Numerical Model of Augustus Temple, unit is meter.

The properties of the model were chosen from the literature and they were compiled according to the numerical model carried out by other researchers. The following properties are assumed for the wall, and foundation and firm soil below the (See Figure 46).

<p style="text-align: center;">WALL and FOUNDATION</p>	<p style="text-align: center;">Density, γ, = 24 kN/m³ Modulus of Elasticity, E = 50 Gpa Cohesion, C = 1MPa Internal friction angle, Φ = 30° Poisson`s ratio, ν = .25 Bulk Modulus, K = 33000 MPa Shear Modulus, G = 20000 MPa</p>
<p style="text-align: center;">SOIL</p>	<p style="text-align: center;">Density, γ, = 20 kN/m³ Modulus of Elasticity, E = 40 Gpa Cohesion, C = .5 MPa Internal friction angle, Φ = 20° Poisson`s ratio, ν = .20 Bulk Modulus, K = 22000 MPa Shear Modulus, G = 17000 MPa</p>

Table 1 – Assumed values of the wall, foundation and soil properties for dynamic analysis

CHAPTER 6

RESULTS OF NUMERICAL MODELING

6.1. Description of the Wall

The walls of the Cella of the Augustus Temple are comprised of the row of the orthostates, situated at the base (in effect a row of stretcher stones of 1.1 m in height), followed by 19 alternating rows of header and stretcher stones (Figure 46). The width of the header stones is 1.0 m, equal to the width of the wall, and that of the stretcher stones about 0.5 m. The orthostate stones have also a width of 0.5m. All stones are approximately 1.0-1.5m in length. Both header and stretcher stones are 0.5 m in height, resulting to a total height of the wall, in its original state, just about 11 m without including the architraves, which is the upper row of larger size stones. The FLAC^{3D} numerical model is also shown in Figure 47 as a scene for this wall simulation.

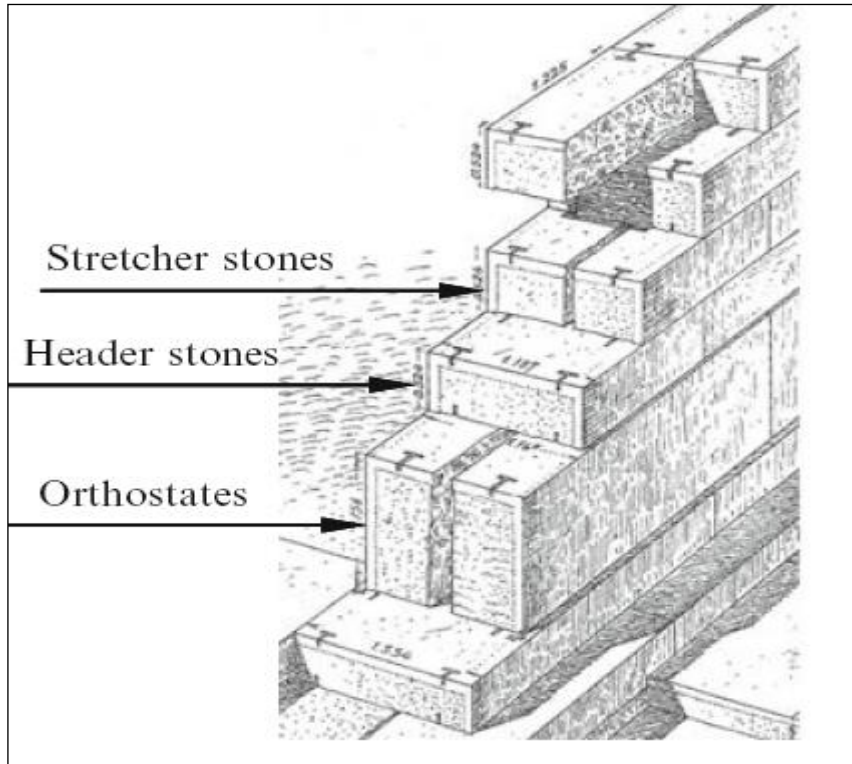


Figure 46 - Schematic view of the cella wall of Augustus temple.

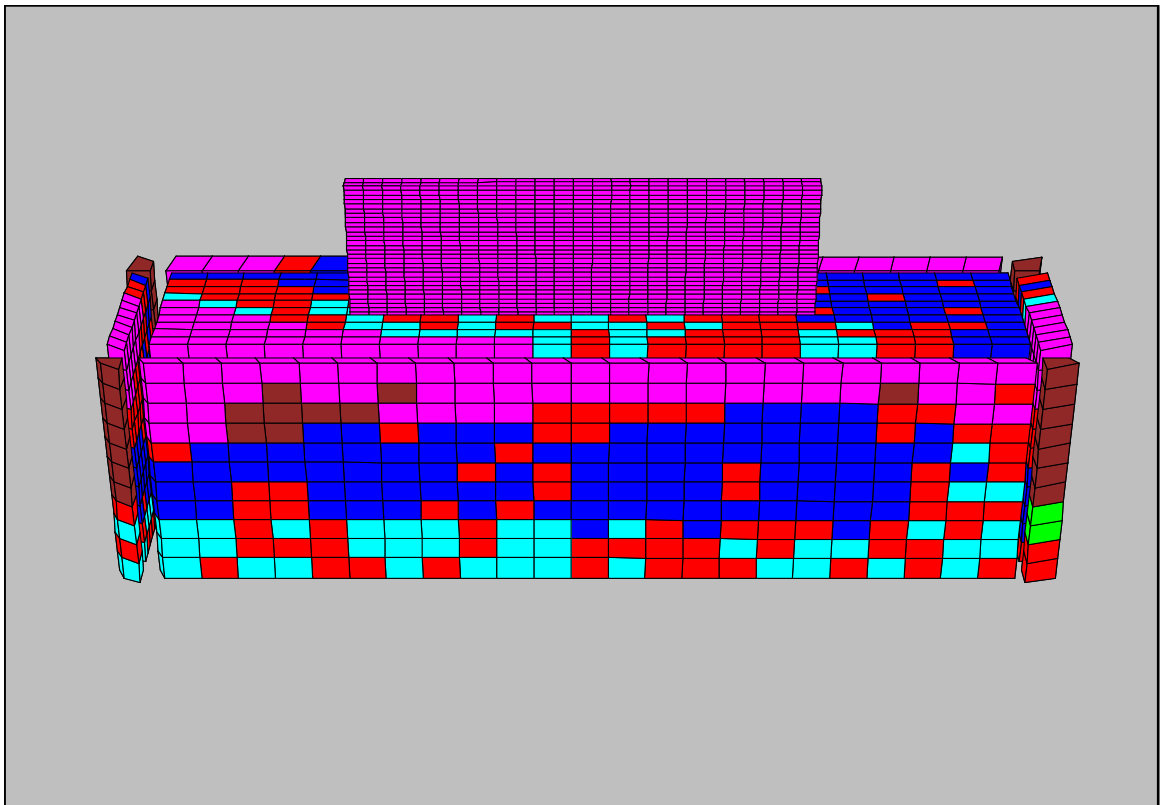


Figure 47 - A scene model from $FLAC^{3D}$ Modeling.

