EXPERIMENTAL AND NUMERICAL ANALYSIS FOR THE COLUMNS OF CATHEDRAL St. GEORGE OF GREEK IN FAMAGUSTA

A THESIS SUBMITTED TO

THE GRADUATE SCHOOL OF APPLIED SCIENCES

OF

NEAR EAST UNIVERSITY

by

MARWAH ALAULDDIN BAHAULDDIN

In Partial Fulfilment of the Requirements for The Degree of Master of Science

In

Civil Engineering

NICOSIA 2014

Marwah Alaulddin Bahaulddin : :"Experimental and Numerical Analysis For The Columns Of Cathedral St. George Of Greek In Famagusta"

Approval of the Graduate School of Applied Sciences

Prof. Dr. İlkay Salihoğlu
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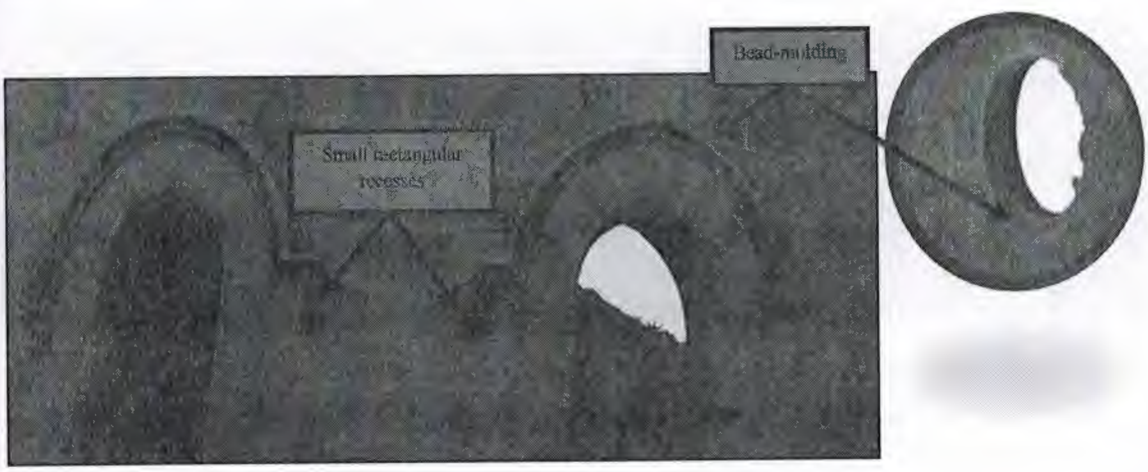

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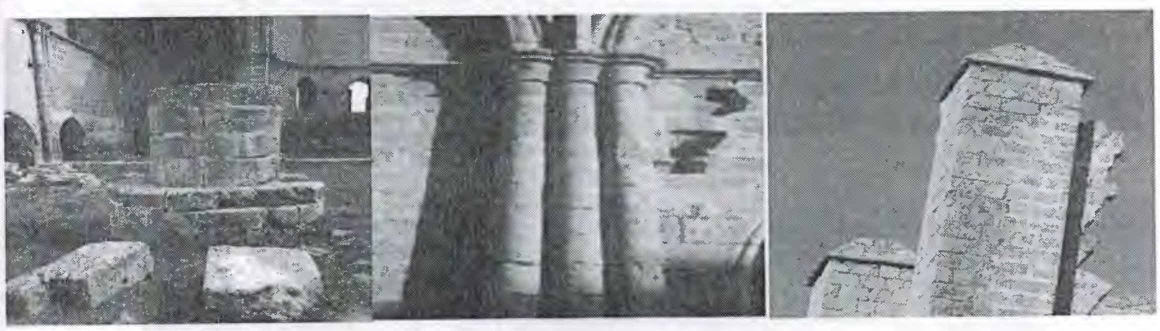

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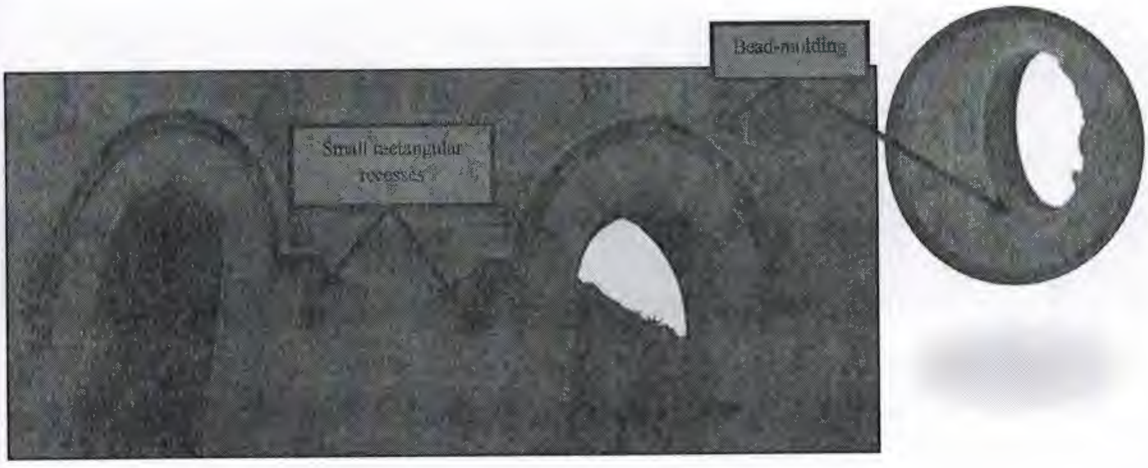

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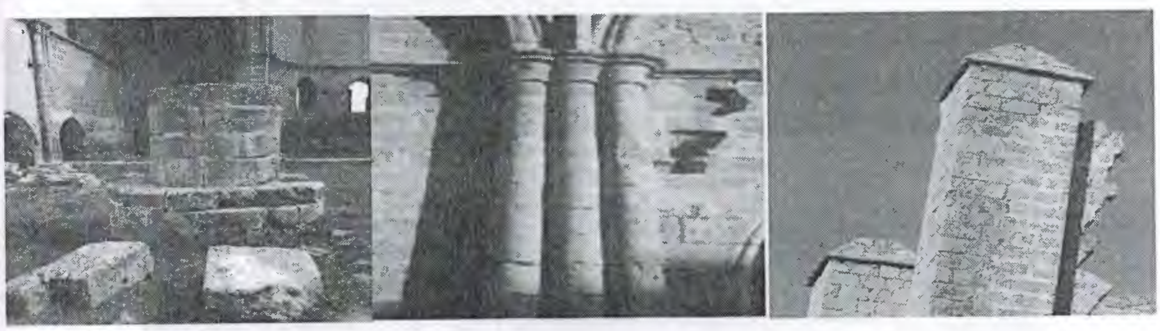

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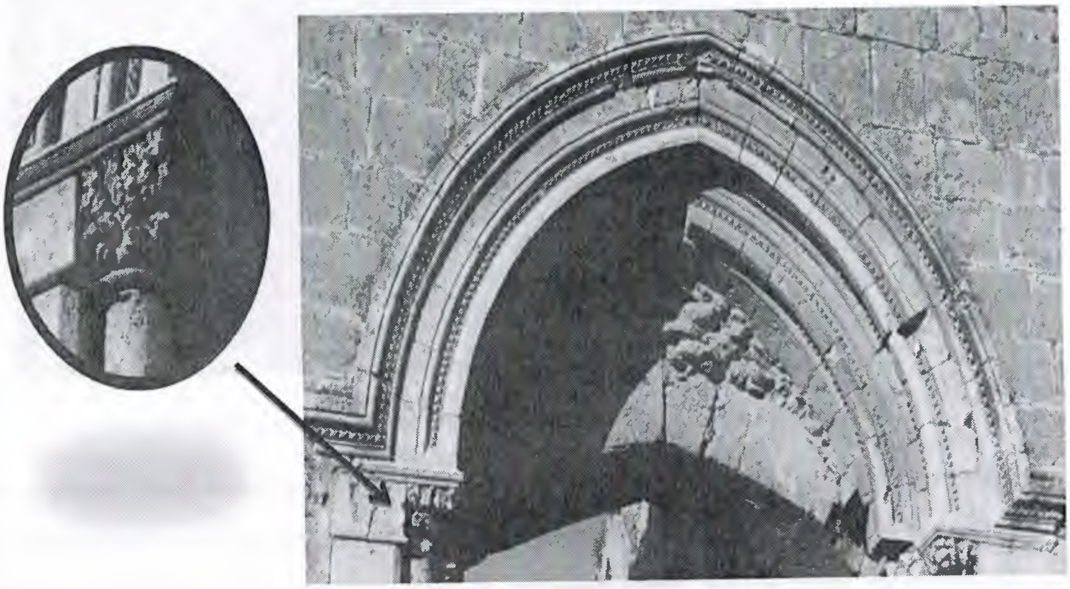

Figure 1.8 The Molding of Arches and Capital of Colonnettes

Under it are three pointed doorways with no buttresses to separate them and the middle one is larger than the other two with no buttresses to separate them; above it is an (oeuil-de-boeuf) with a wide there are no colonnettes on the central doorway but three arches, whose mouldings as shown in fig. 1.8, continue down onto the jambs. There was another doorway in both north and south sides of the nave where the symmetry approach is adopted at that time by the architects in Cyprus

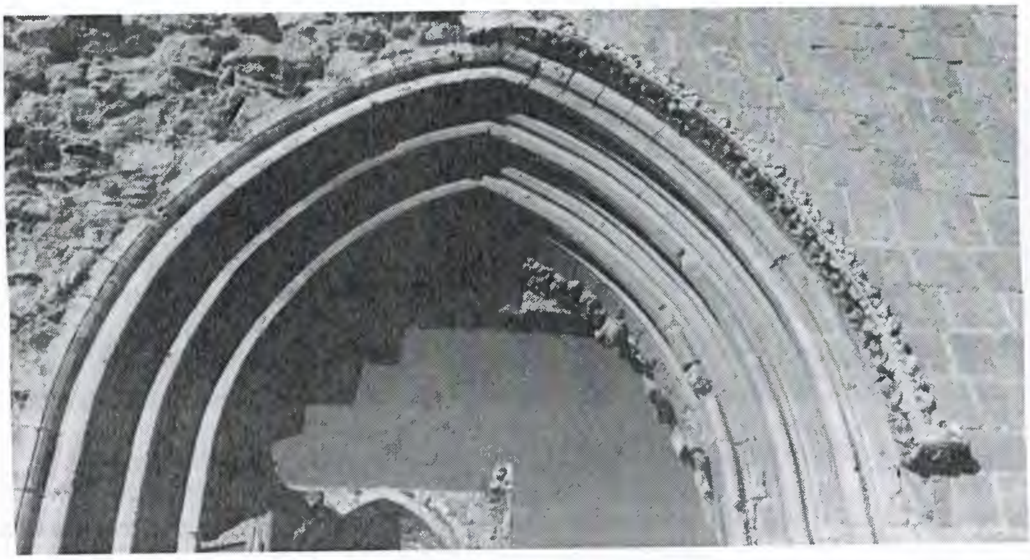

Figure 1.9 The Moldings of Arches of the Central Doorway

There is also a hood-mould carved with a thick torus molding decorated on both sides with two rows of large leaves, all of identical design and are similar to those at the capitals, but are deeply cut and strongly folded. The capitals make a confused effect, all the more inelegant due to the abacus is a plain flattened torus as shown in the fig. 1.9. Church of St. George of Greek includes many of the graves and this is what adopted by Builders in advance , the walls of the corridors have had wide and deep recesses made in them, framed by pointed arches which are carved with elegant moldings and quite clearly intended to house sepulchral monuments. The central dome of the small Byzantine church which has been preserved and joined onto St. George's on the north-east side has twin apses carried on an octagonal drum with mitred windows, was rebuilt at the time of construction of the main church [5, 6].

The interior of cathedral church is entirely covered with well-drawn paintings in the style of Giotto accompanied by numerous inscriptions in Greek as shown below in the figure. 1.10

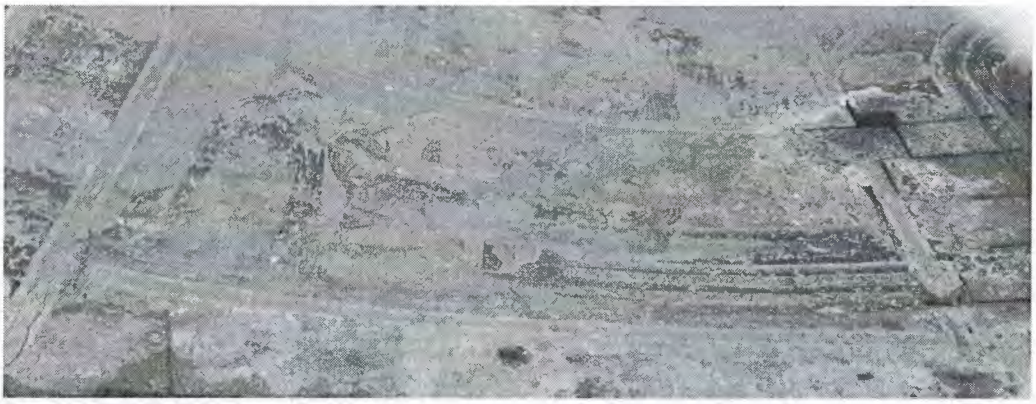

Figure 1.10 The Paintings According to Giotto Style at the Wall of Church

The character of the paintings is certainly Italian, especially in the figures in the southern lateral apse and the aisles, and no the window-surrounds. One of the inscriptions runs around the chamfered edge of the impost of the apsidal semi-dome; but this chamfer made from plaster laid over a groove molding carved with a diaper of small flowers. This detail proves that the painted decoration is later than the construction work; it was probably done in the 16^{th} century [6].

1.3 The Materials Used in the Construction of the Church

Construction materials used in the construction of the cathedral Church of St. George of Greek in particular and is considered one of the important monuments in Famagusta is sandstone. Sandstone may be any color, but the most common colors are tan, brown, yellow, red, gray, pink, white and black. This building using fully dressed rectangularized yellow sandstone units [7, 8]. Yellow sandstone is one of the worldwide famous sandstone. It is also known as Sun Yellow Sandstone. It is very hard sandstone. It is non-porous. It is shiny finished, soft and smooth sandstone. It's used for walls, facades, roofs, landscaping, flooring, wall claddings, balustrade, window cells and surrounds tiles, slabs. It is widely used for sea-shore building due to resistance to water. It contains high amount of feldspar, usually dominated by potassium feldspar [9].

In the next chapter will be detailed the physical and chemical properties of yellow sandstone and the bonding materials that connect them with each other to create this church.

1.4 The Status of Soil in Cyprus

Soil classification began in Cyprus in 1957, according to the methodology of studies designed to collect information regarding the characteristics of the soil chemical and physical, where this classification system was based mainly upon the formation of composition, origin and parent of the materials in the soil. Most of the soil is rated on the island of Cyprus as Red, Sedentary and Alluvial soils. The examination of the main horizons can be classified into various classes by physical and chemical analyses for soil (A, B, C, and D). These types have been classified into soil series according to the C and D horizons [10].

Red soil has a reddish tinge as a result of the presence of iron compounds in the soil composition. Some types of red soil are clays, Clay soil which has a heavy concentration of clay particles and this means the soil stiffness [11].

There are structural parts in civil engineering to be in direct contact with the soil such as the foundations, and this in turn may create the effects of external forces such as earthquakes, act on these systems, neither the structural displacements nor the ground displacements, are independent of each other , the process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil is called soil-structure interaction (SSI) [12], and it will be explain in detail later.

1.5 The Earthquake in Cyprus

An earthquake is malfunction occurs due to sudden rupture of rocks ground by large internal stresses exceed resistant of rock's strength. The malfunction may be newly created by the earthquake rupture or may be present originally. Energy caused by malfunction is transmitted as seismic waves that cause nearly all damaging earthquake effects. The size of an earthquake is often expressed in terms of Richter (or local) magnitude, denoted by ML, and was developed by Charles Richter for California in 1935. Richter magnitude is determined by measuring seismic wave amplitude instrumentally [11].

Cyprus placed between the belt of Alpine and Himalaya. This position is considered the second most area susceptible to the earthquakes on the earth. These earthquakes represent about 15% from the seismic activity in the world. The severity of seismic is attributed to the arc of Cyprus and it is represented the tectonic boundary between the Eurasian plate and African plate. The diving of the African Plate under the Eurasian Plate generates numerous earthquakes along the arc of Cyprus and many active faults inside the island have seen that earthquakes likewise happen along them. In many centuries ago, Cyprus was hit by successive earthquakes. As a result of that, many towns like Famagusta (Salamis) and the capital city Nicosia are destroyed in that period of time. Sixteen earthquakes with intensities of VIII (on modified Mercalli scale) or higher occurred between years 26 B.C. and 1900 A.D. This work addresses the seismic safety of the remaining's of St. George of the Greek Church, in Famagusta, including an inspection and diagnosis. [5], where it will be detailed later.

1.6 Structural Analysis for Church

The Church of St. George of Greek, important model of the old sandstone buildings deserves attention, as this church is built in a way that make them able to withstand a certain type of external forces, these forces are earthquakes and impact forces (cannon balls) [12].
To find out the building technique and materials that used in this church, the SAP 2000'program is going to analyze the sandstone columns of that church to see their behaviors and reactions at force of earthquakes and weight of roof and arches to find out the reason that lead to the collapse and failure this church.

1.7 Literature Review

Church of St. George of Greek is considered one of the most important ancient monuments and historical edifices in the city of Famagusta. This building suffered under earthquakes over the years that led to loose most of the stones that's where the church now is the remnants of walls and columns only. Prior earthquake damage would lead to changes in the structural characteristics which in turn imply changes in the response of the structure against future earthquakes [4, 13].

One of the most important cause's damage to engineering structures during the seismic strikes has been the development of soil liquefaction beneath and around structures. In 1992, J.I.Baez & G.R.Martin made an estimation of current earthquake knowledge on the relative effectiveness of stone pillars for reducing the liquefaction of soil. The limitations on usage of simple analytical techniques like seed and Booker's are noted at1976. The survey of the experimental data indicates that the linear techniques of consolidation are valid only if the ratio of the pore pressure below than 0.5 of pore pressures within the gravel drain has also been spotted to differ, contrary to the assumption that they stay essentially unchanged. The conclusions from the evaluation that the most safe and appropriate technique to reduce the intensity of the earthquake by potential liquefaction resides in identifying the soil. None the less, the research until the present time proposed that the extra benefits arising from the drainage capacity of the stone column might be included in the design considerations [14].

In 2002, explained each of Woo-Seok Bae, Bang-Woong Shin, Byung-Chul a Foundation system ameliorate with stone columns is many obstacles in quantitative analysis of soil-column interaction as a result of that bearing capacity and consolidation behavior of stone column is influenced by different parameters. With reason, the behavior of composite ground improves in the soil-foundation system interface, so the behavior of stone column is better investigated in term of different parameters which affect the horizontal resistance in the interface. In this study, failure technique and different parameters for the behavior of end-bearing stone column groups are investigated under these tests (unit cell consolidation tests and loading tests). The outcomes of model tests are proved by the failure behavior and bearing capacity by FEM analysis. At the end of this research, the influence of design parameters and the improving characteristics of soft ground were proved in this study using FEM results and PR value. Throughout the test outcomes and the PR value computation, bearing capacity of stone column is affected by undrained strength of surrounding ground, area replacement ratio of composite ground and installation of mat. Besides that, behaviors of foundation are affected by diameter and spacing of pile rather than embedment ratio and mat. In addition, the behavior of stone column is essentially affected by initial untrained shear strength of surrounding ground and column spacing. In addition, the analyses through FEM by using Mohr-Coulomb model and PR values are applicable to the estimation of the behavior of stone column [15].

In 2006, Boštjan Pulko and Bojan Majes are submitted analysis the behavior of rigid foundations stabilized using end bearing stone-columns. The surrounding soil and the stone column and are addressed in axial symmetric conditions as a unit cell. The stone column is supposed to treat as a Mohr-Coulomb rigid-plastic material with non-associative flow rule according to the Rowe stress dilatancy theory and the soil as an elastic material. The outcomes of this technique are compared with some analytical techniques and some published works at this field [16].

1.9 Thesis Objectives

The objectives of this thesis are:

1. The study of the properties of constructive materials accredited in the fourteenth century through laboratory testes to determine its ability to resist external forces conditions and the effect of some important factors on the general behavior of stone.
2. Theoretical study and developed to complement existing knowledge related to understanding the behavior of the soil at the site of the Church to determine the properties of the seismic behavior that led to the collapse of the columns of the church.
3. Display the influence of earthquakes on the construction buildings and data collections of earthquakes experienced by Cyprus since the fourteenth century until 2013.
4. To find out the strength of the main columns, its behavior and reactions to external forces due to earthquake "vertical and lateral load" according to the collected data to determine the reason which led to the collapse of the columns and other parts based upon it such as arch and remains of roof by using SAP 2000 program.
5. To identify subjects appropriate for further research on the topic.

1.10 Thesis Layout

The thesis consists of six Chapters arranged as flow:

The first Chapter presents the introduction and literature review on the topic.

The second Chapter discusses the utilized materials in the walls and columns of the Cathedral, the chemical compositions for materials, properties of the sandstones and mortar used in between. In the third chapter, the study is pointed toward status of soil in Famagusta and its effect on the building. In addition, the earthquake in Cyprus is given in details.

Fourth Chapter explains the steps conduct laboratory tests. In the fifth Chapter, present calculations of structural analysis and numerical applications by using SAP2000 of church's columns. Sixth chapter presents the discussions. As well as, it shows the conclusions and suggestion for future work.

1.11 Summary

This chapter presented the history of cathedral church of St. George of Greek since its construction to the present day. As well as, this chapter gave a good background to understand the location and the architecture of this church and the used materials in the construction of the church. The status of soil and the earthquake in Cyprus is discussed. Besides that, the previous researches for many scientific papers in same topic are presented.

CHAPTER TWO

THE UTILIZED MATERIALS AND TECHNOLOGY PROMOTION IN THE CHURCH, CHEMICAL COMPOSITIONS, PHISICAL PROPERTIES AND SANDSTONE DECAY

2.1 Overview

Since the birth of civilization, human being has used building material for tools and for construction applications. The earliest materials were wood, sand, rocks and clay. In addition, the leaves and twigs of plants that have been utilized for the same purpose, the stone walls were the most common used at that period of time where humans were put at the beginning stones only without any connection between the stone masonry, after that began a new phase of building where started holding the stones together using Binders because of the wars and cannon-balls. Sandstone has been widespread utilized for lifting the walls before many centuries to the present day. It has been used for over centuries for making strongholds, forts and castles etc. several stone of construction can be seen in main towns, several civilizations constructed wholly with stone like the Pyramids in Egypt and the remains of the civilization of Inca and churches in Cyprus [17, 18].

2.2 The Materials Utilized in the Church and Technology Promotion

Construction materials used in the construction of the Church of St. George of Greek in particular and almost all the historic monuments in Famagusta is sandstone. Yellow Sandstone is one of the worldwide famous sandstone. It is also known as Sun Yellow Sandstone. It is very hard sandstone and due to non-porous it is widely used for sea-shore building due to resistance to water. It is shiny finished, soft and smooth sandstone. It's used for walls, facades, roofs, landscaping, flooring, wall claddings, balustrade, slabs, and window cells and surrounds tiles [7, 9].

According to the Euro code 8, the kinds of building and behavior of factor relying on the type of masonry that utilized for the elements that resist the earthquakes and the masonry of this church selected to restrict the masonry construction. Because of its low strength of ensile and low flexibility, the unsupported masonry that tracks the provisions of EN 1996 is considered to offer (DCL) low-dissipation capacity and its usage must be restricted, provided that the efficient thickness of the walls, t_{ef}, is not below than the minimum value, $t_{ef,min}$ [19]. The allowable ranges of the upper limit of values for the behavior factor q are shown below in Table 2.1.

Table 2.1: Types of Construction and Upper Limit of the Behavior Factor [48].

Type of construction	Behavior factor q
Unsupported masonry in accordance with EN 1996 alone (recommended only for low seismicity cases).	1,5
unsupported masonry in accordance with EN 1998-1	1,5 - 2,5
Confined masonry	2,0 – 3,0
Reinforced masonry	2,5 - 3,0

Walls of the church were built completely of sand stones put in a systematic style and it hasn't contained on the usual layers. These un coursed walls have two vertical layers (named wythes) of the huge stones in the main building outer walls the total thickness is 123-125 cm, thickness of outer and inner layer is 37 cm (sized 25 w x 50 l x 35h) cm filled in between with small sandstone rubble embedded in a plaster with thickness 50 cm and total thickness of apse walls is 72 cm, thickness of outer and inner layer is 25,37 respectively filled in between with small sandstone rubble embedded in a plaster with thickness 10 cm. All building blocks of wall connected with each other by a mortar with a thickness 1 cm [13]. The fig. 2.1 shows the main outer and apse wall in detail.

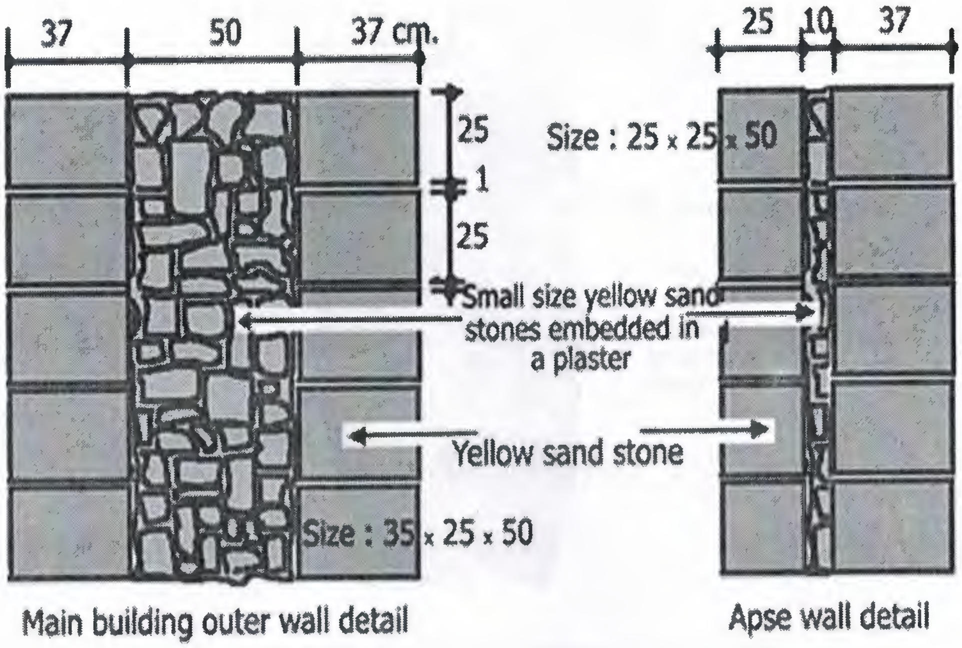

Figure 2.1 The Main Building Wall in Details

Also in India, the stone has been utilized in the construction long time ago

Also in India, the stone has been utilized in the construction long time ago and in a manner similar to the stone walls of the Greek. Because of its carrying capacity for long periods and locally obtainable in abundance where there are great numbers of stone constructions in the towns. In a rustic stone home, the thickness of the stone masonry for the walls was between 600 mm to 1200 mm.

These walls are built with stones developed randomize. As a result of this random arrangement, so the walls of this church don't contain the usual layers where these walls called un coursed wall. The walls of this church involve of two exterior vertical layers and are named wythes. These layers between two horizontal layers of the wall are packaged with loose stone rubble and the bonding material mud. The model of un coursed random (UCR) stone masonry wall is shown below in Figure 2.2.

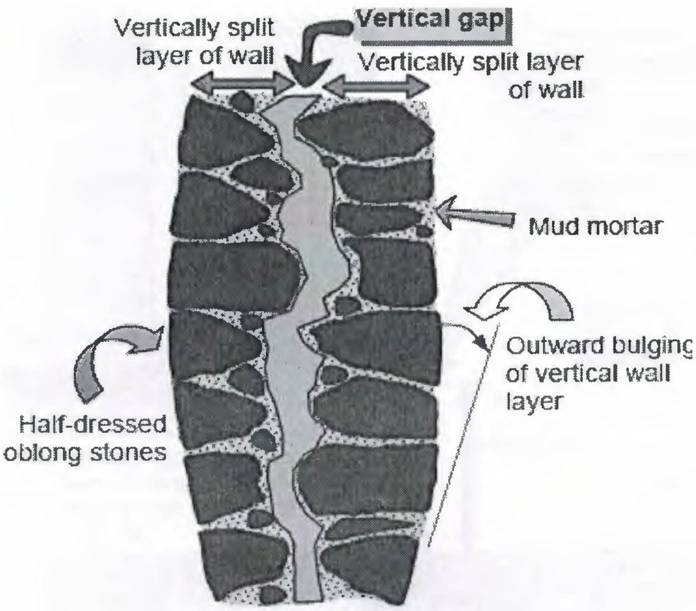

Figure 2.2 The Schematic of the Stone Wall [20].

These buildings are one of the most deficient building systems from earthquake-resistance point of view. The main deficiencies include excessive wall thickness, absence of any connection between the two wythes of the wall, and use of round stones (instead of shaped ones), so it is considered the method of the link between the two wythes with crushed stone and plaster by the Greek is very important in increasing the strength of the walls to resist earthquakes. To avoid the collapse of the stone buildings, under the influence of earthquakes adopted Indians several methods are:

- The wall thickness should not exceed 450mm, used regular stones with avoiding the use of mud mortar in the high seismic zones and replace it with cement-sand mortar should be 1:6 (or richer) and lime-sand mortar 1:3 (or richer).
- Ensure proper bond in masonry to be equal distances which do not exceed 600mm. Through-stones (each extending over full thickness of wall) or a pair of overlapping bond-stones (each extending over at least ¾ths thickness of wall) must be used at every 600mm along the height and at a maximum spacing of 1.2m along the length as shown in the figure 2.3, this technique Been adopted also in the Church of St. George with a little difference where has been using a chock columns to the walls rather than bond-stone.

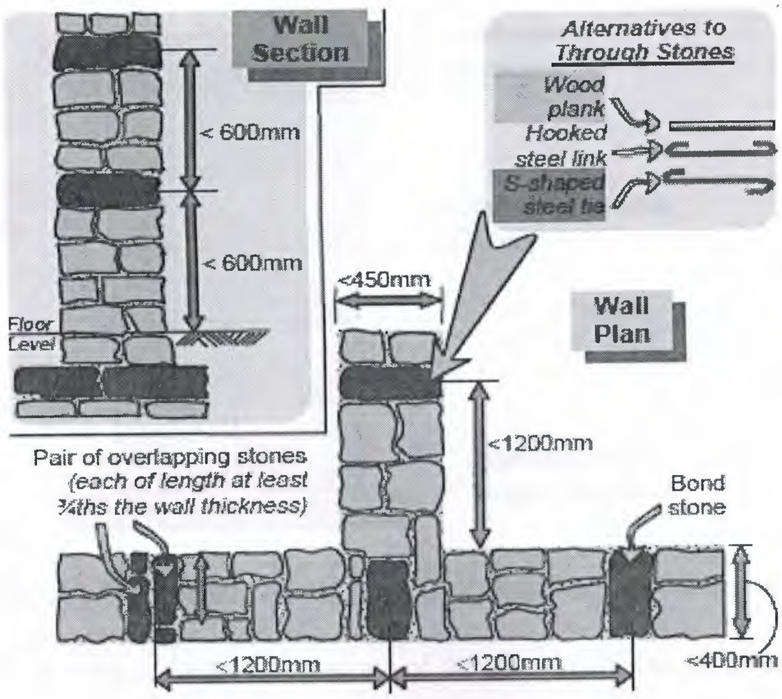

Figure 2.3 The Bond Stone in the Stone Masonry Wall [20]

- Control on overall dimensions and heights: The unsupported length of walls between cross-walls should be limited to 5m; for longer walls, cross supports raised from the ground level called buttresses should be provided at spacing not more than 4m. The height of each store should not exceed 3.0 m. In general, stone masonry buildings should not be taller than two stories when built in cement mortar, and one floor when built in lime or mud mortar. The wall should have a thickness of at least one-sixth its height [20].

Not the walls of the church alone constructed of yellow sandstone as well as the eight main columns of Interior which consider one of the three types of the columns invented by the Greeks which are: Doric style, Ionic style and Corinthian order (The type used in the Church). The columns of church was consists of a huge internal cylindrical shape has diameter 220 cm and height 540 cm and it has pedestal with diameter 240 and height 60 cm its function as joint, building blocks of yellow sand stone also has a circular shape with unequal dimensions (average thickness of one unit is 30 cm) placed in a systematic manner connected with each by a mortar with a thickness 2 cm as shown in the fig. 2.4.

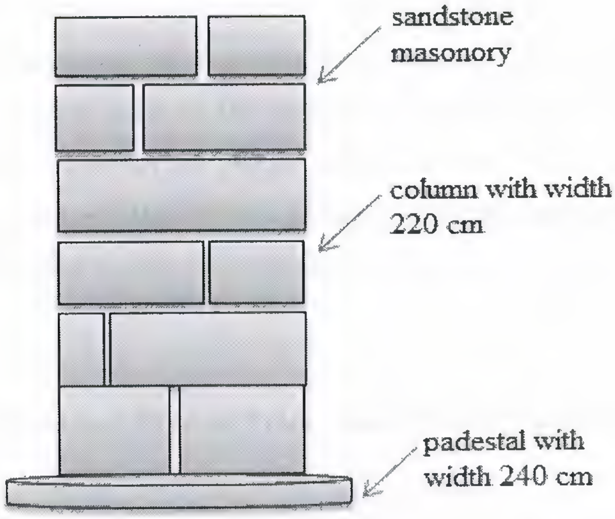

Figure 2.4 The Building Blocks of Yellow Sand Stone of Column

The Greeks used stone material in the construction of the three kinds that have been mentioned of columns, one piece of stone is utilized in the construction. From the architectural side, the type of columns that are used in the construction calling monolithic and this type is consider one of the heavy stones that utilized in constructing the buildings. The other columns that created from stones, they consisted of several portions of stone such as mortared. The utilize of metal pins or stones helps the sectioned columns to link together by carving them with depression or a center hole and that can be seen in several classical locations. It has been observed that, the columns of the Church constructed entirely of sandstone, but the stone interior units were big and take the form quarters or half-circle [21]. As shown in the figure 2.5.

Figure 2.5 Arrangement Units Stone Columns of the Church

The Greeks adopted the architecture precision in the establishment of this church, where they made them a mix of architectural style novelty at the time and high technical engineering in choosing the type of material used in the formation of the Church. The materials used in connecting stone building blocks of the church with each were; cactus extract, lime, egg yolk and H_2O. Benders becomes hard when it sets, resulting in a rigid aggregate structure as well as because it was denser, it better resisted penetration by water [12].

2.3 Chemical Compositions and Physical Properties of Yellow Sandstone and Benders

2.3.1 Yellow Sandstone

Sand-sized minerals or rock grains accumulate together to be a clastic sedimentary rock which called Sandstone, clastic sedimentary rocks are composed of silicate minerals and rock fragments that were transported by moving fluids (as bed load, suspended load, or by sediment gravity flows) which accumulate when slowing down the movement of fluids to rest [22].

The composition of sandstone is quite similar to that of sand, which essentially consists of quartz, with existence a natural cementing material these particles stick together to form sandstone which usually consists of silica, calcium carbonate, or iron oxide. The percentage constitution of each constituent varies between certain limit as shown in the table 2.2

Table 2.2 Percentages of Cementing Materials [23].

Sio_2	93%-94%
Iron(Fe_2 0_3)	1.4%-1.5%
Lime (CaO)	08%-0.9%
Soda (Na_2O) & potash (kro)	1.0%-1.2%
Loss in Ignition (LIO)	1.0%- 1.2%
Magnesia (MgO)	0.2%- 0.25%
Alumina (Al_2O_3)	1.4%- 1.5%

They are highly resistant to acids, alkalis and thermal impact and their insolubility in acids and alkalis is about 97%. Yellow sandstone is Arkosic sandstone. It contains high amount of feldspar, usually dominate by potassium feldspar $KAlSi_3O_8$ or (Potassium Aluminum Silicate) [23].

Feldspars are an important component of many building stones. Potassium feldspars are a group of polymorphs, polymorphs being minerals that have the same chemical composition but slightly different crystal structures. Potassium feldspars are the feldspar minerals in which the silicate tetrahedral and aluminum tetrahedra are bound with potassium ions, rather than sodium or calcium ions as in the plagioclase feldspar subgroup. Using other minerals in the rock to determine the host rock's identity is often the most useful guide to their probable identity [24].

The physical properties of yellow sandstone are:

Associated with most other sedimentary rock types, the capacity of water absorption is 1.67%, medium grained may range widely in degrees of grain sorting and shape structure, bedding is often apparent along with sedimentary structures and fossils, it hardness between 6-7 according to Moh's Scale Density 1.86 kg/m^3, very low porosity can almost neglected, its compressive strength 62.50 kg/cm^2 and Modulus of rupture is14 kg/cm2 [13, 23].

In addition to properties that have been mentioned, the yellow sandstone has the other features such as smooth finishing, perfect texture, very Long life, weather resistance, acid resistance, highly lustrous, high tensile strength and requires no maintenance [23].

2.3.2 Bonding Materials

From ancient times, materials have been modified with all kinds of admixture, aiming to improve their chemical composition, mechanical and physical properties. Binders or other mixtures meant for building purposes have been particularly attractive for testing experimentally a number of natural and artificial additives. Ancient engineers were dependent on natural materials as additives to improve properties of the materials used [25]. The mortar used in cathedral church of St. Georg of Greek is mixtures of three substances are;

Cactus: This material is a plant extract of cactus herbs and roots, its Latin name "opuntia stricta" light yellow in color, its active ingredients is total flavonoids; molecular formula is C19H28O2 and molecular structure as shown in the figure 2.6 [26].

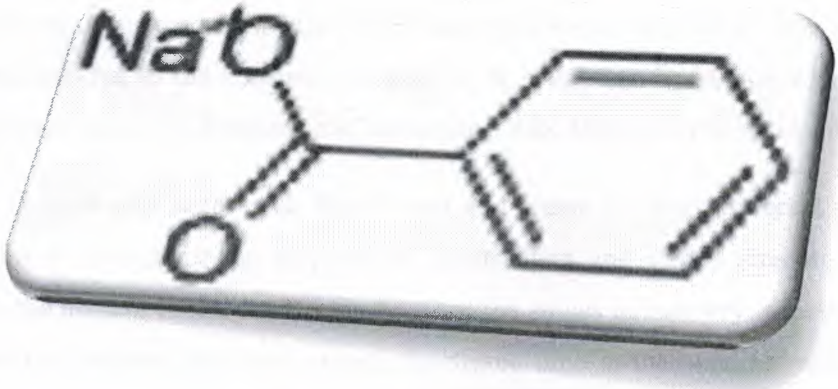

Figure 2.6 The Molecular Structure of Cactus Extract [26].

Still the available literature of ancient materials technologies or the consequences of their modern application in the construction field are scarce, but with recent experiments on the properties of green technology in extracting cactus gum found that its improves durability, strength and plasticity of mortar, where it was found recently that when adding cactus extract to mortars of the standard type used for modern constructions an increase in compressive strength as high as 65 % with respect to standard mortars [25].

Egg Yolk: Use egg yolk in the past as a kind of additives to improve the physical and chemical properties of the binder. The purpose of adding egg yolk had a good performance to strength as a foam material rich in protein can increase strengthen the binder to resist weathering and ensure long-term durability. Recent tests have shown that the strength of mortar added with additive shows higher strength in water curing conditions compared to the air curing conditions where this technology not available in the 14th century [27]. In addition to what has been mentioned, the viscosity of egg yolk is very important to the process of water Retention Refer, the water retention in a mortar was to prevent rapid loss of the mixing water to the air when the mortar contacts a masonry unit with a high absorption rate. Water retention was the mortar's ability to retain its plasticity so that the mason can carefully align and level the units without affect the bond between mortar and unit. Binder must have a good or high degree. Water retention in order to resists a mortar from bleeding when it contact with a masonry unit that has a low absorption rate (as the case with yellow sandstone). If low-absorption masonry units were used with a highly retentive mortar, they may "float" and less retentive mortar may "bleed" moisture [26].

Lime: is the name of the natural mineral which takes place as a result of the fires of coal and the changed limestone due to the volcanic. As well as. It is calcium hydroxide which has organic materials like hydroxides predominate and carbonates. Also lime material is calcium oxide [28].

