Earthquake Damages Influenced by Soil Conditions in Historical Buildings in Istanbul

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SYNOPSIS; This paper is based on the study of the damages by eartquakes on the historical buildings constructed in Bysantine and Ottoman period an represents a preliminary appro toh the problem of identifying the causes of these damages influenced by soil conditions

In this paper, some aspects of soil conditions and foundations systems are given related to the preservation of momument. Especially the presentation is concentrated on the folloving topics;

* An estimation of seismic area and on Design basis rerponse spectra for historical buildings.
* Geotechnicalproblems of the old city Istanbul.
* Statical aspects of masonry of Bysantine an Ottoman buildings.
* Seismic behaviour of the masonry of Bysantine and ottoman buildings.
* Aprevention system for historical buildings against hazardous future earthquakes.

1.INTRODUCTION

Istanbul, the oldest metropolitan capital of the Eeast Roman, Bysantine and Ottoman Empire, is situated on the most active seismic mediterranean zone.

The many Bysantine buildings,Hagia Sophia with the first large dome Ottoman turkish' buildings constructed during many centuries are on this seismic zone which the soil is generally unstable. During the last four thousand years (B.C.2100-1900 AD),1175 earthquakes had occured in Turkey and the surrounding areas limited by 22° 45° E longitudes and 33°45°lattitudes(TUBITAK,1981) During Bysantine and Ottoman periods,Istanbul has been subjected to many earthquakes with great intersities (Manburi,1927).

Since 212 to date,many Bysantine ant Turkish-Ottoman domed buildings were collapsed and Hagia Sophia had largely swaryed, cracked, partly collapsed (Inciyan,1976).

Hagia Sophia is still the object of the risk of further damage as state by various recent studies (Mungan 1966).

Records for earthquakes damages are taken from the documants of Bysantine and Ottoman Emprie.

Accelarations of the earthquakes are found by theoretical colculations taking the serious damages described in the historical documents into consideration.

It is shown that the intensities of the earthquakes that cause serious damages had been greathen then VI (in M.M.Scale) (Arıoğlu Anadol, 1973).

The instensity degrees of the earthquakes have been evaluated according to the (MSK-64) intensity scale. The damages in Istanbul are characterized by staticticai records for a interval of (212)-1967) years (TUBITAK,1981).

According to these findigns a cronological estimation shows that the damages caused by earthquakes are more serious on the buildings con structed on unstable soil then the others wich are on stable soil.

Since 212 up to day, many Bysantine and Turkish Ottomandomed buildings were collapsed and Hagia Sophia had, largely swaved, cracked, partially collapsed, despite its foundation is on a stable soil formation.

Observations on the the diagnosis of damages show that all earthquake damages were influenced by soil conditions during the history.These historical buildings had been constructed on the masonry foundations stiffned with short woden piles or wooden grillage.

The structures, of the buildings be have as a rigit bady against the seismic action.The vibration periods are calculated T = 0,15 0,45 sec, according Turkish seismic code (Çamlıbel,1968).

2. AN ESTIMATION THE SEISMICITY OF ISTANBUL and ON DESIGNS BASIS REPSONSE SPECTRA for HISTORICAL BUILDINGS.

The historical edifices in Istanbul are important structures. Their prevention system's of earthquake resistant design must be governed by special criteria similar to those for nuclear power plants. The proximity of the Marmara sea makes a through assesment of the earthquake potential imparative for the safety of the historical buildings.Before design a prevention system a study must involve the assesment of the basis elastic response spectra with the operating Basis Earthquake and the safe shutdown Earthquake on the basis of the applicable speci fications in order to evaluate the peak ground accelarations (PGA) to be expected at the site. According to the propabilistic and deterministic analysis for the historical buildings the magnitude must be taken 7.o M 7.5 and the (PGA) of the bedrock under the soil materials can be taken (020 0,30 g).The geotechnicalinvestigations made at the site reveal that the site consist of sand stones with shear wave propagation velocities above approximate 700 mm/ sec.(Ulker,1990).

2. GEOTECNİCAL PROBLEMS of THE OLD CITY ISTANBUL

The base of the Northeastern part of the ancient walls is of greywackes and shales of Upper Devonian. Over this, there are lithological sarmation layers of sands and gravels, clays and mactra limestones.

The layer of artificial fill of the city remainings constitute the upper layer. Though the green clay of the sarmation layer causes problems especially on the slopes, the over consolidates clays sands and gravels are reliable as to their settlement and their load bearing capacities.

The Soil of the Golden Horn coasts and Bosphorus is composed of natural alluvions brougth by the rivers and the waste disposal of the city Such a sedimentory soil and inclined bedrock of the area cause important settlement problems in which the damages due to the foundation failures of the buildings often rusult in the impossibility of restoration (AKSOY,1992).

Buildingsover an unstable soil have to be constructed on foundations stiffened with short wooden piles or directly on pile foundations.

Inside the city walls area of Istanbul wooden grillage could be found under the foundations of old masonary buildings constructed on graywackes.

The famous Byzantine and Ottoman mounmauts are situated in this area. One of these Süleymaniye mosque (1550-1557) coustructed by famous architect Sinan has footings getting larger with depth and adapting to rock via a woden grillage filled with mortar. (Aksoy 1962).

3. STATİCAL ASPECTS OF MASONRY OF BYZANTINE AND OTTOMAN BUILDINGS.

The outstanding feature of Byzontine and Ottoman buildings is that some of them still exist.Minor failures have, of course, occured and there have been major catastrophes,but masonry structure is, essentially extremly stable.