6.2. Results and Discussions

The dynamic loading for this problem is a sinusoidal velocity applied at the base of the model in the horizontal directions (the algorithm is given below). The wave has a frequency of 10 Hz and amplitude of 4 in general, but during the parametric study these values were sometimes changed systematically. The amplitude in the x-direction (along the long axis of the wall) in the y-direction (along the width of the wall) is taken equal. The local damping coefficient of 0.125 is applied to give a fraction of critical damping. The dynamic response is calculated using a time-stepping algorithm. The dynamic algorithm is;

```
def setup

    omega = 2.0 * pi * freq
    o_env = 2.0 * pi / env_time
    end

    def wave

        if dytime > env_time

            wave = 0.0

        else

            wave = 0.5 * (1.0-cos(o_env*dytime)) * ampl * sin(omega*dytime)

        endif

    end

    set freq=10 ampl=4.0

    set env_time= 1.0 ; (1 sec attack & decay)

    setup

    damp 0.125 200 stiff
```

The amplitude in the horizontal plane is 4.0 in the example above. In the analysis, the two components of the earthquake are applied simultaneously. A quiet period of one second was used to check that the relative movement to joints had stopped after the earthquake. The observed displacements points are shown in the

figure given below for the comparison of the simulated model with different used program. The velocities were used as the primary seismic input for the analyses.

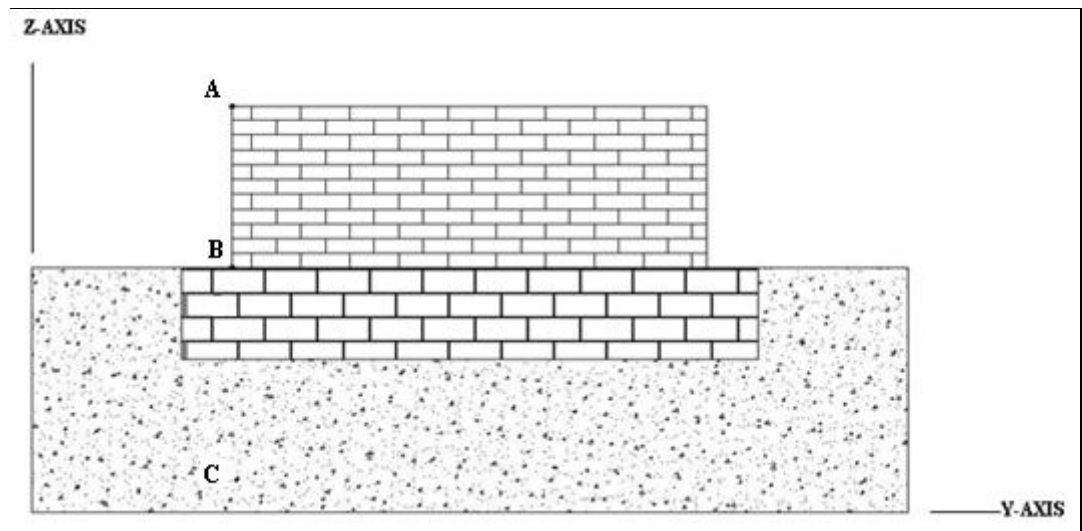


Figure 48 – The investigated displacement especially for y-displacement.

6.2.1. FLAC^{3D} Results

The FLAC^{3D} analysis considers masonry as an assemblage of rigid blocks with no-tension frictional joints and the solutions are based on time-stepping integration of the equations of motion of the individual blocks. The software is fully dynamic and can model the interaction between falling and sliding blocks. Its suitability for modeling crack initiation and propagation, as well as capabilities for modeling large displacements between the different masonry units are some of the strongest capabilities of FLAC^{3D} are. The material properties of the stone and joints were the same as those used in the physical walls obtained from the literature in order to model the walls examined in this study. Though FLAC^{3D} is capable of modeling elastic and nonlinear materials behavior, the blocks were modeled as rigid due to the negligible role of elasticity in the phenomena investigated here.

The initial calculation stages for a dynamic analysis lead to a mechanical equilibrium; the dynamic analysis is then performed. The response of the blockwall and the man-made rock foundation and soils with/without interfaces separating the wall from the foundation and foundation from the soil is modeled. Adopting

interfaces in the model affect the results clearly and different behavior was observed (See Figure 49 and Figure 50). As illustrated in those figures y-displacement changes occur, but the average values are very small in the left top side and in left bottom side of the wall. These values are increasing in the body of the soil and rock foundation.

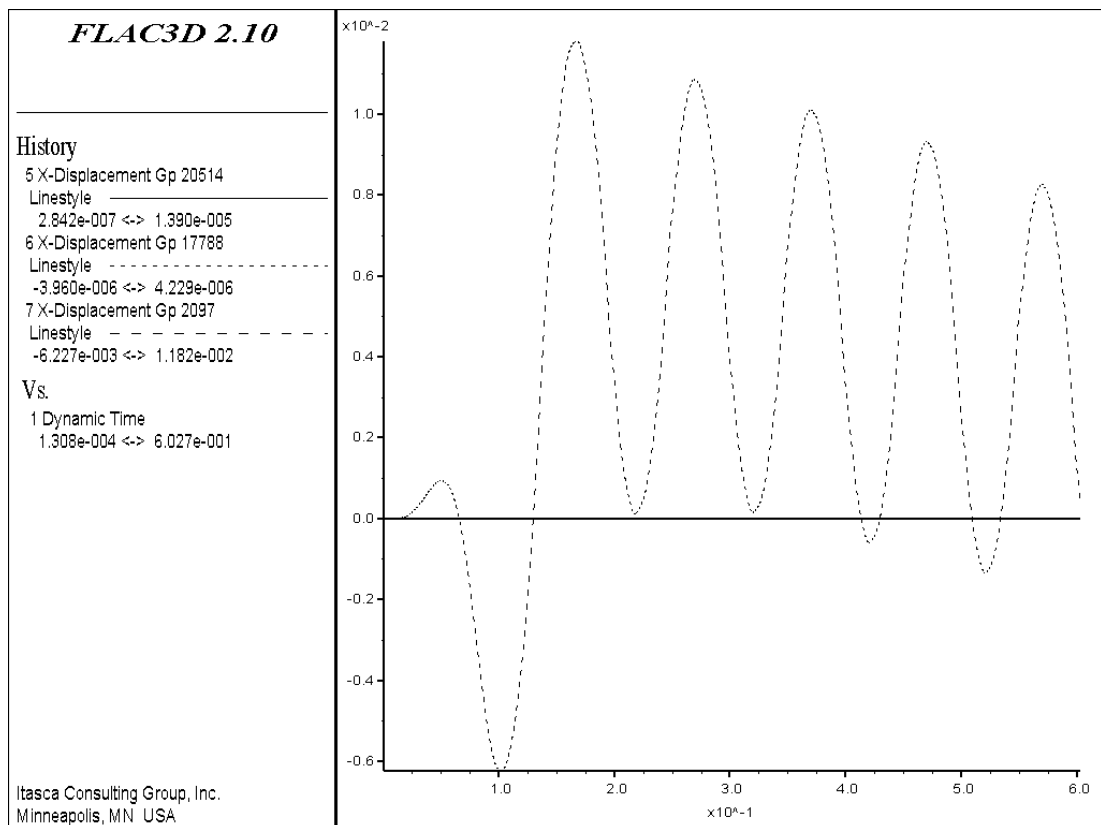


Figure 49 - The y-displacement of the left side of the wall (A, B, C points) without an interface at the bottom of wall (x-displacement shown in the figure above is coordinate system of the program).