Slaked lime is combined with sand, liquid mud and water to create different types bonding material which it utilized for the purposes of construction and slaked lime is called calcium hydroxide. In the ancient times, the linking between the stones in masonry is carried by the lime mortar. When the masonry has been placed, the slaked lime in the bonding material bit by bit starts to interact with carbon dioxide to create limestone and it is called the calcium carbonate. In this reaction, the carbon dioxide has ability to soluble in the rainwater. By heating limestone is transformed into quicklime and by hydration, quicklime is converted to slaked lime. Then by carbonation, slaked lime is converted again to limestone. The process of all these transformations is called the Lime Cycle [29]. As shown below in figure 2.7.

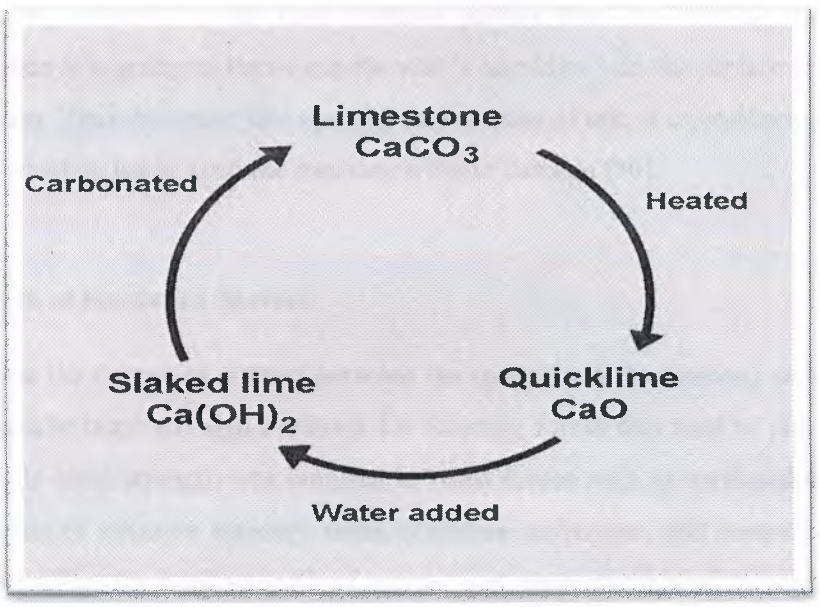

Figure 2.7 The Lime Cycle [29].

There are two main kinds of lime mortar where these types are hydraulic and non-hydraulic. By utilized the water, hydraulic lime is regulated and acquired from lime stone. Non-hydraulic lime requires the air to carbonate and set. It is resulted from high purity of calcium lime stones. Properties of lime mortar are:

- Under cracking conditions, if the quantity of the motion is small then the lime predominantly results abundant micro cracks.
- The soft masonry (such as brick) unit is repeatedly utilized in constructing the historical buildings, and a little movement in the constructions is because of the nature of the foundations.

  This motion smashes the fragile section of the wall. When lime in the bonding material is utilized, the lime is the fragile section in walls, and the cracks in mortar are preferred on the masonry. This helps to reduce the damage and easily reformation. In modern constructing, this movement makes smashes in the fragile section of the wall, and with ordinary Portland cement mortar the bulk exhibition to break is masonry.
- Remains bonding material of lime involve of sand and chalk and these remains can be backed as in the shape of soil's components or in more precise meaning, it didn't contain a disposal issue such as the modern material of mortar.
- The bonding material in the lime contains porous than the bonding material in the cement, then it is going to throw out the wall's humidity into the surface and it will turn into a steam. Thus the water that contains any content of salt, it crystallizes and placed on the lime which is led to keep the masonry without damage [30].

2.4 Bond Strength of Hardened Mortar

Bond strength was the degree of contact between the mortar and the masonry units or in other words was the tensile bond strength available for resisting forces that tend to pull the masonry units apart. Tensile bond strength was required to resist forces such as earthquakes, wind load, shrinkage of mortar or concrete masonry units, Structure movement, and temperature changes. The major factors affect the bond strength of mortar were workmanship of the masonry, quality of the mortar, the characteristic (strength) of the masonry Units, and curing conditions. Bond was high on textured surfaces and low on smooth surfaces. Bond of masonry units was impact by the absorption rates and it tend to retain moisture after they were cured and have relatively low absorption rates, due to hardened and non-porous of sandstone masonry the mortar would reserves water to complete the interactive operations and establish a sufficient bonding strength between them. Furthermore, the tensile bond strength also influence by mortar flow. The proportional relationship between the water content inside the mortar and binding force where an increase of the water content the bond strength also Increases. Relatively, relationship between the water content and the compressive strength of mortar is inverse, where an increase of the water content decreases the compression strength. This can be conclude that using higher water content of mortar was better (with certain limit) and make it is able to retain a workability. In ancient times there was a distinction in good workmanship where can spread the mortar and placing the masonry units in a minimum time move. When the mortar was placed, some of its water will evaporate and some other will absorbed by the masonry units, leaving insufficient water to form a good bond on the next masonry units. The masonry units should not be moved or slid after placed on a bricks and getting its initial assortment to prevent breaking the initial bond. Finally, increasing the proportion of water in the mortar are necessary to improve the conditions of curing and continuation of the hydration for completeness of the chemical reactions of the mixture to reach the sclerosis strength and cohesion required [27].

According to the requirements of the EuroCode8 a minimum strength is required for mortar $f_{m,min}$ = 5 N/mm2 for unreinforced or confined masonry.

2.5 Types of Sandstone Decay

In sandstone elements of the ancient buildings, deep destruction was established. Cases of deterioration of sandstone many depend on the type of stone itself (its physical and chemical properties), kind of superficial working. The various type of degradation: hardening case, exfoliation, contour scaling, granular disintegration, palling and peeling, in addition to efflorescence and black crust occur [31].

Occupies granular disintegration and deep erosion always all the blocks of sandstone in the lower part of the interfaces. Physical and chemical decomposition of sandstone occurs under the influence of many factors, such as groundwater, wind, and the rain, whereas several elements wasted their surface forms wih maintaining the essential parts rarely as shown in the figure 2.8.

Figure 2.8 The Granular Disintegration and Deep Erosion

Peeling is heading to blister and fall off. New opened surface underwent shredder and granular disintegration. The decay of stones that dominate mainly on the facades is exfoliation (as shown below in the figure 2.9). The elementary surface for majority of items was wholly damaged and sheets are separated from the stone element perpendicular to layering.

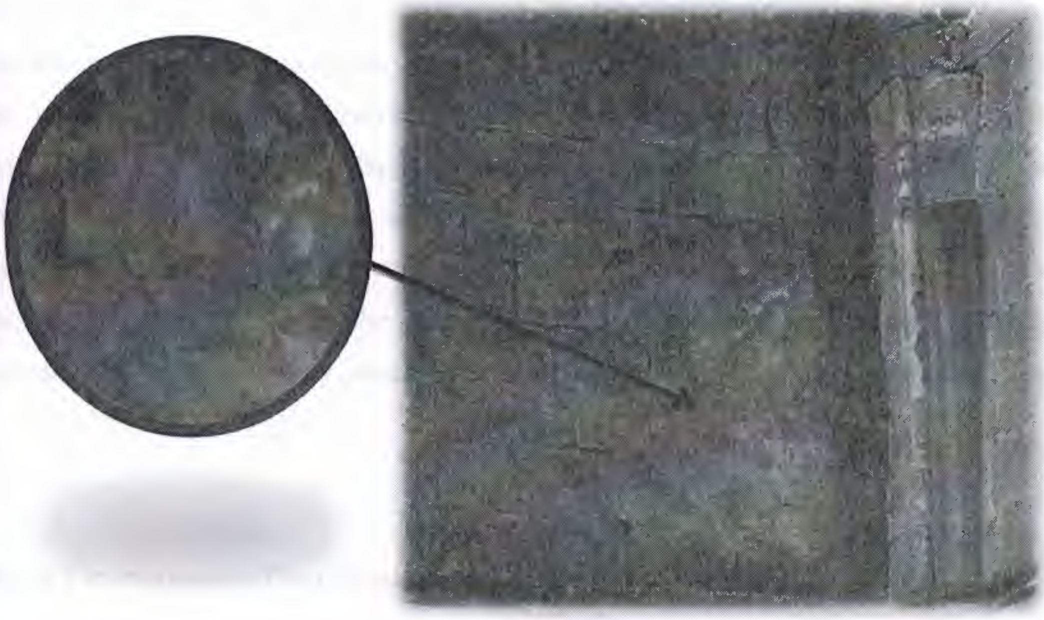

Figure 2.9 The Peeling in the Facades of Sandstone

During dry months, overflow of halite, thenardite, and gypsum locate in the top par of the ground humidity rising to generate black crust which occurs on sheltered sandstone blocks as shown below in the figure 2.10, unattainable for rain. Smoke, the molecules dust or other materials that contaminated the atmosphere and these materials are easy penetrated on blocks with rock faced quoin surface. These crust accelerated to peeling, chipping and exfoliation of blocks of sandstone later [32].

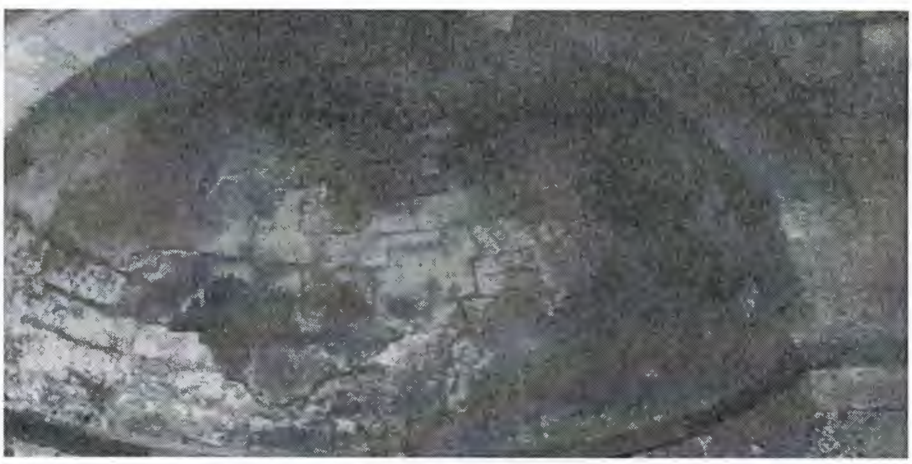

Figure 2.10 The Black Crust of Sandstone

The basic issue of rock's decadence, in the building locations is considered to be the salt crystallization and the water absorption close or below the surface of rock. This is caused by high clay content and the weak matrix material. Then, when the rock is away from the foundation of the structure or it is far from the sea. As well as, the rock is placed in dry environments. It is completely robust without decadence's problem. Problems are generated when the rock has been utilized in structures near the sea. The possible remedial measures to be taken, in the ancient locations, are the protection of the rock from ground and/or sea water absorption and the related salts, by sheltering, water replant coatings, and/or stabilizing agents [33].

2.6 Effect of Environmental Conditions on Sandstone Decay

The velocity of sandstone decay is influenced by climate and atmospheric pollution: composition of the atmosphere and rainwater, direction and velocity of wind, pollutant concentrations of air etc. Generally, all buildings Cyprus are exposed to the medium continental climate with wet and hot summers and a long cold winter, often with fogs and bit of snow. Average yearly precipitation, number of the frost days and the value of high relative humidity winter, accelerate the degradation of sandstones [31, 32].

2.7 Summary

This chapter presented the utilized materials in the Church of St. George and technology promotion. Chemical compositions and physical properties of yellow sandstone and benders are submitted in details form. As well as, types of the sandstone decay and the effect of the environmental conditions on sandstone decay are shown in this chapter.

CHAPTER THREE

STATE OF SOIL AND EARTHQUICKS IN CYPRUS

3.1 Overview

The constructive study for the soil started since the ancient times, where over ten thousand years ago and long before from the invention of writing or usage the metal tools. The urgent need for constructing the buildings, construction of vast irrigation systems and the invention of agriculture brought the need to know the mechanical behavior of the soil which interferes in their behavior with those facilities for the first time. Study the earth and its properties became and still is an important issue of practical necessity [34].

Mechanics of soil is defined as a part of the mechanics since that handle with influence of forces on the soil, where the term of the mechanics can be defined as a physical science branch that handles with the forces as well as the energy and their impact on the structure of buildings. The soil is considered as one of the most widely substances that faced the structural, architectural and civil engineering especially which is placed at or near the ground surface. There are structural parts in civil engineering to be in direct contact with the soil such as the foundations, eventually rest upon rock or soil. Hence, settlement behavior and the load capacity of foundations essentially relies on the underlying soils properties, their behavior and reactions due to the stress imposed by the foundation, and this in turn may create the effects of external forces such as earthquakes, act on these systems itself, neither the structural displacements nor the ground displacements, are independent of each other , the process of the soil response to the influences the motion of the structure and the motion of the structure influences by the response of the soil is called soil-structure interaction (SSI) which considers a special field of earthquake engineering since all seismic structural response is affected by forces of soil structure interaction that effect on structure according to the definition of seismic excitation, so in high degree of material importance from viewpoint of civil engineering is soil ranks if compared with the various materials such as (i.e. brick, concrete, mortar, steel, etc.) which are used in construct all constructions [12, 35].

3.2 State of Soil in Cyprus Island

3.2.1 The General Definition of Soil's Mechanisms

Soil is the basic material that used in construction all types of buildings (huge and normal) such as: the retaining walls and the dams. As well as, structures of buildings whatever the material that from them, eventually they are rest upon soil or rock. It is appropriate from the viewpoint of civil engineering to regard the soil as a structural material where according to its properties of the underlying has been identify the load capacity and settlement behavior under the stress imposed by the foundation [35].

There are structural parts in civil engineering to be in direct contact with the soil such as the foundations. There is a special branch to study the behavior of the soil and buildings combined together that it is so- called soil structure interaction (SSI). Analysis of soil-structure interaction (SSI) consider as a stand-alone field from earthquake engineering. It should be useful to starting with the definition. Common sense refers to that all seismic structural response is a result to the effect of soil structure interaction forces due to affected of structure according to the definition of seismic instigating. the community of engineering identified that the soil-structure interaction taken into consideration only when these forces of interaction are able to alteration the motion of basement in comparison with to the free-field traumatic movements where this land movement recorded on the free soil surface when no structure. The traditional definition of SSI is quite various from the forces of interaction occurrence. SSI occur for all buildings, and always it doesn't able to change the movement of soil. This simple scientific fact that important lead to the important result which is no SSI effects if a structure was based on rigid foundation and it can be analyzed as free-field motion at it. There are two main factors has the ability to change the soil motion by the interaction forces which are: flexibility of the soil foundation and value of the interaction forces. The value of the interaction force can be calculated through the inertia of the structure and base mat acceleration. Consider the heavier part in the given soil site and given free-field seismic excitation is the structure, the soil structure interaction effects incidence the more likely.

Usually the SSI affects hardly be neglected for the civil structures that resting on hard or medium soils where it does not show the considerable signs [12].

In 1943, the book of "Theoretical of Soil Mechanics" for Dr. Karl Terzaghi. Where the author in this book mentioned that the mechanics of soil supply with the job of hypothesis. Since our understanding for the physical characteristics of the subsoil is constantly insufficient or patchy frequently. However, from the view point of the practical side, the working hypothesis that submitted by the mechanics of soil is considered as an important theory of installations for the rest sections of the civil engineering [36].

Soil or rocks are subject to change on an ongoing basis physically and chemically under geologic processes caused by the climate and other prevailing factors such as, leaching, drought, freeze/thaw, vegetation, erosion, rainfall, and other natural processes that cause the profound changes gradually taking place in the soil recipe with over time. Soil profile is considered a consecutive series of nature-related changes from the surface to the layers below the ground surface differ in composition, thickness and the physical characteristic for each layer which it's mainly vary from each other and can be distinguished by differences in the degree of weathering and color. Typically the upper layer of the profile is rich in animal residues and organic plant mixed with particular mineral-based soil. The soil nature depends mainly on sediment accumulation of other mineral particles produced by the physical and chemical disintegration of rocks in addition to water, air and organic material that can be included and which play an essential role in the intensity of the engineering behavior. The origin of soil can be divided to two basic types are; residual, and transported. It advantages are properties depend on the climate and other factors prevailing in the geological site soil as well as this type favorite from the construction to its ability to support foundations and engineering properties predictable. Transported and deposited soils are derived by the movement of soil from one location to the other by natural means such as wind, water, ice, and gravity.

The character of the resulting deposit often expresses the modes of transportation and deposition and the source material that's where deposits by water include alluvial flood plains, coastal plains, and beaches, deposits by wind include sand dunes and loess and deposits by melting ice include glacial till and outwash. Each substance of soil behavioral properties that depend on the geological origin, and are usually the poorest soils in terms of engineering properties are transported by wind [35].

3.2.2 Soil Classification in Cyprus

For the great importance of understanding the behavior of mechanical soil and its impact on the construction of buildings was adopted soil classification system on the island of Cyprus in accordance with the methodology of studies aiming to collect physical and chemical properties of the soil where this system has been adopted since the beginning of 1957. Soil classification system adopted mainly on the formation of composition, origin and parent of the materials in the soil [10].

The first soil classification system used was based mainly upon the formation, the origin and the parent materials of soils. Accordingly, soils were classified as Red soils, sedentary soils, and alluvial or colluvial soils. Usually, an examination of the master horizons (A, B, C, D) including soil physical and chemical analyses were carried out in order to classify the soils of these groups into soil series and types. Major soil constrains in Cyprus can be divided into two major categories; The first category includes deep soils located mainly in the valley areas, the second one includes shallow soils lying on geological formations of the mountain and semi mountain areas [37].

Generally that type mostly on the island of Cyprus is red soil which has a reddish tinge as a result of the presence of iron compounds in the soil composition. Some types of red soil are clays, Clay soil which has a heavy concentration of clay particles and this means the soil stiffness [10].

Located Famagusta over Terrace deposits which are mainly formed by Calcarenites, sands and gravels, precisely and according to the information that has been obtained from the Geological Survey in Cyprus the depth or thickness of each layer and type of material composed, as shown in the table 3.1:

Table 3.1: The Soil Layers in Famagusta

Depth/thickness (m)	Type of layer
0,00- 0.50	Terra- roosa
1.00	
0.50- 3.00	Calcarenite
1.00- 5.00	
3.00- 20.00	sandstone
5.00- 25.00	
20.00- …….	Marl- clay stone
25.00- …….	

Geological map of the Cyprus island as shown below in the figure 3.1, describes the soil layers for each region, where it was found that the site of the church inside the fort of city Famagusta the cursor with Wight color consisting mainly of sandstone, silts, clays, calcarenite and gravels [38].

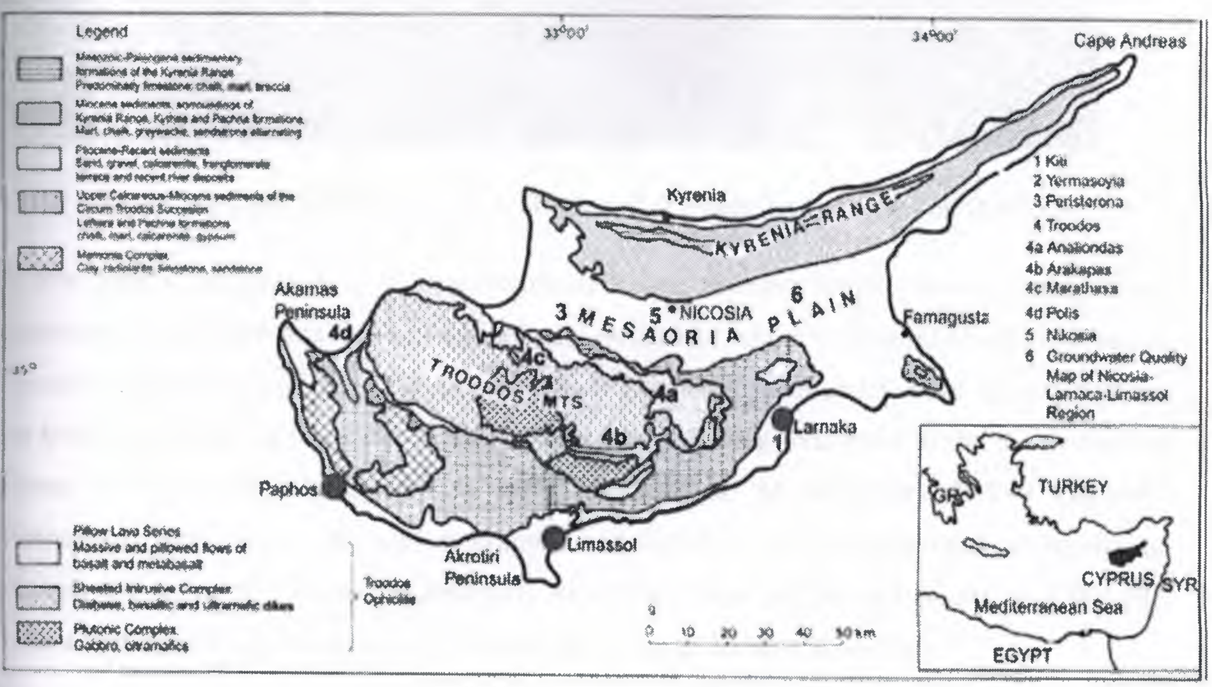

Figure 3.1 Geological Map of the Cyprus Island [38].

Presence of organic matter results in an inhomogeneous and anisotropic fabric, which further complicating the engineering behavior of these soils.

3.2.3 Laboratory testing of soil Church

To simulate the soil conditions of the cathedral church of Greek of the real problem as close as possible. This research depended on the report prepared for the soil conditions of the St. Nicholas cathedral church, where this church located 100 m far from the other church (as shown in the figure 3.1 captured by Google earth).

Figure 3.2 Church of St. George of Greek and St. Nicholas Cathedral on One Font

Where shallow seismic survey sand geotechnical drilling were performed. Seismic surveys were conducted by a receiver cable and 48 geophones positioned with 1 m interval along the Western facade of the structure (Fig. 3.2) in order to obtain 2 dimensional P-and S-wave velocity profiles up to30 m depth along this cross section. Geotechnical drilling took place at the South western corner of the structure until 30.2 m depth was reached. At every1.5m, SPT-N (Standard Penetration Test) values were also determined and disturbed samples were taken to be able to classify the formations below the structure. Results indicate that the soil condition at this site with a specific $Vs_{,30}$ (the rate velocity of shear wave up to 30 m) was 560 m/s.

It was calculated from the following expression:

$$v_{s,30} = \frac{30}{\sum \frac{h_i}{v_i}} \tag{2.1}$$

This value corresponds to the B Ground type, described by the stratigraphic profiles and parameters given in Table 3.2 according to E.C8.

Table 3.2: Ground Type According to Eurocode8

Ground Type	Description of stratigraphic profile	Parameters		
		vs,30 (m/s)	**NSPT (blows/30cm)**	**cu (kPa)**
A	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.	> 800	-	-
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of metres in thickness, characterised by a gradual increase of mechanical properties with depth.	360 – 800	> 50	> 250
C	Deep deposits of dense or mediumdense sand, gravel or stiff clay with thickness from several tens to many hundreds of metres.	180 – 360	15-50	70-250
D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.	< 180	< 15	< 70
E	A soil profile consisting of a surface alluvium layer with vs values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with vs > 800 m/s.			
S1	< 100 (indicative)		-	10-20
S2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A – E or S1			

Regarding for motions up to a depth of 4 m artificial fill of clay, sand and gravel mix exists. Between 4 and 20 m, calcareous sandstone and below 20m up to the end of the borehole, hard salty clay was encountered. Results indicate up to 15%lower velocity values at the Southern end of the cross section analyzed than the Northern end between the depth values of 10 - 30m [39].

Fig. 3.3 Church of St. Nicholas Cathedral [39].

Seismic waves move faster through hard rock than through soft rock and sediments. As the waves pass from harder to softer rocks, the waves slow down and their amplitude increases. Thus shaking tends to be stronger at sites with softer surface layers, where seismic waves move more slowly. This leads to the fact that the increased capacity of amplitude seismic due to slowdown waves at the upper layers consisting mainly of clay, sand, and a little gravel thing that leads to an increased risk of earthquakes on the structure of the Church where found that the ground motion above soft soils can be more than 10 times stronger than at neighboring sites on rock for small ground motions [40].

3.2 Earthquakes in Cyprus Island

3.2.1 General concept of earthquakes

An earthquake is malfunction occurs due to sudden rupture of rocks ground by large internal stresses exceed resistant of rock's strength. The malfunction may be newly created by the earthquake rupture or may be present originally. Energy caused by malfunction is transmitted as seismic waves that cause nearly all damaging earthquake effects. When the break line (the fault) between two blocks of rock suddenly moves, the movement causes vibration (seismic waves) to race rapidly out ward in all directions from the focus the point at ground level directly above the facus is called epicenter as shown in the fig 3.4. The size of an earthquake is often expressed in terms of Richter (or local) magnitude, denoted by ML, and was developed by Charles Richter for California in 1935. Richter magnitude is determined by measuring the amount of seismic energy released by an earthquake (seismic wave amplitude) [11].

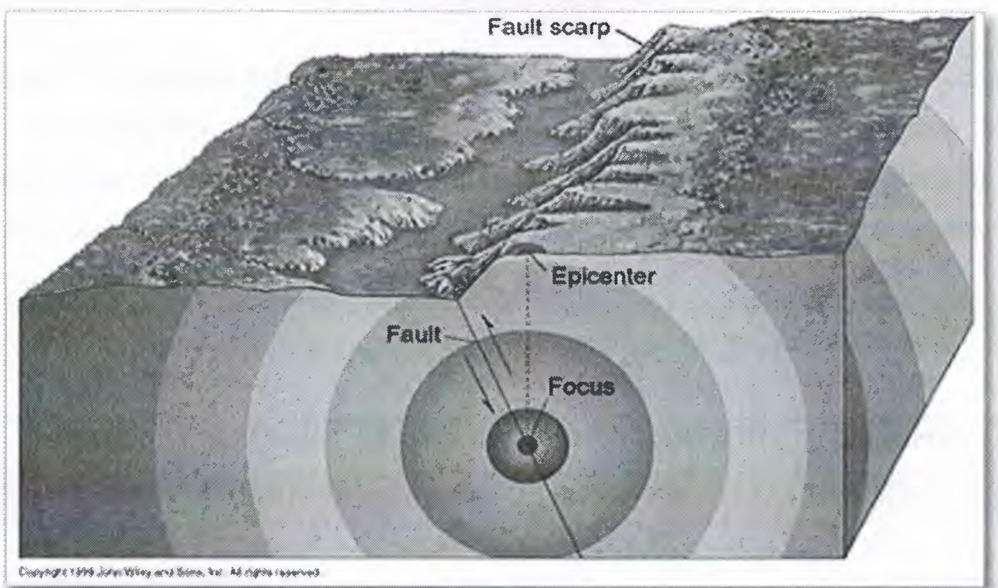

Figure 3.4 Earthquake's Mechanism [11].

3.2.2 History of Earthquakes in Cyprus

The last archaeological discoveries and the historical sources display that Cyprus was exposed to the successive earthquakes since many times ago. These successive earthquakes smashed Famagusta's city (Salamis) and it also destroyed the town of Nicosia. By using the modified Mercalli scale, Cyprus was exposed to sixteen of the earthquakes with intensities of VIII between 26 BC and 1900 (Anno Domini). In 76 A.D, Pafos was damaged along with Kition and Salamis, where this is the strongest earthquake that ever knock down Cyprus. Town of Salamis and Pafos's city were damaged once more between 332 A.D and 342 A.D [7, 41].

More accurate data have been collected, regarding the earthquakes occurring in Cyprus and the surrounding offshore area since 1896, when seismological stations started operating in neighboring countries. The situation regarding the accuracy and completeness of the earthquake recordings improved considerably after 1984, with the establishment of a seismological station in Cyprus and its continual expansion and upgrading. A better picture of the seismicity of the Cyprus region started developing and the areas with higher seismic activity were more clearly recognized. In the time period 1896-2004, more than 400 earthquakes with their epicenters on Cyprus and the surrounding region were felt in several areas of Cyprus. Of these the following 14 earthquakes caused damage and in some of them there were many victims [41].

The history of earthquakes suffered by Cyprus cities since 26 BC can be observed in the table 3.3 below which describes latitude and longitude values depending on the intensity scale of earthquake using descriptive scale – the Modified Mercalli Intensity Scale is given in Roman Numerals where values range from I to XII (Roman Numerals were converted to numbers in the digital database. Values range from 1 to 12.) [42, 43].

Table 3.3: History of Earthquakes in Cyprus [42].

Date	Latitude	Longitude	DESCRIBTION	Remarks
26 (B.C.)	-	-	VII	PA
15 (B.C.)	-	-	IX	PA
76	-	-	X, IX,X	SA,PA,LR
110	36.20	36.00	VIII	-

332	-	-	VIII	SA
342	-	-	X	PA
367	-	-	VIII	AK
394	-	-	VII	PA, SA
500	36.12	35.90	VI	-
526	36.12	35.90	VI	-
1183	-	-	VIII	PA
1222 May	-	-	IX,VIII,VII	PA,LI,NI
1268	-	-	V	CY
1491 Apr 25	-	-	VII,VI,V	NI,MG,PA
1546 Sep 29	-	-	VI	NI,MG
1567 Apr 25	-	-	VI	PA
1577 Oct 28	-	-	VI,V,V	LI,NI,SA
1718 Dec 19	-	-	VIII	NI
1735 Dec	-	-	VII	MG
1741	-	-	VI	MG
1822 Aug 13	-	-	VI	MG,LR
1822 Sep 5	36.00	36.00	VI	-
1854	36.12	35.90	VI	-
1873	36.12	35.90	VI	-

3.2.3 Seismic Classification of Cyprus Island

Cyprus placed between the belt of Alpine and Himalaya. This position is considered the second most area susceptible to the earthquakes on the earth. These earthquakes represent about 15% from the seismic activity in the world. The severity of seismic is attributed to the arc of Cyprus and it is represented the tectonic boundary between the Eurasian plate and African plate as shown below in figure 3.5. The diving of the African Plate under the Eurasian Plate generates numerous earthquakes along the arc of Cyprus and many active faults inside the island have seen that earthquakes likewise happen along them [7].

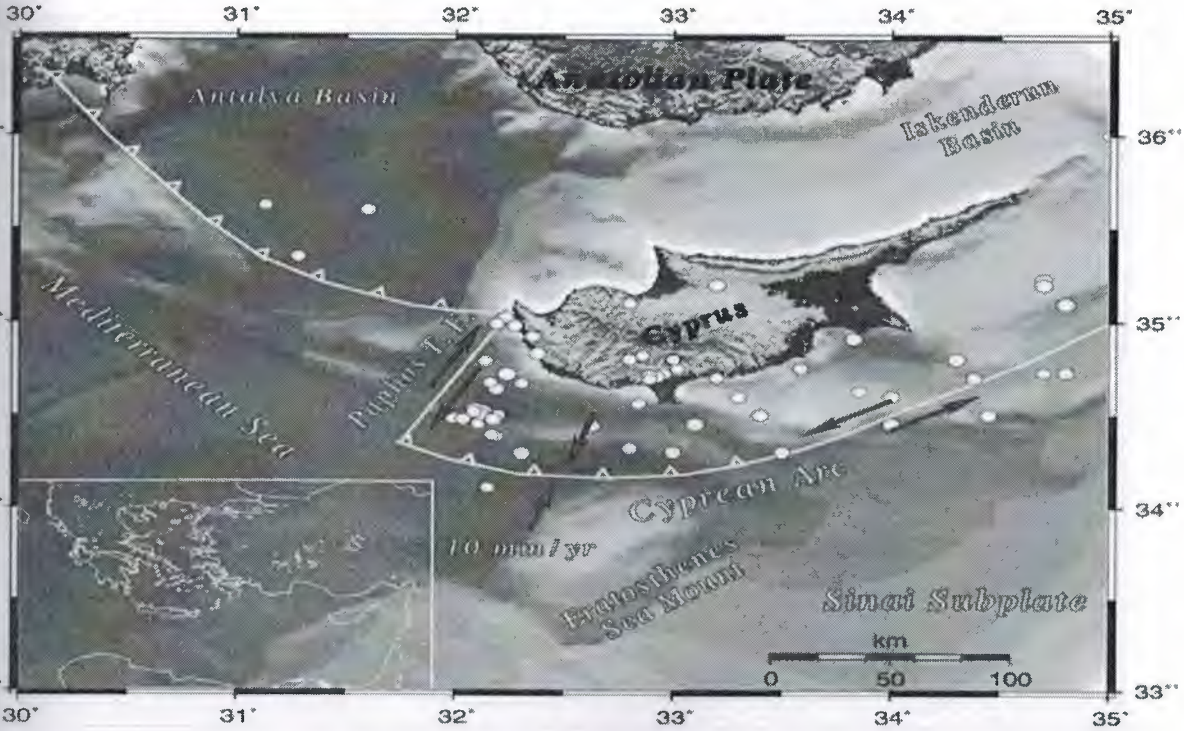

Figure 3.5 Geomorphologic Map of the Study Area with Plate Boundaries and Relative Motion. Epicentral Distribution of Shallow Earthquakes with M ≥5.0 [7]

The regional stress evolution is calculated in the area of the Cyprean Arc that constitutes a segment of the plate boundary between Eurasian and African lithospheric plates. The seismic activity onshore and offshore the southern coast of Cyprus Island is primarily caused by slip on faults arranged obliquely to the plate boundary. Earthquake interaction is a fundamental feature of seismicity, leading to earthquake sequences, clustering, or aftershocks. One interaction criterion that promises a deeper understanding of earthquake occurrence. A tectonic zone which starts at Castelorizo Island near turkey and continues south of cyprus to end up north at the area of the turkey-Syria border as shown in the figure 3.5 below. The structure of the Cyprian arc is complicated; there is not a clear view on whether it is a plate boundary [(McKenzie, 1972) in Ambraseys and Adams, 1992], or a broad zone of thrusting, [Rostein and Kafka, 1982) in Ambraseys and Adams, 1992] there is evidence (earthquakes at sub crustal depths) that sub duct ion is occurring in the Antalya basin, the north-west part of the arc, and there is an unproven theory that this sub duction zone extends towards Cyprus. It accommodates the convergence between the African plate to the south and the Anatolian Plate to the north in the eastern Mediterranean [44, 45].

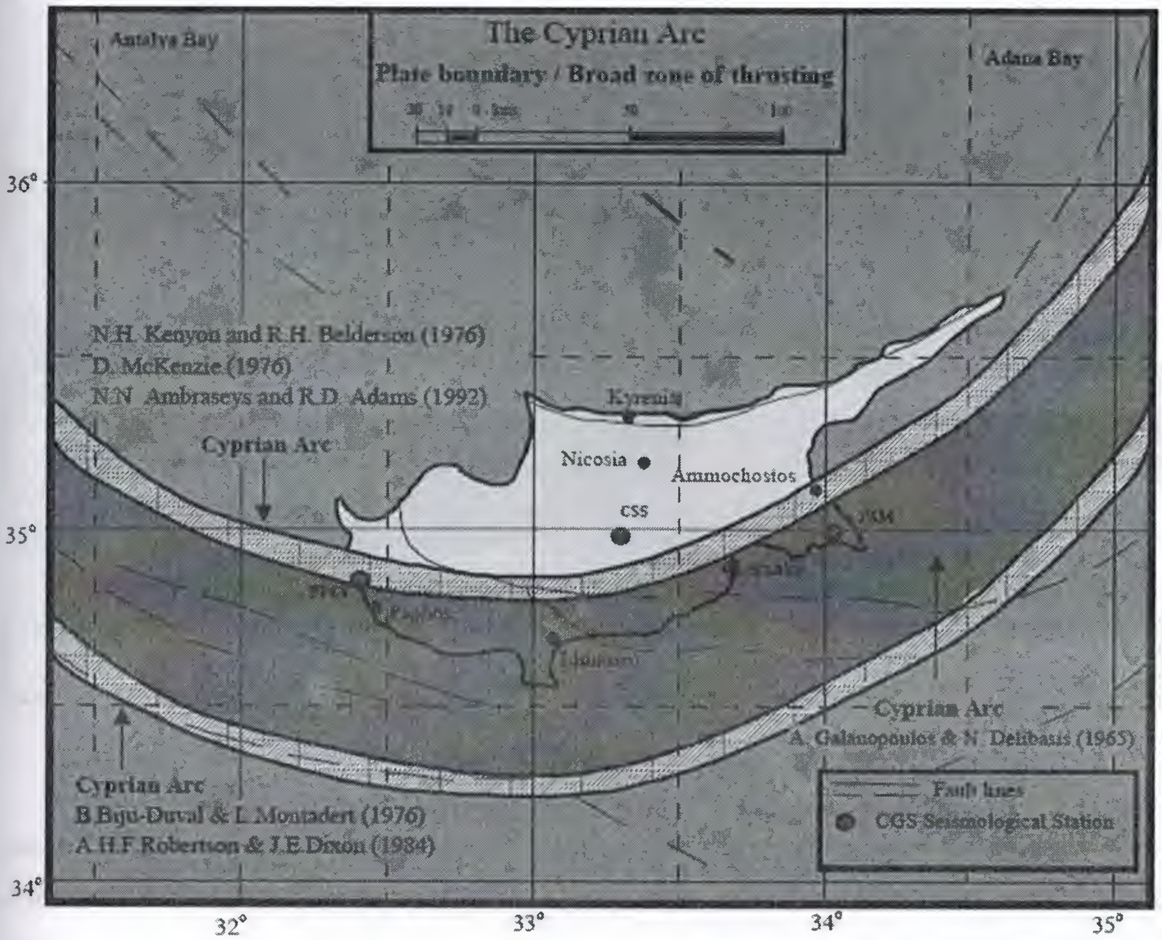

Figure 3.6 Cyprian Arc (after Kythreoti et al., 1998) [44]

Seismic zones of Cyprus Island were divided to three different regions as shown in the figure 3.6 that have been identified by the commission for the Revision of the zones of the Cyprus Ant seismic Code, this three different zones have three different values (0.15 g, 0.20 g and 0.25 g) of the maximum expected ground acceleration (PGA) with 10% probability to be exceeded in 50 years, where G=9.81m/s^2 [46].

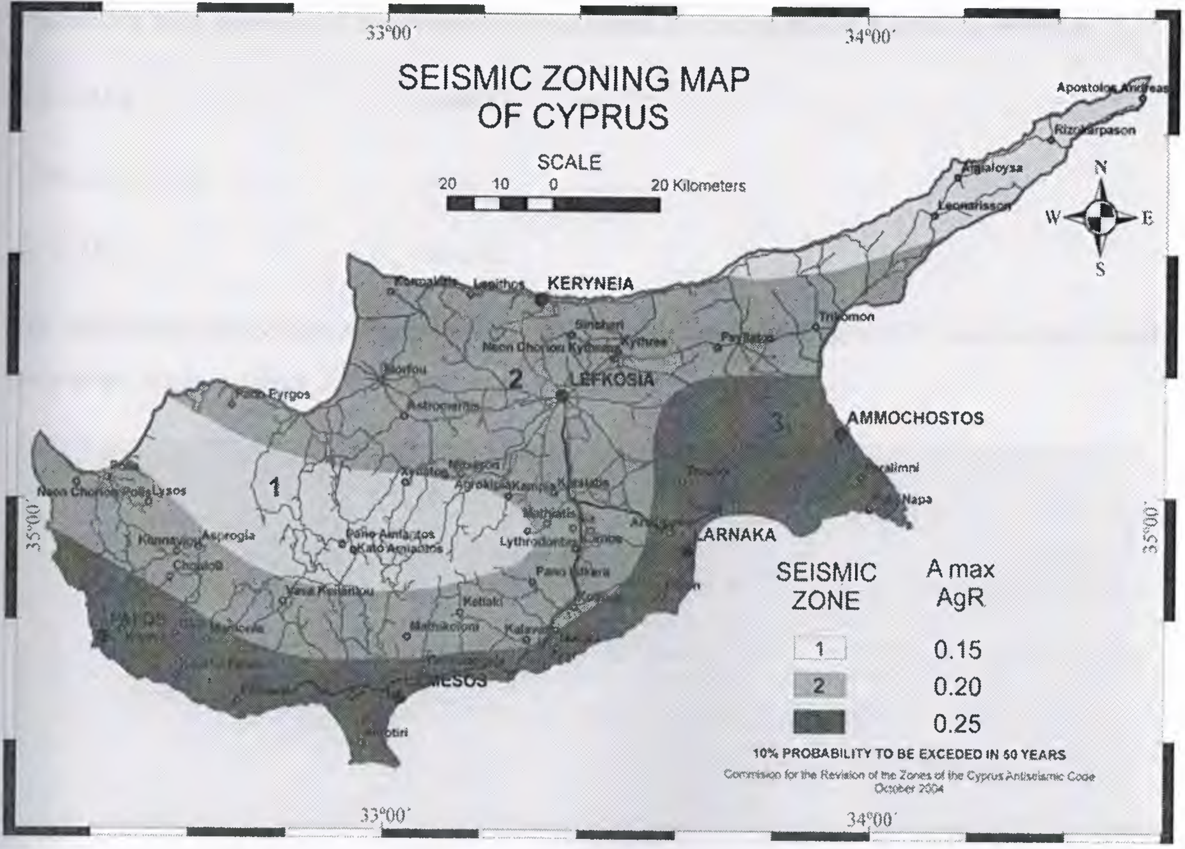

Figure 3.7 Map of the Seismic Zone of Cyprus [40]

According to the Seismic Hazard Map of Cyprus, the maximum peak ground acceleration (PGA) at the rocks for the south and the west region of the island, where Famagusta is included, is about 0.25g. This value is the highest within the whole territory compared with the minimum PGA of 0.15g, which occurs in the north and center regions. In addition, the map above is definition of reference peak ground acceleration on type a ground. It is to be emphasized zonation is done on a macro basis and should be modified considering local soil conditions and require further micro zonation studies. As shown in the figure 3.7, Famagusta (research site) is located over Terrace deposits which are mainly formed by Calcarenites, sands and gravels, increasing the seismic demand to about 0.35g, when compared to areas that are covered with rock, where it is represent the brown area that mean the upper limit pointer in Cyprus which comprises the upper layers of clay, sand and a little gravel. According to the fact that seismic waves move faster through hard rock than through softer rock and sediments .As the waves pass from harder (sandstone) to softer (clay and sand), the waves slow down and their amplitude increases [40, 42].