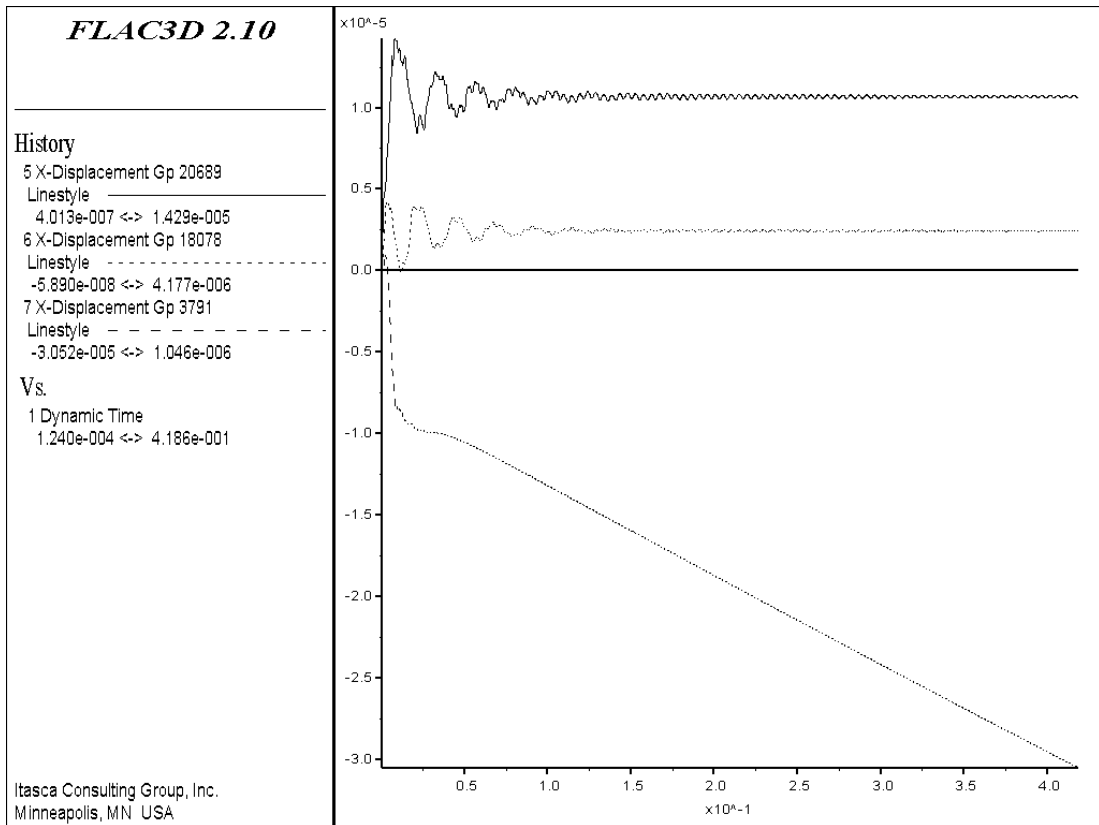


Figure 50 - The y-displacement of the left side of the wall (A, B, C points) with an interface at the bottom of the wall (x-displacement shown in the figure above is coordinate system of the program).

Figure 50 shows the displacement vectors, for the model without interfaces, after about 5 seconds of shaking. The block wall has moved downward by approximately 1.60 m at this time. The state contours after 5 seconds of shaking are plotted in Figure 51.

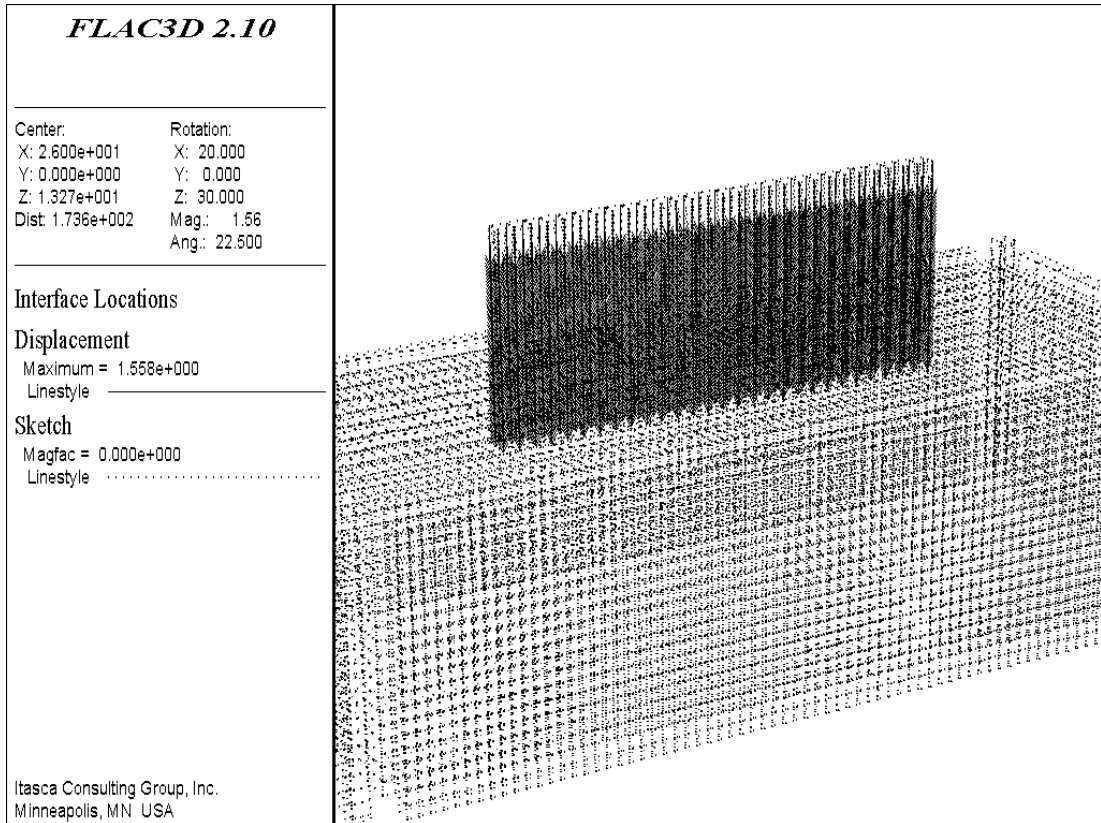


Figure 51 - The displacement vectors after 5 second shaking.

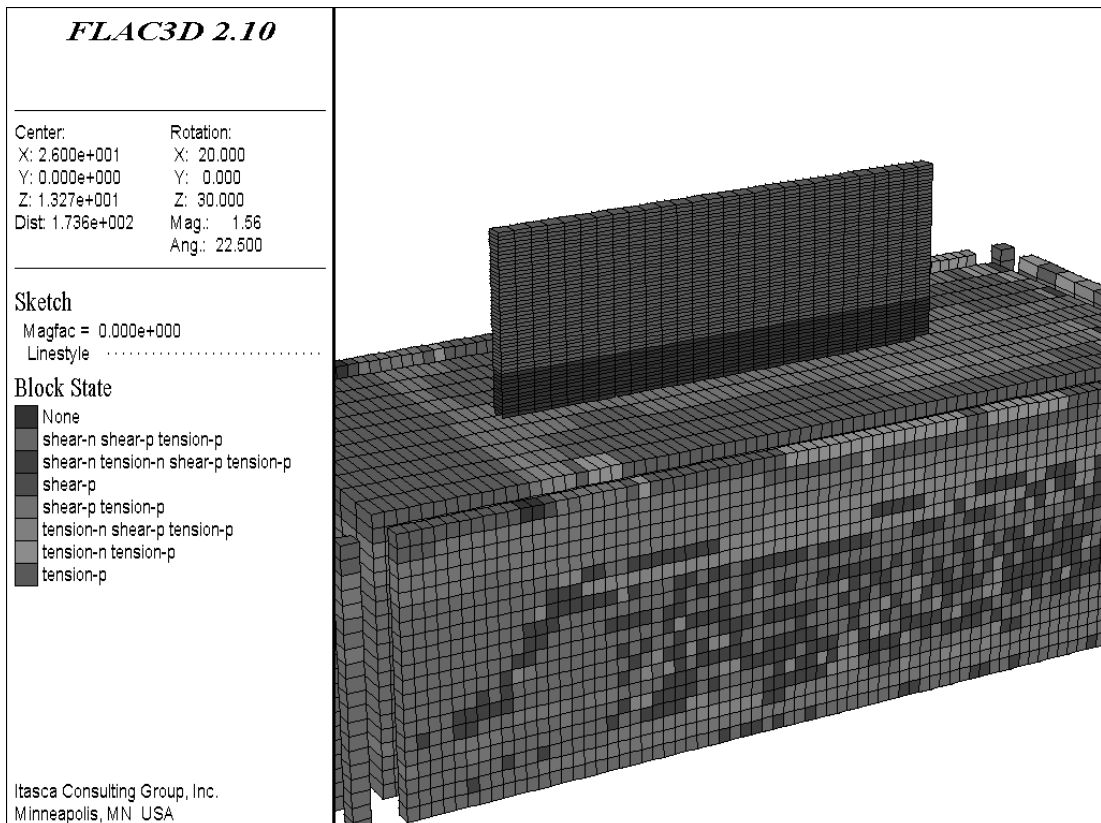


Figure 52 - The state of the model after 5 second shaking.

The z-displacements of the model were influenced by the placement of interface at the bottom of the wall. Placement of interface has decreased the earthquake influence on the wall in terms of download displacement.

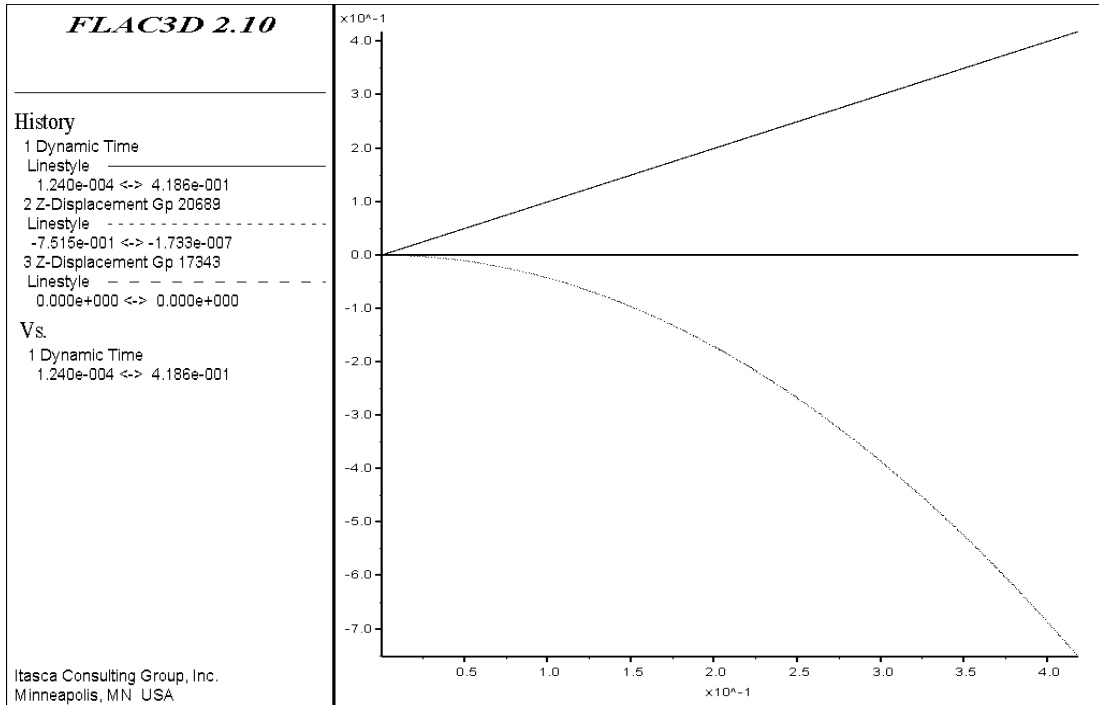


Figure 53 - z-displacements at the A, B, C points of the wall with an interface.

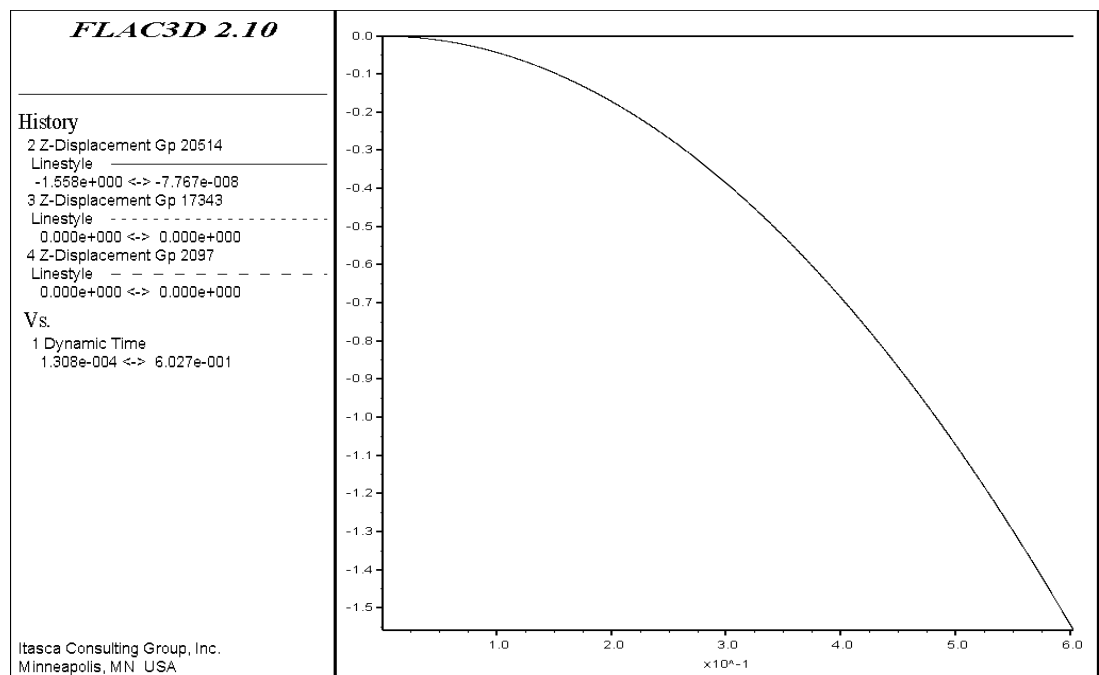


Figure 54 - z-displacements at the A, B, C points of the wall without an interface.