The zoning map is proposed to division Cyprus Island according to the following criterion:

$A \geq 0.24$ g zone I

$0.18g \leq A < 0.24g$ zone II

$A < 0.18g$ zone III

The Bayesian estimate hazard map in term of PGA and corresponding to 475 years is duplicated on a larger scale in figure 3.8 below.

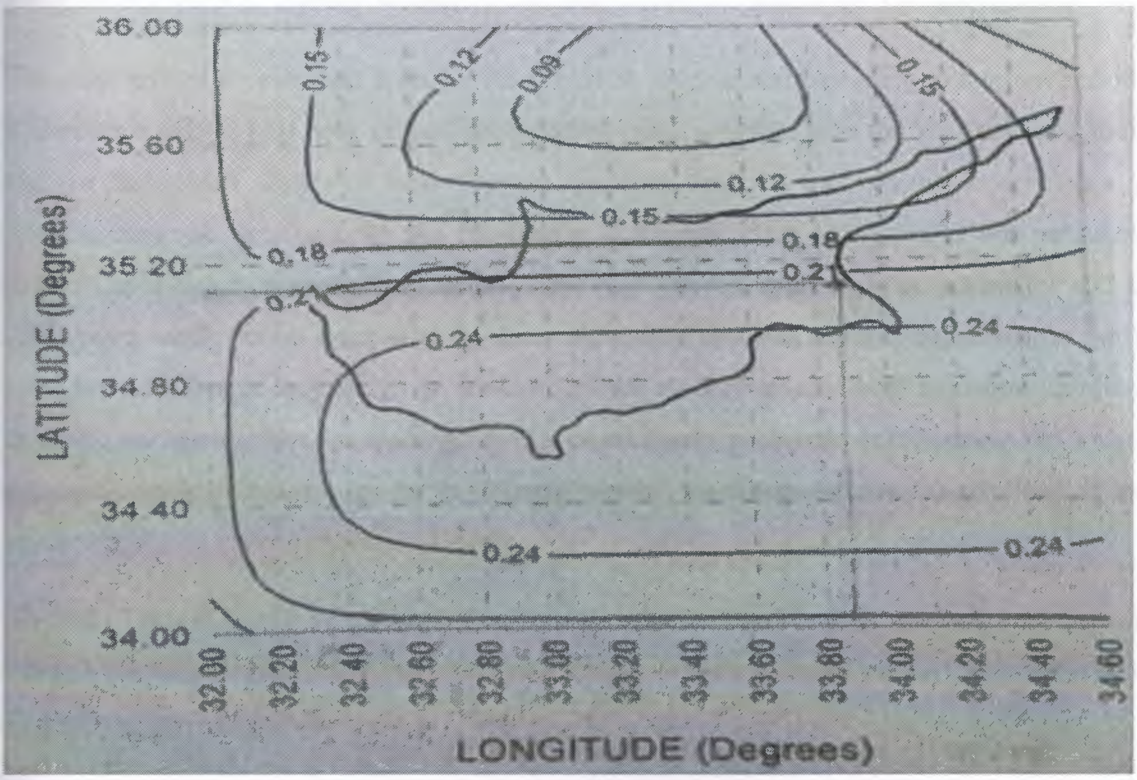

Figure 3.8 A proposed Macro Seismic Zonation Map [42]

The macro seismic zonation map above showing location of Famagusta from the seismic zone within II zone ($0.18g \leq A < 0.24g$) at the latitude and longitude (35.12, 33.88) respectively [42].

While a similar map of instrumental recordings of the Seismicity and Seismic Zones of Cyprus (as shown in the figure 3.7) gives the results presented in below.

Zone I	0.15
Zone II	0.2
Zone III	0.25

Map of the Seismicity Seismic Zones showing location of Famagusta at the latitude 35° 8' 0" and longitude 33° 77.5' 0" and the Seismicity available within the region are 3.0- 4.0, 4.0-5.0.

The peak ground acceleration level for the site of St. George corresponding to a return period of 475 years is 0.29g. This peak ground acceleration value, together with the $V_{s,30}$ value of 560m/s and the Eurocode8 suggested base response spectrum function was utilized to develop a site specific response spectrum for the St. George Cathedral. The 475 years return period was selected specifically because Euro code 8 base response spectrums can be scaled for 475 and 2475 years return period level sand the latter represents an unrealistically high seismic loading level for the focus of this study. In addition, all the modern structures of Famagusta are being designed for the earthquake loading of 475 years return period hence obtaining the level of damage and rehabilitation costs for St. Georg Cathedral for this specific earthquake loading level would allow making comparisons [47, 48].

Through Table 3.3 will be assigned the highest amount seismic was subjected by St. George Church through Structural age based on latitude and longitude that showing the location of the Famagusta from seismic intensity [42, 49].

Table 3.4: The Seismic Values were Suffered by Famagusta City Since 14 Th Century [42, 49].

Seq.	**Date**	**Latitude**	**Longitude**	**MAGNITUD**
1	1491 Apr.25	36.12	35.90	VI
2	1546 Sep.29	-	-	VI

3	1735 Dec.	-	-		VII
4	1741	-	-		VI
5	1822 Aug.13	36.12	35.40		VI
6	1822 Sep.53	36.00	36.00		VI
7	1854	36.12	35.90		VI
7	1873	-	-		VI
9	1900 Jun.5	34.00	34.5		5.7
10	1900	35.20	33.20		5.9
11	1900 Mar.3	-	-		-
12	1901 Feb.28	-	-		-
13	1902 Jan.17	-	-		-
14	1902 Mar.14	-	-		-
15	1903 Apr.23	-	-		-
16	1918 Sep.29	35.200	34.700	12:07:05	6.5
17	1919 Aug.19	-	-	20:17:02	5.4
18	1919 Aug.29	-	-	20:17:00	5.0
19	1924 Feb.18	34.500	34.000	17:03:56	5.8
20	1924 Jun.9	35.200	33.300	21:34:35	4.6
21	1940 Jul.24	34.500	34.500	22:15:01	5.7
22	1961 Oct.15	34.980	33.830	01:46:10	5.5
23	1941 Jan.20	35.200	34.600	03:36:05	6.5
24	1948 May.22	34.890	33.810	08:11:29	4.1
25	1994 Aug.11	35.270	34.740	06:56:02	4.1
26	2001 Oct.1	35.050	33.950	19:22:43	4.0

3.3 Behavior of Structure due to Earthquakes

3.3.1 Introduction

The nonlinearity is the most important and significant property of a structure which mainly comes from local failure or micro failure of its components in addition to the materials nonlinearity of their constituent. At small amplitudes, a structure may usually be considered linear [50]. The performance of buildings through the powerful earthquakes was utilized as ancient methods to train the workers on the appropriate build and incorrect build of seismic load resisting systems. In areas that were populated since a long period of time, and that are exposed to the different powerful earthquakes. The steps of design have developed and that produce a perfect performance in the structures. Due to the regional disparities in the styles of building, the procedures of design are not globally applicable. The destructive capacity of the powerful earthquakes is completely famous and is satisfied as an essential assumption by the several of design codes. During the infrequent earthquake, destruction in the structures is acceptable but the total damage in the structures is not acceptable in any case [51].

3.3.2 Structural Performance during Earthquakes

Harms caused by the earthquake relies on the several major elements like the build quality, the duration of the earthquake, status of the soil, frequency, seismic intensity and the content of earth movement. In order to make sure that the construction has enough strength must be designed with high ductility.

To study the performance of the earthquake for any structures during the intensity of shockwave, site condition effects on building damage, ground shaking effects on structures. The fundamental causes of the damage that is caused by the earthquake must be identified, where these causes are: tsunamis, shaking of ground, fire and ground failure.

- **Ground Shaking:** The essential reason of the earthquake that caused the damage on the buildings is ground shaking, where all constructors on the surface of land are going to respond to the vibration of the earth with different degrees. Earthquake can harm or smash any constructor unless these buildings were constructed and built or enhanced to resist the intensity of the earthquake. Earthquake motions have random nature so that the Seismic design loads are extremely difficult.

The ground shaking itself affected on the structure by several factors such as:

- **Inertia Forces:** Constructors are mechanically repaired to the earth as seen below in figure 3.7 (a). In the patchy mode and because of the inertia of the masses, the vibration and shaking in the position superstructure with its contents will occur. When the building's base is unexpectedly displaced to the right side, the reaction of the building is toward the left side. Where this movement toward the left side was due to the invisible force and this force is called inertia forces as shown below in figaure.3.9 (b). In fact, the mass of the building is caused this motion in opposite direction. this movement is considered as complicated process on account of the earth moves at the same time with each other in three orthogonal directions during the earthquake as shown below in Figure 3.9 (b), (c), and (d).

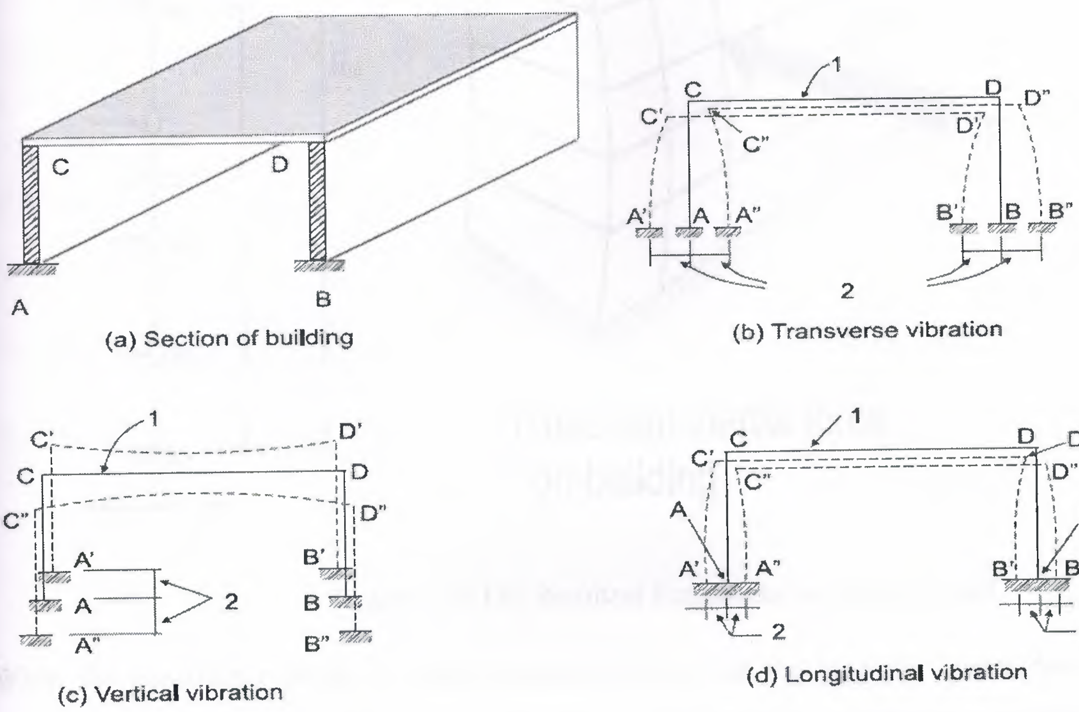

Figure 3.9 Seismic Vibrations of Any Building in General [50]

- **Seismic load:** The seismic load is denoted by the force "F" as seen below in figure 3.11. Also, the seismic load is called the resultant of the lateral force. F is completely various from the wind load, live load, impact and dead loads. The action of horizontal force that hit the constructor looks like the effect of the horizontal earth movement.

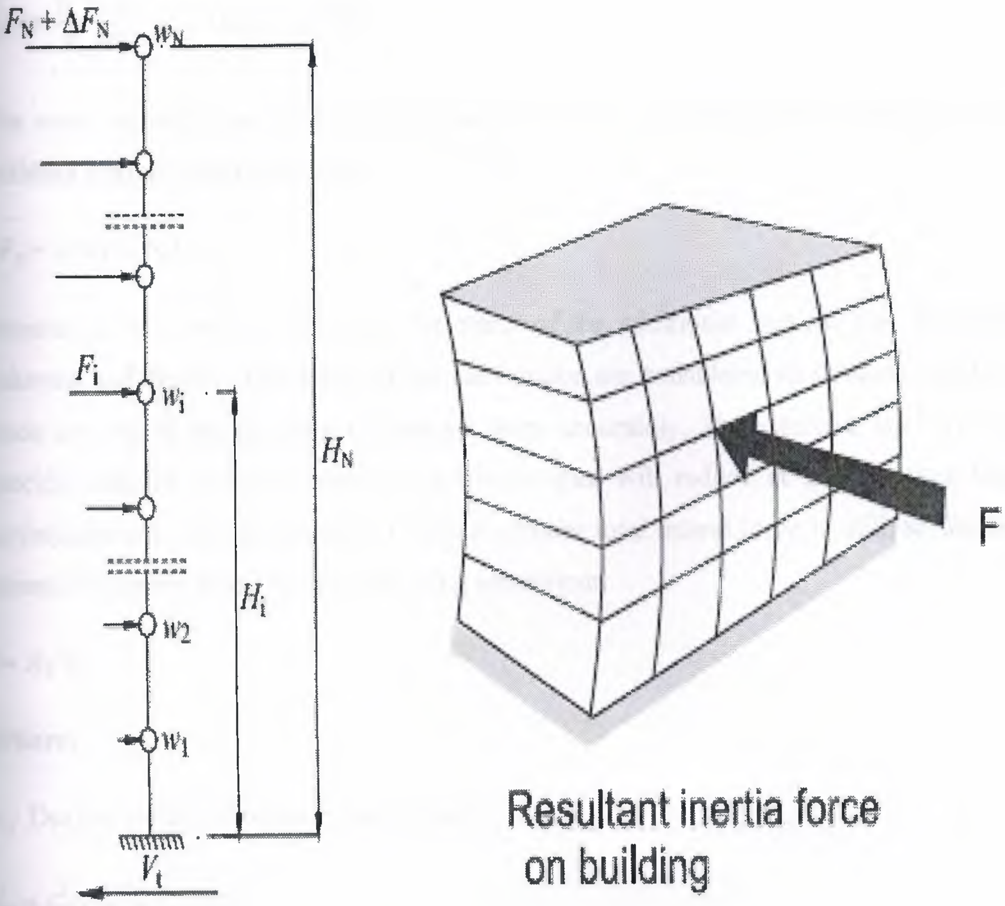

Figure 3.10 The Resultant Earthquake on Building [50]

When the constructor moves in sophisticated technique, at the base the inertia forces are generated due to the mass of constructor and its component. These forces are considered as counterproductive forces which cause the movement in the building in some case or the damage in other case. The value of this horizontal (lateral) force can be calculated from the following equation [50]:

$$F = (V_t - \Delta F_N)\ \frac{w_i\ H_i}{\sum_{j=1}^{n} w_j\ H_j} \quad (3.1)$$

Total Equivalent Seismic Load V_t (base shear), acting on the entire building due to the earthquake direction shall be determined by;

$$V_t = \frac{W\ A(T)}{R_a(T)} > \quad 0.10\ A_{\circ} I W \quad (3.2)$$

The value of additional equivalent seismic load, ΔF_N that acting at the last story (roof N) of the building shall be determined by;

$$\Delta F_N = 0.0075\ \mathrm{N}\ V_t \quad (3.3)$$

Because of the vertical vibration, the effect of the additional vertical load is impacted on the columns and beams. The loads of the earthquake are considered as dynamic loads where these loads are out of the question to forecast them accurately. The effective load will increase at a specific amount of time, while the effective load will reduce at another time because every earthquake has various proprieties. The minimum total lateral force is utilized for designing the seismic as shown below in the following equivalent.

$$F = A_T \mathrm{W} \quad (3.4)$$

Where:

A_T Design horizontal seismic coefficient.

$$A_T = (\frac{Z}{2} * \frac{S_{a(T)}}{g})\ /\ (\mathrm{R/I}) \quad (3.5)$$

- Z factor or the factor the of seismic zone: This value of seismic zone depends on the type of seismic zone, according to the table 3.5

Table 3.5: Seismic Zone Factor [57]

Seismic zone	**II**	**III**	**IV**	**V**
Seismic Intensity	Low	Moderate	Severe	Very severe
Zone Factor	0.1	0.16	0.24	0.36

The number 2 in the denominator of Z is used as factor to reduce the maximum considered earthquake (MCE) zone factor to the design basic earthquake factor (DBE) factor.

- I or the Importance Factor: the constructor's design of any building must be depended on their applications before the earthquake and after it. Such as buildings that provide necessary utilities for instance: schools, infirmaries, monumental structures, power houses, important bridges, subways, firefighting's center, meeting stations and others. The value of the importance factor for the constructors that mentioned above is 1.5 and they should be designed accordingly, while the value of the importance factor is equal to 1.0 for general buildings and houses.
- R or the Concept of Response Reduction Factor: this factor based on the perceived seismic damage performance of the structure is characterized by brittle deformations, in addition to the type of soil, as shown in the table 3.6. The ratio of (R / I) shall not be greater than 1.0.

Table 3.6: Value of Reduction Factor [57]

S. No.		Lateral Load Resisting System	R
A.		Building Frame System Alone	
	1.	Ordinary RC Moment-Resisting Frame	3
	2.	Special RC Moment-Resisting Frame	5
	3.	Steel Frame with Concentric Braces	4
	4.	Steel Frame with Eccentric Braces	5
	5.	Steel Moment Resisting Frame	5
B.		Load Bearing Masonry Wall Buildings	
	1.	Un-reinforced	1.5
	2.	Reinforced with horizontal RC Bands	2.5

	3.	Reinforced with horizontal RC Bands and vertical bars at Corners & Jambs	3
C.		Ordinary Reinforced Concrete Shear Walls	3
D.		Ductile Shear Walls	4

Nature of the Seismic Stresses: The structural components like walls, columns and beams. Before the earthquake, these elements can only carrying the vertical loads. But it will be exposed to the horizontal seismic forces after the earthquakes opposite to its direction, where these elements must to bear the horizontal forces of shearing and bending forces. The stress of the net tensile generates when the vertical compression is smaller than the bending tension. In this issue above, if the components of constriction like stone and brick masonry are weak in tension, the cracks are going to generate and that cracks will decrease the effective area for withstanding the bending in any time. In figure 3.12, this figure below illustrates that during the earthquake the column's resistance for the strength in tension and shear.

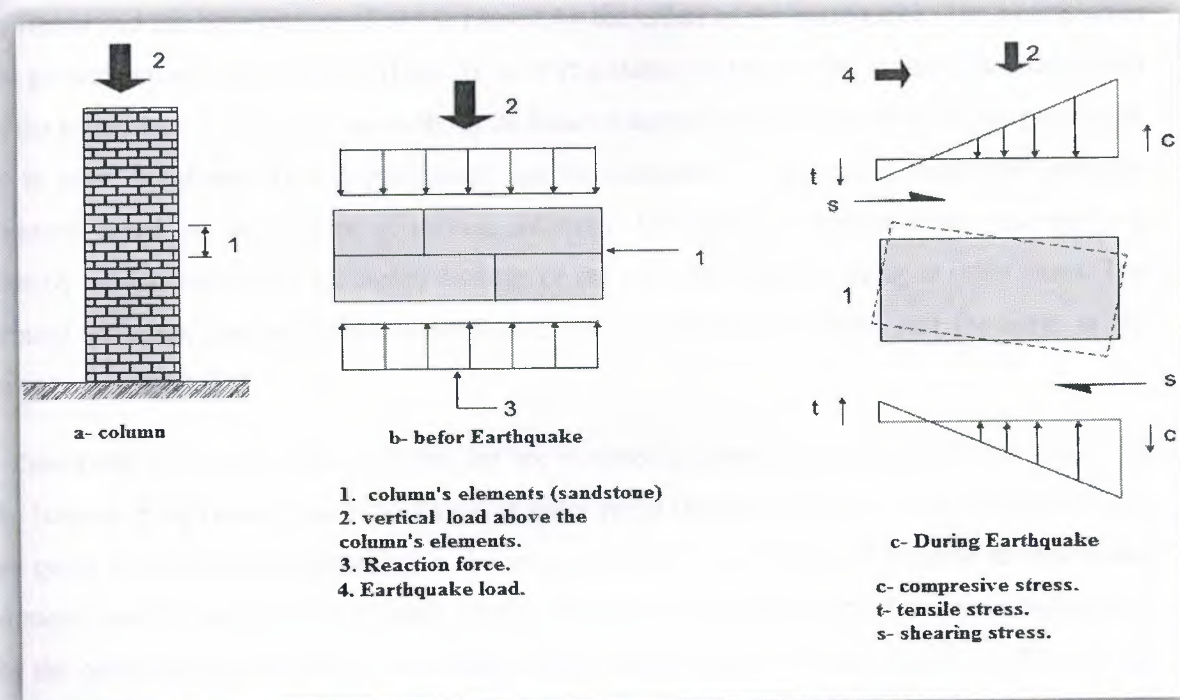

Figure 3.12 Stress Condition in Column Elements [50]

- **Important Parameters in Seismic Design:** there are numerous characteristics and factors that are considered remarkable from the viewpoint of the seismic design, such as:

i) The Characteristics of Building Material:

- Strength in tension or compression and shear
- Modulus of elasticity.
- Unit weight.

The properties that have been mentioned above will be explained in detail in the next chapter in addition to the values that were obtained from the laboratory tests.

ii) Dynamic proprieties of the construction system: this system consists of modes and damping.

iii) Load-deflection characteristics of construction elements.

- **Ground failure**: the rupture of the ground across the fault region, sattlement, the ground collapses and the liquefaction of soil is caused by the effect of the earthquake. The laceration in the ground across a fault zone perhaps for a short distance or perhaps be to more than thousands of the kilometers. Movement the earth for its location across the fault is horizontal, perpendicular or in both directions. This displacement can be calculated in meters or centimeter and this distance based on the amount of seismic intensity. Obviously, a rupture makes the building directly astride and causes extensive damage or the collapse of the building in other cases. The ground collapses can smash the construction, but the settlement creates just the harm in the constructions [50, 52].

- **Tsunamis:** the seismic waves of the sea are commonly generated by a unexpected motion of the bottom of the ocean. Since the waves of water reach the landfall, the velocity of these waves are going to reduce with increasing in the wave's height from 5 meter to 8 meter in some cases or more than this value in other cases. In some cases, the seismic waves of the sea is subversive for the constructions that was constructed in that coastal regions or have a certain effect on the buildings near the coast as is the case in the Church of St. George of Greek [52].

3.3.3 Ductility

Is considered one of the most important properties of the buildings especially ones designed to resist earthquakes. Ductility is meant the ability of the building to sway, bend, and deform by large amounts without much damages or collapse. Of the fragile nature of the materials and faulty design of structures through the use of materials differ in their ductility. Brittle materials crack under load; some examples are brick, adobe and concrete blocks. It is not surprising that most of the damage during the past earthquakes was to unreinforced masonry structures constructed of brittle materials, poorly tied together. The addition of steel reinforcements can add ductility to brittle materials. Reinforced concrete, for example, can be made ductile by proper use of reinforcing steel and closely spaced steel ties. But this is different in facilities that were full addressed of one substance without reinforced, where resistance to horizontal and vertical effects resulting from earthquakes depends on the susceptibility of the material to lateral load, tensile, bending and shear [51].

3.3.4 Undesirable Structural Behavior

The main properties of the lateral load resisting system is the construction should be as a cell unified coherent where it submit a uninterrupted load track to the establishment. Inertial loads that improve by virtue of the speed up of singular components (beam, arch) should be moved from the reaction of components to storey membranes, to perpendicular components (such as column) in the lateral load system, into establishment, and finally to the earth. The frustration to support enough toughness and strength of each component in the system or the frustration in the link the individual element properly as to ensure transmission of lateral loads that opposite to the behavior of individual can lead to completely collapse of the system. [53].

Inertial loads that improve in each component should be afforded to the perpendicular components (columns) by horizontal storey membranes. The membranes of diaphragms, with suitable the props and the limit of components must be supplied with enough intensification to transport these forces [54, 55].

Sudden changes in stiffness, strength, or mass in either vertical or horizontal planes of a building can result in distributions of lateral loads and deformations different from those that are anticipated for uniform structures. The most common form of vertical discontinuity arises because of unintended effects of nonstructural elements. The problem is most severe in structures having relatively flexible lateral load resisting systems because in that case the nonstructural component can compose a significant portion of the total stiffness [56].

Excess drift can lead to excessive distortion, and thence, damage, of structural and nonstructural components. Because repair cost is the primary measure of the success of a building that has survived an earthquake, so damage control is essential. Control of damage in nonstructural components is important because they typically comprise a significant majority of the total value of a building [57].

3.5 Summary

This chapter gave a good background to understand the state of soil and its classification in Cyprus Island. Besides that, the general concept of earthquakes and the successive earthquakes in Cyprus that hit this island before many centuries to the present day are presented in details. Also in this chapter, the behavior of structure due to earthquakes and the structural performance during earthquakes are submitted well.

CHAPTER FOUR

LABORATORY TESTS OF YELLOW SANDSTONE

4.1 Introduction

This study focuses on the structural analysis for columns of Church of cathedral St. George. Church's pillars was completely built from yellow sandstone units where this helps to reduce the likelihood of increased damage the element (column) when exposed to the forces of differently or contrary forces are capable of address them . The earthquake loads are dynamic and impossible to predict precisely in advance, where at certain instants of time the effective load is increased, at others it is decreased.

The yellow sandstone is characterized by high density and hardness because of the porosity in it is a very few. The sandstone masonry gave a good behavior under forces of loading and the pressure while it was giving a high behavior under the bending force. In this section the procedures of a current work will be discussed in detail, where these procedures include many important tests on the masonries of columns which are necessary for the requirements of the program SAP2000 to analyze church's columns that collapsed due to the seismic intensity in addition to the study the behaviors of these masonry under the influence of earthquakes from the viewpoint of mechanical structural elements.

4.2 Compressive Strength and Breakage Load-P

The columns are considered the essential theme or the backbone in this study, therefore it was necessary to set the highest vertical load that can be carried, especially that the vertical elements are designed to carry only the vertical forces that pre-exposure to earthquakes. In order to access the reasons for the collapse of church columns, the two cubic sample of yellow sandstone has been taken with dimensions (10 * 10 * 10) cm and it was subjected to load of 9.9 KN. as shown below in the figure 4.1.

Figure 4.1 Demonstrates the Failure of the Sample under Compressive Forces

Where the higher value to resist the force of compression was 0.44 Mega Pascal.

4.3 Bending Strength and Fracture Load-T

This test is consider a very important for the designed structural elements such as walls, beams and columns to know the behavior of these elements in resisting breakage before earthquake especially it was designed mainly to carry the vertical force. After earthquake, these elements (wall, beam and column) should be able to carry the influences of shearing and horizontal bending which are going to bend these elements. In order to set higher durability in the masonry of yellow sandstone, Sample was taken with dimensions (20*10 * 10) cm, it was subjected to the bend load of 3.6 KN. as shown in the figure 4.2, and the recorded value was 0.51 Mega Pascal.

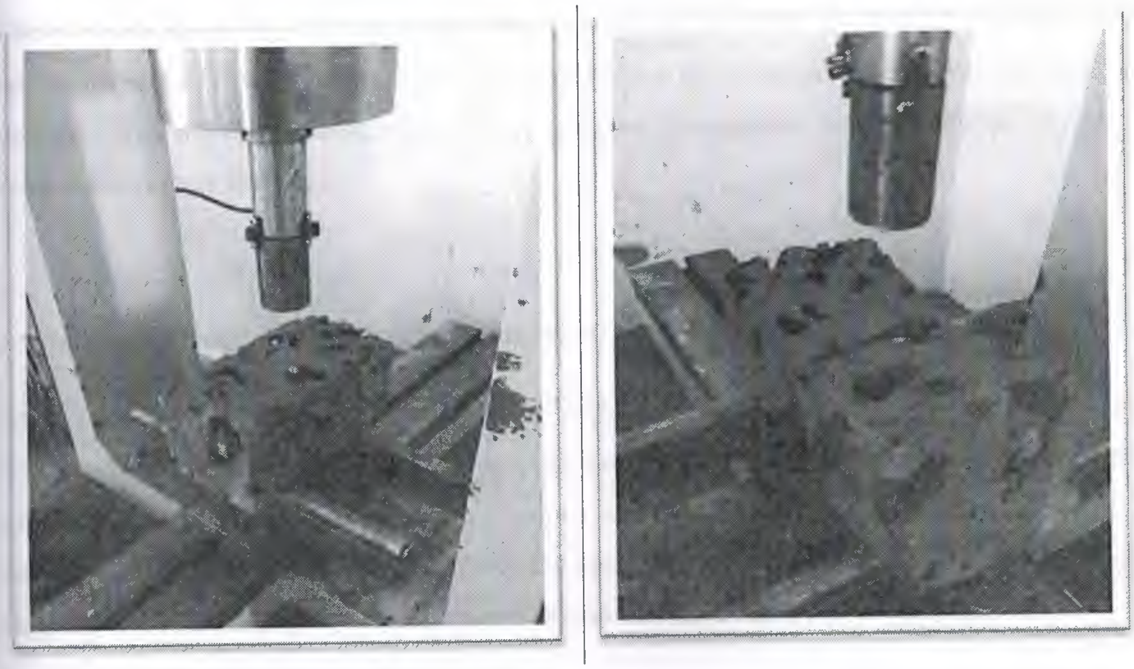

Figure 4.2 Examination of the Sample under the Bend Force

When exposure to the earthquakes, the columns are going to bend under the influence of increasing the tensile strength that excess of the amount of vertical compression, so net tensile stress will occur. As result of that, the cracks will occur in these columns as shown in the figure 4.3.

Figure 4.3 Cracks of Column Masonry Due to High Tension Force

These cracks are going to reduce the effective area for resisting the bending moment of the sandstone masonry, where these masonry characterized by the weakness in resisting the tensile strength. As a roll the tensile strength is deferent from compressive strength significantly and its values also is quite different.

4.4 Specific Gravity Test (weight per unit value)

Specific gravity refers to the ratio of density of any substance. This is a very important value in set the weight of the yellow sandstone per cubic meter and through this value can calculate the weight of the elements that based on the columns such as arches and roofs. Besides that, when the value of the specific gravity is high then the durability of sandstone units is going to be high also and this increase the stamina of external forces and environmental conditions.

Cubic Sample of yellow sandstone was taken with dimensions (20*10*10) cm, a dry weight of the sample has been appointed where the value was 2240 Kg/m^3 as shown below in the figure 4.4.

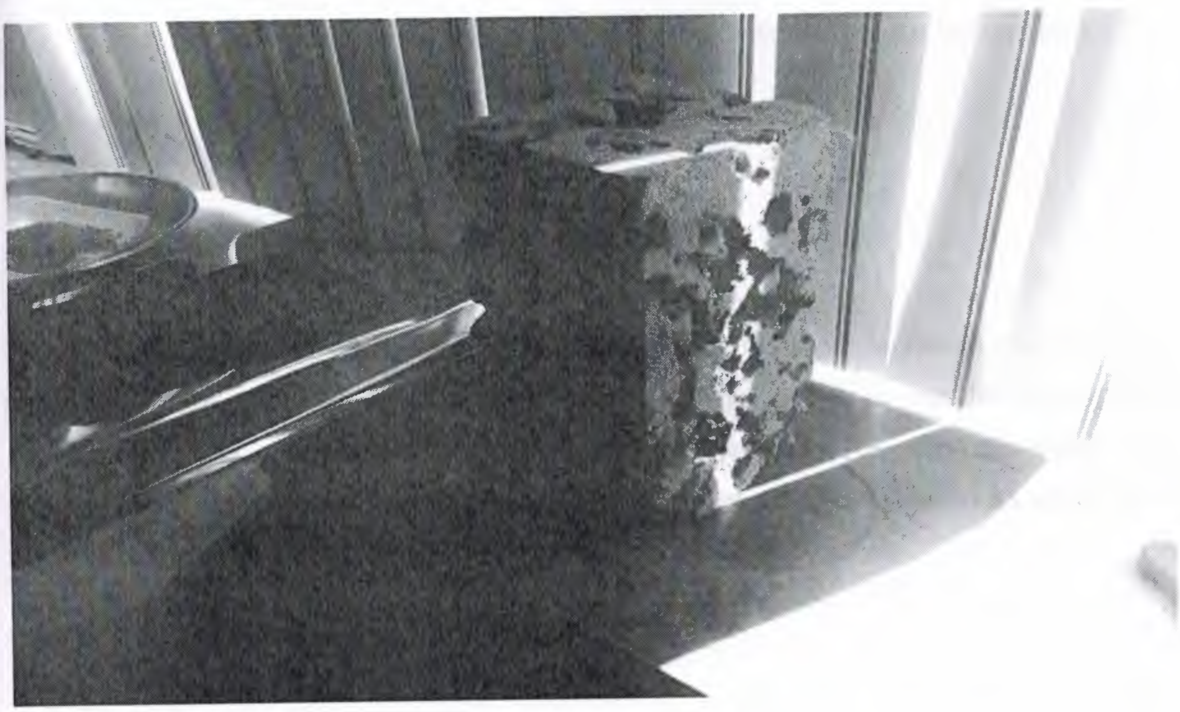

Figure 4.4 Specific Gravity of Dry Yellow Sandstone

The sample was dived in water for 4 hours, then the weight of this sample has been assigned where was 2330 Kg/m^3 as shown below in the figure 4.5 (a), after that it was placed in the oven for one day at a temperature of $105c^{\circ}$ as shown in the figure 4.5 (b), then has been set its weight.

(a) (b)

Figure 4.5 (a) Immersion the Sample in Water, (b) The Method of Drying the Sample

The final result to examine the sample of yellow sandstone was 2280 Kg/m^3.

4.5 Modulus of Elasticity

The modulus of elasticity or elastic modulus is one of the most important properties and parameters from the point of view of the seismic design and it is consider mathematical description of the materials tendency to deformation elastically (i.e, non-permanent) when influenced by external force, the elastic modulus of an element is the slope of its stress–strain curve of the area that has been elastic deformation.

A rock sample has been cut to cylindrical shape, and the ends were machined flat. The sample of yellow sandstone was placed in a loading frame as shown below in the figure 4.6 at ordinary temperature (the desired test temperature).

Figure 4.6 The Test Method of Elasticity Modulus

Axial load was continuously increased on the specimen, and deformation was monitored as a function of load. Through the values that were obtained during the examination and make mathematical calculations have been obtained the value of the elastic modulus of the church stone, where it was 3.05249 t/m^2, the value that obtained relatively high, this is because a stiffer material will give a higher modulus of elasticity.

EXPERIMENTAL AND NUMERICAL ANALYSIS FOR THE COLUMNS OF CATHEDRAL St. GEORGE OF GREEK IN FAMAGUSTA

A THESIS SUBMITTED TO

THE GRADUATE SCHOOL OF APPLIED SCIENCES

OF

NEAR EAST UNIVERSITY

by

MARWAH ALAULDDIN BAHAULDDIN

In Partial Fulfilment of the Requirements for
The Degree of Master of Science

In

Civil Engineering

NICOSIA 2014

Marwah Alaulddin Bahaulddin : :"Experimental and Numerical Analysis For The Columns Of Cathedral St. George Of Greek In Famagusta"

Approval of the Graduate School of Applied Sciences

Prof. Dr. İlkay Salihoğlu
Director

We certify this thesis is satisfactory for the award of the Degree of Master of Science in Civil Engineering

Examining Committee in charge:

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a. atun.

Assoc. Prof. Dr. Kabir Sadeghi, Committee Chairman, Faculty of Engineering, GAU.

Assist. Prof. Dr. Pınar Akpınar, Committee Member, Civil Engineering Department, NEU.

DECLARATION

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name: MARWA ALAULDDIN BAHAULDDIN

Signature:

Date: 7-3-2014

ABSTRACT

This thesis addressed the theoretical study of the soil behavior at the site of the cathedral church of Greek, where this study based on the previously studies to identify its classification that it depended on the Eurocode8 and display the influence of the earthquakes on the construction buildings in general. As well as, it presents the data collections of earthquakes experienced by the church since its inception until now.

This thesis mainly discusses about the ancient yellow sandstone columns as one of the important elements in enhancing the structural strength. In order to analyze columns of the church been studying physical and chemical properties of the material used in mortar theoretically and physical properties and parameters are most important from the point of view of the seismic design of columns through laboratory tests for masonry of yellow sandstone such as; Compression strength, Tension strength, Modulus of Elasticity, Poison's Ratio, unit weight, Bending strength, weight of unit volume, especially that the Cathedral Church of St. George of Greek exposed to strong seismic shocks through its structural age.

The program that was used in the analysis the church columns is SAP 2000, depending on the values that have been obtained from laboratory testing of the yellow sand stone and the data collected of earthquakes to find out the strength of the columns, its reactions to lateral and vertical load to in addition to the reason that led to the collapse of the columns and other parts based upon it such as arch and of roofs.

Keyword: Yellow Sandstone, Decay of Stones, Sandstone Columns, Cactus Extract, Egg yolk, Soil of Cyprus, Earthquake.

ÖZET

Bu tez St. George Kilisesi'nin bulunduğu bölgedeki zeminle ilgili teorik bir çalışmadır. Zeminin sınıflandırılması ve depremin binalar üzerindeki etkisi hakkında var olan çalışmalar ile Eurocode 8 den yardım alınmıştır. Ayrıca bu çalışmada kilisenin kuruluşundan günümüze kadar yaşanmış depremlerle ilgili bilgilerde sunulmuştur.

Yapısal dayanımın ana ögesi olarak kullanılmış olan, antik sarı kumtaşından yapılmış kolonlarla ilgili geniş bir çalışma yapılmıştır. Kolonlardaki harçta kullanılan malzemenin fiziksel ve kimyasal özellikleri teorik olarak incelenmiştir. St. George Kilisesi tarihi boyunca sismik şoklara maruz kalmış olduğundan ötürü gerekli parametrelerin ölçümü yapılmıştır. Kolonların dizaynında önemi olan sismik parametreler ve fiziksel özelliklerin elde edilebilmesi için laboratuvar testleri yapılmıştır. Bu testlerden bazıları; basınç dayanım, gerilme dayanım, elastisite modülü, poisson oranı, birim ağırlık, bükülme dayanımı, birim hacim ağırlığı vs.

Sarı kumtaşı ve depremle ilgili toplanan bilgiler SAP2000 programında kolonların analizi ve yatay ve dikey reaksiyonları bulmak için kullanılmıştır. Kolon, tavan, kemer vb. elemanların zarar görmesine yol açan yükler bu şekilde bulunmuştur.