6.2.2. SAP 2000 Results

SAP2000, finite element analysis is executed for this model. This software shows forces, moments, displacements (along x, y and z directions), on the structure in three-dimension. Model of wall and some outputs are shown in Figures 55, 56 and 57. The same material properties are used in SAP2000 analysis those are given in section 5.2.

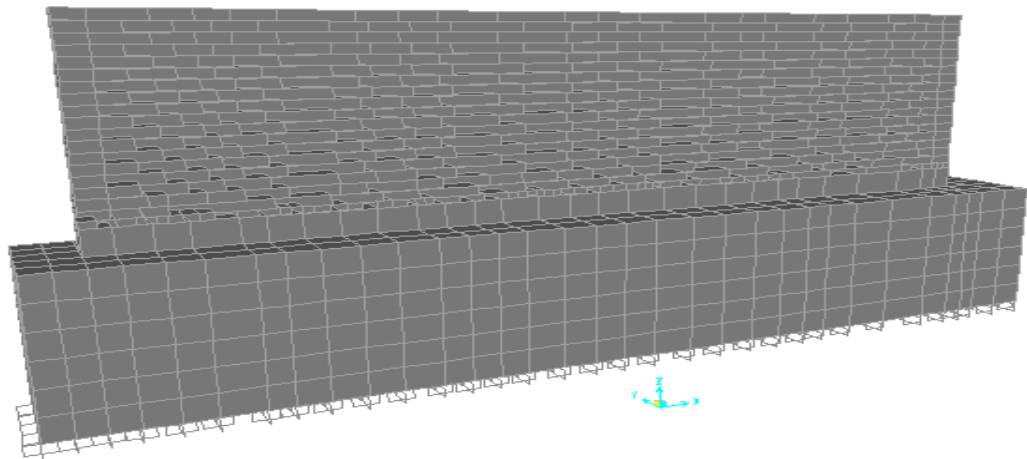


Figure – 55 Model of the wall in SAP2000 software

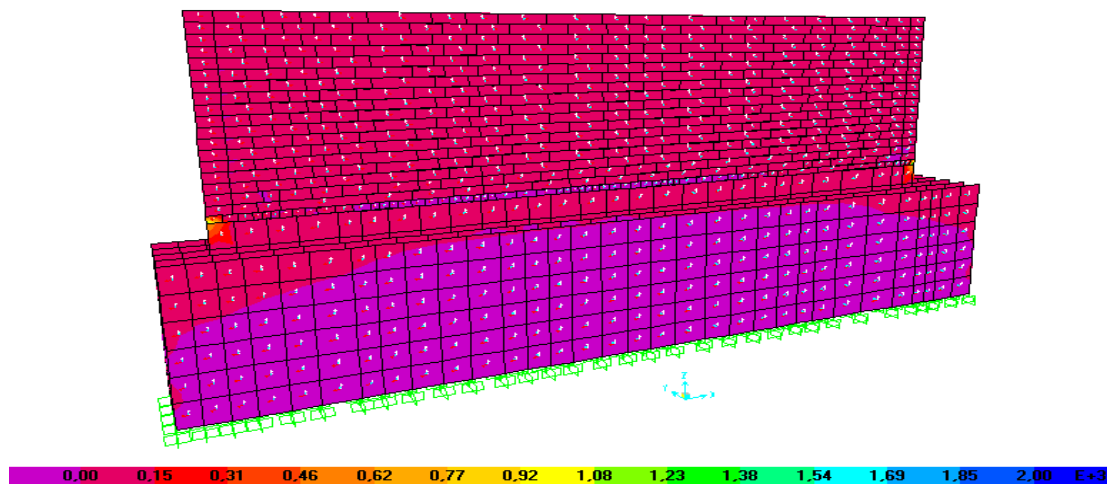


Figure –56 Moments are showing on the wall, units in kN/m^2

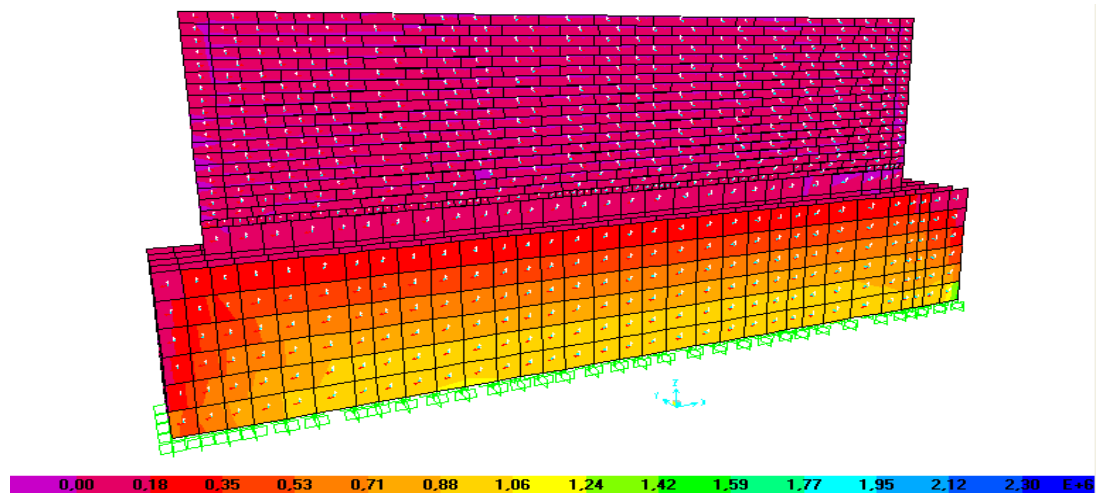


Figure – 57 Normal Stresses are showing on the wall, units in kN/m^2

6.2.3. 3DEC Results

The analysis was done by using 3DEC Version 4.00 to investigate the effect of the foundation and earthquake parameters to the more than 2,000 year old and still standing historical Augustus Temple's east side wall.

The earthquake loading was performed by using the commands given in the previous section below for 3DEC analyses; the same function was also applied for the FLAC^{3D} modeling. There several factors those were changed and compared to see the effect on “y-displacement” values. These values are frequency, amplitude, attack-decay time and damp values.

The z-displacement at the top of the wall with the placement of two discontinuities in the wall is too much smaller than the one without discontinuities. Other components of the displacement of the wall are greater than the one with discontinuity. From these results it can be stated that the discontinuity in the wall affects the z-displacement in a positive manner but do not influence the other displacement components with a remarkable level.

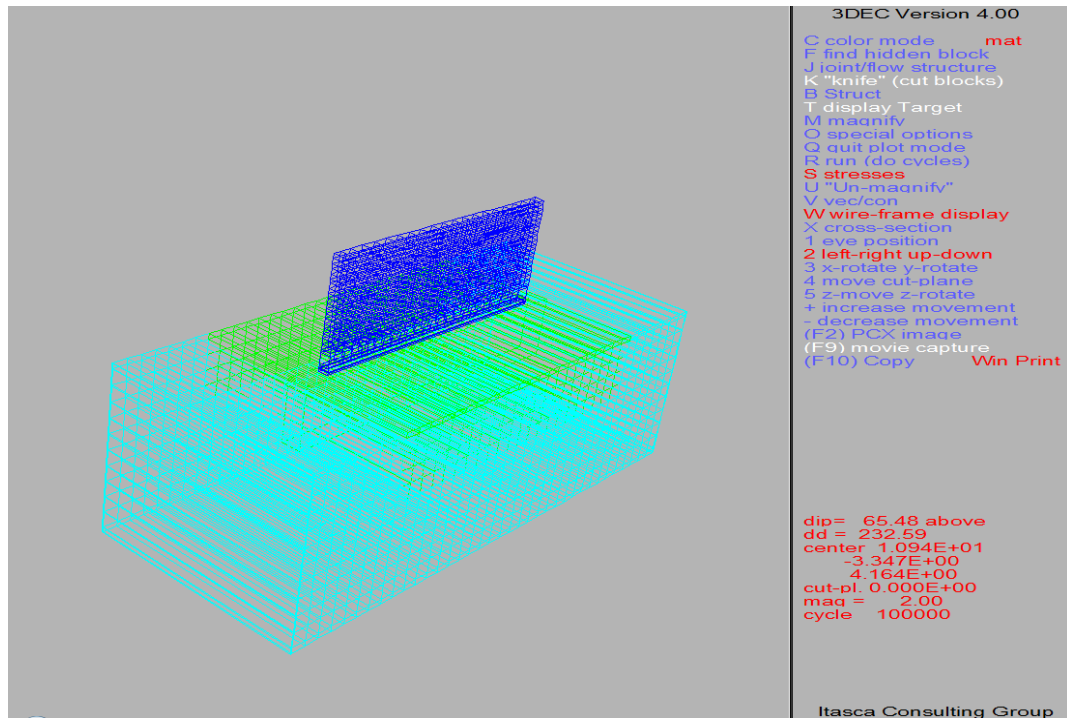


Figure 58 – General view of the east side wall and surrounding boundary with foundation (3DEC) [4].

In order to simulate real earthquake effect acting on the structure and ground, the damping was used and it gives more deflections comparing with no damp analysis. Stiffer structure is absorbing the forces better, but gives more deflections comparing with no damping analysis. Consequently, analysis has to be done by using damping. The analysis boundaries (edge coordinates) are close to the wall and selected using similar examples in 3DEC manuals.

From the Figures 59, 60 and 61, the effect of the interfaces (joints) on the displacements can be observed clearly. The collapse of the wall is occurred after 5 seconds shaking without interfaces. If the interface is implemented this collapse mechanism is vanished.

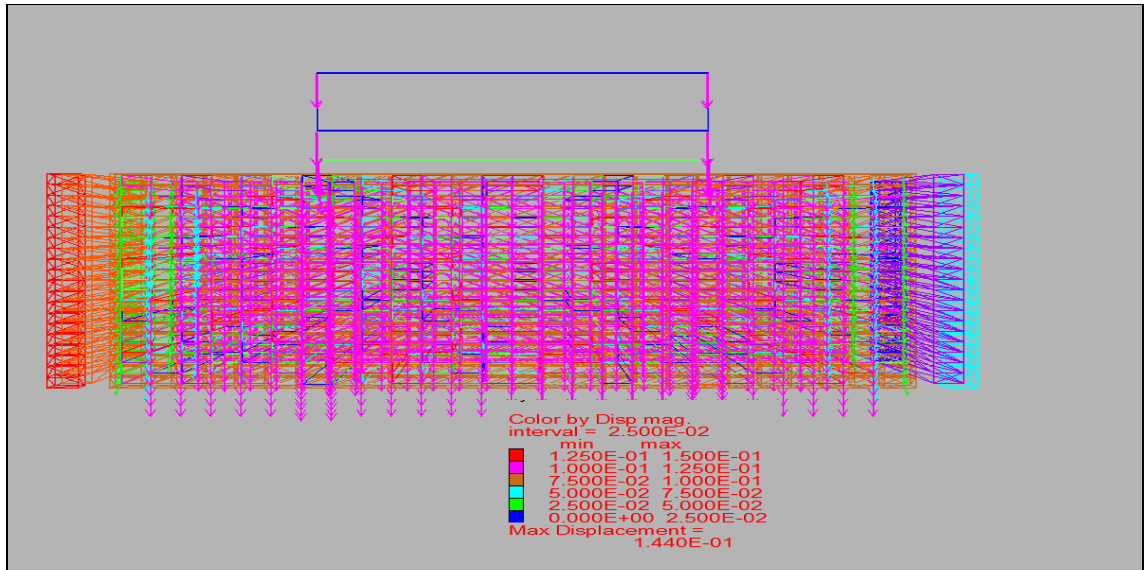


Figure 59 - The scene of the wall displacement vectors with discontinuities.

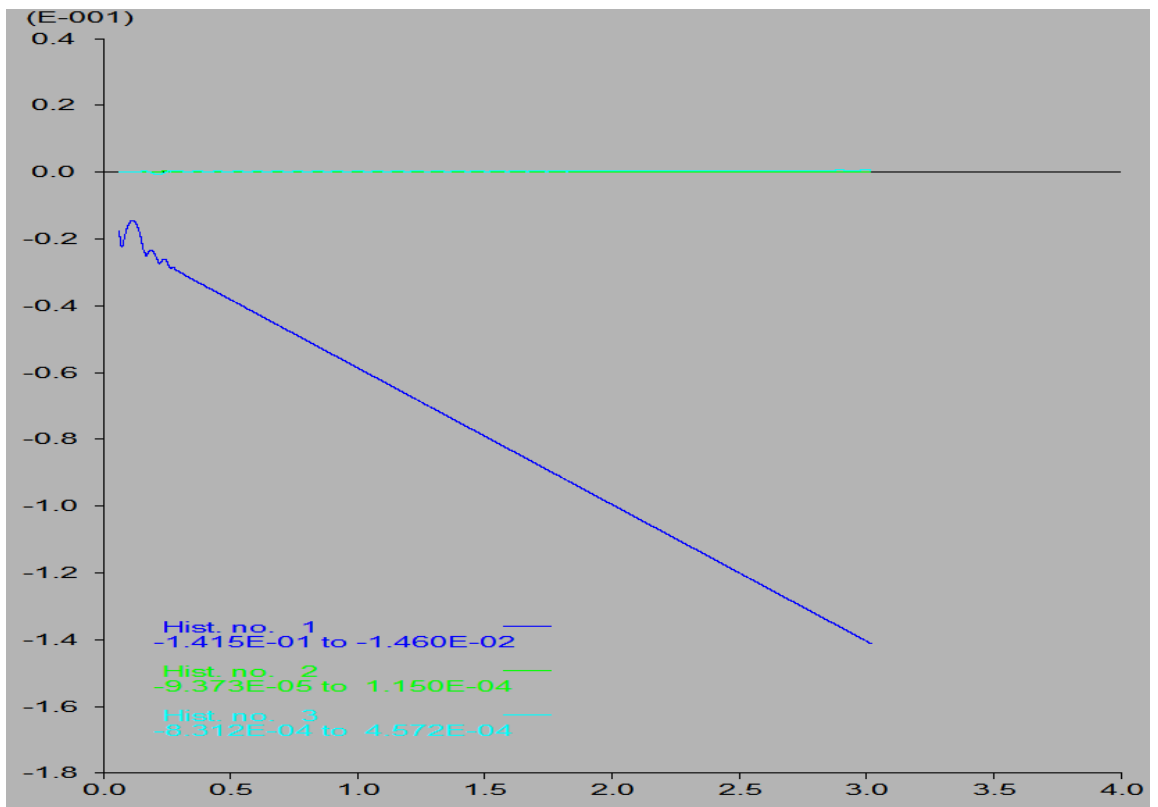


Figure 60 - The displacements x , y and z , at the top of the wall, point A, with discontinuity (Hist. no.1 = z -displacement , Hist. no.2 = y -displacement Hist. no.3 = x -displacement).