Anahtar kelimeler: Sarı Kumtaşı, Taşların Parçalanması (çürümesi), Kaktüs Ekstraktı, Yumurta Sarısı, Kıbrıs Zemini, Deprem

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Dedicated to my family who have been with me thought it all……

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LIST OF SYMBOLS

t_{ef}	Effective Thickness of the Wall.
q	Upper Limit of the Behavior Factor.
$V_{s,30}$	Average Shear Wave Velocity up to 30 m
$V_{i,}, h_i$	Denote the Thickness (in Meters).
T	Vibration Period of a Linear Single Degree of Freedom System.
T_B	Lower Limit of the Period of the Constant Spectral Acceleration.
T_C	Upper Limit of the Period of the Constant Spectral Acceleration.
T_D	The Beginning Value of the Constant Displacement Response Range of the Spectrum.
η	The Damping Correction Factor with a Reference Value of $\eta = 1$ for 5% Viscous Damping.
F	Design Seismic Load in Equivalent Seismic Load Method.
N	Total Number of Stories of Building From the Foundation Level.
ΔF_N	Additional Equivalent Seismic Load Acting on the N'th Story (top) of Building.
V_t	Total Equivalent Seismic Load Acting on the Building (Base Shear) in the Earthquake Direction Considered.
W_i	Weight of i'th Story of Building by Considering Live Load Participation Factor.
W_j	Total Weight of Building Calculated by Considering Live Load Part- Icipation Factor.
H_i	Height of i'th storey of Building [m].
H_j	Total Height of Building [m].
A(T)	Spectral Acceleration Coefficient.

$A_\circ$	Effective Ground Acceleration Coefficient.
I	Building Importance Factor.
$R_a(T)$	Seismic Load Reduction Factor.
S(T)	Spectrum Coefficient.
S_{ve}	Vertical Spectrum.
$S_e(T)$	Elastic Response Spectrum.
a_{vg}	Design Ground Acceleration in the Vertical Direction.
A	Area of Each Roof 's Zone.
m	Mass of stone.
p	Unit weight of yellow sand stone.
$A_{fillers}$	Area of fillers.

LIST OF ABBREVIATIONS

PGE	Peak Ground Acceleration
SSI	Soil Structure Interaction
G	Ground Acceleration.
S	Soil Factor.
SPT	Soil Penetration Test.
W	Total Weight of Building.
Z	Seismic Zone Factor.

CHAPTER ONE

INTRODUCTION

1.1 Background

Many centuries ago, Cyprus was a Greek and Phoenician colony where the judgment in that city passed through many various regimes. The southern side of Famagusta almost occupied by the Greek quarter where there were numerous small Byzantine churches [1].

The cathedral Church of the Greeks was one of the firm constructions in the fourteenth century where it built in 1360 at the Greek side of the Greek Orthodox in the Gothic style. The cathedral Church of St. George of the Greeks was facing the Latin Cathedral which it was a plainer and slightly shorter copy as shown below in the figuer 1.1.

Figure 1.1 The Similarities between Greek Orthodox Cathedral and Latin Cathedral.

It was dedicated to St. George and took the place of an earlier and much smaller Byzantine one. Veneration for this ancient sanctuary prevented its demolition; all that was done was to restore it and to incorporate its north wall in the wall of the southern aisle of the new cathedral, turning it into chapel was perhaps scene of the cult of the body of Epiphanies, Bishop of salamis, after the sixteenth century was famous residues loss [2].

There is no documentary evidence for the foundation data of St. Georg, This church named under that name Proportion to the victims of the riots that occurred at the coronation of Peter II out the city towards the ruins of salamis and who were buried in it [3].

This church has been left completely in 1571 when established the battery by the Turks on the rock to the south-east of the harbor, where was suffering severely from a battery fire, and can be observed the marks of cannon-balls on the walls of the apse until now, as shown in the fig 1.1.and due to the seismic nature of Famagusta so subjected to earthquake forces more than once throughout their life, Prior earthquake damage would lead to changes in the structural characteristics which in turn imply changes in the response of the structure against future earthquakes , This can be seen from the successive earthquakes on the church where earthquakes that hit it in 1556, demolition the fractional destroyed of the standing roof in wholly form. The earthquakes that occurred between 1735 and 1741 in that city damaged the 80% of the walls and columns of Famagusta's church. The most of the stones for the church were loose. Therefore, the cathedral church of St. George is now remaining of columns and walls without roofs. The Greeks of today give the name of St. George to the former Nestorian church and the cathedral that have been described ruined and disused for a long time [4.5].

1.1 The Location:

The Church of the Greeks is situated in the south east part of Famagusta's city, placed at the eastern part of Mediterranean Sea. The exact position for Famagusta's church is 35.12 at the north and 33.94 at the east [6].

1.2 Architecture of Church:

The architectural style of the church is a mixture of the Byzantine and Gothic styles. And it is very plain. The apse and the two apsidioles are Simi-circular, roofed with conical semi-domes. Each side-apse has a pointed window between which and the impost of the vault there is a pretty wide stretch of wall, marked off by moldings, to receive a pointed frieze. The main apse, which is very high-built, has two rows of three windows each, also pointed. All these windows are small [5] the fig. 1.2 shows all of those details.

Figure 1.2 Detail of Shape of the Exterior Walls

The apices are a trilobite shape by the cusps ending in a fleur-de-lis as in the Latin cathedral. In the cloisters at Bellapais, on the north doorway of St. Catherine's church in Nicosia and in the round windows of St. Francis's church in Famagusta. The angles of the splays are ornamented with a bead-molding. On the outside there is a hood-mould over the top of the windows. Between the main apses and the Sid-apses there are two small rectangular recesses, accessible from the inside; they were possibly used as sacristies or perhaps confessionals [6] as shown in the figure1.3. They are lit by an arrow-slit pierced low down in a niche whose top is carved with an imitation of ribbed vaulting.

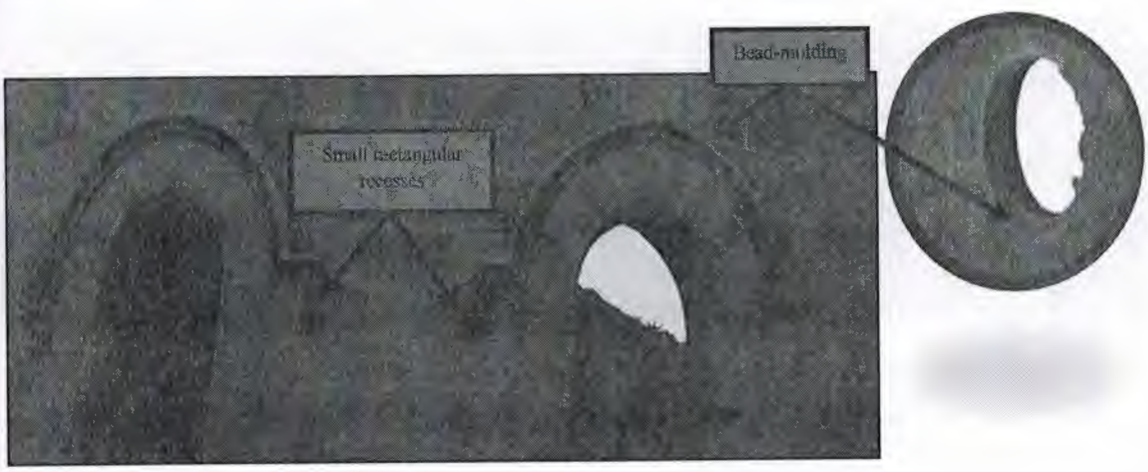
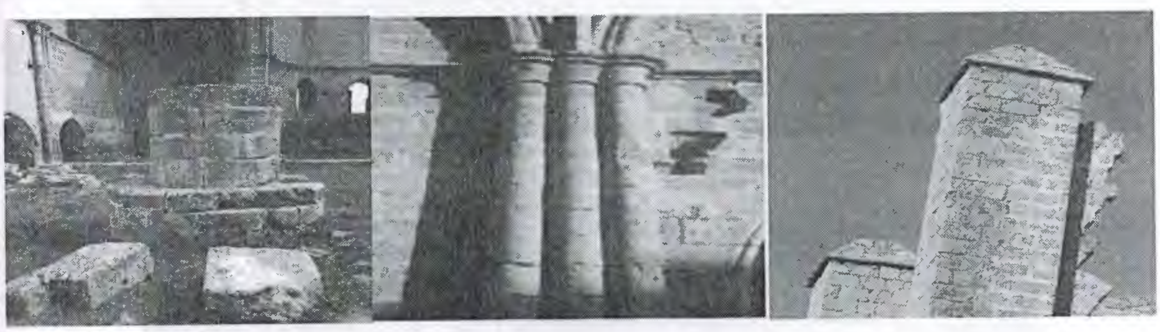


Figure 1.3 Demonstrates A bead-Molding when Outer Edge

Corridors and nave had polygonal vaults and aisles decorated with molding as shown in the figure 1.4;

Figure 1.4 The Ribbed Vault and Decorates by Molding.

This church has twenty-three column, fifteen of them within the main walls and eight huge internal cylindrical shape with diameter 220 cm distributed parallel as shown in the figure 1.5(a), it has circular piers such as those of St. Nicholas and SS. peter and Paul but distinctly coarser; the capitals are circular and incurved but the bell is only very slightly convex or rather is merely a section of a cone, a degenerate from which can be seen in Cypriot buildings of the 14^{th} century and in Provence. Columns of nave has a triple groups of colunnettes based on abacuses of the main piers and have capitals of square pyramid shape with an angle of 45°; as shown in the fig. 1.5(c). In the Corridors, there is a series of triple groups of slender columns have base and capitals like those in columns of nave as shown in the figure 1.5 (b). The pointed windows of the corridors and the nave were quite large.



(a) (b) (c)

Figure 1.5 Shapes of Columns for Corridors and Nave

There is now a vaulted one in the easternmost of the northern corridor is preserved, sharp angles of ribs and composition highly similar pattern of champagne. Between the vaulting and the flat roof that a huge jars are embedded in the masonry as shown in the figure 1.6; Function improved

acoustics and lighting, like those which are found in the vaulting of stazousa (beau-lieu) in Cyprus and of the church just south of the Carmelite church in Famagusta.

Figure 1.6 Huge Jars and Embedded Material between Arches and Flat Roof

The west end as shown in the fig.1.7 had a false gable according to unreliable information provided by Gibellino's engraving.

Figure 1.7 The West End of Church

The upper part was completely destroyed, surmounted by a corbelled gallery supported on two quadrant courses at the height of the aisle roofs. Are accessible through a staircase built into an octagonal turret in the south-west corner. splay. The tympana are missing. The two lateral

doorways have two arches with molding that rest on colonnettes whose capitals are carved with clusters of leaves as shown in the fig. 1.8; Above this gallery there was a window opening into the nave of church; the side-pieces are decorated with grooves and two colonnettes.

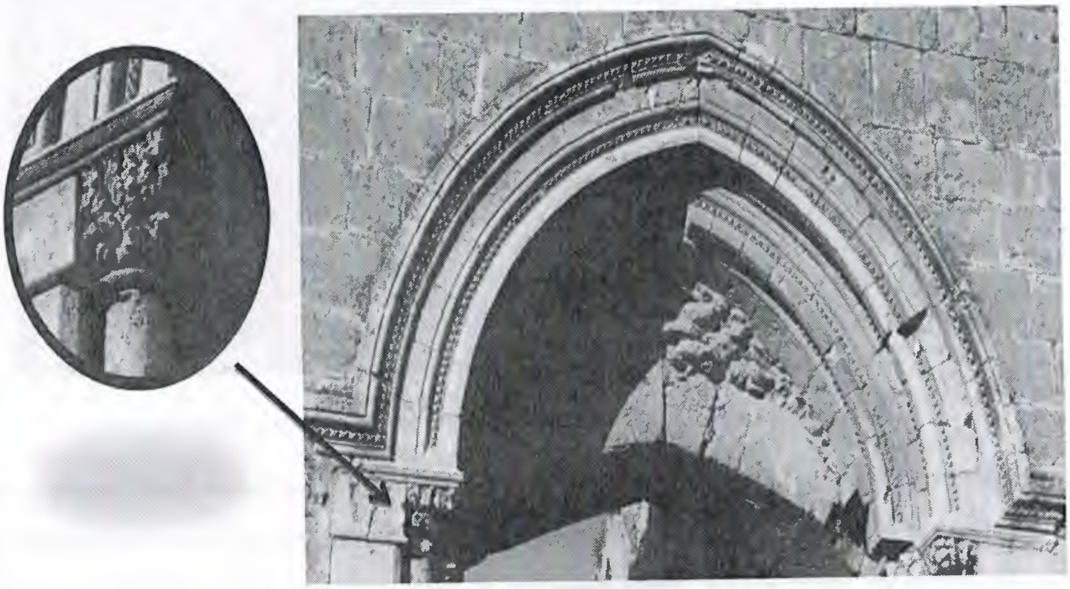


Figure 1.8 The Molding of Arches and Capital of Colonnettes

Under it are three pointed doorways with no buttresses to separate them and the middle one is larger than the other two with no buttresses to separate them; above it is an (oeuil-de-boeuf) with a wide there are no colonnettes on the central doorway but three arches, whose mouldings as shown in fig. 1.8, continue down onto the jambs. There was another doorway in both north and south sides of the nave where the symmetry approach is adopted at that time by the architects in Cyprus

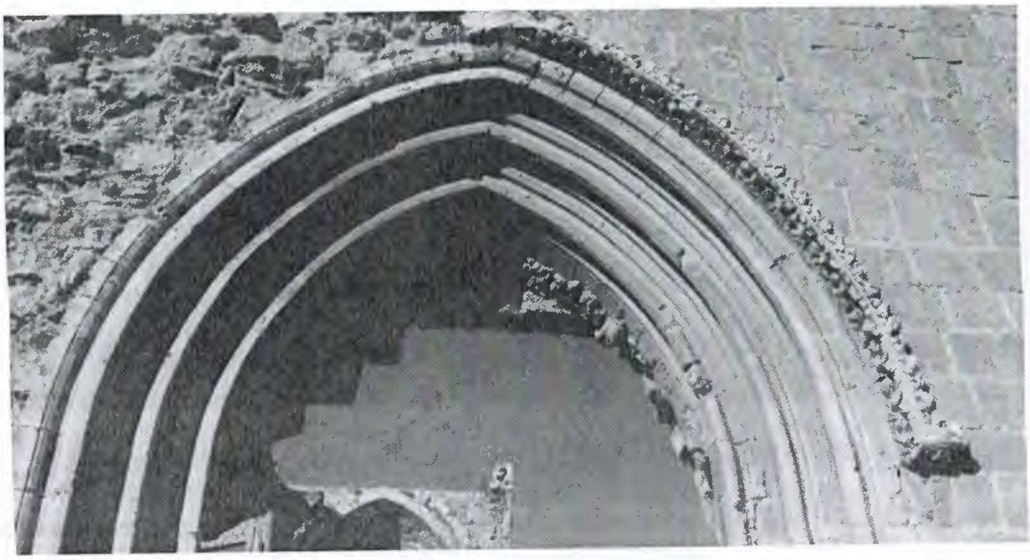


Figure 1.9 The Moldings of Arches of the Central Doorway

There is also a hood-mould carved with a thick torus molding decorated on both sides with two rows of large leaves, all of identical design and are similar to those at the capitals, but are deeply cut and strongly folded. The capitals make a confused effect, all the more inelegant due to the abacus is a plain flattened torus as shown in the fig. 1.9. Church of St. George of Greek includes many of the graves and this is what adopted by Builders in advance , the walls of the corridors have had wide and deep recesses made in them, framed by pointed arches which are carved with elegant moldings and quite clearly intended to house sepulchral monuments. The central dome of the small Byzantine church which has been preserved and joined onto St. George's on the north-east side has twin apses carried on an octagonal drum with mitred windows, was rebuilt at the time of construction of the main church [5, 6].

The interior of cathedral church is entirely covered with well-drawn paintings in the style of Giotto accompanied by numerous inscriptions in Greek as shown below in the figure. 1.10

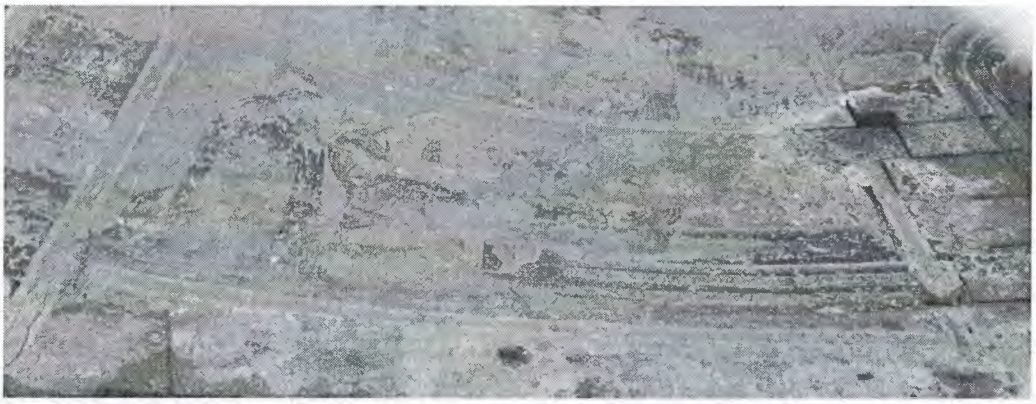


Figure 1.10 The Paintings According to Giotto Style at the Wall of Church

The character of the paintings is certainly Italian, especially in the figures in the southern lateral apse and the aisles, and no the window-surrounds. One of the inscriptions runs around the chamfered edge of the impost of the apsidal semi-dome; but this chamfer made from plaster laid over a groove molding carved with a diaper of small flowers. This detail proves that the painted decoration is later than the construction work; it was probably done in the 16^{th} century [6].

1.3 The Materials Used in the Construction of the Church

Construction materials used in the construction of the cathedral Church of St. George of Greek in particular and is considered one of the important monuments in Famagusta is sandstone. Sandstone may be any color, but the most common colors are tan, brown, yellow, red, gray, pink, white and black. This building using fully dressed rectangularized yellow sandstone units [7, 8]. Yellow sandstone is one of the worldwide famous sandstone. It is also known as Sun Yellow Sandstone. It is very hard sandstone. It is non-porous. It is shiny finished, soft and smooth sandstone. It's used for walls, facades, roofs, landscaping, flooring, wall claddings, balustrade, window cells and surrounds tiles, slabs. It is widely used for sea-shore building due to resistance to water. It contains high amount of feldspar, usually dominated by potassium feldspar [9].

In the next chapter will be detailed the physical and chemical properties of yellow sandstone and the bonding materials that connect them with each other to create this church.

1.4 The Status of Soil in Cyprus

Soil classification began in Cyprus in 1957, according to the methodology of studies designed to collect information regarding the characteristics of the soil chemical and physical, where this classification system was based mainly upon the formation of composition, origin and parent of the materials in the soil. Most of the soil is rated on the island of Cyprus as Red, Sedentary and Alluvial soils. The examination of the main horizons can be classified into various classes by physical and chemical analyses for soil (A, B, C, and D). These types have been classified into soil series according to the C and D horizons [10].

Red soil has a reddish tinge as a result of the presence of iron compounds in the soil composition. Some types of red soil are clays, Clay soil which has a heavy concentration of clay particles and this means the soil stiffness [11].

There are structural parts in civil engineering to be in direct contact with the soil such as the foundations, and this in turn may create the effects of external forces such as earthquakes, act on these systems, neither the structural displacements nor the ground displacements, are independent of each other , the process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil is called soil-structure interaction (SSI) [12], and it will be explain in detail later.

1.5 The Earthquake in Cyprus

An earthquake is malfunction occurs due to sudden rupture of rocks ground by large internal stresses exceed resistant of rock's strength. The malfunction may be newly created by the earthquake rupture or may be present originally. Energy caused by malfunction is transmitted as seismic waves that cause nearly all damaging earthquake effects. The size of an earthquake is often expressed in terms of Richter (or local) magnitude, denoted by ML, and was developed by Charles Richter for California in 1935. Richter magnitude is determined by measuring seismic wave amplitude instrumentally [11].

Cyprus placed between the belt of Alpine and Himalaya. This position is considered the second most area susceptible to the earthquakes on the earth. These earthquakes represent about 15% from the seismic activity in the world. The severity of seismic is attributed to the arc of Cyprus and it is represented the tectonic boundary between the Eurasian plate and African plate. The diving of the African Plate under the Eurasian Plate generates numerous earthquakes along the arc of Cyprus and many active faults inside the island have seen that earthquakes likewise happen along them. In many centuries ago, Cyprus was hit by successive earthquakes. As a result of that, many towns like Famagusta (Salamis) and the capital city Nicosia are destroyed in that period of time. Sixteen earthquakes with intensities of VIII (on modified Mercalli scale) or higher occurred between years 26 B.C. and 1900 A.D. This work addresses the seismic safety of the remaining's of St. George of the Greek Church, in Famagusta, including an inspection and diagnosis. [5], where it will be detailed later.

1.6 Structural Analysis for Church

The Church of St. George of Greek, important model of the old sandstone buildings deserves attention, as this church is built in a way that make them able to withstand a certain type of external forces, these forces are earthquakes and impact forces (cannon balls) [12].
To find out the building technique and materials that used in this church, the SAP 2000'program is going to analyze the sandstone columns of that church to see their behaviors and reactions at force of earthquakes and weight of roof and arches to find out the reason that lead to the collapse and failure this church.

1.7 Literature Review

Church of St. George of Greek is considered one of the most important ancient monuments and historical edifices in the city of Famagusta. This building suffered under earthquakes over the years that led to loose most of the stones that's where the church now is the remnants of walls and columns only. Prior earthquake damage would lead to changes in the structural characteristics which in turn imply changes in the response of the structure against future earthquakes [4, 13].

One of the most important cause's damage to engineering structures during the seismic strikes has been the development of soil liquefaction beneath and around structures. In 1992, J.I.Baez & G.R.Martin made an estimation of current earthquake knowledge on the relative effectiveness of stone pillars for reducing the liquefaction of soil. The limitations on usage of simple analytical techniques like seed and Booker's are noted at1976. The survey of the experimental data indicates that the linear techniques of consolidation are valid only if the ratio of the pore pressure below than 0.5 of pore pressures within the gravel drain has also been spotted to differ, contrary to the assumption that they stay essentially unchanged. The conclusions from the evaluation that the most safe and appropriate technique to reduce the intensity of the earthquake by potential liquefaction resides in identifying the soil. None the less, the research until the present time proposed that the extra benefits arising from the drainage capacity of the stone column might be included in the design considerations [14].

In 2002, explained each of Woo-Seok Bae, Bang-Woong Shin, Byung-Chul a Foundation system ameliorate with stone columns is many obstacles in quantitative analysis of soil-column interaction as a result of that bearing capacity and consolidation behavior of stone column is influenced by different parameters. With reason, the behavior of composite ground improves in the soil-foundation system interface, so the behavior of stone column is better investigated in term of different parameters which affect the horizontal resistance in the interface. In this study, failure technique and different parameters for the behavior of end-bearing stone column groups are investigated under these tests (unit cell consolidation tests and loading tests). The outcomes of model tests are proved by the failure behavior and bearing capacity by FEM analysis. At the end of this research, the influence of design parameters and the improving characteristics of soft ground were proved in this study using FEM results and PR value. Throughout the test outcomes and the PR value computation, bearing capacity of stone column is affected by undrained strength of surrounding ground, area replacement ratio of composite ground and installation of mat. Besides that, behaviors of foundation are affected by diameter and spacing of pile rather than embedment ratio and mat. In addition, the behavior of stone column is essentially affected by initial untrained shear strength of surrounding ground and column spacing. In addition, the analyses through FEM by using Mohr-Coulomb model and PR values are applicable to the estimation of the behavior of stone column [15].

In 2006, Boštjan Pulko and Bojan Majes are submitted analysis the behavior of rigid foundations stabilized using end bearing stone-columns. The surrounding soil and the stone column and are addressed in axial symmetric conditions as a unit cell. The stone column is supposed to treat as a Mohr-Coulomb rigid-plastic material with non-associative flow rule according to the Rowe stress dilatancy theory and the soil as an elastic material. The outcomes of this technique are compared with some analytical techniques and some published works at this field [16].

1.9 Thesis Objectives

The objectives of this thesis are:

1. The study of the properties of constructive materials accredited in the fourteenth century through laboratory testes to determine its ability to resist external forces conditions and the effect of some important factors on the general behavior of stone.
2. Theoretical study and developed to complement existing knowledge related to understanding the behavior of the soil at the site of the Church to determine the properties of the seismic behavior that led to the collapse of the columns of the church.
3. Display the influence of earthquakes on the construction buildings and data collections of earthquakes experienced by Cyprus since the fourteenth century until 2013.
4. To find out the strength of the main columns, its behavior and reactions to external forces due to earthquake "vertical and lateral load" according to the collected data to determine the reason which led to the collapse of the columns and other parts based upon it such as arch and remains of roof by using SAP 2000 program.
5. To identify subjects appropriate for further research on the topic.

1.10 Thesis Layout

The thesis consists of six Chapters arranged as flow:

The first Chapter presents the introduction and literature review on the topic.

The second Chapter discusses the utilized materials in the walls and columns of the Cathedral, the chemical compositions for materials, properties of the sandstones and mortar used in between. In the third chapter, the study is pointed toward status of soil in Famagusta and its effect on the building. In addition, the earthquake in Cyprus is given in details.

Fourth Chapter explains the steps conduct laboratory tests. In the fifth Chapter, present calculations of structural analysis and numerical applications by using SAP2000 of church's columns. Sixth chapter presents the discussions. As well as, it shows the conclusions and suggestion for future work.

1.11 Summary

This chapter presented the history of cathedral church of St. George of Greek since its construction to the present day. As well as, this chapter gave a good background to understand the location and the architecture of this church and the used materials in the construction of the church. The status of soil and the earthquake in Cyprus is discussed. Besides that, the previous researches for many scientific papers in same topic are presented.

CHAPTER TWO

THE UTILIZED MATERIALS AND TECHNOLOGY PROMOTION IN THE CHURCH, CHEMICAL COMPOSITIONS, PHISICAL PROPERTIES AND SANDSTONE DECAY

2.1 Overview

Since the birth of civilization, human being has used building material for tools and for construction applications. The earliest materials were wood, sand, rocks and clay. In addition, the leaves and twigs of plants that have been utilized for the same purpose, the stone walls were the most common used at that period of time where humans were put at the beginning stones only without any connection between the stone masonry, after that began a new phase of building where started holding the stones together using Binders because of the wars and cannon-balls. Sandstone has been widespread utilized for lifting the walls before many centuries to the present day. It has been used for over centuries for making strongholds, forts and castles etc. several stone of construction can be seen in main towns, several civilizations constructed wholly with stone like the Pyramids in Egypt and the remains of the civilization of Inca and churches in Cyprus [17, 18].

2.2 The Materials Utilized in the Church and Technology Promotion

Construction materials used in the construction of the Church of St. George of Greek in particular and almost all the historic monuments in Famagusta is sandstone. Yellow Sandstone is one of the worldwide famous sandstone. It is also known as Sun Yellow Sandstone. It is very hard sandstone and due to non-porous it is widely used for sea-shore building due to resistance to water. It is shiny finished, soft and smooth sandstone. It's used for walls, facades, roofs, landscaping, flooring, wall claddings, balustrade, slabs, and window cells and surrounds tiles [7, 9].

According to the Euro code 8, the kinds of building and behavior of factor relying on the type of masonry that utilized for the elements that resist the earthquakes and the masonry of this church selected to restrict the masonry construction. Because of its low strength of ensile and low flexibility, the unsupported masonry that tracks the provisions of EN 1996 is considered to offer (DCL) low-dissipation capacity and its usage must be restricted, provided that the efficient thickness of the walls, t_{ef}, is not below than the minimum value,$t_{ef,min}$ [19]. The allowable ranges of the upper limit of values for the behavior factor q are shown below in Table 2.1.

Table 2.1: Types of Construction and Upper Limit of the Behavior Factor [48].

Type of construction	Behavior factor q
Unsupported masonry in accordance with EN 1996 alone (recommended only for low seismicity cases).	1,5
unsupported masonry in accordance with EN 1998-1	1,5 - 2,5
Confined masonry	2,0 – 3,0
Reinforced masonry	2,5 - 3,0

Walls of the church were built completely of sand stones put in a systematic style and it hasn't contained on the usual layers. These un coursed walls have two vertical layers (named wythes) of the huge stones in the main building outer walls the total thickness is 123-125 cm, thickness of outer and inner layer is 37 cm (sized 25 w x 50 l x 35h) cm filled in between with small sandstone rubble embedded in a plaster with thickness 50 cm and total thickness of apse walls is 72 cm, thickness of outer and inner layer is 25,37 respectively filled in between with small sandstone rubble embedded in a plaster with thickness 10 cm. All building blocks of wall connected with each other by a mortar with a thickness 1 cm [13]. The fig. 2.1 shows the main outer and apse wall in detail.

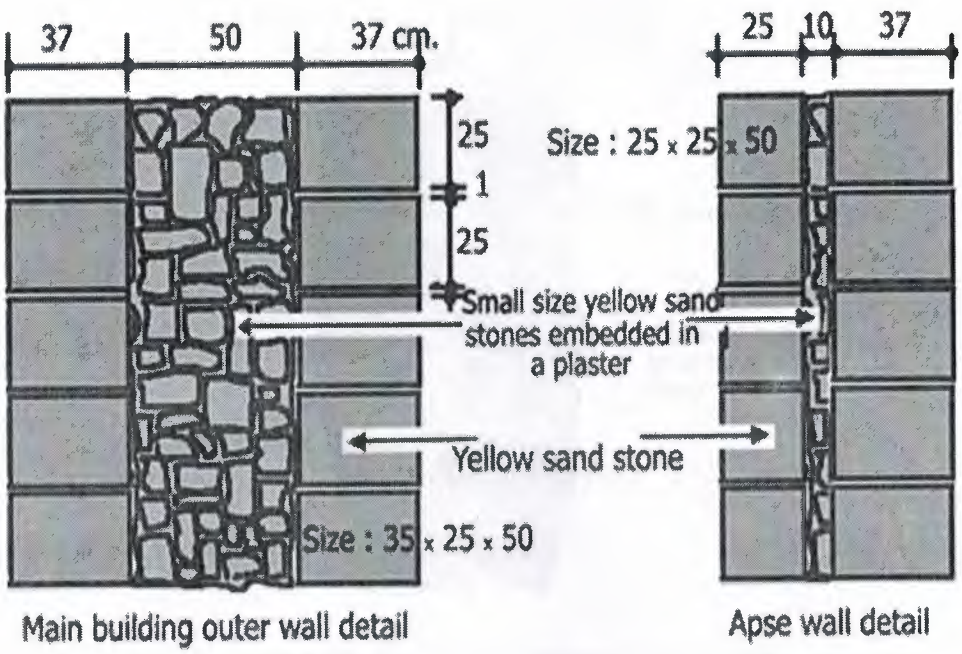


Figure 2.1 The Main Building Wall in Details

Also in India, the stone has been utilized in the construction long time ago

Also in India, the stone has been utilized in the construction long time ago and in a manner similar to the stone walls of the Greek. Because of its carrying capacity for long periods and locally obtainable in abundance where there are great numbers of stone constructions in the towns. In a rustic stone home, the thickness of the stone masonry for the walls was between 600 mm to 1200 mm.

These walls are built with stones developed randomize. As a result of this random arrangement, so the walls of this church don't contain the usual layers where these walls called un coursed wall. The walls of this church involve of two exterior vertical layers and are named wythes. These layers between two horizontal layers of the wall are packaged with loose stone rubble and the bonding material mud. The model of un coursed random (UCR) stone masonry wall is shown below in Figure 2.2.

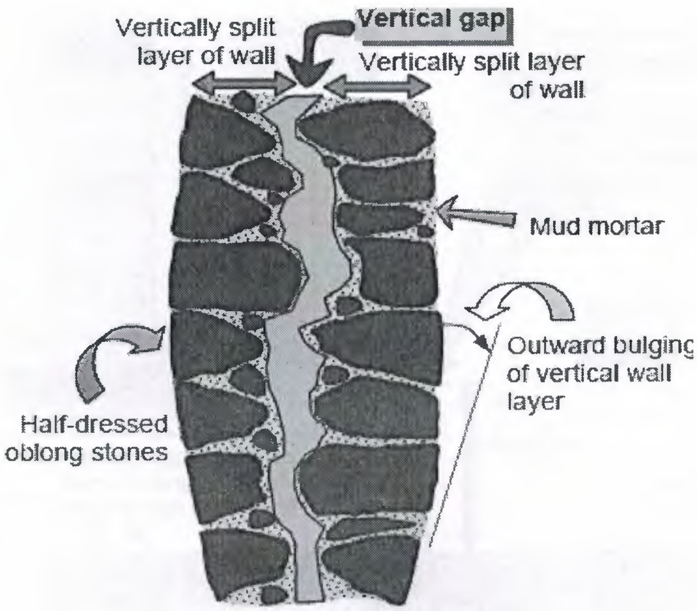


Figure 2.2 The Schematic of the Stone Wall [20].

These buildings are one of the most deficient building systems from earthquake-resistance point of view. The main deficiencies include excessive wall thickness, absence of any connection between the two wythes of the wall, and use of round stones (instead of shaped ones), so it is considered the method of the link between the two wythes with crushed stone and plaster by the Greek is very important in increasing the strength of the walls to resist earthquakes. To avoid the collapse of the stone buildings, under the influence of earthquakes adopted Indians several methods are:

- The wall thickness should not exceed 450mm, used regular stones with avoiding the use of mud mortar in the high seismic zones and replace it with cement-sand mortar should be 1:6 (or richer) and lime-sand mortar 1:3 (or richer).
- Ensure proper bond in masonry to be equal distances which do not exceed 600mm. Through-stones (each extending over full thickness of wall) or a pair of overlapping bond-stones (each extending over at least ¾ths thickness of wall) must be used at every 600mm along the height and at a maximum spacing of 1.2m along the length as shown in the figure 2.3, this technique Been adopted also in the Church of St. George with a little difference where has been using a chock columns to the walls rather than bond-stone.

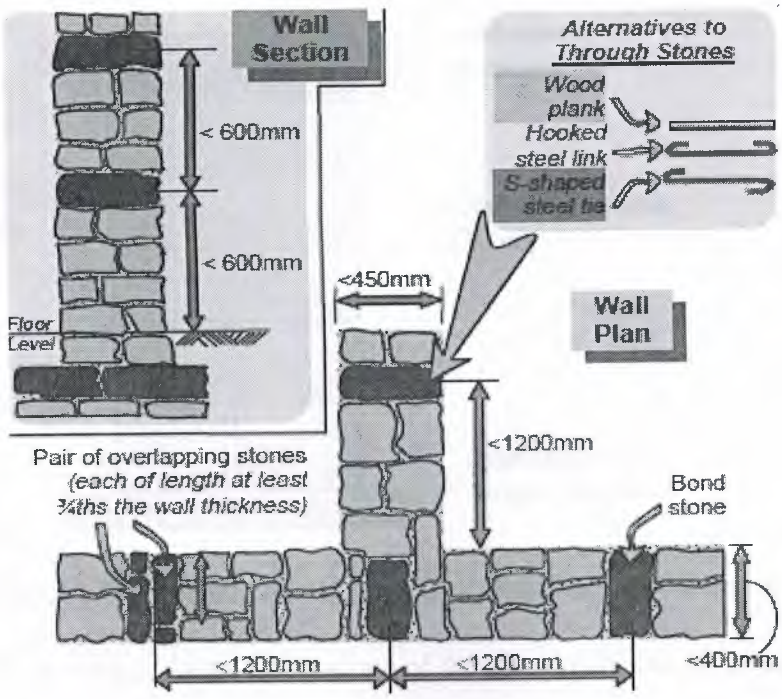


Figure 2.3 The Bond Stone in the Stone Masonry Wall [20]

- Control on overall dimensions and heights: The unsupported length of walls between cross-walls should be limited to 5m; for longer walls, cross supports raised from the ground level called buttresses should be provided at spacing not more than 4m. The height of each store should not exceed 3.0 m. In general, stone masonry buildings should not be taller than two stories when built in cement mortar, and one floor when built in lime or mud mortar. The wall should have a thickness of at least one-sixth its height [20].

Not the walls of the church alone constructed of yellow sandstone as well as the eight main columns of Interior which consider one of the three types of the columns invented by the Greeks which are: Doric style, Ionic style and Corinthian order (The type used in the Church). The columns of church was consists of a huge internal cylindrical shape has diameter 220 cm and height 540 cm and it has pedestal with diameter 240 and height 60 cm its function as joint, building blocks of yellow sand stone also has a circular shape with unequal dimensions (average thickness of one unit is 30 cm) placed in a systematic manner connected with each by a mortar with a thickness 2 cm as shown in the fig. 2.4.

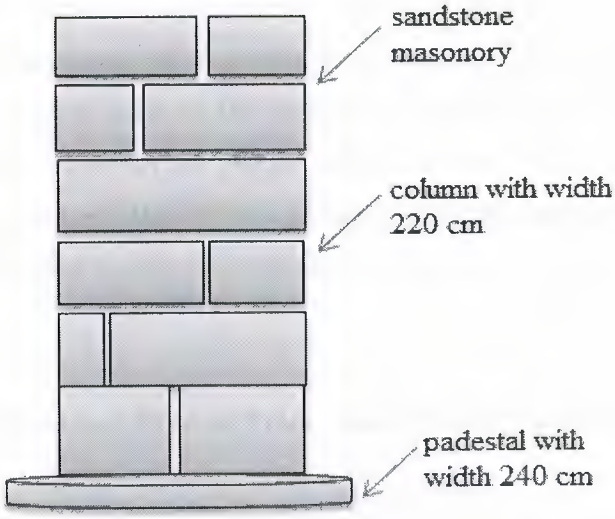


Figure 2.4 The Building Blocks of Yellow Sand Stone of Column

The Greeks used stone material in the construction of the three kinds that have been mentioned of columns, one piece of stone is utilized in the construction. From the architectural side, the type of columns that are used in the construction calling monolithic and this type is consider one of the heavy stones that utilized in constructing the buildings. The other columns that created from stones, they consisted of several portions of stone such as mortared. The utilize of metal pins or stones helps the sectioned columns to link together by carving them with depression or a center hole and that can be seen in several classical locations. It has been observed that, the columns of the Church constructed entirely of sandstone, but the stone interior units were big and take the form quarters or half-circle [21]. As shown in the figure 2.5.

Figure 2.5 Arrangement Units Stone Columns of the Church

The Greeks adopted the architecture precision in the establishment of this church, where they made them a mix of architectural style novelty at the time and high technical engineering in choosing the type of material used in the formation of the Church. The materials used in connecting stone building blocks of the church with each were; cactus extract, lime, egg yolk and H_2O. Benders becomes hard when it sets, resulting in a rigid aggregate structure as well as because it was denser, it better resisted penetration by water [12].

2.3 Chemical Compositions and Physical Properties of Yellow Sandstone and Benders

2.3.1 Yellow Sandstone

Sand-sized minerals or rock grains accumulate together to be a clastic sedimentary rock which called Sandstone, clastic sedimentary rocks are composed of silicate minerals and rock fragments that were transported by moving fluids (as bed load, suspended load, or by sediment gravity flows) which accumulate when slowing down the movement of fluids to rest [22].

The composition of sandstone is quite similar to that of sand, which essentially consists of quartz, with existence a natural cementing material these particles stick together to form sandstone which usually consists of silica, calcium carbonate, or iron oxide. The percentage constitution of each constituent varies between certain limit as shown in the table 2.2

Table 2.2 Percentages of Cementing Materials [23].

Sio_2	93%-94%
Iron(Fe_2 O_3)	1.4%-1.5%
Lime (CaO)	08%-0.9%
Soda (Na_2O) & potash (kro)	1.0%-1.2%
Loss in Ignition (LIO)	1.0%- 1.2%
Magnesia (MgO)	0.2%- 0.25%
Alumina (Al_2O_3)	1.4%- 1.5%

They are highly resistant to acids, alkalis and thermal impact and their insolubility in acids and alkalis is about 97%. Yellow sandstone is Arkosic sandstone. It contains high amount of feldspar, usually dominate by potassium feldspar $KAlSi_3O_8$ or (Potassium Aluminum Silicate) [23].

Feldspars are an important component of many building stones. Potassium feldspars are a group of polymorphs, polymorphs being minerals that have the same chemical composition but slightly different crystal structures. Potassium feldspars are the feldspar minerals in which the silicate tetrahedral and aluminum tetrahedra are bound with potassium ions, rather than sodium or calcium ions as in the plagioclase feldspar subgroup. Using other minerals in the rock to determine the host rock's identity is often the most useful guide to their probable identity [24].

The physical properties of yellow sandstone are:

Associated with most other sedimentary rock types, the capacity of water absorption is 1.67%, medium grained may range widely in degrees of grain sorting and shape structure, bedding is often apparent along with sedimentary structures and fossils, it hardness between 6-7 according to Moh's Scale Density 1.86 kg/m^3, very low porosity can almost neglected, its compressive strength 62.50 kg/cm^2 and Modulus of rupture is14 kg/cm2 [13, 23].