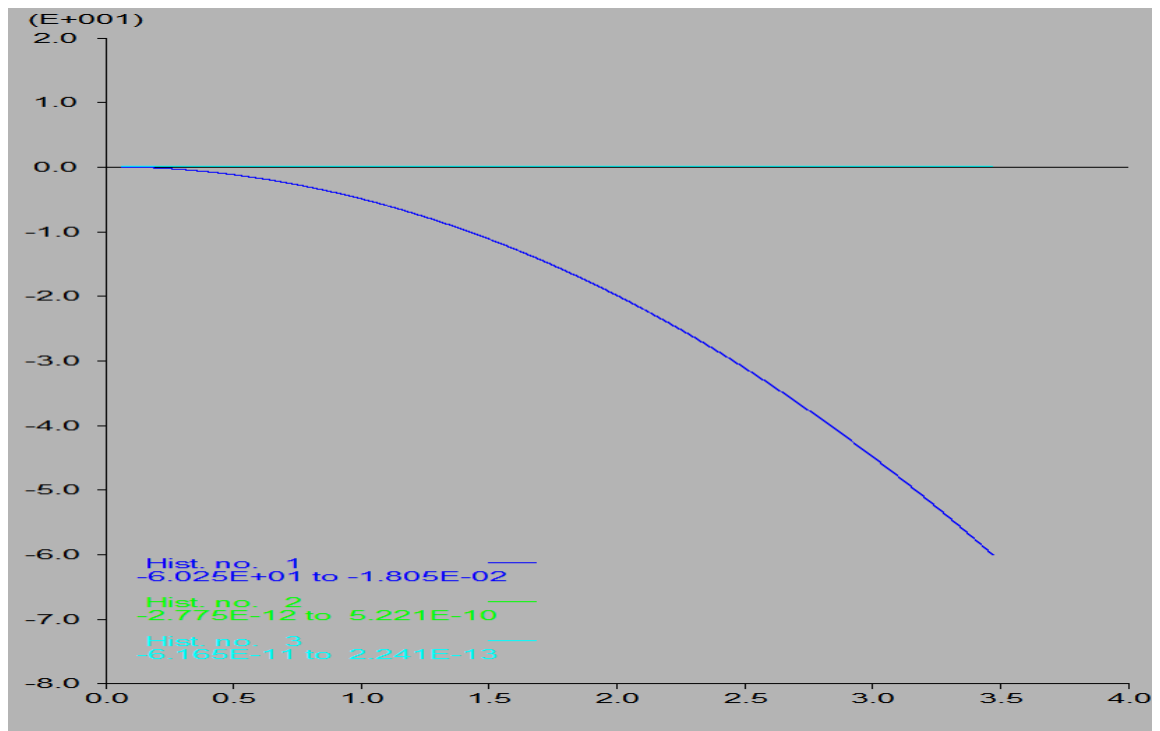


Figure 61 - The displacements x , y and z , at the top of the wall, point A, without discontinuity. (Hist. no.1 = z -displacement , Hist. no.2 = y -displacement Hist. no.3 = x -displacement).

6.2.4. Comparison of Results

6.2.4.1. Displacement Results of the Analyses

The y -displacements at the points A, B, and C as shown in Figure 48 are compiled in Table 2. The wide spread distribution of the y -displacement can be observed. The FLAC^{3D} and 3DEC results show similarity but SAP2000 results show uniformity for the model. From these analyses, it can be revealed that the precise results can be obtained from 3DEC as it considers the joint behavior and soil-structure interaction more than the others. Besides, the discontinuity has effect on the displacement of the wall. These interfaces absorb the earthquake intensity.

POINT	FLAC ^{3D} (m)		SAP 2000 (m)	3DEC (m)	
	With Discontinuity	Without Discontinuity		With Discontinuity	Without Discontinuity
A	1.43×10^{-5}	1.398×10^{-5}	- 0.0054	0.142	-60
B	4.18×10^{-6}	4.23×10^{-6}	- 0.0056	-0.00018	2.08×10^{-8}
C	-3.05×10^{-5}	1.18×10^{-2}	0.0329	0.023	5.22×10^{-10}

*Table 2 – Y- Displacements of the wall (Plus (+) means direction is upward
↑ , Minus (-) means direction is downward ↓).*

Changing the frequencies amplitude and decay time effects were also analyzed. There is no clear effect on the displacements but the behaviour of the state was affected by the variation of these values. This topic has to be investigated in more details. The period of earthquake is also dominant on the displacements and this was clearly observed from these analyses.

CHAPTER 7

CONCLUSION

Using the “displacement” values, the results of FLAC^{3D}, SAP2000 and 3DEC analysis have been compared to each other. There are also other factors that are collected from the analysis, but “displacement” values give a brief idea to the engineer how the structure behaves under different conditions. Interfaces are inserted between wall and foundation to show the isolation effect of structure.

The amplitude and frequency values are changed in order to understand the effect of the earthquake parameters to the structure. Increasing amplitude and the frequency of the earthquake increases “displacement” value as expected, but not too much.

Applying interface between foundation and the wall affect the displacement values clearly. This shows how the foundation helps to reduce the displacement values. The boundary limits are also changed in one of the analysis and larger boundary limits give more displacement values. Because, larger boundary limits give more area to the movement of the structure under earthquake loading.

3DEC and FLAC^{3D} analysis was compared in terms of three different scenarios. Including foundation of the structure, not including foundation and rigid boundary scenarios are the ones to check the effect to the structure. All scenarios were done with the same earthquake loading to see the differences.

No foundation run gives less “displacement” values comparing with foundation run. This is because the extra foundation weight acting on the soil and the displacement values are higher with more force on the soil. Stiff foundation boundary also gives less displacement as expected.

FLAC^{3D} and 3DEC gives the designer to input the structure in three dimensions. The interaction between the units in the structure can also be observed. This is very helpful to the designer and the accuracy of the calculation increases with detail that the designer can enter to the software. From this study, it can be concluded that SAP2000 program can be used for the structural problem rather than the geotechnical cases.

FLAC^{3D} and 3DEC analysis are done by using earthquake scenario taken from the 3DEC manual. However, changing amplitude, frequency does not make remarkable changes on displacement values. The parameters that can change the displacement values are found to be the shaking time and implementing interfaces to the bottom and on the wall. Changing these values effect the displacement values directly. Thus, finding a real earthquake effect at the analysis needs a further research on FLAC^{3D} and 3DEC input. The computation procedures and assumptions are all different for both softwares. Also, the soil parameters, structure properties and earthquake conditions are entered in a different way. Including all these differences, these acceptable displacement values shows the assumptions that were made are quite close the real conditions. Thus, both analyses give an idea about the real structural behavior.

The assessments of the SAP2000 Finite Element results were very difficult as its nature. It is understood from these results that the finite element program is not suitable for the analysis of the stone type masonry building in terms of dynamic analysis.

The depth of the foundation is around 6 meters deep. The deep foundation helps the wall to absorb forces better than walls with shallow foundations. The foundation isolates the forces acting on the wall very well.

Dry stone multiple leaf buildings exhibit unique behavior under both normal and seismic conditions. Understanding and analyzing these structures involves acquiring a detailed knowledge of construction techniques, material properties, site history and environmental conditions.

Without the ability to calculate and wholly predict failure modes in dry stone structures, a thorough assessment of all known factors and present conditions

delineates areas of weakness. Identifying unknown aspects of construction and enabling factors proves just as important as understanding failure mechanisms.

By isolating and reducing the deteriorative elements and monitoring critical structural displacements, possible failure mechanisms can be identified and preventive measures can be implemented.

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<http://www.csiberkeley.com/products_SAP.html>

APPENDIX

A. SAMPLE INPUT FOR 3DEC

new

config dyna

;;;;;;;;;

;;;;;;;;;

; The discontinuity applied on the Wall

;

;;;;;;;;;

; masonry WALL

;;;;;;;;;

po reg 0 28 0 11 0 1

jset dip 0 org 0 5 0

change dip 0 jmat 1

jset dip 0 org 0 2 0

change dip 0 jmat 1

prop jmat 1 jkn 10000 jks 2000 fric 0.001

;;;;;;;;;

;Temel geometrisi

;

;;;;;;;;;

po reg -12 40 -20.0 0 -10 10

.....
.....

change 0 28 .0 11 0 1 mat 1

change -12 40 -20.0 0 -10 10 mat 2

mark xr 0 28 yr 0 11 zr 0 1 reg 1

hide reg 1

jset dip 90 dd 90 orig 14 -20 0 sp 2 num 80

change dip 90 dd 90 jmat 2

jset dip 0 orig 14 -10 0 sp 1 num 40

change dip 0 jmat 2

seek

insitu stress 0 0 0 0 0 0 ygrad 0.001 0.0020 0.001 0 0 0

gen -12 40 -20.0 0 -10 10; edge 20

;

prop jmat 2 jkn 30000 jks 12000 coh 1e6 tens 1e6

;

prop mat=1 dens=0.002400 k=33000 G=20000

change mat 1 cons 1

prop mat 2 shear=17000 bulk=22000 dens=.002000 fric=30 cohes=.5 dil=0 tens=.050

change mat 2 cons 2

.....

bound yr -20 -20.1 yvel 0.0

bound xr -12 -12.1 xvel 0.0

```

bound xr 40. 40.1 xvel 0.0
bound zr -10 -10.1 zvel 0.0
bound zr 10. 10.1 zvel 0.0
grav 0 -10 0
cycle 1000
hist ydis 0,11,0.5
hist xdis 0,11,0.5
hist zdis 0,11,0.5
hist ydis 0 -19 0.5
hist xdis 0 -19 0.5
hist zdis 0 -19 0.5
hist ydis 0 .1 0.5
hist xdis 0 .1 0.5
hist zdis 0 .1 0.5
;impulse load
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
def setup
omega = 2.0 * pi * freq
o_env = 2.0 * pi / env_time
end
def wave
if dytime > env_time
wave = 0.0
else
wave = 0.5 * (1.0-cos(o_env*dytime)) * ampl * sin(omega*dytime)
endif
end
set freq=10.0 ampl=4.0 ;
set env_time= 1 ; (1 sec attack & decay)
setup

```

.....
.....

;

;

ffield apply gap 2 thick 2

bound yr -20 -20.1 zvel 1.0 hist wave ;

bound yr -20 -20.1 xvel 1 hist wave ;

bound yr -20 -20.1 xvisc yvisc zvisc

damp 0.05 200 stiff

cy time 2.0

B. SAMPLE INPUT FOR FLAC^{3D}

```
;
new
conf dyn
;dyn off
;
; generate foundation and wall and soil and without interfaces
gen zone bri p0 0,-10,0 p1 52,-10,0 p2 0,10,0 p3 0,-10,16 size 76 10 20 ; soil
geometry
;

gen zone bri p0 12,-.5,16.0 p1 40,-.5,16.0 p2 12,.5,16 p3 12,-.5,26.55 size 28,1,50;
wall

group block x=12,40 y=-.5,.5 z=16.0,26.55
group soil x=0.0,52.0 y=-10.0,10.0 z=0.0 16.0

model elas range group block
model mohr range group soil

prop shear=17e9 bulk=22e9 dens=2000 fric=30 cohes=.5e6 dil=0 tens=.05e6 range
group soil

prop shear=20e9 bulk=33e9 dens=2400 fric=30 cohes=1e5 dil=0 tens=0.10e6 range
group block
```

```
;interface 2 prop coh=1e3 fric=10 dil=0 kn=10.000e3 ks=5.000e3 ten=10e3
```

```
;interface 2 prop coh=0. fric=10. dil=0. kn=10 ks=10 ten=1
```

```
set grav 0, 0, -9.81
```

```
fix x y z range z -.1 .1
```

```
fix x y range y -10.1 9.9
```

```
fix x y range y 9.9 10.1
```

```
fix x y range x -.1 .1
```

```
fix x y range x 51.9 52.1
```

```
ini szz -3.2e5 grad 0 0 20000
```

```
ini sxx -1.6e5 grad 0 0 10000
```

```
ini syy -1.6e5 grad 0 0 10000
```

```
step 2000
```

```
free x y z
```

```
apply ff
```

```
fix z range y -.1 .1
```

```
fix z range y 9.9 10.1
```

```
fix z range x -10.1 9.9
```

```
fix z range x 51.9 52.1
```

```
fix z range z -.1 .1
```

```
set dyn damp local 0.125
```

```
set dyn time 0
```

```

ini xv 0 yv 0 zv 0 xdisp 0 ydisp 0 zdisp 0
;impulse seismic wave
;
def setup
  omega = 2.0 * pi * freq
  o_env = 2.0 * pi / env_time
end

def wave
  if dytime > env_time
    wave = 0.0
  else
    wave = 0.5 * (1.0-cos(o_env*dytime)) * ampl * sin(omega*dytime)
  endif
end

set freq=10.0 ampl=4.0 ; (0.4 g)
set env_time= 1 ; (2 sec attack & decay)

setup

apply xvel 1.0 hist wave ran z -.1 .1
apply yvel 1.0 hist wave ran z -.1 .1

hist dytime ;1

hist gp zdisp 11.9,-.0,26 ; 2
hist gp zdisp 11.9,-.0,16 ;3
hist gp zdisp 11.9,-.0,2 ;4
  hist gp xdisp 11.9,-.0,26 ; 5
hist gp xdisp 11.9,-.5,16 ; 6
hist gp xdisp 11.9,-.0,2 ;7

```

hist gp ydisp 11.9,-.0,26 ;8

hist gp ydisp 11.9,-.0,16 ; 9

hist gp ydisp 11.9,-.0,2 ;10

solve age 2.