In addition to properties that have been mentioned, the yellow sandstone has the other features such as smooth finishing, perfect texture, very Long life, weather resistance, acid resistance, highly lustrous, high tensile strength and requires no maintenance [23].

2.3.2 Bonding Materials

From ancient times, materials have been modified with all kinds of admixture, aiming to improve their chemical composition, mechanical and physical properties. Binders or other mixtures meant for building purposes have been particularly attractive for testing experimentally a number of natural and artificial additives. Ancient engineers were dependent on natural materials as additives to improve properties of the materials used [25]. The mortar used in cathedral church of St. Georg of Greek is mixtures of three substances are;

Cactus: This material is a plant extract of cactus herbs and roots, its Latin name "opuntia stricta" light yellow in color, its active ingredients is total flavonoids; molecular formula is C19H28O2 and molecular structure as shown in the figure 2.6 [26].

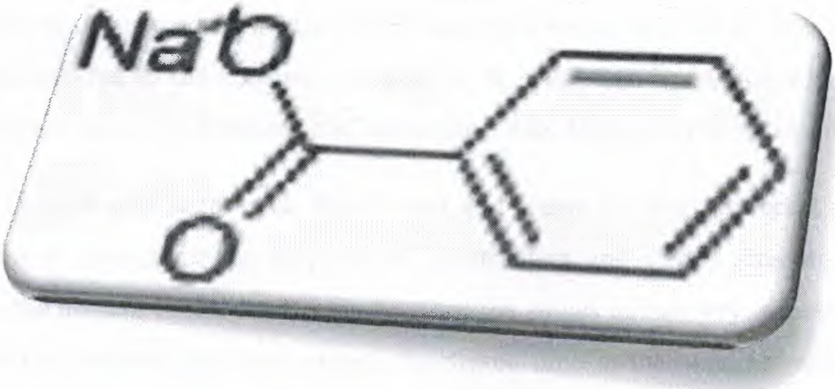


Figure 2.6 The Molecular Structure of Cactus Extract [26].

Still the available literature of ancient materials technologies or the consequences of their modern application in the construction field are scarce, but with recent experiments on the properties of green technology in extracting cactus gum found that its improves durability, strength and plasticity of mortar, where it was found recently that when adding cactus extract to mortars of the standard type used for modern constructions an increase in compressive strength as high as 65 % with respect to standard mortars [25].

Egg Yolk: Use egg yolk in the past as a kind of additives to improve the physical and chemical properties of the binder. The purpose of adding egg yolk had a good performance to strength as a foam material rich in protein can increase strengthen the binder to resist weathering and ensure long-term durability. Recent tests have shown that the strength of mortar added with additive shows higher strength in water curing conditions compared to the air curing conditions where this technology not available in the 14^{th} century [27]. In addition to what has been mentioned, the viscosity of egg yolk is very important to the process of water Retention Refer, the water retention in a mortar was to prevent rapid loss of the mixing water to the air when the mortar contacts a masonry unit with a high absorption rate. Water retention was the mortar's ability to retain its plasticity so that the mason can carefully align and level the units without affect the bond between mortar and unit. Binder must have a good or high degree. Water retention in order to resists a mortar from bleeding when it contact with a masonry unit that has a low absorption rate (as the case with yellow sandstone). If low-absorption masonry units were used with a highly retentive mortar, they may "float" and less retentive mortar may "bleed" moisture [26].

Lime: is the name of the natural mineral which takes place as a result of the fires of coal and the changed limestone due to the volcanic. As well as. It is calcium hydroxide which has organic materials like hydroxides predominate and carbonates. Also lime material is calcium oxide [28].

Slaked lime is combined with sand, liquid mud and water to create different types bonding material which it utilized for the purposes of construction and slaked lime is called calcium hydroxide. In the ancient times, the linking between the stones in masonry is carried by the lime mortar. When the masonry has been placed, the slaked lime in the bonding material bit by bit starts to interact with carbon dioxide to create limestone and it is called the calcium carbonate. In this reaction, the carbon dioxide has ability to soluble in the rainwater. By heating limestone is transformed into quicklime and by hydration, quicklime is converted to slaked lime. Then by carbonation, slaked lime is converted again to limestone. The process of all these transformations is called the Lime Cycle [29]. As shown below in figure 2.7.

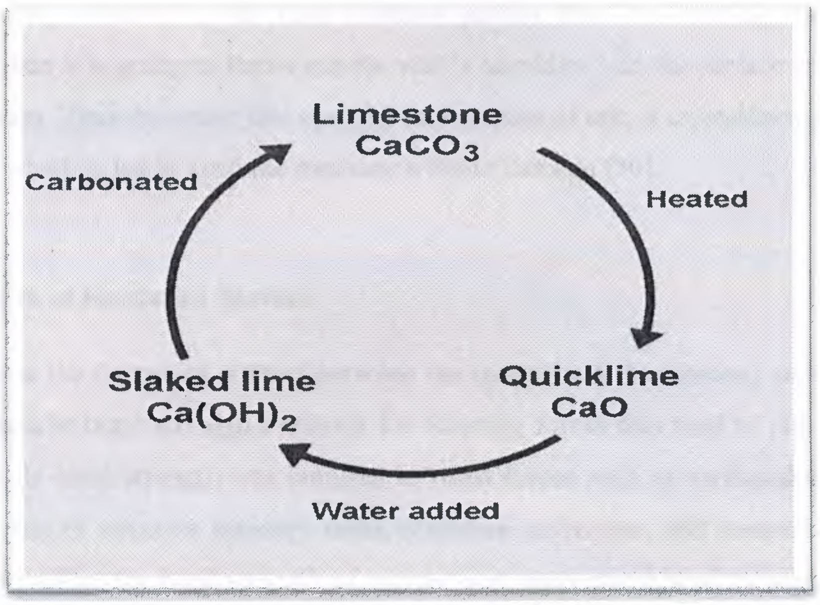


Figure 2.7 The Lime Cycle [29].

There are two main kinds of lime mortar where these types are hydraulic and non-hydraulic. By utilized the water, hydraulic lime is regulated and acquired from lime stone. Non-hydraulic lime requires the air to carbonate and set. It is resulted from high purity of calcium lime stones. Properties of lime mortar are:

- Under cracking conditions, if the quantity of the motion is small then the lime predominantly results abundant micro cracks.
- The soft masonry (such as brick) unit is repeatedly utilized in constructing the historical buildings, and a little movement in the constructions is because of the nature of the foundations.

  This motion smashes the fragile section of the wall. When lime in the bonding material is utilized, the lime is the fragile section in walls, and the cracks in mortar are preferred on the masonry. This helps to reduce the damage and easily reformation. In modern constructing, this movement makes smashes in the fragile section of the wall, and with ordinary Portland cement mortar the bulk exhibition to break is masonry.
- Remains bonding material of lime involve of sand and chalk and these remains can be backed as in the shape of soil's components or in more precise meaning, it didn't contain a disposal issue such as the modern material of mortar.
- The bonding material in the lime contains porous than the bonding material in the cement, then it is going to throw out the wall's humidity into the surface and it will turn into a steam. Thus the water that contains any content of salt, it crystallizes and placed on the lime which is led to keep the masonry without damage [30].

2.4 Bond Strength of Hardened Mortar

Bond strength was the degree of contact between the mortar and the masonry units or in other words was the tensile bond strength available for resisting forces that tend to pull the masonry units apart. Tensile bond strength was required to resist forces such as earthquakes, wind load, shrinkage of mortar or concrete masonry units, Structure movement, and temperature changes. The major factors affect the bond strength of mortar were workmanship of the masonry, quality of the mortar, the characteristic (strength) of the masonry Units, and curing conditions. Bond was high on textured surfaces and low on smooth surfaces. Bond of masonry units was impact by the absorption rates and it tend to retain moisture after they were cured and have relatively low absorption rates, due to hardened and non-porous of sandstone masonry the mortar would reserves water to complete the interactive operations and establish a sufficient bonding strength between them. Furthermore, the tensile bond strength also influence by mortar flow. The proportional relationship between the water content inside the mortar and binding force where an increase of the water content the bond strength also Increases. Relatively, relationship between the water content and the compressive strength of mortar is inverse, where an increase of the water content decreases the compression strength. This can be conclude that using higher water content of mortar was better (with certain limit) and make it is able to retain a workability. In ancient times there was a distinction in good workmanship where can spread the mortar and placing the masonry units in a minimum time move. When the mortar was placed, some of its water will evaporate and some other will absorbed by the masonry units, leaving insufficient water to form a good bond on the next masonry units. The masonry units should not be moved or slid after placed on a bricks and getting its initial assortment to prevent breaking the initial bond. Finally, increasing the proportion of water in the mortar are necessary to improve the conditions of curing and continuation of the hydration for completeness of the chemical reactions of the mixture to reach the sclerosis strength and cohesion required [27].

According to the requirements of the EuroCode8 a minimum strength is required for mortar $f_{m,min}$ = 5 N/mm2 for unreinforced or confined masonry.

2.5 Types of Sandstone Decay

In sandstone elements of the ancient buildings, deep destruction was established. Cases of deterioration of sandstone many depend on the type of stone itself (its physical and chemical properties), kind of superficial working. The various type of degradation: hardening case, exfoliation, contour scaling, granular disintegration, palling and peeling, in addition to efflorescence and black crust occur [31].

Occupies granular disintegration and deep erosion always all the blocks of sandstone in the lower part of the interfaces. Physical and chemical decomposition of sandstone occurs under the influence of many factors, such as groundwater, wind, and the rain, whereas several elements wasted their surface forms wih maintaining the essential parts rarely as shown in the figure 2.8.

Figure 2.8 The Granular Disintegration and Deep Erosion

Peeling is heading to blister and fall off. New opened surface underwent shredder and granular disintegration. The decay of stones that dominate mainly on the facades is exfoliation (as shown below in the figure 2.9). The elementary surface for majority of items was wholly damaged and sheets are separated from the stone element perpendicular to layering.

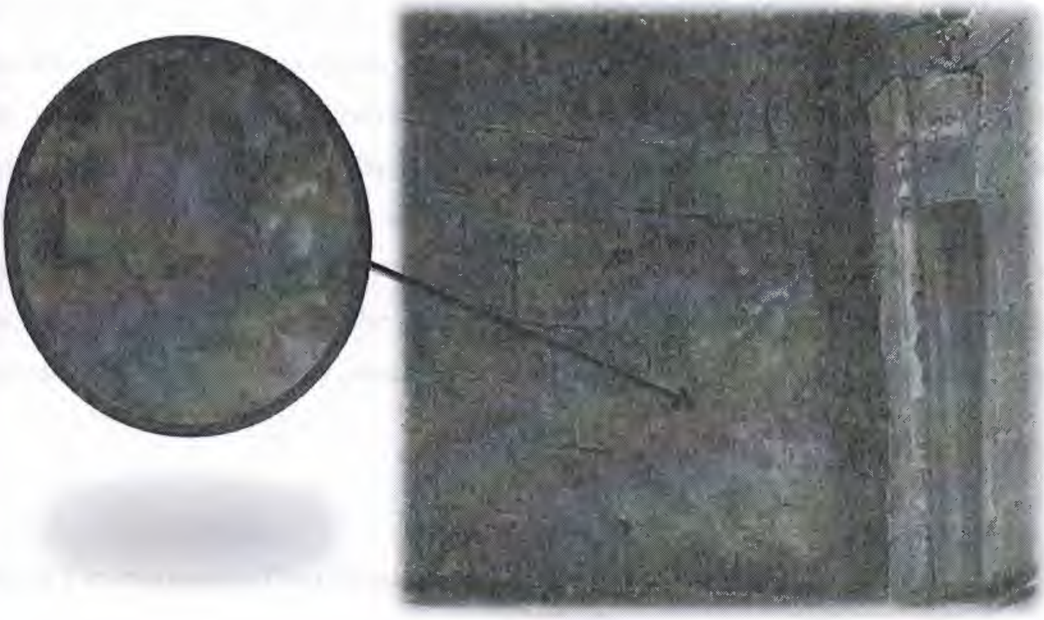


Figure 2.9 The Peeling in the Facades of Sandstone

During dry months, overflow of halite, thenardite, and gypsum locate in the top par of the ground humidity rising to generate black crust which occurs on sheltered sandstone blocks as shown below in the figure 2.10, unattainable for rain. Smoke, the molecules dust or other materials that contaminated the atmosphere and these materials are easy penetrated on blocks with rock faced quoin surface. These crust accelerated to peeling, chipping and exfoliation of blocks of sandstone later [32].

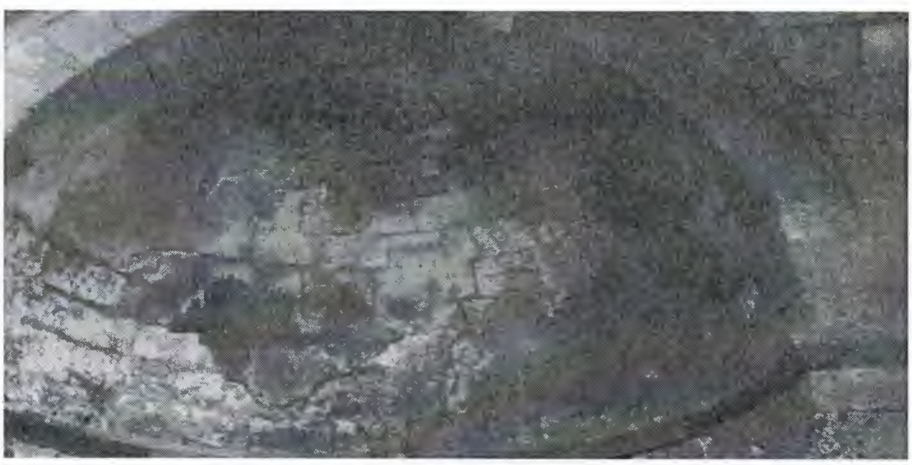


Figure 2.10 The Black Crust of Sandstone

The basic issue of rock's decadence, in the building locations is considered to be the salt crystallization and the water absorption close or below the surface of rock. This is caused by high clay content and the weak matrix material. Then, when the rock is away from the foundation of the structure or it is far from the sea. As well as, the rock is placed in dry environments. It is completely robust without decadence's problem. Problems are generated when the rock has been utilized in structures near the sea. The possible remedial measures to be taken, in the ancient locations, are the protection of the rock from ground and/or sea water absorption and the related salts, by sheltering, water replant coatings, and/or stabilizing agents [33].

2.6 Effect of Environmental Conditions on Sandstone Decay

The velocity of sandstone decay is influenced by climate and atmospheric pollution: composition of the atmosphere and rainwater, direction and velocity of wind, pollutant concentrations of air etc. Generally, all buildings Cyprus are exposed to the medium continental climate with wet and hot summers and a long cold winter, often with fogs and bit of snow. Average yearly precipitation, number of the frost days and the value of high relative humidity winter, accelerate the degradation of sandstones [31, 32].

2.7 Summary

This chapter presented the utilized materials in the Church of St. George and technology promotion. Chemical compositions and physical properties of yellow sandstone and benders are submitted in details form. As well as, types of the sandstone decay and the effect of the environmental conditions on sandstone decay are shown in this chapter.

CHAPTER THREE

STATE OF SOIL AND EARTHQUICKS IN CYPRUS

3.1 Overview

The constructive study for the soil started since the ancient times, where over ten thousand years ago and long before from the invention of writing or usage the metal tools. The urgent need for constructing the buildings, construction of vast irrigation systems and the invention of agriculture brought the need to know the mechanical behavior of the soil which interferes in their behavior with those facilities for the first time. Study the earth and its properties became and still is an important issue of practical necessity [34].

Mechanics of soil is defined as a part of the mechanics since that handle with influence of forces on the soil, where the term of the mechanics can be defined as a physical science branch that handles with the forces as well as the energy and their impact on the structure of buildings. The soil is considered as one of the most widely substances that faced the structural, architectural and civil engineering especially which is placed at or near the ground surface. There are structural parts in civil engineering to be in direct contact with the soil such as the foundations, eventually rest upon rock or soil. Hence, settlement behavior and the load capacity of foundations essentially relies on the underlying soils properties, their behavior and reactions due to the stress imposed by the foundation, and this in turn may create the effects of external forces such as earthquakes, act on these systems itself, neither the structural displacements nor the ground displacements, are independent of each other , the process of the soil response to the influences the motion of the structure and the motion of the structure influences by the response of the soil is called soil-structure interaction (SSI) which considers a special field of earthquake engineering since all seismic structural response is affected by forces of soil structure interaction that effect on structure according to the definition of seismic excitation, so in high degree of material importance from viewpoint of civil engineering is soil ranks if compared with the various materials such as (i.e. brick, concrete, mortar, steel, etc.) which are used in construct all constructions [12, 35].

3.2 State of Soil in Cyprus Island

3.2.1 The General Definition of Soil's Mechanisms

Soil is the basic material that used in construction all types of buildings (huge and normal) such as: the retaining walls and the dams. As well as, structures of buildings whatever the material that from them, eventually they are rest upon soil or rock. It is appropriate from the viewpoint of civil engineering to regard the soil as a structural material where according to its properties of the underlying has been identify the load capacity and settlement behavior under the stress imposed by the foundation [35].

There are structural parts in civil engineering to be in direct contact with the soil such as the foundations. There is a special branch to study the behavior of the soil and buildings combined together that it is so- called soil structure interaction (SSI). Analysis of soil-structure interaction (SSI) consider as a stand-alone field from earthquake engineering. It should be useful to starting with the definition. Common sense refers to that all seismic structural response is a result to the effect of soil structure interaction forces due to affected of structure according to the definition of seismic instigating. the community of engineering identified that the soil-structure interaction taken into consideration only when these forces of interaction are able to alteration the motion of basement in comparison with to the free-field traumatic movements where this land movement recorded on the free soil surface when no structure. The traditional definition of SSI is quite various from the forces of interaction occurrence. SSI occur for all buildings, and always it doesn't able to change the movement of soil. This simple scientific fact that important lead to the important result which is no SSI effects if a structure was based on rigid foundation and it can be analyzed as free-field motion at it. There are two main factors has the ability to change the soil motion by the interaction forces which are: flexibility of the soil foundation and value of the interaction forces. The value of the interaction force can be calculated through the inertia of the structure and base mat acceleration. Consider the heavier part in the given soil site and given free-field seismic excitation is the structure, the soil structure interaction effects incidence the more likely.

Usually the SSI affects hardly be neglected for the civil structures that resting on hard or medium soils where it does not show the considerable signs [12].

In 1943, the book of "Theoretical of Soil Mechanics" for Dr. Karl Terzaghi. Where the author in this book mentioned that the mechanics of soil supply with the job of hypothesis. Since our understanding for the physical characteristics of the subsoil is constantly insufficient or patchy frequently. However, from the view point of the practical side, the working hypothesis that submitted by the mechanics of soil is considered as an important theory of installations for the rest sections of the civil engineering [36].

Soil or rocks are subject to change on an ongoing basis physically and chemically under geologic processes caused by the climate and other prevailing factors such as, leaching, drought, freeze/thaw, vegetation, erosion, rainfall, and other natural processes that cause the profound changes gradually taking place in the soil recipe with over time. Soil profile is considered a consecutive series of nature-related changes from the surface to the layers below the ground surface differ in composition, thickness and the physical characteristic for each layer which it's mainly vary from each other and can be distinguished by differences in the degree of weathering and color. Typically the upper layer of the profile is rich in animal residues and organic plant mixed with particular mineral-based soil. The soil nature depends mainly on sediment accumulation of other mineral particles produced by the physical and chemical disintegration of rocks in addition to water, air and organic material that can be included and which play an essential role in the intensity of the engineering behavior. The origin of soil can be divided to two basic types are; residual, and transported. It advantages are properties depend on the climate and other factors prevailing in the geological site soil as well as this type favorite from the construction to its ability to support foundations and engineering properties predictable. Transported and deposited soils are derived by the movement of soil from one location to the other by natural means such as wind, water, ice, and gravity.

The character of the resulting deposit often expresses the modes of transportation and deposition and the source material that's where deposits by water include alluvial flood plains, coastal plains, and beaches, deposits by wind include sand dunes and loess and deposits by melting ice include glacial till and outwash. Each substance of soil behavioral properties that depend on the geological origin, and are usually the poorest soils in terms of engineering properties are transported by wind [35].

3.2.2 Soil Classification in Cyprus

For the great importance of understanding the behavior of mechanical soil and its impact on the construction of buildings was adopted soil classification system on the island of Cyprus in accordance with the methodology of studies aiming to collect physical and chemical properties of the soil where this system has been adopted since the beginning of 1957. Soil classification system adopted mainly on the formation of composition, origin and parent of the materials in the soil [10].

The first soil classification system used was based mainly upon the formation, the origin and the parent materials of soils. Accordingly, soils were classified as Red soils, sedentary soils, and alluvial or colluvial soils. Usually, an examination of the master horizons (A, B, C, D) including soil physical and chemical analyses were carried out in order to classify the soils of these groups into soil series and types. Major soil constrains in Cyprus can be divided into two major categories; The first category includes deep soils located mainly in the valley areas, the second one includes shallow soils lying on geological formations of the mountain and semi mountain areas [37].

Generally that type mostly on the island of Cyprus is red soil which has a reddish tinge as a result of the presence of iron compounds in the soil composition. Some types of red soil are clays, Clay soil which has a heavy concentration of clay particles and this means the soil stiffness [10].

Located Famagusta over Terrace deposits which are mainly formed by Calcarenites, sands and gravels, precisely and according to the information that has been obtained from the Geological Survey in Cyprus the depth or thickness of each layer and type of material composed, as shown in the table 3.1:

Table 3.1: The Soil Layers in Famagusta

Depth/thickness (m)	Type of layer
0,00- 0.50	Terra- roosa
1.00	
0.50- 3.00	Calcarenite
1.00- 5.00	
3.00- 20.00	sandstone
5.00- 25.00	
20.00- …….	Marl- clay stone
25.00- …….	

Geological map of the Cyprus island as shown below in the figure 3.1, describes the soil layers for each region, where it was found that the site of the church inside the fort of city Famagusta the cursor with Wight color consisting mainly of sandstone, silts, clays, calcarenite and gravels [38].

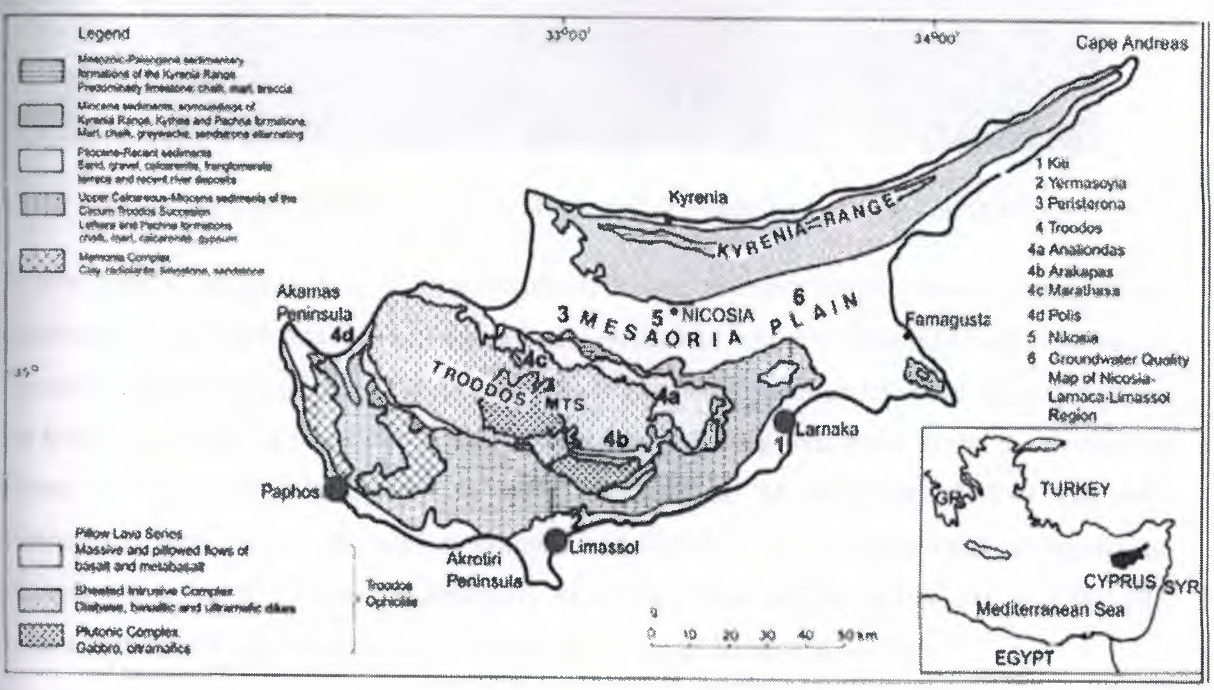


Figure 3.1 Geological Map of the Cyprus Island [38].

Presence of organic matter results in an inhomogeneous and anisotropic fabric, which further complicating the engineering behavior of these soils.

3.2.3 Laboratory testing of soil Church

To simulate the soil conditions of the cathedral church of Greek of the real problem as close as possible. This research depended on the report prepared for the soil conditions of the St. Nicholas cathedral church, where this church located 100 m far from the other church (as shown in the figure 3.1 captured by Google earth).

Figure 3.2 Church of St. George of Greek and St. Nicholas Cathedral on One Font

Where shallow seismic survey sand geotechnical drilling were performed. Seismic surveys were conducted by a receiver cable and 48 geophones positioned with 1 m interval along the Western facade of the structure (Fig. 3.2) in order to obtain 2 dimensional P-and S-wave velocity profiles up to30 m depth along this cross section. Geotechnical drilling took place at the South western corner of the structure until 30.2 m depth was reached. At every1.5m, SPT-N (Standard Penetration Test) values were also determined and disturbed samples were taken to be able to classify the formations below the structure. Results indicate that the soil condition at this site with a specific $Vs_{,30}$ (the rate velocity of shear wave up to 30 m) was 560 m/s.

It was calculated from the following expression:

$$v_{s,30} = \frac{30}{\sum \frac{h_i}{v_i}} \tag{2.1}$$

This value corresponds to the B Ground type, described by the stratigraphic profiles and parameters given in Table 3.2 according to E.C8.

Table 3.2: Ground Type According to Eurocode8

Ground Type	Description of stratigraphic profile	Parameters		
		vs,30 (m/s)	**NSPT (blows/30cm)**	**cu (kPa)**
A	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.	> 800	-	-
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of metres in thickness, characterised by a gradual increase of mechanical properties with depth.	360 – 800	> 50	> 250
C	Deep deposits of dense or mediumdense sand, gravel or stiff clay with thickness from several tens to many hundreds of metres.	180 – 360	15-50	70-250
D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.	< 180	< 15	< 70
E	A soil profile consisting of a surface alluvium layer with vs values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with vs > 800 m/s.			
S1	< 100 (indicative)	-		10-20
S2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A – E or S1			

Regarding for motions up to a depth of 4 m artificial fill of clay, sand and gravel mix exists. Between 4 and 20 m, calcareous sandstone and below 20m up to the end of the borehole, hard salty clay was encountered. Results indicate up to 15%lower velocity values at the Southern end of the cross section analyzed than the Northern end between the depth values of 10 - 30m [39].

Fig. 3.3 Church of St. Nicholas Cathedral [39].

Seismic waves move faster through hard rock than through soft rock and sediments. As the waves pass from harder to softer rocks, the waves slow down and their amplitude increases. Thus shaking tends to be stronger at sites with softer surface layers, where seismic waves move more slowly. This leads to the fact that the increased capacity of amplitude seismic due to slowdown waves at the upper layers consisting mainly of clay, sand, and a little gravel thing that leads to an increased risk of earthquakes on the structure of the Church where found that the ground motion above soft soils can be more than 10 times stronger than at neighboring sites on rock for small ground motions [40].

3.2 Earthquakes in Cyprus Island

3.2.1 General concept of earthquakes

An earthquake is malfunction occurs due to sudden rupture of rocks ground by large internal stresses exceed resistant of rock's strength. The malfunction may be newly created by the earthquake rupture or may be present originally. Energy caused by malfunction is transmitted as seismic waves that cause nearly all damaging earthquake effects. When the break line (the fault) between two blocks of rock suddenly moves, the movement causes vibration (seismic waves) to race rapidly out ward in all directions from the focus the point at ground level directly above the facus is called epicenter as shown in the fig 3.4. The size of an earthquake is often expressed in terms of Richter (or local) magnitude, denoted by ML, and was developed by Charles Richter for California in 1935. Richter magnitude is determined by measuring the amount of seismic energy released by an earthquake (seismic wave amplitude) [11].

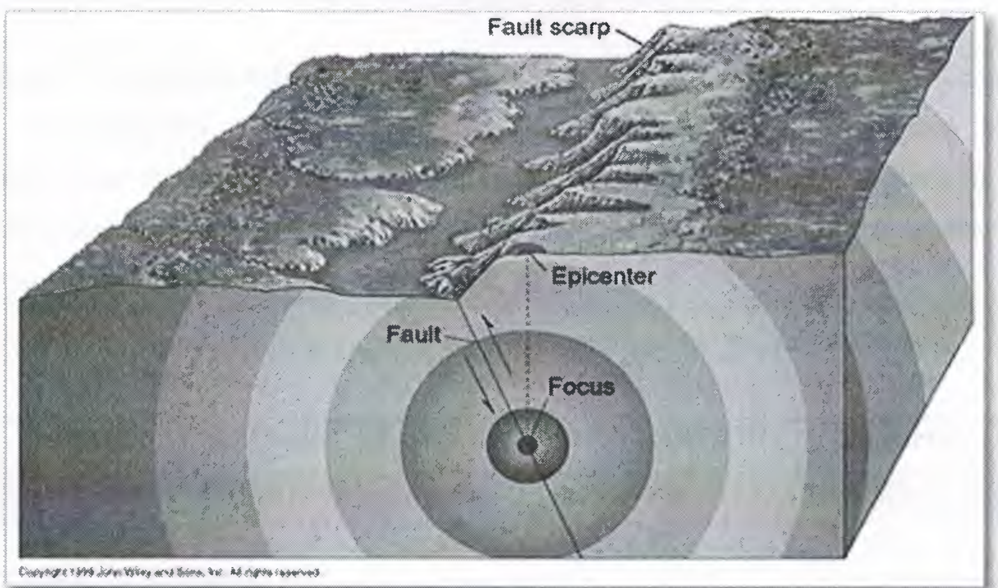


Figure 3.4 Earthquake's Mechanism [11].

3.2.2 History of Earthquakes in Cyprus

The last archaeological discoveries and the historical sources display that Cyprus was exposed to the successive earthquakes since many times ago. These successive earthquakes smashed Famagusta's city (Salamis) and it also destroyed the town of Nicosia. By using the modified Mercalli scale, Cyprus was exposed to sixteen of the earthquakes with intensities of VIII between 26 BC and 1900 (Anno Domini). In 76 A.D, Pafos was damaged along with Kition and Salamis, where this is the strongest earthquake that ever knock down Cyprus. Town of Salamis and Pafos's city were damaged once more between 332 A.D and 342 A.D [7, 41].

More accurate data have been collected, regarding the earthquakes occurring in Cyprus and the surrounding offshore area since 1896, when seismological stations started operating in neighboring countries. The situation regarding the accuracy and completeness of the earthquake recordings improved considerably after 1984, with the establishment of a seismological station in Cyprus and its continual expansion and upgrading. A better picture of the seismicity of the Cyprus region started developing and the areas with higher seismic activity were more clearly recognized. In the time period 1896-2004, more than 400 earthquakes with their epicenters on Cyprus and the surrounding region were felt in several areas of Cyprus. Of these the following 14 earthquakes caused damage and in some of them there were many victims [41].

The history of earthquakes suffered by Cyprus cities since 26 BC can be observed in the table 3.3 below which describes latitude and longitude values depending on the intensity scale of earthquake using descriptive scale – the Modified Mercalli Intensity Scale is given in Roman Numerals where values range from I to XII (Roman Numerals were converted to numbers in the digital database. Values range from 1 to 12.) [42, 43].

Table 3.3: History of Earthquakes in Cyprus [42].

Date	Latitude	Longitude	DESCRIBTION	Remarks
26 (B.C.)	-	-	VII	PA
15 (B.C.)	-	-	IX	PA
76	-	-	X, IX,X	SA,PA,LR
110	36.20	36.00	VIII	-

332	-	-	VIII	SA
342	-	-	X	PA
367	-	-	VIII	AK
394	-	-	VII	PA, SA
500	36.12	35.90	VI	-
526	36.12	35.90	VI	-
1183	-	-	VIII	PA
1222 May	-	-	IX,VIII,VII	PA,LI,NI
1268	-	-	V	CY
1491 Apr 25	-	-	VII,VI,V	NI,MG,PA
1546 Sep 29	-	-	VI	NI,MG
1567 Apr 25	-	-	VI	PA
1577 Oct 28	-	-	VI,V,V	LI,NI,SA
1718 Dec 19	-	-	VIII	NI
1735 Dec	-	-	VII	MG
1741	-	-	VI	MG
1822 Aug 13	-	-	VI	MG,LR
1822 Sep 5	36.00	36.00	VI	-
1854	36.12	35.90	VI	-
1873	36.12	35.90	VI	-

3.2.3 Seismic Classification of Cyprus Island

Cyprus placed between the belt of Alpine and Himalaya. This position is considered the second most area susceptible to the earthquakes on the earth. These earthquakes represent about 15% from the seismic activity in the world. The severity of seismic is attributed to the arc of Cyprus and it is represented the tectonic boundary between the Eurasian plate and African plate as shown below in figure 3.5. The diving of the African Plate under the Eurasian Plate generates numerous earthquakes along the arc of Cyprus and many active faults inside the island have seen that earthquakes likewise happen along them [7].

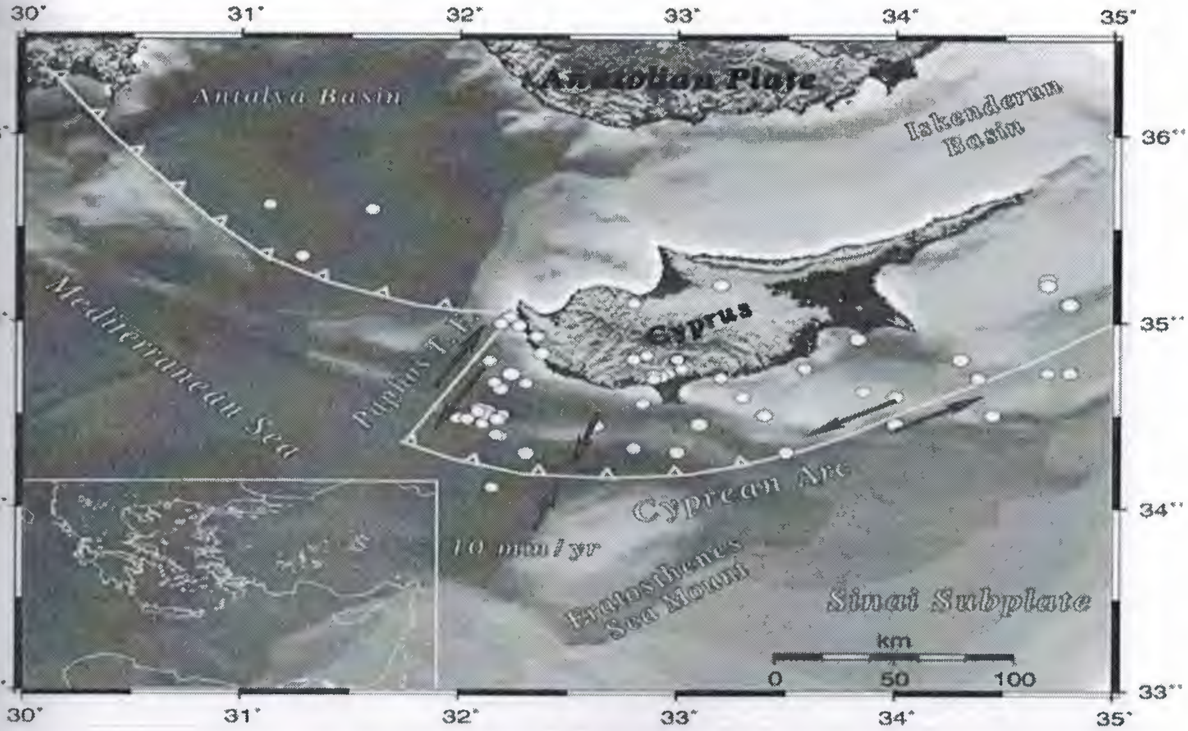


Figure 3.5 Geomorphologic Map of the Study Area with Plate Boundaries and Relative Motion. Epicentral Distribution of Shallow Earthquakes with M ≥5.0 [7]

The regional stress evolution is calculated in the area of the Cyprean Arc that constitutes a segment of the plate boundary between Eurasian and African lithospheric plates. The seismic activity onshore and offshore the southern coast of Cyprus Island is primarily caused by slip on faults arranged obliquely to the plate boundary. Earthquake interaction is a fundamental feature of seismicity, leading to earthquake sequences, clustering, or aftershocks. One interaction criterion that promises a deeper understanding of earthquake occurrence. A tectonic zone which starts at Castelorizo Island near turkey and continues south of cyprus to end up north at the area of the turkey-Syria border as shown in the figure 3.5 below. The structure of the Cyprian arc is complicated; there is not a clear view on whether it is a plate boundary [(McKenzie, 1972) in Ambraseys and Adams, 1992], or a broad zone of thrusting, [Rostein and Kafka, 1982) in Ambraseys and Adams, 1992] there is evidence (earthquakes at sub crustal depths) that sub duct ion is occurring in the Antalya basin, the north-west part of the arc, and there is an unproven theory that this sub duction zone extends towards Cyprus. It accommodates the convergence between the African plate to the south and the Anatolian Plate to the north in the eastern Mediterranean [44, 45].

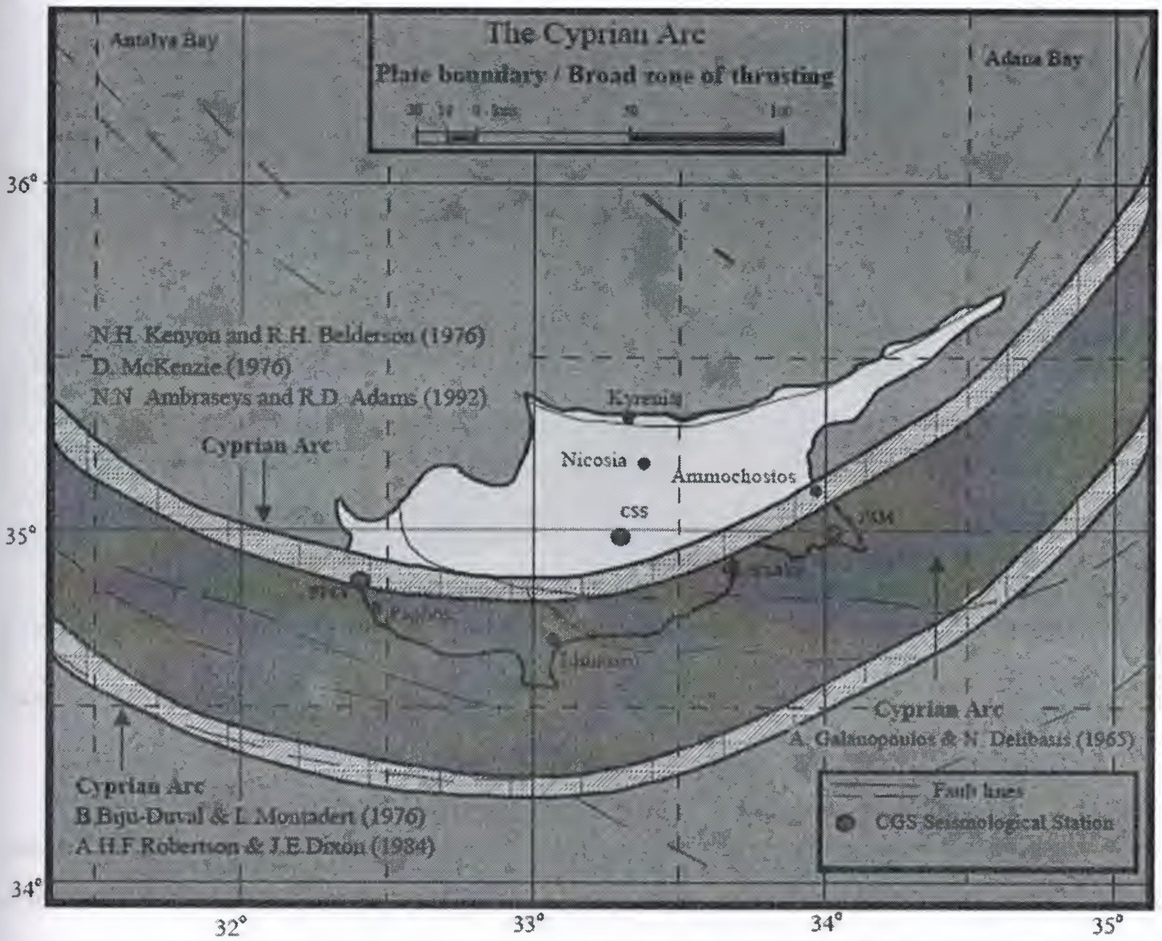


Figure 3.6 Cyprian Arc (after Kythreoti et al., 1998) [44]

Seismic zones of Cyprus Island were divided to three different regions as shown in the figure 3.6 that have been identified by the commission for the Revision of the zones of the Cyprus Ant seismic Code, this three different zones have three different values (0.15 g, 0.20 g and 0.25 g) of the maximum expected ground acceleration (PGA) with 10% probability to be exceeded in 50 years, where G=9.81m/s^2 [46].

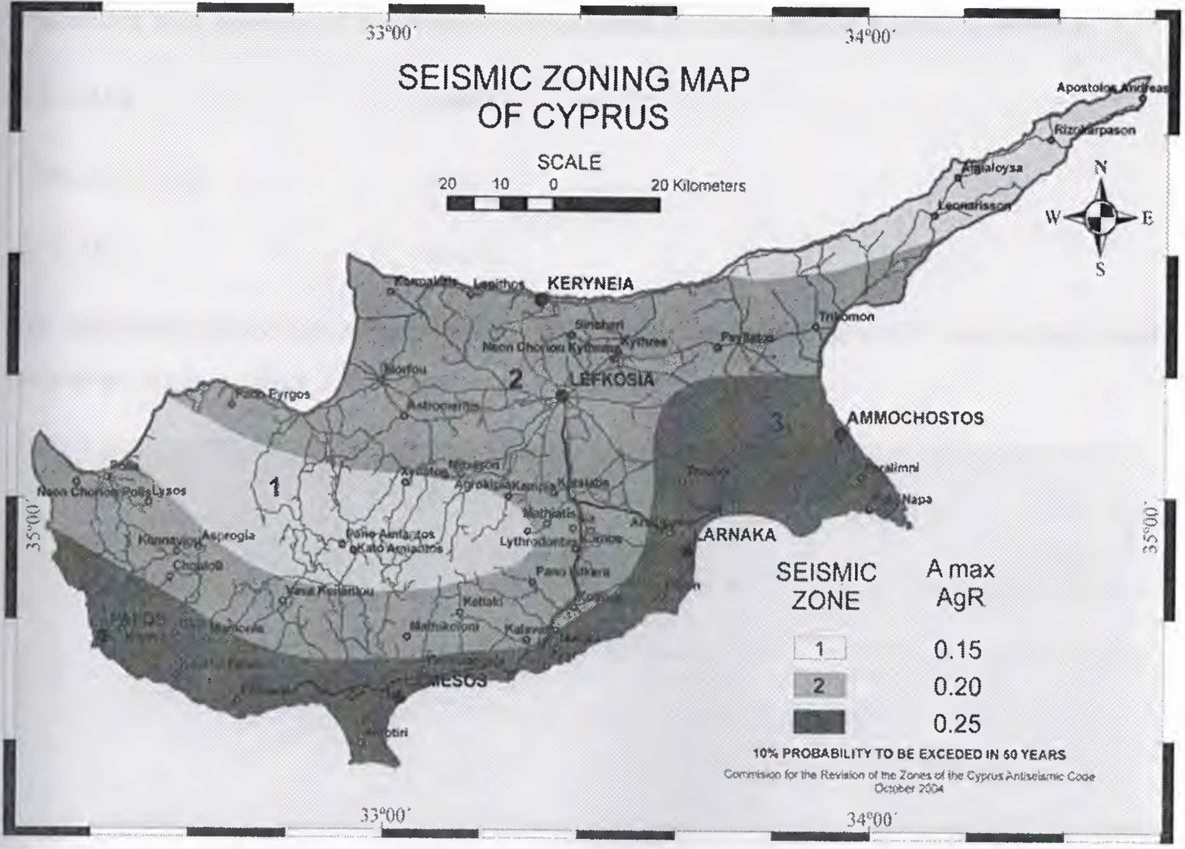


Figure 3.7 Map of the Seismic Zone of Cyprus [40]

According to the Seismic Hazard Map of Cyprus, the maximum peak ground acceleration (PGA) at the rocks for the south and the west region of the island, where Famagusta is included, is about 0.25g. This value is the highest within the whole territory compared with the minimum PGA of 0.15g, which occurs in the north and center regions. In addition, the map above is definition of reference peak ground acceleration on type a ground. It is to be emphasized zonation is done on a macro basis and should be modified considering local soil conditions and require further micro zonation studies. As shown in the figure 3.7, Famagusta (research site) is located over Terrace deposits which are mainly formed by Calcarenites, sands and gravels, increasing the seismic demand to about 0.35g, when compared to areas that are covered with rock, where it is represent the brown area that mean the upper limit pointer in Cyprus which comprises the upper layers of clay, sand and a little gravel. According to the fact that seismic waves move faster through hard rock than through softer rock and sediments .As the waves pass from harder (sandstone) to softer (clay and sand), the waves slow down and their amplitude increases [40, 42].

The zoning map is proposed to division Cyprus Island according to the following criterion:

A ≥ 0.24 g	zone I
0.18g ≤A <0.24g	zone II
A <0.18g	zone III

The Bayesian estimate hazard map in term of PGA and corresponding to 475 years is duplicated on a larger scale in figure 3.8 below.

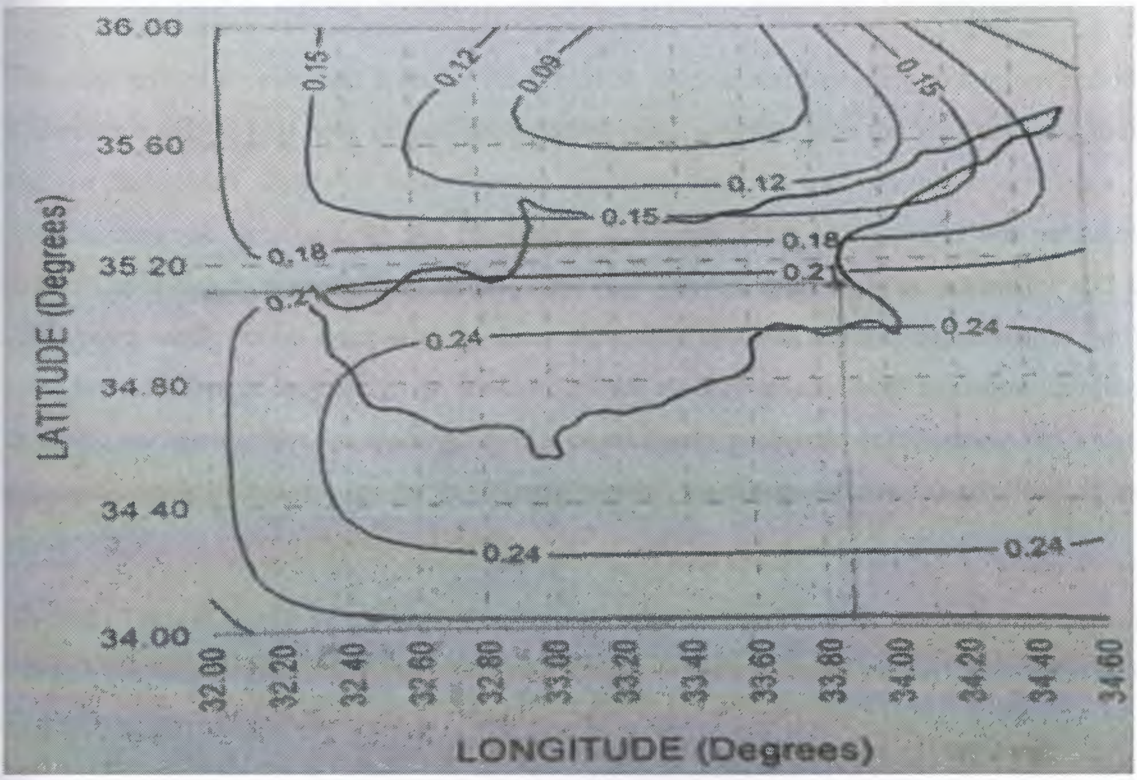


Figure 3.8 A proposed Macro Seismic Zonation Map [42]

The macro seismic zonation map above showing location of Famagusta from the seismic zone within II zone (0.18g ≤A <0.24g) at the latitude and longitude (35.12, 33.88) respectively [42].

While a similar map of instrumental recordings of the Seismicity and Seismic Zones of Cyprus (as shown in the figure 3.7) gives the results presented in below.

Zone I 0.15

Zone II 0.2

Zone III 0.25

Map of the Seismicity Seismic Zones showing location of Famagusta at the latitude 35° 8' 0" and longitude 33° 77.5' 0" and the Seismicity available within the region are 3.0- 4.0, 4.0-5.0.

The peak ground acceleration level for the site of St. George corresponding to a return period of 475 years is 0.29g. This peak ground acceleration value, together with the $V_{s,30}$ value of 560m/s and the Eurocode8 suggested base response spectrum function was utilized to develop a site specific response spectrum for the St. George Cathedral. The 475 years return period was selected specifically because Euro code 8 base response spectrums can be scaled for 475 and 2475 years return period level sand the latter represents an unrealistically high seismic loading level for the focus of this study. In addition, all the modern structures of Famagusta are being designed for the earthquake loading of 475 years return period hence obtaining the level of damage and rehabilitation costs for St. Georg Cathedral for this specific earthquake loading level would allow making comparisons [47, 48].

Through Table 3.3 will be assigned the highest amount seismic was subjected by St. George Church through Structural age based on latitude and longitude that showing the location of the Famagusta from seismic intensity [42, 49].

Table 3.4: The Seismic Values were Suffered by Famagusta City Since 14 Th Century [42, 49].

Seq.	Date	Latitude	Longitude	MAGNITUD
1	1491 Apr.25	36.12	35.90	VI
2	1546 Sep.29	-	-	VI

3	1735 Dec.	-	-		VII
4	1741	-	-		VI
5	1822 Aug.13	36.12	35.40		VI
6	1822 Sep.53	36.00	36.00		VI
7	1854	36.12	35.90		VI
7	1873	-	-		VI
9	1900 Jun.5	34.00	34.5		5.7
10	1900	35.20	33.20		5.9
11	1900 Mar.3	-	-		-
12	1901 Feb.28	-	-		-
13	1902 Jan.17	-	-		-
14	1902 Mar.14	-	-		-
15	1903 Apr.23	-	-		-
16	1918 Sep.29	35.200	34.700	12:07:05	6.5
17	1919 Aug.19	-	-	20:17:02	5.4
18	1919 Aug.29	-	-	20:17:00	5.0
19	1924 Feb.18	34.500	34.000	17:03:56	5.8
20	1924 Jun.9	35.200	33.300	21:34:35	4.6
21	1940 Jul.24	34.500	34.500	22:15:01	5.7
22	1961 Oct.15	34.980	33.830	01:46:10	5.5
23	1941 Jan.20	35.200	34.600	03:36:05	6.5
24	1948 May.22	34.890	33.810	08:11:29	4.1
25	1994 Aug.11	35.270	34.740	06:56:02	4.1
26	2001 Oct.1	35.050	33.950	19:22:43	4.0

3.3 Behavior of Structure due to Earthquakes

3.3.1 Introduction

The nonlinearity is the most important and significant property of a structure which mainly comes from local failure or micro failure of its components in addition to the materials nonlinearity of their constituent. At small amplitudes, a structure may usually be considered linear [50]. The performance of buildings through the powerful earthquakes was utilized as ancient methods to train the workers on the appropriate build and incorrect build of seismic load resisting systems. In areas that were populated since a long period of time, and that are exposed to the different powerful earthquakes. The steps of design have developed and that produce a perfect performance in the structures. Due to the regional disparities in the styles of building, the procedures of design are not globally applicable. The destructive capacity of the powerful earthquakes is completely famous and is satisfied as an essential assumption by the several of design codes. During the infrequent earthquake, destruction in the structures is acceptable but the total damage in the structures is not acceptable in any case [51].

3.3.2 Structural Performance during Earthquakes

Harms caused by the earthquake relies on the several major elements like the build quality, the duration of the earthquake, status of the soil, frequency, seismic intensity and the content of earth movement. In order to make sure that the construction has enough strength must be designed with high ductility.

To study the performance of the earthquake for any structures during the intensity of shockwave, site condition effects on building damage, ground shaking effects on structures. The fundamental causes of the damage that is caused by the earthquake must be identified, where these causes are: tsunamis, shaking of ground, fire and ground failure.

- **Ground Shaking:** The essential reason of the earthquake that caused the damage on the buildings is ground shaking, where all constructors on the surface of land are going to respond to the vibration of the earth with different degrees. Earthquake can harm or smash any constructor unless these buildings were constructed and built or enhanced to resist the intensity of the earthquake. Earthquake motions have random nature so that the Seismic design loads are extremely difficult.

The ground shaking itself affected on the structure by several factors such as:

- **Inertia Forces:** Constructors are mechanically repaired to the earth as seen below in figure 3.7 (a). In the patchy mode and because of the inertia of the masses, the vibration and shaking in the position superstructure with its contents will occur. When the building's base is unexpectedly displaced to the right side, the reaction of the building is toward the left side. Where this movement toward the left side was due to the invisible force and this force is called inertia forces as shown below in figaure.3.9 (b). In fact, the mass of the building is caused this motion in opposite direction. this movement is considered as complicated process on account of the earth moves at the same time with each other in three orthogonal directions during the earthquake as shown below in Figure 3.9 (b), (c), and (d).

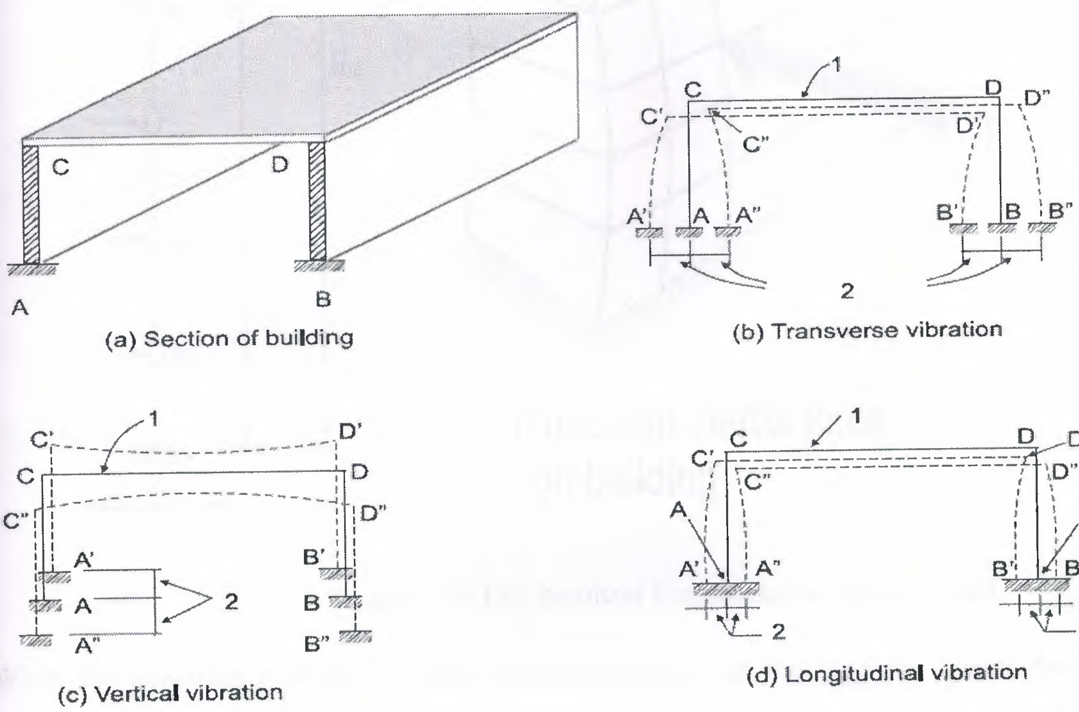


Figure 3.9 Seismic Vibrations of Any Building in General [50]

- **Seismic load:** The seismic load is denoted by the force "F" as seen below in figure 3.11. Also, the seismic load is called the resultant of the lateral force. F is completely various from the wind load, live load, impact and dead loads. The action of horizontal force that hit the constructor looks like the effect of the horizontal earth movement.

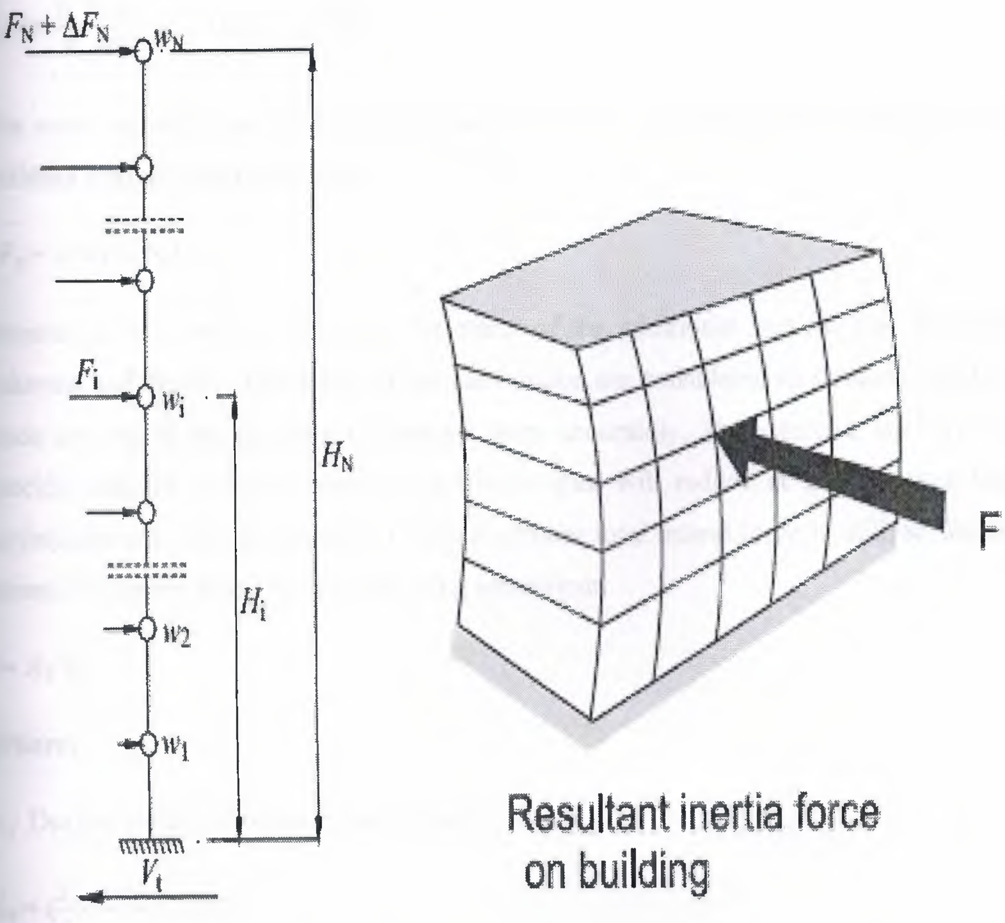


Figure 3.10 The Resultant Earthquake on Building [50]

When the constructor moves in sophisticated technique, at the base the inertia forces are generated due to the mass of constructor and its component. These forces are considered as counterproductive forces which cause the movement in the building in some case or the damage in other case. The value of this horizontal (lateral) force can be calculated from the following equation [50]:

$$F = (V_t - \Delta F_N)\ \frac{w_i\ H_i}{\sum_{j=1}^{n} w_j\ H_j} \tag{3.1}$$

Total Equivalent Seismic Load V_t (base shear), acting on the entire building due to the earthquake direction shall be determined by;

$$V_t = \frac{W\,A(T)}{R_a(T)} > \quad 0.10\,A_{\circ}IW \tag{3.2}$$

The value of additional equivalent seismic load, ΔF_N that acting at the last story (roof N) of the building shall be determined by;

$$\Delta F_N = 0.0075\ \mathrm{N}\ V_t \tag{3.3}$$

Because of the vertical vibration, the effect of the additional vertical load is impacted on the columns and beams. The loads of the earthquake are considered as dynamic loads where these loads are out of the question to forecast them accurately. The effective load will increase at a specific amount of time, while the effective load will reduce at another time because every earthquake has various proprieties. The minimum total lateral force is utilized for designing the seismic as shown below in the following equivalent.

$$F = A_T \mathrm{W} \tag{3.4}$$

Where:

A_T Design horizontal seismic coefficient.

$$A_T = \left(\frac{Z}{2} * \frac{S_{a(T)}}{g}\right) / \ (\mathrm{R/I}) \tag{3.5}$$

- Z factor or the factor the of seismic zone: This value of seismic zone depends on the type of seismic zone, according to the table 3.5

Table 3.5: Seismic Zone Factor [57]

Seismic zone	**II**	**III**	**IV**	**V**
Seismic Intensity	Low	Moderate	Severe	Very severe
Zone Factor	0.1	0.16	0.24	0.36

The number 2 in the denominator of Z is used as factor to reduce the maximum considered earthquake (MCE) zone factor to the design basic earthquake factor (DBE) factor.

- I or the Importance Factor: the constructor's design of any building must be depended on their applications before the earthquake and after it. Such as buildings that provide necessary utilities for instance: schools, infirmaries, monumental structures, power houses, important bridges, subways, firefighting's center, meeting stations and others. The value of the importance factor for the constructors that mentioned above is 1.5 and they should be designed accordingly, while the value of the importance factor is equal to 1.0 for general buildings and houses.
- R or the Concept of Response Reduction Factor: this factor based on the perceived seismic damage performance of the structure is characterized by brittle deformations, in addition to the type of soil, as shown in the table 3.6. The ratio of (R / I) shall not be greater than 1.0.

Table 3.6: Value of Reduction Factor [57]

S. No.		Lateral Load Resisting System	R
A.		Building Frame System Alone	
	1.	Ordinary RC Moment-Resisting Frame	3
	2.	Special RC Moment-Resisting Frame	5
	3.	Steel Frame with Concentric Braces	4
	4.	Steel Frame with Eccentric Braces	5
	5.	Steel Moment Resisting Frame	5
B.		Load Bearing Masonry Wall Buildings	
	1.	Un-reinforced	1.5
	2.	Reinforced with horizontal RC Bands	2.5

	3.	Reinforced with horizontal RC Bands and vertical bars at Corners & Jambs	3
C.		Ordinary Reinforced Concrete Shear Walls	3
D.		Ductile Shear Walls	4

Nature of the Seismic Stresses: The structural components like walls, columns and beams. Before the earthquake, these elements can only carrying the vertical loads. But it will be exposed to the horizontal seismic forces after the earthquakes opposite to its direction, where these elements must to bear the horizontal forces of shearing and bending forces. The stress of the net tensile generates when the vertical compression is smaller than the bending tension. In this issue above, if the components of constriction like stone and brick masonry are weak in tension, the cracks are going to generate and that cracks will decrease the effective area for withstanding the bending in any time. In figure 3.12, this figure below illustrates that during the earthquake the column's resistance for the strength in tension and shear.

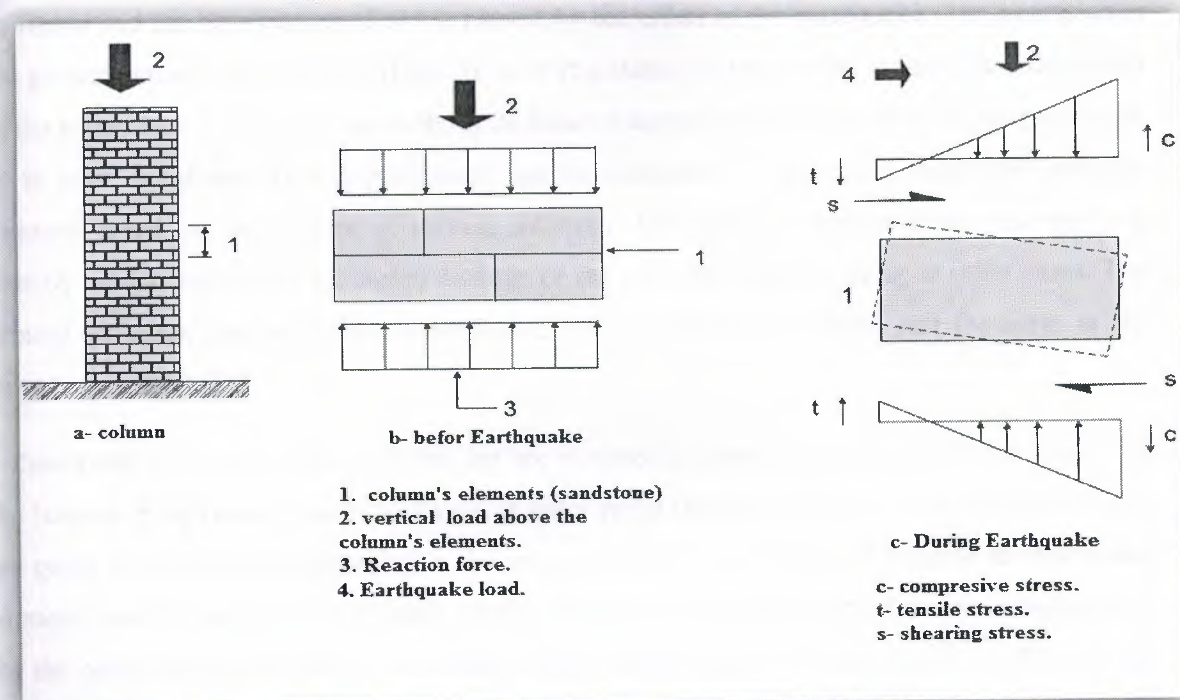


Figure 3.12 Stress Condition in Column Elements [50]

- **Important Parameters in Seismic Design:** there are numerous characteristics and factors that are considered remarkable from the viewpoint of the seismic design, such as:

i) **The Characteristics of Building Material:**

- Strength in tension or compression and shear
- Modulus of elasticity.
- Unit weight.

The properties that have been mentioned above will be explained in detail in the next chapter in addition to the values that were obtained from the laboratory tests.

ii) **Dynamic proprieties of the construction system**: this system consists of modes and damping.

iii) **Load-deflection characteristics of construction elements.**

- **Ground failure**: the rupture of the ground across the fault region, sattlement, the ground collapses and the liquefaction of soil is caused by the effect of the earthquake. The laceration in the ground across a fault zone perhaps for a short distance or perhaps be to more than thousands of the kilometers. Movement the earth for its location across the fault is horizontal, perpendicular or in both directions. This displacement can be calculated in meters or centimeter and this distance based on the amount of seismic intensity. Obviously, a rupture makes the building directly astride and causes extensive damage or the collapse of the building in other cases. The ground collapses can smash the construction, but the settlement creates just the harm in the constructions [50, 52].

- **Tsunamis:** the seismic waves of the sea are commonly generated by a unexpected motion of the bottom of the ocean. Since the waves of water reach the landfall, the velocity of these waves are going to reduce with increasing in the wave's height from 5 meter to 8 meter in some cases or more than this value in other cases. In some cases, the seismic waves of the sea is subversive for the constructions that was constructed in that coastal regions or have a certain effect on the buildings near the coast as is the case in the Church of St. George of Greek [52].

3.3.3 Ductility

Is considered one of the most important properties of the buildings especially ones designed to resist earthquakes. Ductility is meant the ability of the building to sway, bend, and deform by large amounts without much damages or collapse. Of the fragile nature of the materials and faulty design of structures through the use of materials differ in their ductility. Brittle materials crack under load; some examples are brick, adobe and concrete blocks. It is not surprising that most of the damage during the past earthquakes was to unreinforced masonry structures constructed of brittle materials, poorly tied together. The addition of steel reinforcements can add ductility to brittle materials. Reinforced concrete, for example, can be made ductile by proper use of reinforcing steel and closely spaced steel ties. But this is different in facilities that were full addressed of one substance without reinforced, where resistance to horizontal and vertical effects resulting from earthquakes depends on the susceptibility of the material to lateral load, tensile, bending and shear [51].

3.3.4 Undesirable Structural Behavior

The main properties of the lateral load resisting system is the construction should be as a cell unified coherent where it submit a uninterrupted load track to the establishment. Inertial loads that improve by virtue of the speed up of singular components (beam, arch) should be moved from the reaction of components to storey membranes, to perpendicular components (such as column) in the lateral load system, into establishment, and finally to the earth. The frustration to support enough toughness and strength of each component in the system or the frustration in the link the individual element properly as to ensure transmission of lateral loads that opposite to the behavior of individual can lead to completely collapse of the system. [53].

Inertial loads that improve in each component should be afforded to the perpendicular components (columns) by horizontal storey membranes. The membranes of diaphragms, with suitable the props and the limit of components must be supplied with enough intensification to transport these forces [54, 55].

Sudden changes in stiffness, strength, or mass in either vertical or horizontal planes of a building can result in distributions of lateral loads and deformations different from those that are anticipated for uniform structures. The most common form of vertical discontinuity arises because of unintended effects of nonstructural elements. The problem is most severe in structures having relatively flexible lateral load resisting systems because in that case the nonstructural component can compose a significant portion of the total stiffness [56].

Excess drift can lead to excessive distortion, and thence, damage, of structural and nonstructural components. Because repair cost is the primary measure of the success of a building that has survived an earthquake, so damage control is essential. Control of damage in nonstructural components is important because they typically comprise a significant majority of the total value of a building [57].

3.5 Summary

This chapter gave a good background to understand the state of soil and its classification in Cyprus Island. Besides that, the general concept of earthquakes and the successive earthquakes in Cyprus that hit this island before many centuries to the present day are presented in details. Also in this chapter, the behavior of structure due to earthquakes and the structural performance during earthquakes are submitted well.

CHAPTER FOUR

LABORATORY TESTS OF YELLOW SANDSTONE

4.1 Introduction

This study focuses on the structural analysis for columns of Church of cathedral St. George. Church's pillars was completely built from yellow sandstone units where this helps to reduce the likelihood of increased damage the element (column) when exposed to the forces of differently or contrary forces are capable of address them . The earthquake loads are dynamic and impossible to predict precisely in advance, where at certain instants of time the effective load is increased, at others it is decreased.

The yellow sandstone is characterized by high density and hardness because of the porosity in it is a very few. The sandstone masonry gave a good behavior under forces of loading and the pressure while it was giving a high behavior under the bending force. In this section the procedures of a current work will be discussed in detail, where these procedures include many important tests on the masonries of columns which are necessary for the requirements of the program SAP2000 to analyze church's columns that collapsed due to the seismic intensity in addition to the study the behaviors of these masonry under the influence of earthquakes from the viewpoint of mechanical structural elements.

4.2 Compressive Strength and Breakage Load-P

The columns are considered the essential theme or the backbone in this study, therefore it was necessary to set the highest vertical load that can be carried, especially that the vertical elements are designed to carry only the vertical forces that pre-exposure to earthquakes. In order to access the reasons for the collapse of church columns, the two cubic sample of yellow sandstone has been taken with dimensions (10 * 10 * 10) cm and it was subjected to load of 9.9 KN. as shown below in the figure 4.1.

Figure 4.1 Demonstrates the Failure of the Sample under Compressive Forces

Where the higher value to resist the force of compression was 0.44 Mega Pascal.

4.3 Bending Strength and Fracture Load-T

This test is consider a very important for the designed structural elements such as walls, beams and columns to know the behavior of these elements in resisting breakage before earthquake especially it was designed mainly to carry the vertical force. After earthquake, these elements (wall, beam and column) should be able to carry the influences of shearing and horizontal bending which are going to bend these elements. In order to set higher durability in the masonry of yellow sandstone, Sample was taken with dimensions (20*10 * 10) cm, it was subjected to the bend load of 3.6 KN. as shown in the figure 4.2, and the recorded value was 0.51 Mega Pascal.

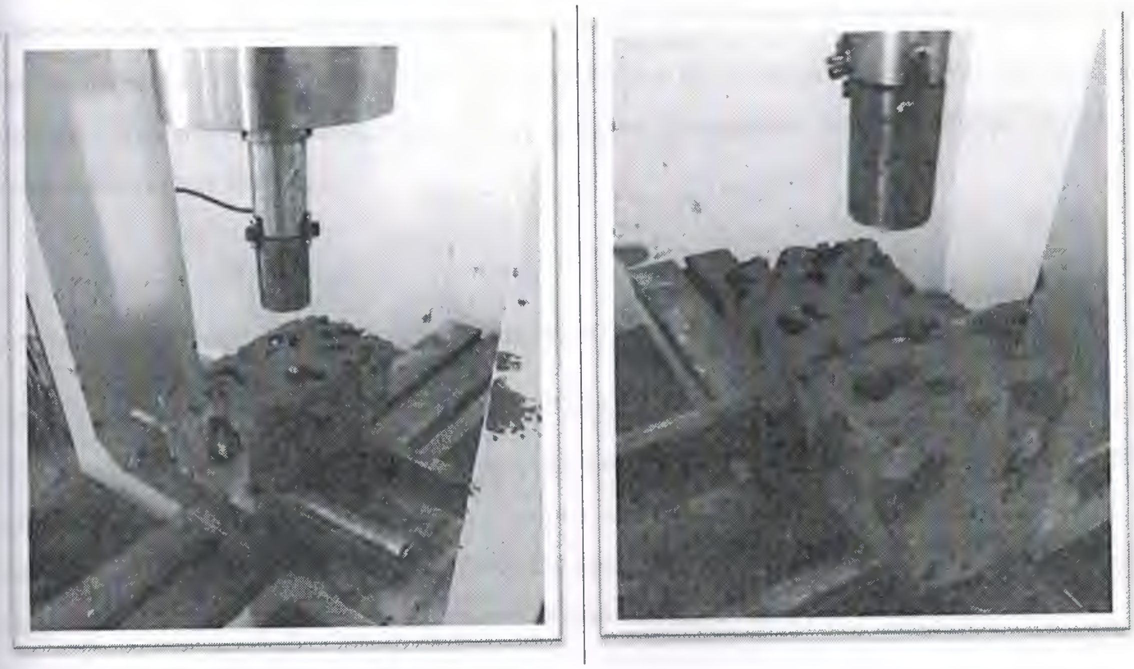


Figure 4.2 Examination of the Sample under the Bend Force

When exposure to the earthquakes, the columns are going to bend under the influence of increasing the tensile strength that excess of the amount of vertical compression, so net tensile stress will occur. As result of that, the cracks will occur in these columns as shown in the figure 4.3.

Figure 4.3 Cracks of Column Masonry Due to High Tension Force

These cracks are going to reduce the effective area for resisting the bending moment of the sandstone masonry, where these masonry characterized by the weakness in resisting the tensile strength. As a roll the tensile strength is deferent from compressive strength significantly and its values also is quite different.

4.4 Specific Gravity Test (weight per unit value)

Specific gravity refers to the ratio of density of any substance. This is a very important value in set the weight of the yellow sandstone per cubic meter and through this value can calculate the weight of the elements that based on the columns such as arches and roofs. Besides that, when the value of the specific gravity is high then the durability of sandstone units is going to be high also and this increase the stamina of external forces and environmental conditions.

Cubic Sample of yellow sandstone was taken with dimensions (20*10*10) cm, a dry weight of the sample has been appointed where the value was 2240 Kg/m^3 as shown below in the figure 4.4.

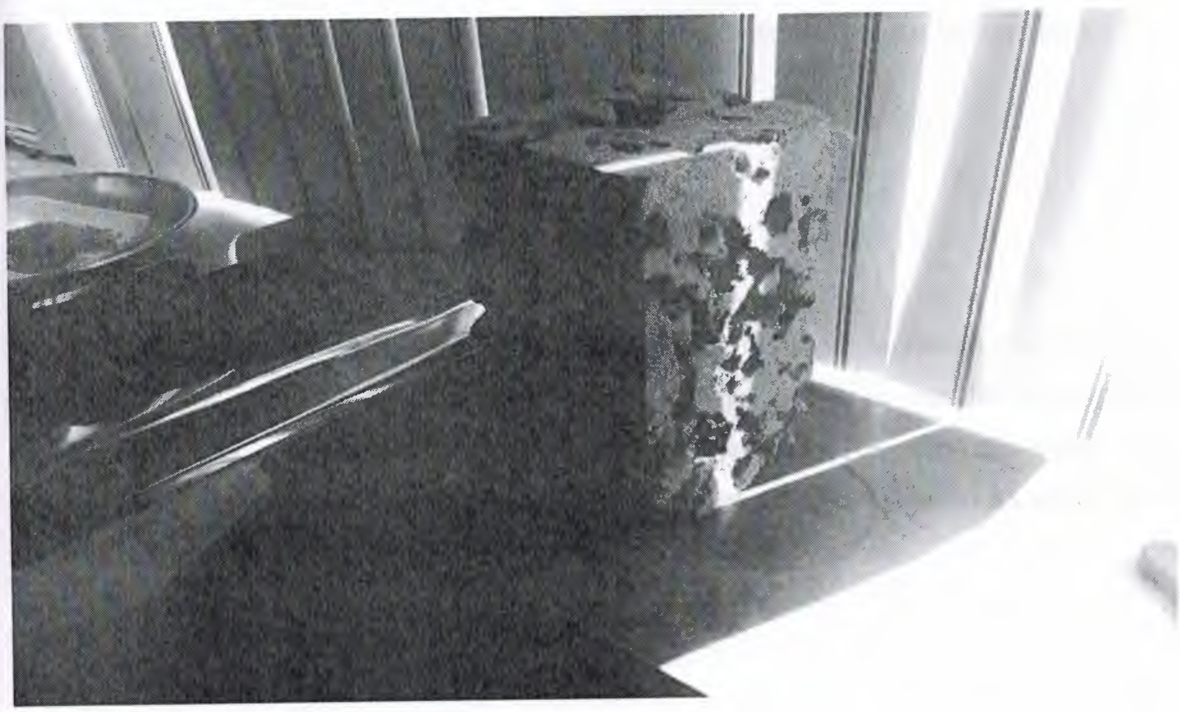


Figure 4.4 Specific Gravity of Dry Yellow Sandstone

The sample was dived in water for 4 hours, then the weight of this sample has been assigned where was 2330 Kg/m^3 as shown below in the figure 4.5 (a), after that it was placed in the oven for one day at a temperature of $105c^{\circ}$ as shown in the figure 4.5 (b), then has been set its weight.

(a) (b)

Figure 4.5 (a) Immersion the Sample in Water, (b) The Method of Drying the Sample

The final result to examine the sample of yellow sandstone was 2280 Kg/m^3.

4.5 Modulus of Elasticity

The modulus of elasticity or elastic modulus is one of the most important properties and parameters from the point of view of the seismic design and it is consider mathematical description of the materials tendency to deformation elastically (i.e, non-permanent) when influenced by external force, the elastic modulus of an element is the slope of its stress–strain curve of the area that has been elastic deformation.

A rock sample has been cut to cylindrical shape, and the ends were machined flat. The sample of yellow sandstone was placed in a loading frame as shown below in the figure 4.6 at ordinary temperature (the desired test temperature).

Figure 4.6 The Test Method of Elasticity Modulus

Axial load was continuously increased on the specimen, and deformation was monitored as a function of load. Through the values that were obtained during the examination and make mathematical calculations have been obtained the value of the elastic modulus of the church stone, where it was 3.05249 t/m^2, the value that obtained relatively high, this is because a stiffer material will give a higher modulus of elasticity.

4.6 Poison's Ratio

The value of Poisson's ratio (υ) is greatly affected by nonlinearities at low stress levels in the axial and lateral stress-strain curves. On the other word, it is the negative value of the transverse to axial strain.

In order to set this ratio in the yellow sandstone of the St. George Church, The sample of stone was taken in a cylindrical shape as shown below in the Figure 4.7

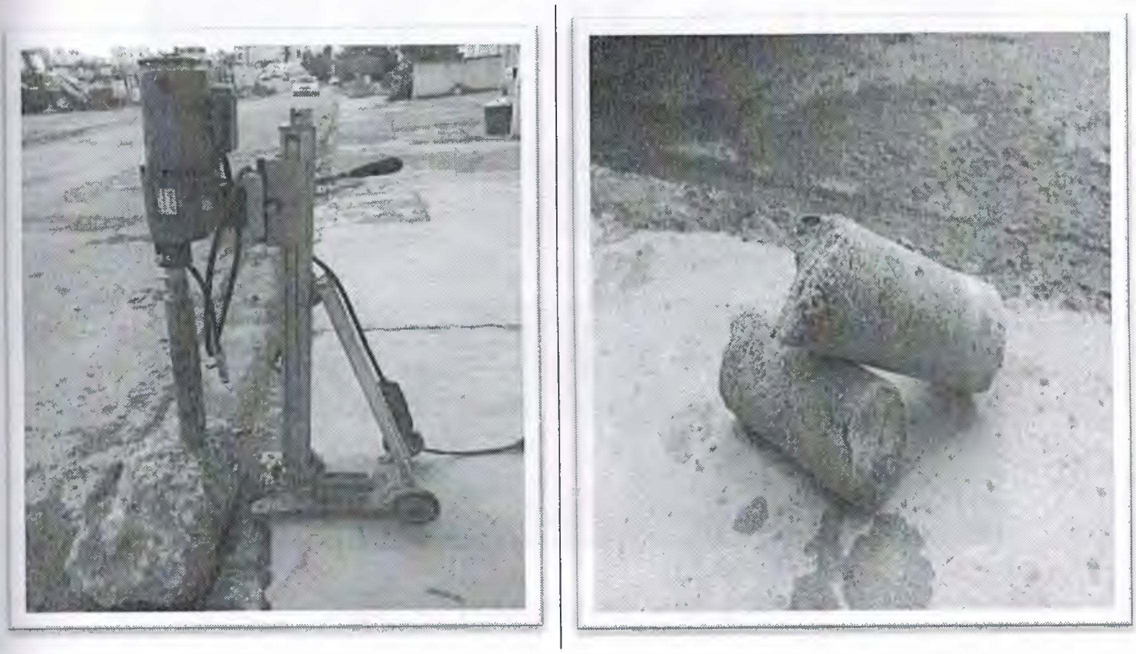


Figure 4.7 The Sampling Technique and Its Form

The sample was put vertically in the testing apparatus then pressure has been shed on one of its directions, as shown in the figure 4.8. This compression make the stone tends to expand in the other two directions perpendicular to the direction of pressure off, Poisson's ratio is consider a measure of this effect.

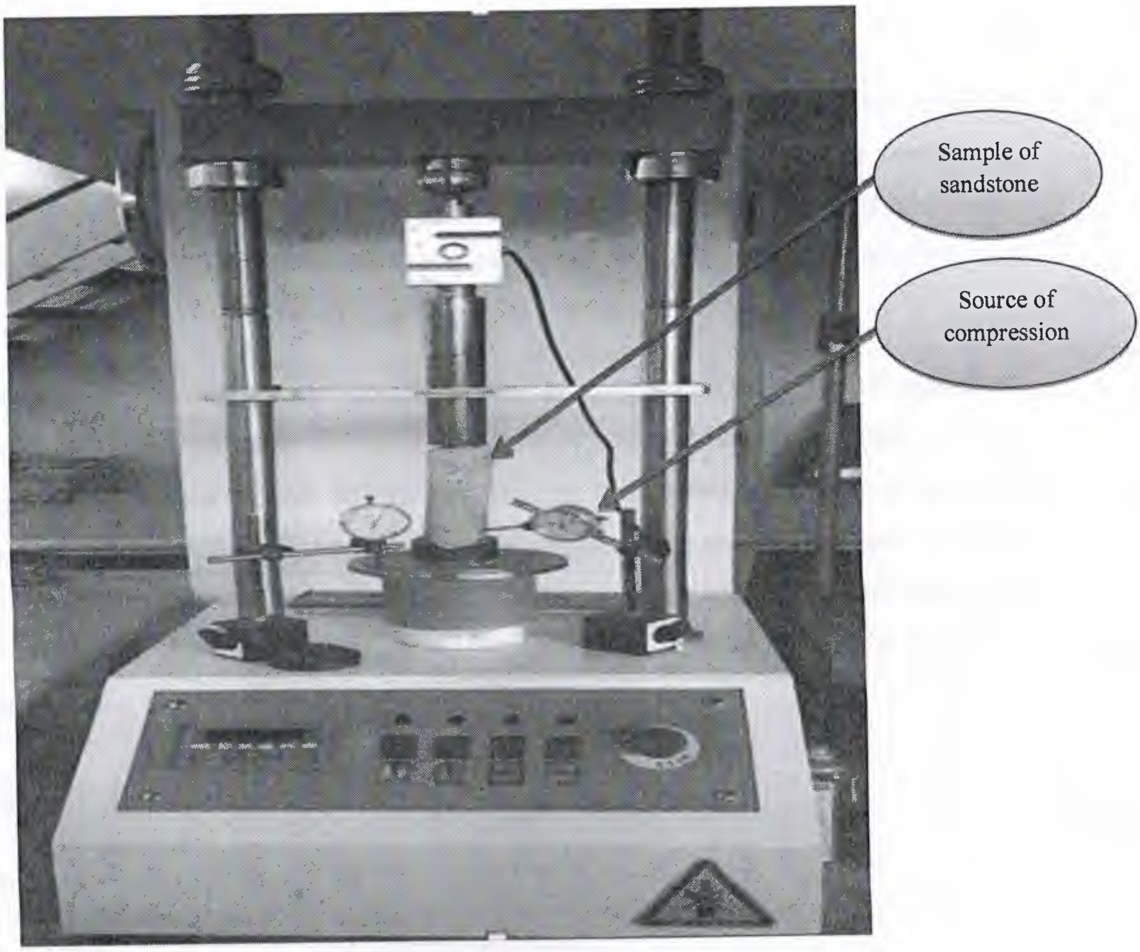


Figure 4.8 Poisson's Ratio Testing Device

Poisson's ratio was obtained through the following equation:

$$\upsilon = -\frac{d\varepsilon_{trans}}{d\varepsilon_{axial}}$$

Where:

$\varepsilon_{\ transfer}$; Negative for axial tension and positive for axial compression.

ε_{axial}; Positive for axial tension, negative for axial compression.

Finally, Poisson's ratio was recorded as 0.29 under comparison Is50 Mpa.

4.7 Water Absorption Coefficient due to Capillary Action

One of the more features that is characterized by yellow sandstone, it has a low porosity and impermeable to water, these features make it a great resistant to harsh weather conditions, especially rain. This is one of the most important factors that led to the survival of the many constructed monuments of yellow sandstone to this day, which is the Church of St. George is one of them.

In order to identify the water absorption coefficient due to capillary action of yellow sandstone three cylindrical samples were taken with area 22.90, 23.07 and 23.24 cm2 respectively, where the dry weight of them were 561.26, 522.41 and 516.36g respectively, after that it has been immersed in water for a period of 600 seconds, then the weight of wet samples has been assigned where they were 534.72, 538.59 and 539.26g. After the completion of all the necessary information to calculate the water absorption coefficient due to capillary action, the following equation was applied:

$$C_{w,s} = \frac{m_{so,s} - m_{dry}}{A_s \sqrt{t_{so}}} * 10^6 \qquad (4.1)$$

Where the average value was 268 $g/m^2 x s^{0.5}$

4.8 Summary

This chapter focused on the laboratory tests of yellow sand stone, where the compressive strength and breakage load are submitted. As well as, the bending strength and fracture load-T are determined. Besides that, the values of the specific gravity, modulus of elasticity and poison's ratio are calculated in this chapter.

CHAPTER FIVE

CALCULATIONS, NUMERICAL APPLICATIONS

5.1 Introduction

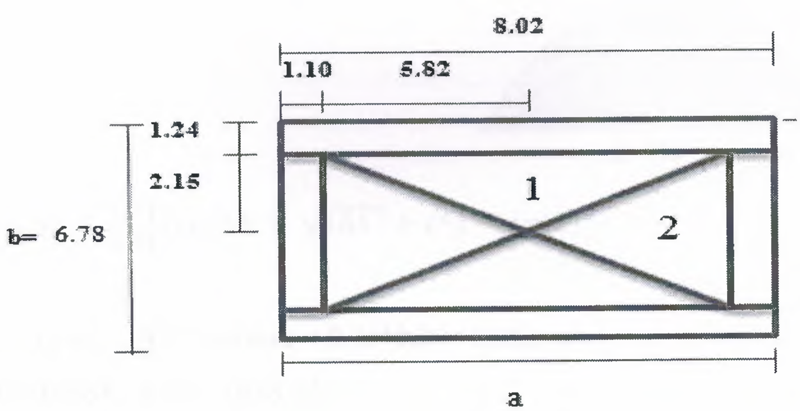
This chapter includes the calculations of dead loads hanging over the Church's columns such as; weight of the roofs, weight of the main arches, weight of the secondary arches -bearing roof, weight of the internal and external fillings) to calculate the compressive strength of these columns for these loads according to the values obtained by laboratory and calculate the lateral forces according to the dead loads and seismic forces for each column, then by SAP2000 will set the amount of the compression forces on the columns and seismic forces (lateral forces) according to the collection information since the establishment of the Church to this day to get the maximum moment suffered by the Church columns.

5.2 Calculations

These calculations are divided into two parts; the first is dead loads (vertical forces on the column) and horizontal forces (lateral loads) resulting from the earthquakes.

5.2.1 Dead Loads Calculations

- **Weight of roofs**



Zone A

$A_1 = \frac{2}{3} a * \frac{b}{2}$ (area of prabola) (5.1)

$A_2 = \frac{2}{3} * 4.01 * 4.30 = 11.49\ m^2$

Total area at zone A = 2(18.16) + 2(11.49) = 59.3 m^2

W= m* g (5.2)

m = $\rho * V$ (5.3)

V = A * t (5.4)

= 59.3 $m^2 * 0.30\ m = 17.79\ m^3$

$\rho_{stone} = 2280 \frac{Kg}{m^3}$ (According to the laboratory test)

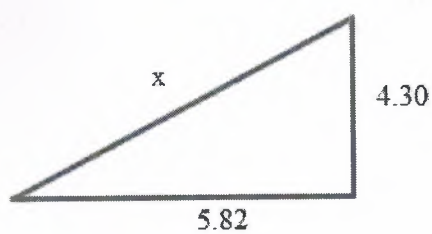
m = 2280* 17.97 = 40971.6 kg

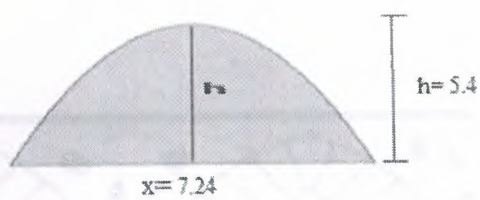
W_{A1}= 40971.6* 9.81 = 401.932 KN

- **Weight of the secondary arches**

X = $\sqrt{(5.82)^2 + (4.30)^2}$

X= 7.24 m





$L_{arch=} 0.5\sqrt{16h^2} + x^2 + \left[\frac{x^2}{8h}\right]\left[Ln\left(4h + \sqrt{16h^2} + x^2\right) - Ln(x)\right]$ (5.5)

L = 13.59 m

L for two side = 27.18 m ; A of one unit = 0.25*0.25= 0.063 m^2

m = $\rho * v$ = 2280 * 0.063* 13.59 = 1936.575

w = m*g

w= 1836.575* 9.81

= 18.998 KN.

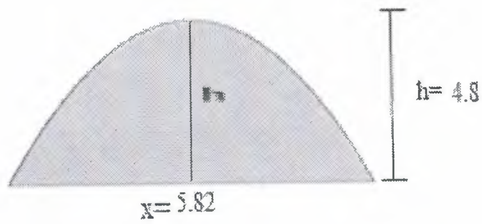
- Weight of the main interior arches between columns

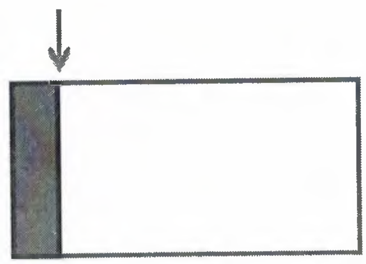
$L_{arch} = 11.72\ m$

$A_{stone} = 0.4 * 0.5 = 0.2\ m^2$

m = 2280 * 0.2 * 11.72 = 5344.32

w= 5344.32* 9.81= 52.728 KN





- Weight of the arch at edge zone A_1

Where the stone used in it with cylindrical shape

$$A = \frac{\Pi\ (0.40)^2}{4} = 0.13\ m^2$$

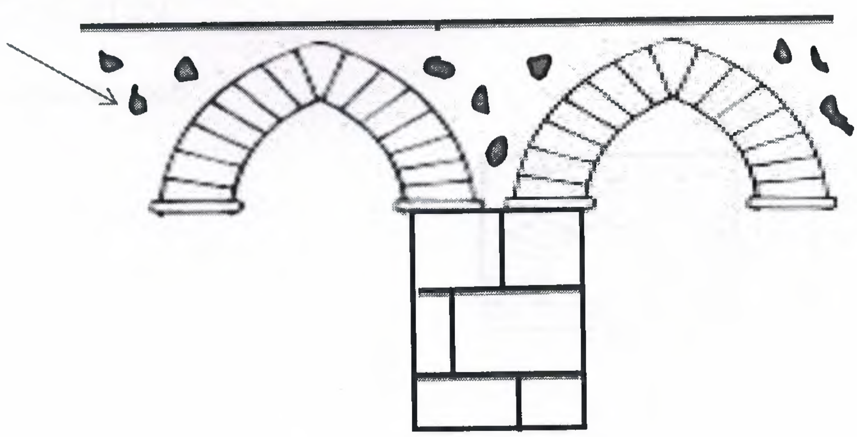
(5.6)

By Using Parabola's equation.

L= 12 m

W= 12*0.13*2280*9.81 = 34.892 KN.

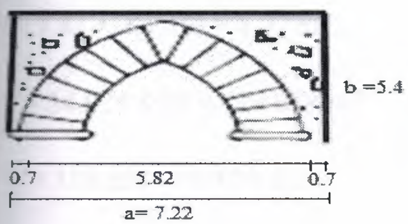
- Weight of fillers between main arches



$A_{filler} = [a * b] - [\frac{2}{3}\, a`\, b`]$ (5.7)

$= [7.22*5.4] - [\frac{2}{3}\, 4.8 * 5.82]$

$= 20.37\ m^2$

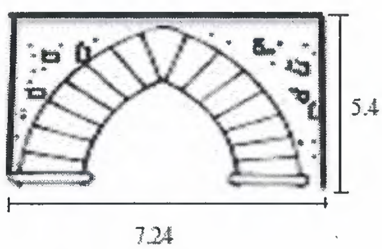


$V = A * t = 20.37 * 2.0 = 40.74\ m^3$

$W = v * \rho_{filler} * g$

W = 40.74* 1750 * 9.81 = 699.199 KN

- Weight of fillers at secondary arches- chock roof



$A_{fillers} = [7.24 * 5.4] - [2l3 * 7.24 * 5.4]$

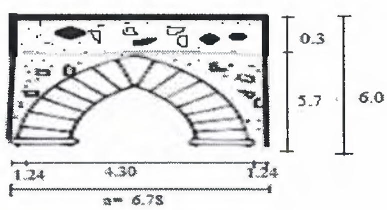
$A_{fillers} = 13.04\ m^2$

For two side (x) $A_{filler} = 26.07\ m^2$

$V = A * t = 26.07 * 0.4 = 10.428\ m^3$

W = 10.428* 1750* 9.81 = 179.023 KN

- Weight of fillers out side the roof



$A_{fillers}$ =[6.78*6]−$\left[\frac{2}{3}*5.7*6.7\right]$

$A_{fillers} = 14.92\ m^2$

t = dis. c-c of column (5.8)

t= 5.82 + 2(1.10) = 8.02 m

V= 14.92* 8.02 = 119.658 m^3

W= 119.658* 1750*9.81

W= 2045.236 KN

Total weight at zone $A_1 =$ 401.932+ 18.998+ 52.728+ 34.892+ 699.199+ 179.023+ 2045.236

$A_1 = A_3$ = 3432.01 KN

$B_1 = B_3 = W_{A1} * \frac{X_{B1}}{X_{A2}}$ (5.9)

= 3432.01 * $\frac{6.9}{8.02}$ = 2952.73 KN

$C_1 = C_3 = 3432.01 * \frac{9.20}{8.02}$

= 3936.97 KN

$D_1 = D_2 = B_1 = 2952.73\ KN$

$E_1 = E_3 = 3432.38 * \frac{7.20}{8.02}$

= 3081.44 KN

- Weight of roof at A_2 (meddle)

By using parabola area equation

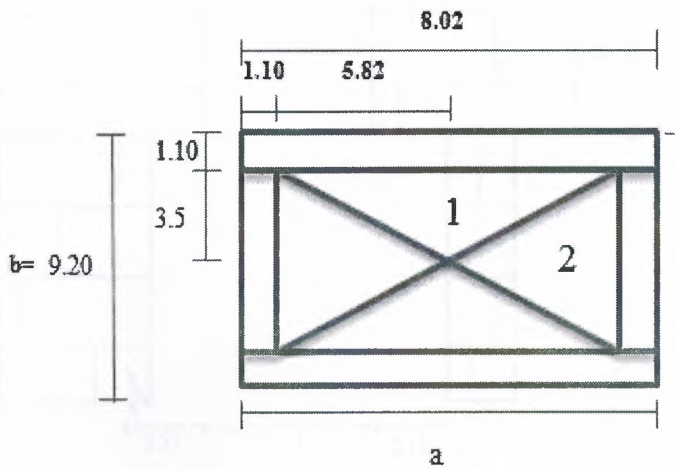
$A_1 = 20.85\ m^2$

A_2= 18.71 m^2

Total area of zone $A_2 = 79.12\ m^2$

W = 79.12*0.3*2280*9.81

W=530.898KN



Zone A2

- Weight of the secondary arches that chock the roof

X= $\sqrt{(5.82)^2 + (8.5)^2} = \ 10.30\ m$

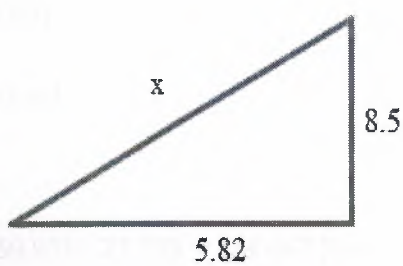
By using parabolic equation to find L

$L_{arch} = 15.61\ m\ ; \quad two\ side = 31.22\ m$

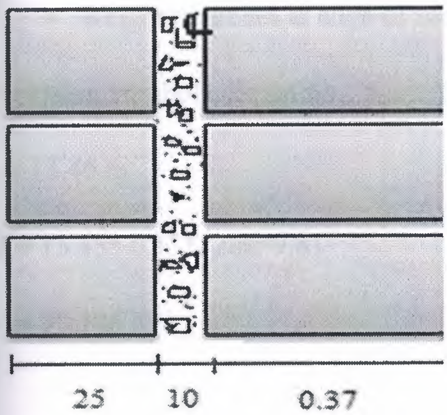
V= 31.22* 0.063 = 1.967 m^3

W = 1.967* 2280* 9.81

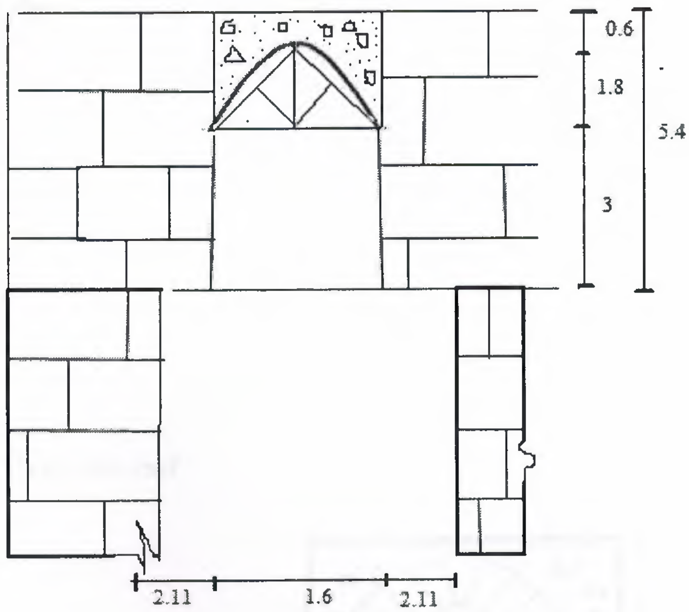
W= 43.995 KN



- Weight of the wall above the column



The wall was containing from 3 part as shown above.



Weight of interior stone of the wall= (2.11+1.10)* 5.4* 0.25 *2280*9.81 = 387.706 KN

Weight of outside stone of the wall= 3.21 * 5.4*2280 *0.37 *9.81= 143.451 KN

Weight of filler between them= 0.10*5.4*3.21* 9.81*1750= 29.758 KN

Total weight of wall = 387.706+ 143.451+ 29.758 = 560.915 KN

The filler area up the window= [2.4*1.6]-[2/3*1.6*1.8] = 1.92 m2

Weight the filler= 1.92*0.72*1750*9.81 = 23.723 KN

Total weight for one side= weight of filler+ weight of wall 560.951+ 23.723 = 584.647 KN

Total weight= 584.647 *2 = 1169.295 KN

- Weight of arches at edge of zone A_2

By Using Parabolic Equation .

L= 13.45 m

W= 13.45* 0.13*2280*9.81

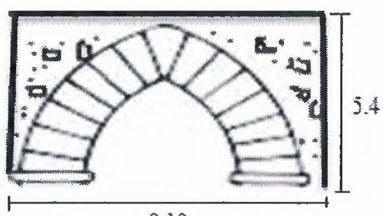
W= 39.108 KN

- Weight of secondary arches that chock the roof

x= $\sqrt{49 + 33.87}$

x= 9.10 m

L= 14.78 m (by using parabolic equ.)



$W_{arch} = 14.78 * 0.13 * 2280 * 9.81$

= 42.976 KN

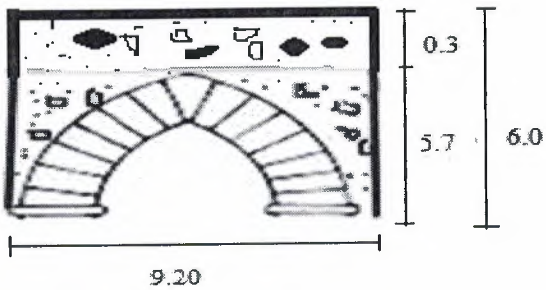
For two side w = 85.951 KN

- Weight of fillers between secondary arches

W= 2(16.38*0.13*1750*9.81)

W= 73.113 KN

- Weight of filler outside the roof at meddle



A= [6*9.20] – [34.96]

= 20.24 m^2

$W_{filler} = [5.82 + 2.20] * 20.24 * 1750*9.81$

=2786.711KN

- total weight at meddle roof with height 16.2 m

W_{A2} =530.898 +43.995 +1169.295 +39.108 +85.951+73.113 +2786.711

= 4729.071 KN

$$B_2 = 4729.071 * \frac{6.9}{8.02} = 4068.652\ KN$$

$$C_2 = 4729.071 * \frac{9.2}{8.02} = 5424.869\ KN$$

$$D_2 = B_2 = 4068.652\ KN$$

$$E_2 = 4729.071 * \frac{7.20}{8.02} = 4245.550\ KN$$

Total load carried by each column= 0.25(weight of the roofs that standing on it)

Column 1= 0.25(A1+ B1+A2+B2)

= 0.25(3432.01+ 2952.73+ 4729.071+ 4068.6520)

= 3795.616 KN

Column 2 = 0.25 (B1+CA+B2+C2)

= 4095.760 KN

Column 3= 0.25 (C1+D1+C2+D2)

= 4095.805 KN

Column 4 = 0.25 (D1+E1+D2+E2)

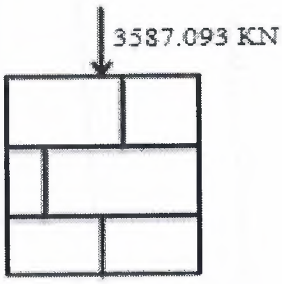
= 3587.093 KN

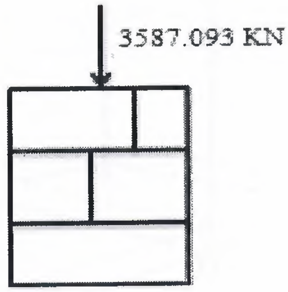
C1

C2

C3

C4





Validation of calculations be through comparison the dead loads carried by each column with maximum compression force borne by it according to the results that have been obtained laboratory, where

$P_C < 105\ t/m^2$

$$A_{Column} = \frac{\pi D^2}{4} = \frac{\pi * (2.20)^2}{4} = 3.79 m^2$$

$$P_{C2} = \frac{w}{A_{column}} = \frac{379.6}{3.79} = 100.16\ \text{t}/m^2 < 105\ \text{t}/m^2 \quad \text{ok.}$$

$$P_{C2} = \frac{w}{A_{column}} = \frac{409.6}{3.79} = 108.07\ \text{t}/m^2 > 105 \text{t}/m^2 \quad \text{not ok.}$$

$$P_{C3} = P_{C2} = 108.07\ \text{t}/m^2 \quad > 105 \quad \text{not ok}$$

$$P_{C4} = \frac{358.71}{3.79} = 94.65\ \text{t}/m^2 \quad < 105\ \text{t}/m^2 \quad \text{ok.}$$

By using SAP 2000 will be verify the strength of the columns due to dead loads that hanging on it as shown below in the model 5.1

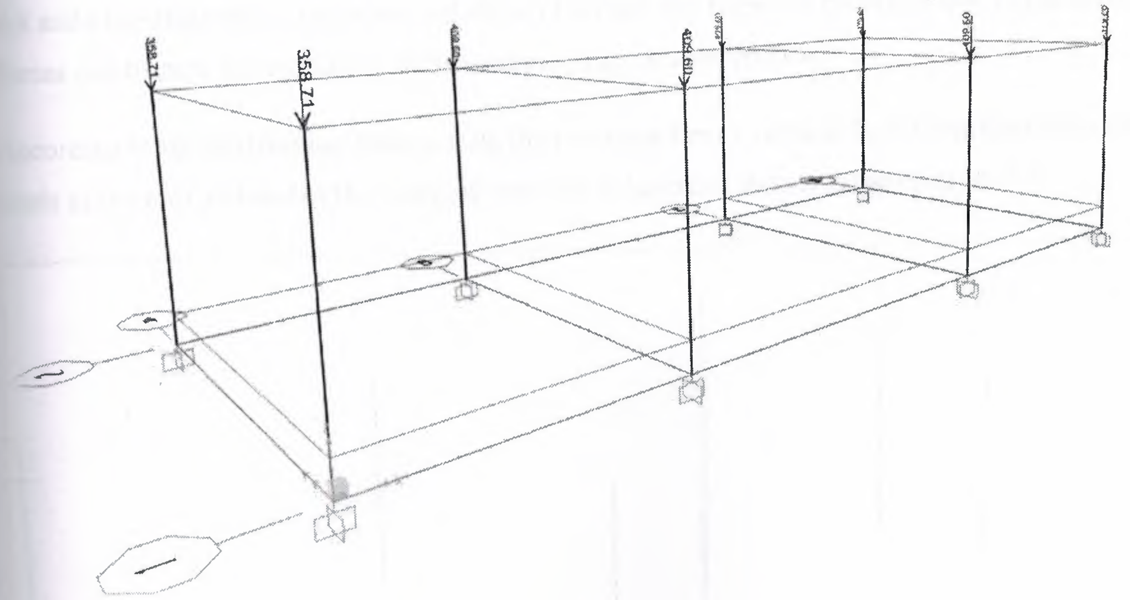


Figure 5.1 Church Columns under Dead Load

After analyzing the vertical loads that hanging over the columns were obtained the following results as shown in the diagram 5.2.

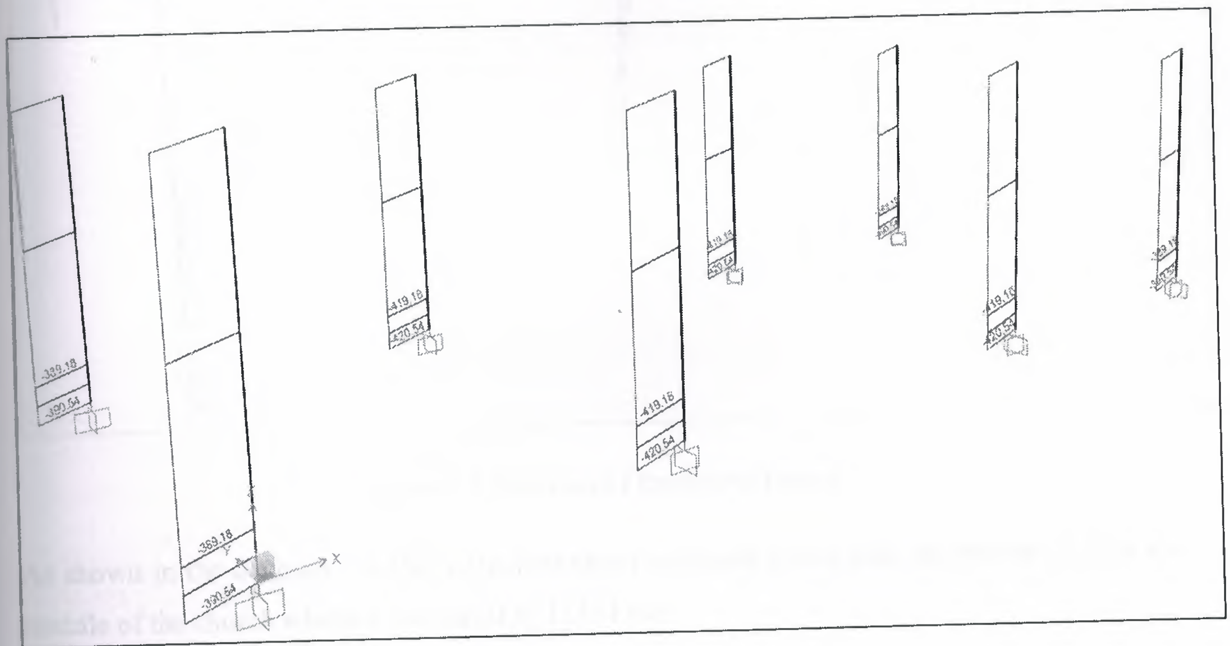


Figure 5.2 Diagram of Axial Load

An audit the diagrams of moments and shear observed that there are no values due to the vertical forces and there is not any defect in Structural design or construction.

According to the analysis has been getting the reactions forces vertical forces resulting from dead loads of the roof and arches that hanging over the columns as shown in the diagram 5.3.

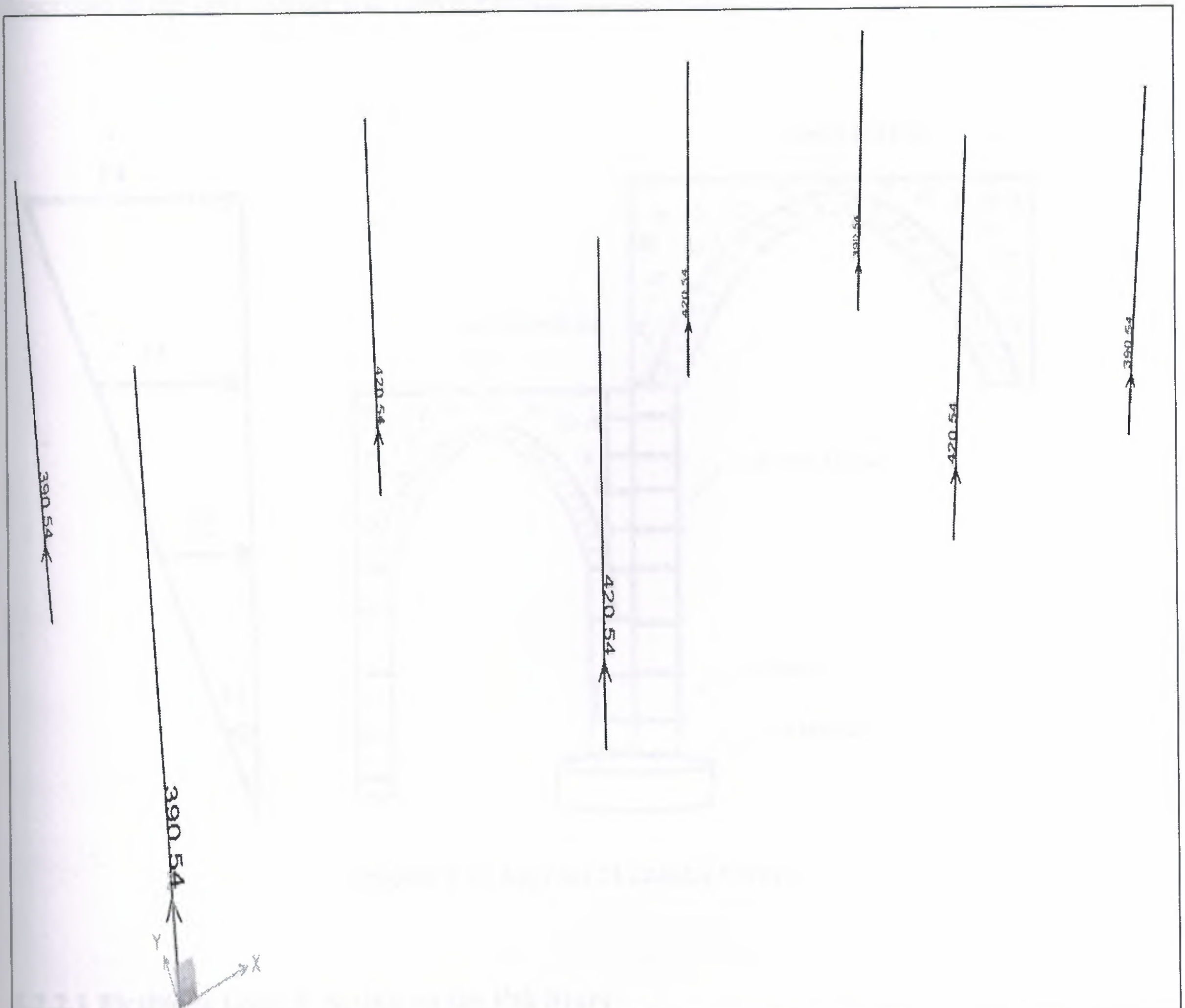


Figure 5.3 Diagram of Reactions Forces

As shown in the diagram 5.3 above the maximum reactions forces were at column (2,3) at the meddle of the church where it was equal to 11354 tan.

5.2.2 Lateral Forces due to Earthquake (Total Design Force)

According to the diagram (5.4) there are four forces affect horizontally, first one at pedestal with high 0.6 m ,second force at head of column with high 5.4m, third force at first level of roof with high 10.8m, forth force at second level of roof with high 16.2m, where this church as described in the first chapter was unsymmetrical architecturally.

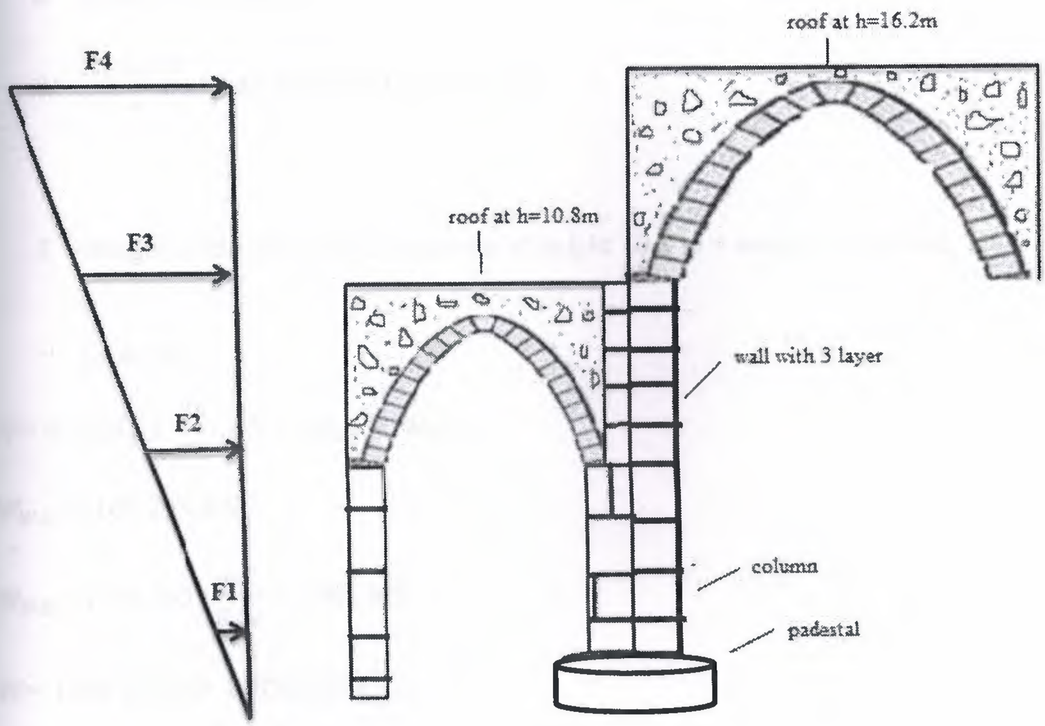


Figure 5.4 Diagram of Lateral Forces

5.2.2.1 Fictitious Load F Acting on the i'th Story

The main equation to find these forces is:

$$F= \frac{W_i * H_i}{W_j * H_j} \tag{5.10}$$

There are four lateral forces, this is mean calculate the weights of four parts depending on the force effect at each part in the building as shown above in the figure (5.4).

1. Weight of the pedestal

$$W= \frac{\pi\,(2.40)^2}{4} * 0.60*2280*\,9.81 = 60.68\ KN$$

2. Weight of the column

$$W= \frac{\pi\,(2.20)^2}{4} * 4.8*\,2280*\,9.81= 407.90\ KN$$

3. Weight of the roof and accessories at height 10.8 m + weight of the wall

- Column 1

$$W= 0.25(A_1 + B_1) + 0.5\,(W_{WA} + W_{WB}) \qquad (5.11)$$

W_{Wa}= 1169.295 KN

W_{WB}= 1169.295* $\frac{6.9}{8.02}$ = 1006 KN

W= 1596.19 KN+ 1087.65 KN

W= 2683.84 KN

- Column 2

W= 0.25 $(B_1 + C_1)$+ 0.5$(W_{WB} + W_{WC})$

W_{Wc} = 1169.295* $\frac{9.2}{8.02}$ = 1341.34 KN

W = 1722.43 KN + 1173.67 KN

$W = 2896.1$ KN

- Column 3

$W\ at\ column3 = W\ at\ column\ 2$= 2896.1 KN

- Column 4

W= 0.25 $(D_1 + E_1) + 0.5(W_{WD} + W_{WE})$

W_{WE}= 1169.295*$\frac{7.20}{8.02}$ = 1049.74 KN

W= 1508.43 KN+ 1027.87 KN

W= 2536.3 KN

4. Weight of the roof and accessories at height 16.2 m

W_{A2}= 3559.78 KN

- Column 1

W= 0.25(W_{A2}+ W_{B2})

$W_{B2} = 3559.78 * \frac{6.9}{8.02}$ = 3062.65 KN

W= 1655.61 KN

- Column 2

W= 0.25 $(W_{B2} + W_{C2})$

$W_{C2} = 3559.78 * \frac{9.20}{8.02}$ = 4083.54 KN

W= 1786.55 KN

- <u>Column 3</u>

W at column 2= W at column 3 = 1786.55 KN

- <u>Column 4</u>

W= 0.25 $(W_{D2} + W_{E2})$

$W_{E2} = 3559.78 * \frac{7.20}{8.02}$ = 3195.81 KN

W= 1819.84 KN

To find the lateral forces on each column will be applied the mean equation four times, according to the requirements of the building consisting of four levels of the forces.

<u>Column 1</u>

$F_1 = \frac{W_i H_i}{W_j H_j}$

Total weight = $W_{padestel} + W_{column} + W_{10.2} + W_{16.2}$ (5.12)

Total weight = 60.68 + 407.90 + 2683.84 + 1655.61 = 4808.03 KN

Total height = 16.2 m

$F_1 = \frac{60.68*0.6}{4808.03*16.2}$ = 0.001

$F_2 = \frac{407.90*4.8}{4808.03*16.2}$ = 0.25

$F_3 = \frac{2683.84*10.8}{4808.03*16.2}$ = 0.372

$F_4 = \frac{1655.61*16.2}{4808.03*16.2} = 0.344$

Column 2

$F_1 = 0.001$

$F_2 = 0.25$

$F_3 = \frac{2896.1*10.8}{4808.03*16.2} = 0.402$

$F_4 = \frac{1786.55*16.2}{4808.03*16.2} = 0.372$

Column 3

$F_1 = 0.001$

$F_2 = 0.25$

$F_3 = 0.402$

$F_4 = 0.372$

Column 4

$F_1 = 0.001$

$F_2 = 0.25$

$F_3 = \frac{2536.3*10.8}{4808.03*16.2} = 0.352$

$F_4 = \frac{1819.84*16.2}{4808.03*16.2} = 0.379$

5.2.2.2 Determination of Total Equivalent Seismic Load

Total Equivalent Seismic Load (base shear) V_t , acting on the entire building due to the earthquake direction is determined by;

$$V_t = \frac{W*A(T)}{R_a(T)} \geq 0.10\ ZIW \qquad (5.13)$$

$$A_T = \left(\frac{Z}{2} * \frac{S_T}{g}\right) / \text{(R/I)} \qquad (5.14)$$

When $T_A \leq T \leq T_B$

$S_T = 2.5$

When $T_A < T$

$R_a 1.5(T) = R = 1.5$

Depending on the table below

Number of zone	T_A	T_B
Z1	0.10	0.30
Z2	0.15	0.40
Z3	0.15	0.60
Z4	0.20	0.90

$A_T = [\frac{0.16}{2} * \frac{2.5}{9.81}]/1 = 0.02$

$V_t = \frac{4808.03*0.02}{1.5} = 64.11$ KN $\geq 0.10 * 0.16 * 1.5 * 4808.03 = 115.393$

$$\Delta F_N = 0.0075\ NV_t \qquad (5.15)$$

$= 1.44$

$$F_i = (V_t - \Delta F_v) * F \qquad (5.16)$$

$F = \frac{W_i H_i}{W_j H_j}$ (calculated above)

Column 1

F_{i1}= (64.11-1.44) * 0.001= 0.063 KN

F_{i2}= 62.67* 0.25 = 15.668 KN.

F_{i3} = 62.67* 0.372= 23.313 KN

$F_{i4} + \Delta F_N$= (62.67* 0.334) +1.44= 22.372 KN

Column 2

F_{i1}= 62.67* 0.001= 0.063 KN

F_{i2}= 62.67 * 0.25= 15.668 KN

F_{i3}= 62.67* 0.402= 25.193 KN

$F_{i4} + \Delta F_N$= (62.67* 0.372) +1.44= 24.753 KN.

Column 3

F_{i1}= 62.67* 0.001= 0.063 KN

F_{i2}= 62.67 * 0.25= 15.668 KN.

F_{i3}= 62.67 * 0.402= 25.193 KN.

$F_{i4} + \Delta F_N$= (62.67* 0.372) +1.44= 24.753 KN.

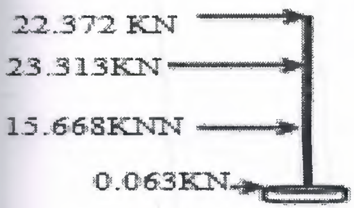
Column 4

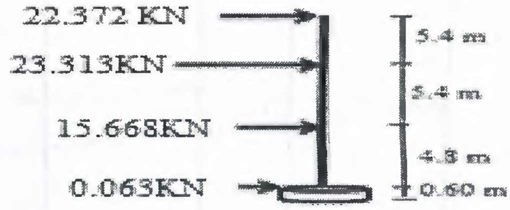
F_{i1}= 62.67* 0.001 = 0.063 KN.

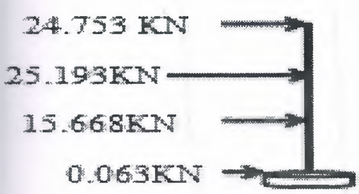
F_{i2}= 62.67 * 0.25 = 15.668 KN.

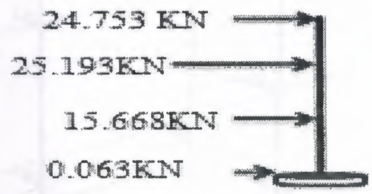
F_{i3}= 62.67* 0.352= 22.059 KN.

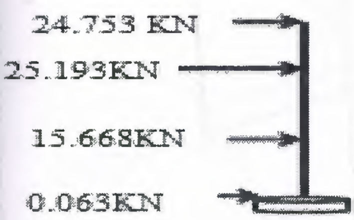
$F_{i4} + \Delta F_N$= (62.67* 0.379) +1.44= 25.192 KN.

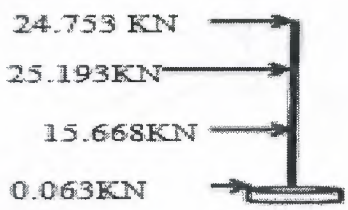


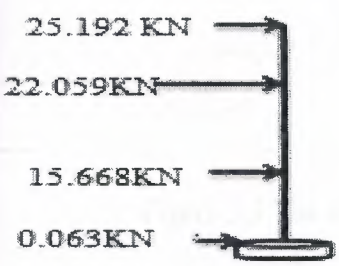


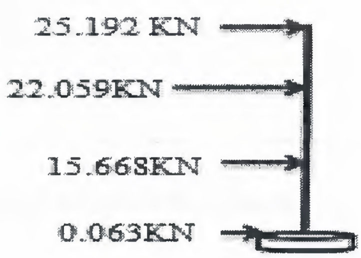












SAP 2000 has been using in analysis church columns through the shed dead loads (compressive forces) on the columns in addition to lateral forces caused by earthquakes for each joint from the zero level to the highest peak of the church (the meddle roof) as shown in the figure 5.5

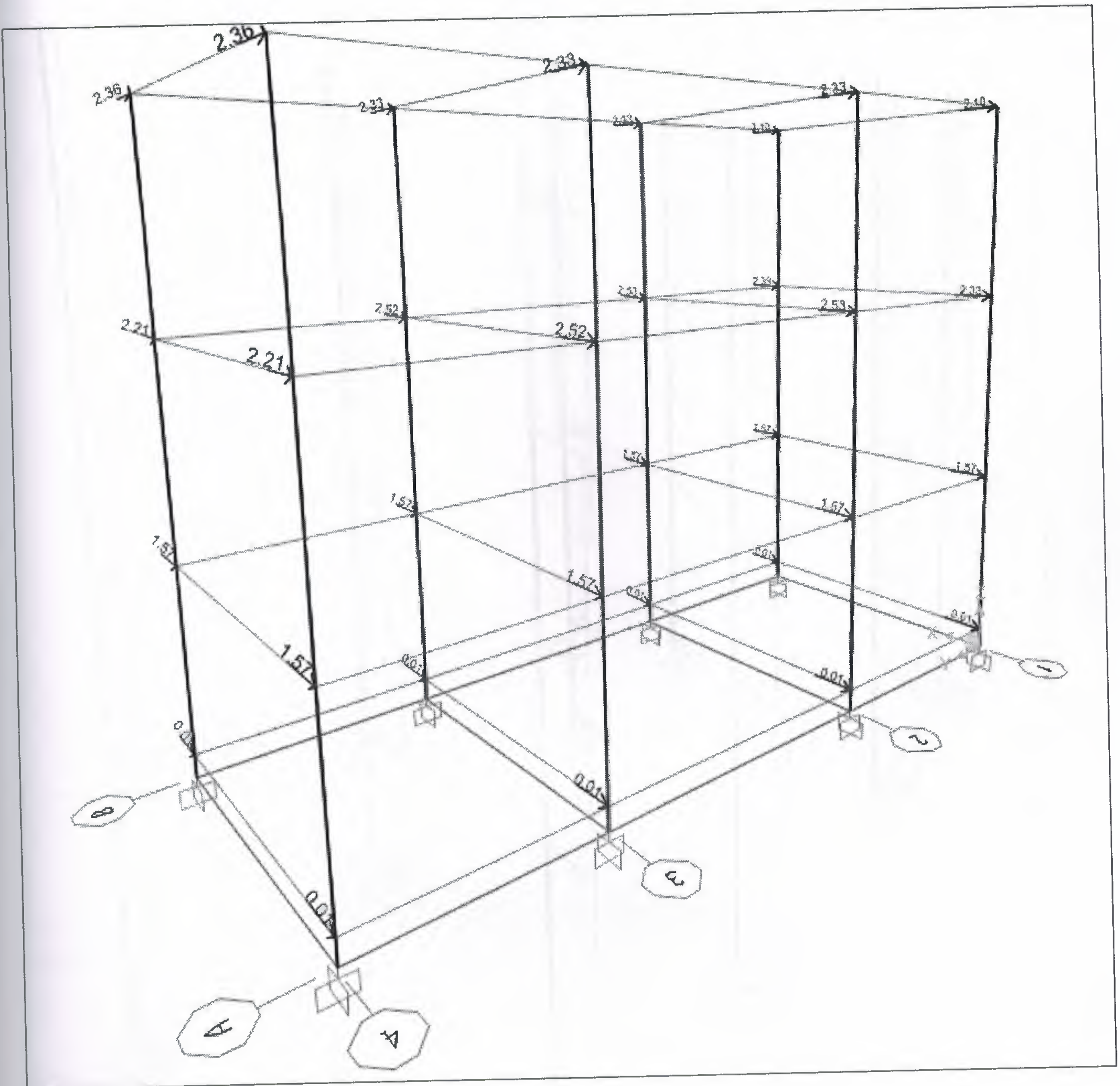


Figure 5.5 The Lateral Forces on the Columns and Roofs of the Church

The diagram below shows the shear value due to lateral forces (earthquake) where there are no any noticeable effects for shearing.

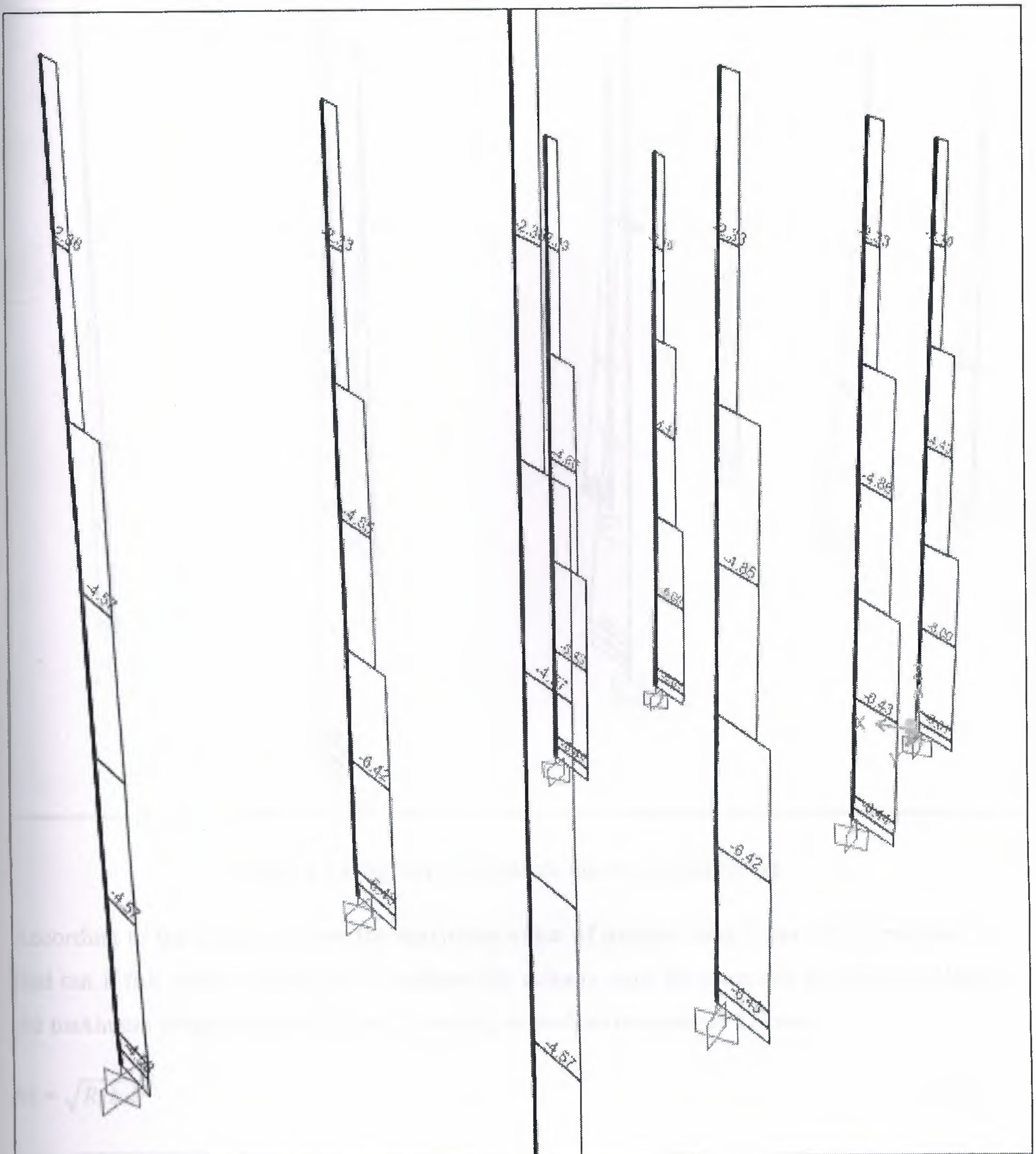


Figure 5.6 Diagram of Shear due to Earthquake

The results of the analysis lateral forces due to earthquakes indicate the following values of moments as shown below in the diagram 5.7.

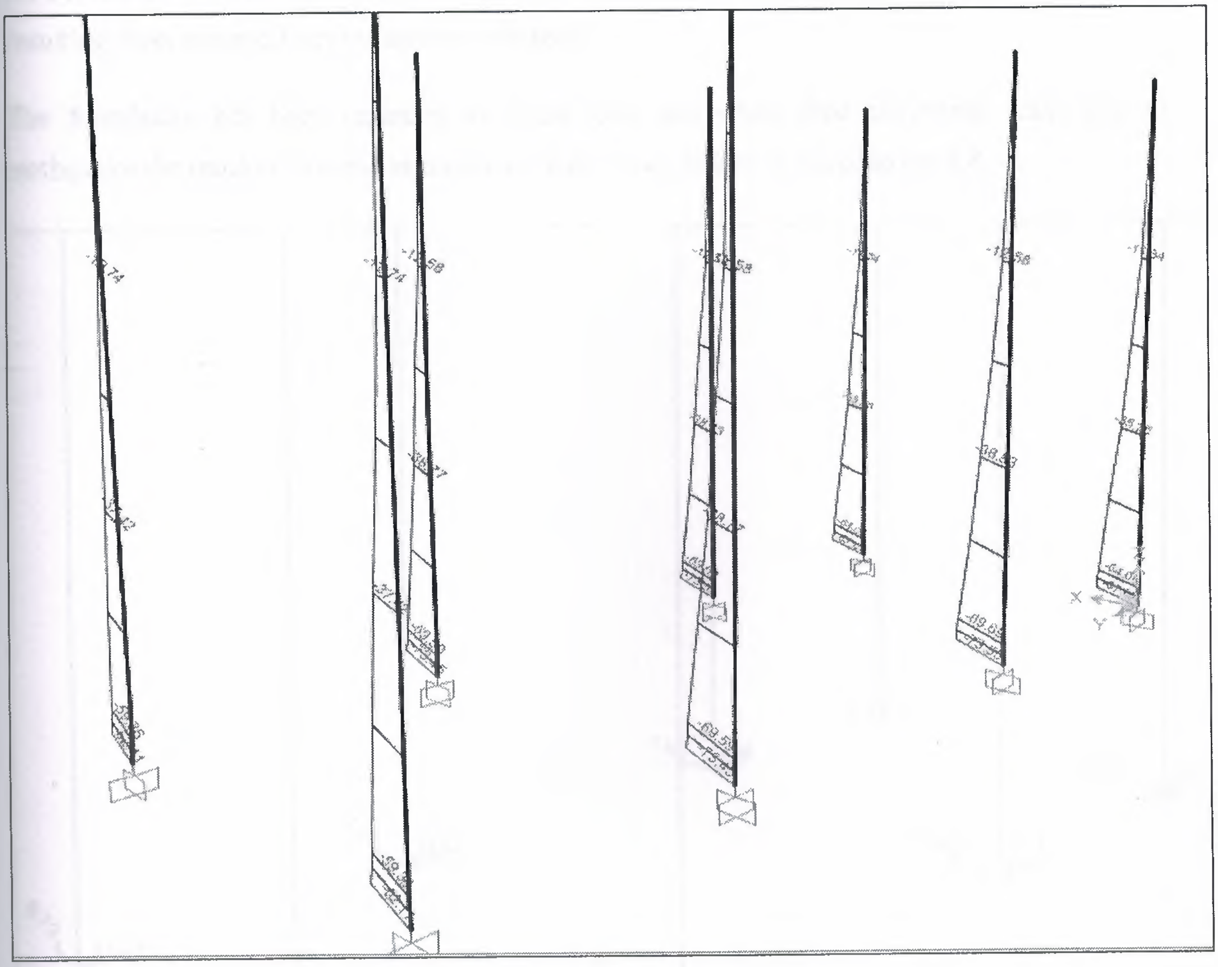


Figure 5.7 Diagram of Moments due to Lateral Forces

According to the diagram above the maximum value of moment was 74.04 t.m at pedestal. To find out if this value was enough to collapse the column must be compared it with the value of the maximum torque endures column according to its determinants, as follows:

$$M = \sqrt{R_s b d^2} \tag{5.17}$$

$$= \sqrt{85 * (2.40)^3}$$

M = 34.28 t.m (at pedestal).

$M = \sqrt{85 * (2.20)^3} = 30.08$ t.m   (for column).

As a result for the moment calculations all columns of church were unable to withstand moments resulting from seismic forces therefore collapsed.

The foundation has been regarded as fixed joint and when shed horizontal loads due to earthquake the results of reactions forces were as shown below in the diagram 5.8.

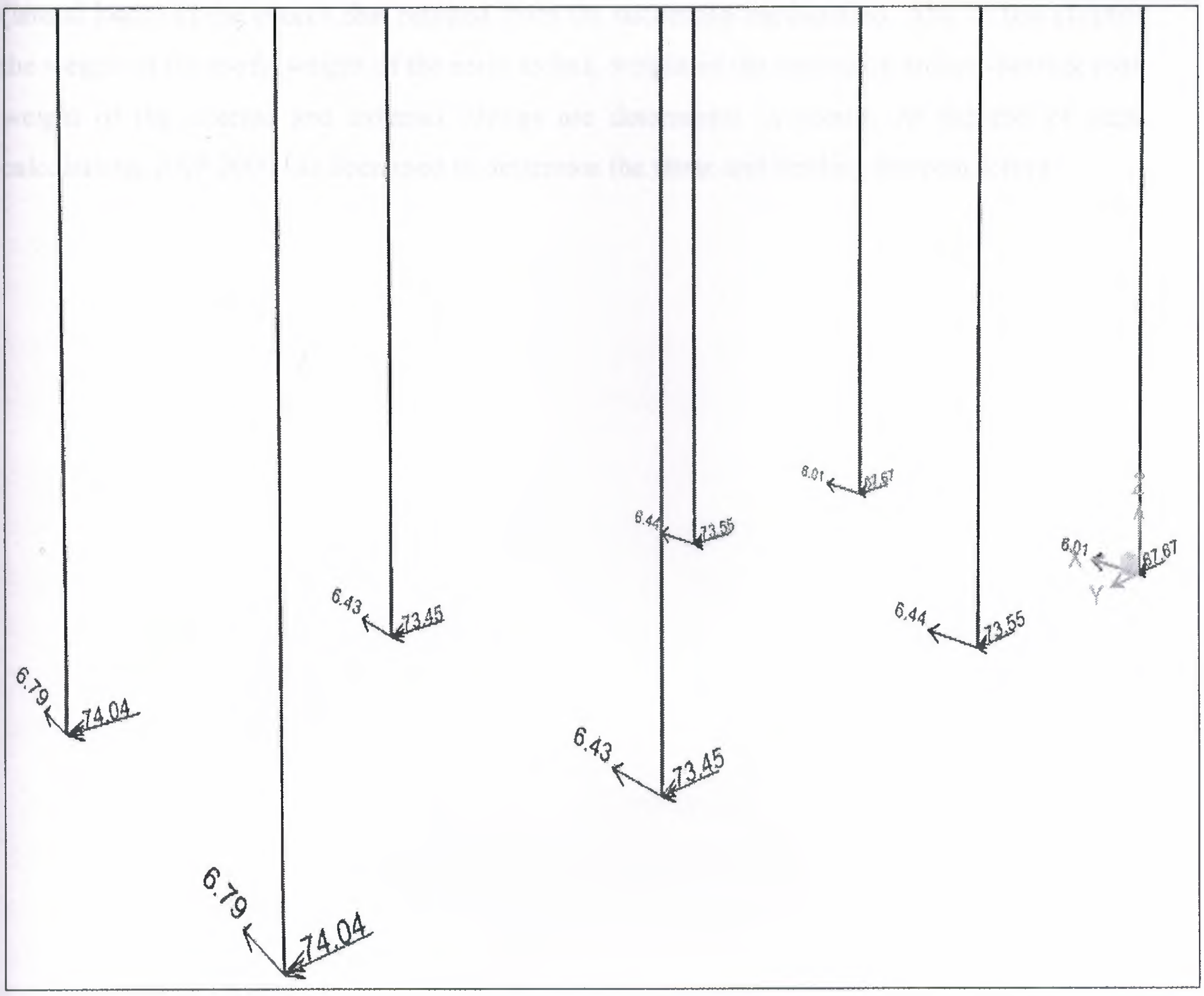


Figure 5.8 Diagram of Joint Reactions

Where all value of reactions in X-direction equal to shear forces and this confirms that the impact of shear is not effective even under the influence of seismic forces, but as shown above the value of reactions at Y- direction was high so all columns have the possibility of failure at this direction.

5.3 Summary

This chapter submitted the dead loads (vertical forces on the column) and horizontal forces (lateral loads) of the church that resulted from the successive earthquakes. Also in this chapter, the weight of the roofs, weight of the main arches, weight of the secondary arches -bearing roof, weight of the internal and external fillings are determined in details. At the end of these calculations, SAP 2000 has been used to determine the shear and bending moment forces.

CHAPTER SIX

DISCUSSION, CONCLUSIONS AND SUGGESTION FOR FUTURE WORK

6.1 Discussion

Church of St. George of Greek suffered from successive earthquakes during its structural life which led to collapse of their columns and roofs. Therefore, nowadays this church is only remains of the walls. Through the structural analysis for the church's columns, the centrism columns were in critical status where the value of the compressive strength was 108.07 t/m^2 for each a centrism column. This value exceed the limit's value of the compressive strength which was obtained from the laboratory testing of yellow sandstone and it was equal to 105 t/m^2. Therefore, the columns of this church were bearing only vertical loads before the earthquake while they must be able to withstand shear forces and bending moment after the seismic forces and this is indicating that the initial point of a structural failure was due to the lateral forces.

The strength in shear and moment is important for resistance of the earthquake. Through the usage of SAP2000 to analyze Church's columns numerically is founded that the highest value of base shear was 6.79 ton where this value was ≥ total equivalent seismic load (base shear), where the equivalent seismic load equals 6.4 ton and the maximum value of the bending moment was 74.04 t.m at pedestal where this value was more than the limit's value of the maximum bending moment design of columns (30.08 t.m).

According to the obtained outcomes, the church's pillars had been collapsed when the earthquake was more than or equal to 5.5 of the seismic intensity. The church's pillars had been cracked when the earthquake was less than 5.5 of the seismic intensity and this reduces the effective area for the resisting bending moment and shear. These considerations fit with the history of the church's collapse. The history of this church referred to the successive earthquakes that hit the church and shaken their roofs and columns down through the ages, where these earthquakes made the dramatic changes in the structural characteristics of this church. Besides that, it knocked down the almost already shaken walls and columns.

There are other factors that may accelerate the collapse of this church such as: the irregular shape of the church, where this church was designed in the deferent levels of the roofs and this is considered one of the fundamental factors in accelerating the damage during exposure to the earthquakes. As well as, also the defects in the foundation design are considered the most essential factors that will speed up the fall of the church.

6.2 Conclusions

Church of St. George of Greek was one of the important ancient historical monuments, which collapsed under the impact of successive seismic forces before thousands years since the fourteenth century to the present day. This study depended on the columns of Church, where it was fully analyzed by providing all the necessary requirements for the structural analysis under the influences of seismic forces as shown below:

- Identify the properties of the accredited constructive materials in the fourteenth century through the laboratory tests to determine their ability to resist external forces conditions and the effect of some important factors on the general behavior of the stones.
- the theoretical developed study to complement the existing knowledge that related with understanding the behavior of the soil at the site of this church to determine the properties of the seismic behavior on the construction buildings in general. According to [39], the average shear wave velocity was 560 m/s. Due to the E.C8. ($V_{s,30}$ = 360<560 <800) m/s, the type of soil was grade B.
- One of the most important parameters from the viewpoint of the seismic design is the properties of the building material that determines the success or failure in the construction building. Through the laboratory tests of yellow sandstone, the obtained results were as follows:
  - ✓ Strength in tension was 113 t/m^2. In general, the yellow sandstone giving a high behavior under the bending forces. This value considers a very important for the designed structural elements especially that it was designed to carry only the vertical forces pre-exposure to earthquakes. According to the design requirements this value was quite satisfactory.

- ✓ Strength in compression was 105 t/m^2, where this value was necessary to set the highest vertical load that can be carried by church's columns. From the physical side, the value of compressive strength was relatively good.
- ✓ Modulus of elasticity was3.05249 t/m^2. This value is good relatively for sandstone as a brittle material where the elasticity modulus is description of the materials tendency to deformation elastically.
- ✓ Unit weight was 2.280 t/m^3. The value of unit weight was high and this lead to high durability and increases the stamina of external forces and environmental conditions.
- ✓ Poisson's ratio was 0.29. This value was quit acceptable especially the maximum range of poison's ratio not more than 0.5, and this result was good to the behavior of yellow sand stone due to low stress.

- According to the results above ,the columns of the church are analyzed as the following:

  - ✓ Due to the values of the compressive strength (weight of roofs and arches) the results of the first and the fourth columns (the terminal columns) for each side of the church were (100.16 and 94.65) t/m^2 . While the results of the second and third columns (the centrism columns) for each side of the church were 108.07 t/m^2. These values were compared with the value of durability of these columns. According to the laboratory tests, the durability value was equal to 105 t/m^2 for each column (the terminal and centrism columns). Because of the values of the compressive strength for the centrism columns exceeded the allowable range, the centrism columns more vulnerable to the collapse from the terminal columns during the earthquake.
  - ✓ Due to the lateral forces of the earthquake , these forces are considered as four forces which they distributed to four joints (pedestal, head of column, roof at height of 10.8 m and roof at height of 16.2 m) and the results are calculated for each column as the following:

    - Column 1 (0.01, 1.57, 2.33and 20.93) ton from pedestal to the level 16.2m.
    - Column 2 (0.01, 1.57, 2.51and 2.33) ton.

- Column 3 (0.01, 1.57, 2.52and 2.33) ton.
- *Column 4 (0.01, 1.57, 2.21*and *2.38)* ton.

- According to these values above, SAP 2000 is used in the structural analysis to determine the moment and the shear for each column. The obtained outcomes by using SAP 2000 during the earthquake more than or equal to 5.5 of the seismic intensity as shown below:

  - ✓ At the first column, the value of shear was 6.01 ton and the value of moment was 67.67 T.M.
  - ✓ At the second column, the value of shear was 6.44 ton and the value of moment was 73.55 T.M.
  - ✓ At the third column, the value of shear was 6.43 ton and the value of moment was 73.45 T.M.
  - ✓ At the forth column, the value of shear was 6.79 ton and the value of moment was 74.04 T.M.

According to these value above, the shear's value for each column exceeded the Total Equivalent Seismic Load (V_t) where V_t = 6.4 ton. Besides that, the moment's value for each column of that church exceeded the durability's value where this value is equal to 30.08 T.M. Due to exceed the allowable limits of the shear and moment values, Church of St. George of Greek collapsed during that period of time.

6.3 Suggestion for Future Work

In spite of the obtained results from the analysis of the structural columns for this church were satisfactory but there are many interesting points that can be implemented in the future, among them are:

- Laboratory examination for the bonding material between the sandstone units in terms of all characteristics together and analysis their efficiency to link the relatively heavy units such as sandstone. This laboratory examination is considered one of the most essential tests to find out the secondary reasons that led to increase the crakes in the building or even the acceleration in the building's demolition. Therefore, the failures in the construction mainly due to the earthquakes or perhaps the construction materials were below the required level.

- Until now there is no information about the nature and type of the foundations for this church, although the fact that most of the buildings structurally strong fail due to insufficient inadequate foundation design under the influence of seismic forces.

6.4 Summary

This chapter presented the experimental outcomes that have been taken from the laboratory and by using SAP 2000. Besides that, these obtained results are compared and discussed to determine the causes that led to collapse Church of St. George of Greek in details. Also in this chapter, the suggestion for future work is presented.

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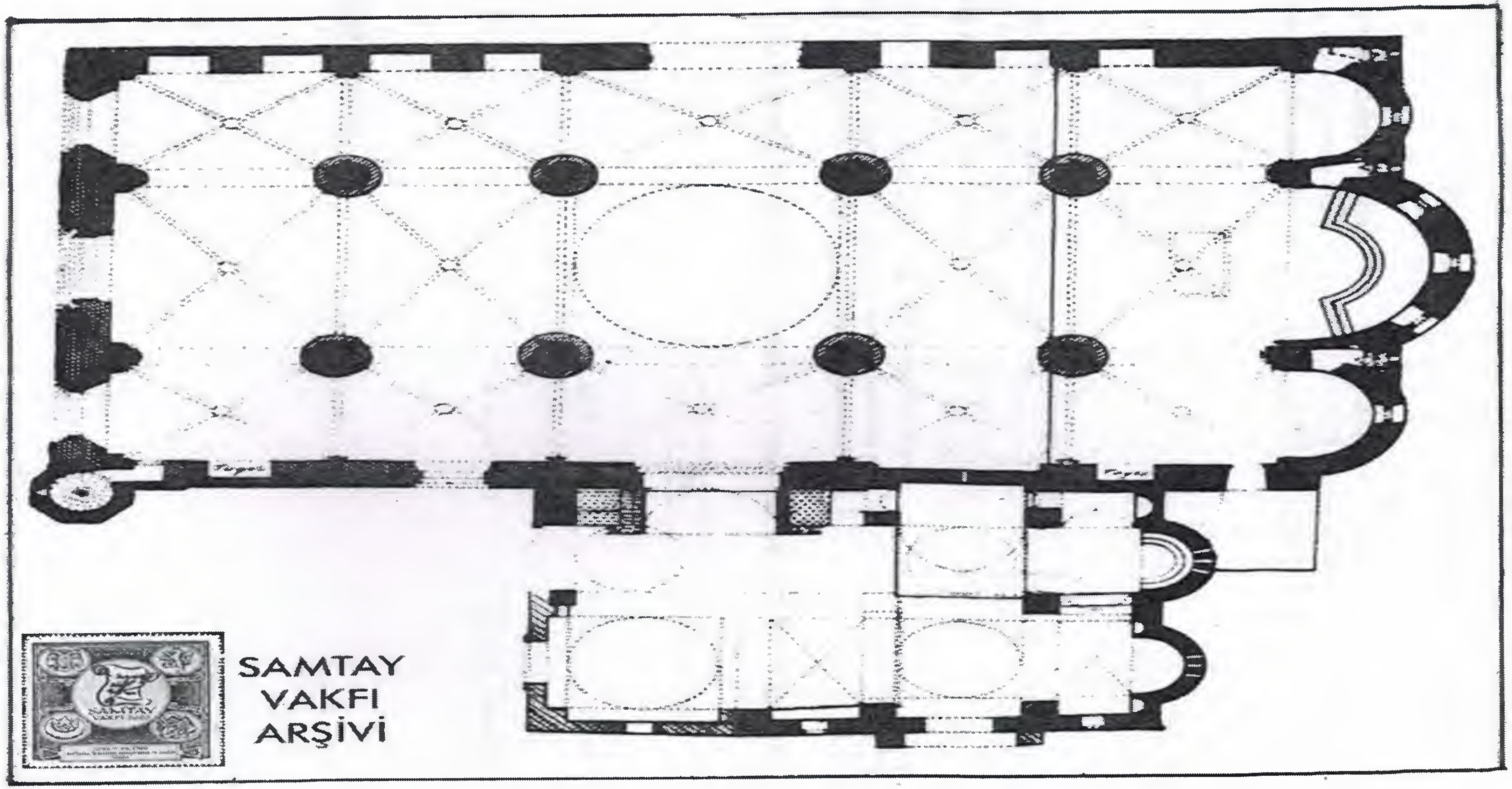
APPENDIX A

Scheme of Cathedral St. George of Greek in Famagusta



APPENDIX B
Labratory Tests

Nokta Yükü Dayanım İndisi Tablosu				
-kasyon	Örnek Sayısı	Min. $I_{s(50)}$ (kg/cm²)	Ortalama $I_{s(50)}$ (kg/cm²)	Max. $I_{s(50)}$ (kg/cm²)
umtaşı Blok	2	2,89	4,52	6,15

Ortalama Min. Nokta Yükü Dayanım İndisi = 2,89 kg/cm²
Ortalama Avr. Nokta Yükü Dayanım İndisi = 4,52 kg/cm²
Ortalama Max. Nokta Yükü Dayanım İndisi = 6,15 kg/cm²

Min. σci = 34,68 kg/cm²
Ort. σci = 54,24 kg/cm²
Max. σci = 73,80 kg/cm²

Bu değerlere göre Min. Nihai Taşıma Gücü (qu_{min}) = 2,11 kg/cm²
Ort. Nihai Taşıma Gücü (qu_{max}) = 3,31 kg/cm²
Max. Nihai Taşıma Gücü (qu_{max}) = 4,50 kg/cm²

En olumsuz durumdaki Zeminin Emniyetle Taşıyabileceği Gerilme = 0,70 kg/cm²
Ortalama durumdaki Zeminin Emniyetle Taşıyabileceği Gerilme = 1,10 kg/cm²
En olumlu durumdaki Zeminin Emniyetle Taşıyabileceği Gerilme = 1,50 kg/cm²

Kaya Zeminler İçin Elastisite Modülü Hesabı (Value for Modulus of Elasticity)

Öngörülen **"MR"** değeri; 200 mertebesindedir.

→ Ei = 6.936,00 kg/cm²

Erm = 305,25 kg/cm²

Es = 3.052,49 Ton/m²

GEOTEST
ZEMİN KAYA VE YAPI MALZEMELERİ
LABORATUVARI

KTMMOB

İNŞAAT MÜHENDİSLERİ ODASI
CHAMBER OF CIVIL ENGINEERS
Mehmet Göze (Asl)
YAPI MALZEMELERİ LABORATUVARI

İMO

Referans : 2013-B07

Report of Compressive Strength and Breakage Load Tests :

Rapor Tarihi: 16/09/2013

Konu: Kıbrıs Türk İnşaat Mühendisleri Odası Yapı Malzemeleri Laboratuvarında yapılan Sarı Kumtaşı Basınç Dayanımı ve Kırılma yükü sonuçları aşağıdaki gibidir.

Deneyi Talep Eden : Marwa Aladdin
Üretim Tarihi : -

Numuneye Ait Bilgiler:

Üretici Firma : -
Numune Adeti : 1
Boyutları : 100X100X100

Numune Tanımı : Sarı Kumtaşı
II. SINIF (DELİKLİ)
Numunenin Rengi : Sarı
Numunenin Şekli :

Yapılan Deney Sonuçları:

Deney Sonucu Bulunan Değerler		
Numune No	Kırılma Yükü(kN)	Karakteristik Basınç Dayanımı- P(Mpa)
1	9,9	0,44
Ortalama	9,9	0,44
Minimum	9,9	0,44

Deneyi Yapan
Turgut Öztüner
Laboratuar Şefi

Onay

K.T.M.M.O.B.
İnşaat Mühendisleri Odası
Mehmet GÖZE (Asl)
Yapı Malzemeleri Laboratuvarı
Tel.: 225 65 69 - YK 284

Adres: Organize Sanayi Bölgesi
5.Sok. No.13 Lefkoşa KKTC
web page: www.ktimo.org
e-mail:laboratuvar@ktimo.org

Tel : +90 392 225 6569
Tel : +90 392 228 5210
Fax : +90 392 225 6547

ÖZGÜL AĞIRLIK DENEY RAPORU (Report of Gravity's Test) :

Referans : OA13-04 Rapor Tarihi: 16/09/2013

Konu: Kıbrıs Türk İnşaat Mühendisleri Odası Yapı Malzemeleri Laboratuvarında yapılan Sarı Kumtaş özgül ağırlığı deney sonuçları aşağıdaki gibidir.

FİRMA VEYA KİŞİ BİLGİLERİ:

Deneyi İsteyen Firma/Kişi : Marwa Aladdin

NUMUNE BİLGİLERİ:

Numunenin Tanımı : 100X100X200
Sarı Kumtaşı - II. SINIF (DELİKLİ)

Numunenin Geldiği Ocak : -

DENEY SONUÇLARI:

Kullanılan Metod :Tel Sepet Metodu

1- Kuru Birim Hacim Ağırlığı ρ_p :2240 Kg/m^3
2- Kuru Birim Hacim Ağırlığı ρ_p :2330 Kg/m^3
3- Kuru Birim Hacim Ağırlığı ρ_p :2280 Kg/m^3

Ortalama Kuru Tane yoğunluğu ρ_p :2280 Kg/m^3

Deneyi Yapan
Turgut Öztüner
Laboratuar Şefi

Onay
Enver Toker
İnşaat Mühendisi

İnşaat Mühendisleri Odası
Mehmet GÖZE (Asi)
Yapı Malzemeleri Laboratuvarı
Tel.: 225 65 69 - YK 284

GEOTEST
Zemin Kaya ve Yapı Malzemeleri Laboratuvarı
Dr. Küçük Bulvarı Hamitköy Kavşağı Yaysat Arkası Yay Sokak D.1 Lefkoşa, Mersin 10 – TURKEY
Tel: 0392 225 7047 Faks: 0392 225 7047 Cep: 0533 863 8151 e-mail:mastermap2005@hotmail.com

KAPİLER SU EMME TAYİNİ **Determination Of Water Absorption Due To Capillary Action**	**FORM NO :** ZML 2013-22 **TS EN 772-11**
PROJE: **Project**	**DENEYİ YAPAN KURULUŞ:** GEOTEST Zemin Kaya Ve Yapı Malzemeleri Laboratuarı
TARİH:03.11.2013	

ÖRNEK NO Sample No	**ÖRNEKLEME DERİNLİĞİ** Depth Of Sampling **(m)**	**ÖRNEĞİN DENEY ÖNCESİ KURU AĞIRLIĞI** Dry Weight Of Sample Before Test m_{dry} **(g)**	**BRÜT YÜZEY ALANI** Area A_s **(cm^2)**	**SUYA BATIRMA SÜRESİ** Time of immersion **(Seconds)** **(t_{so})**	**ÖRNEĞİN DENEY SONRASI YAŞ AĞIRLIĞI** Wet Weight Of Sample After Test $m_{so,s}$ **(g)**	**KAPİLER SU EMME KATSAYISI** Water absorption coefficient due to capillary action $C_{w,s} = \frac{m_{so,s} - m_{dry}}{A_s \sqrt{t_{so}}} \times 10^6$ **[$g/(m^2 x s^{0,5})$]**	**KAYAÇ TANIMI** Rock Description
1	Yüzeyden Blok	516,26	22,90	600	534,72	255	Yapay Blok
2	Yüzeyden Blok	522,41	23,07	600	538,59	222	Yapay Blok
3	Yüzeyden Blok	516,36	23,24	600	539,26	311	Yapay Blok
						ORTALAMA	**263**

* Bu deney sonuç formu ve ekinde verilen deney sonuç grafikleri sadece laboratuvarımıza teslim edilen numunelere aittir.
* Numunenin alındığı yerin ve kaynağının değişmesi nedeni ile oluşacak değişikliklerden sorumluluk taşınmaz.
* Bu deney sonuç formu ve ekinde verilen deney sonuç grafikleri laboratuvarımızın izni olmadan kısmen veya tamamen kopyalanamaz, değiştirilemez alıntı yapılamaz.

GEOTEST
ZEMİN KAYA VE YAPI MALZEMELERİ LABORATUVARI - M.S. 10710