Hagia Sophia suffered, fairlv early in its life, two severe earthquakes; the extraordinary consequence was not that on each occasion, one quarter of the highdome fell, but that, on each occasion three quarters of the dome remained standing.

The continual settlements an shifts of foundations experienced by every building seem to cause the masonry structure no terminal distress.

İt is true that masonry may be apparently disfigured by more or less extensive cracking.

Such cracks, however, can continue to exit for centuries and are not signs of imminent,or indeec eventual collepse,Rather,cracks are indications of the way the masonry has adaptep itself to its enviromment;

the craeked state is the natural state of **masonry**. The basic assumption of the behaviour of masonry. is that it is a material unable **to accept tension**. Any change in geometry is therefore liable to cause cracking and to the effective subdivision of the original complex structure into a number of simpler elements.

Masonry building as an assemblage of stones or briques, placed one on another to form a stable structure. Mortar may be used to fill intestices, but this mortar will have been weak initially,and may have decayed with time, and cannot be assumed to add strength to the coustruction.

Stability of the whole is assured by the compaction under gravity of the various elements; a general state of compressive stress can exist, but only feeble tensions can be resisted.

4. SEISMIC BEHAVIOUR of masonry BYZANTINE AND OTTOMAN MONUMENTS

The masonry Byzantine and Ottoman monuments can be classified in accordance with their function into the following categories:

* Buildings of worship (churches, mosques)
* Public buildings (palaces e.t.c)
* Fortifications (walls, towers e.t.c)

The most mumerous from the obove categories are the buildings of worship, especially the churches and mosques are in use. All these buildings have masonry vaulted and domed structures. According to the structural analysis for vaults and domes comes out that the followings types of damage may be observed in the domed buildings:

a) Radial cracks in the drum-ring and the lower part of the dome.
b) Horizontal cracks on the basis of the drum, in the interior of the drum, especially when it is high with windows.
c) Cracks at the key of the vaults.
d) Diagonal cracks at the spandrels of the pierced piers.
e) Diagonal cracks at the piers or at the Substutute **shear walls of the cross at the** central bay.

All types of cracks occured during earthquakes have been observed in the momunets in İstanbul. The damages observed in the momuments had been influenced by soil conditions as stated by various recent research.. The structures of the buildings behave as a rigit bady against seismic action. Their vibration periods are calculated T = 015-045 sec. according to the Turkish seismic codes.

Taking consideration the earthquake damages in the past these historical buildings are still the object the risk of futher damages.

5. PREVENTION SYSTEM FOR HISTORICAL BUILDINGS AGAINST TO THE HAZARDOUS FUTURE EARTHQUAKES

In this paper a prevention system is proposed against the hazardous future earthquakes. An underground structure system of concrete piles jointed by concrete bars to the foundation of building can absorbe the hazardous energy and can increase the vibration period of building. A design of pilerows around the building isolated of seismic vibrations can absorb o lot of seismic energy. Concrete piles can be embedded in an elastic media and this elastic cover in periphery of piles can isolate the piles from the seismic vibrations. During a seismic action the building tied to the piles embedded in the soil starts to the forced vibration. During these forced vibrations all the seismic energy will be absorbed by the concrete piles.

The seismic energy that will be absorbed by the structure of building can be reduced to zero according to the geometry of piles system dimensions and the absorbility of the piles.

In the (Figure 1.) the pile rows in plane are shown around any building. All the historical buildings have the masonry rigit foundations.They behave as a rigit body against seismic action.

Their vibration periods are calculated (0,15 0,45) sec. according Turkish seismic code. (Çamlıbel,88)

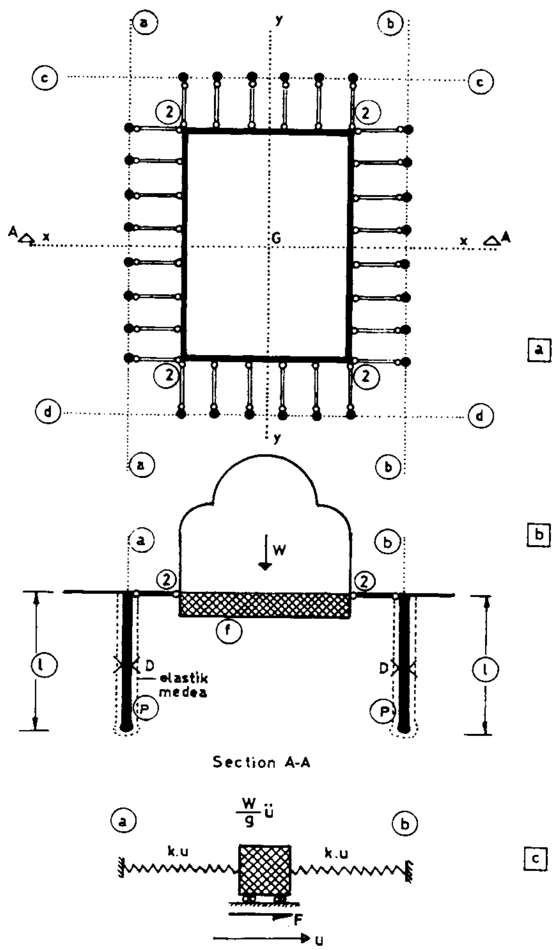

Figure 1. APREVENTİON SYSTEM DESİGN

According to the plan scheme of the foundation (Figure 1.),the piles rows (a,b) paralel to y-y direction and piles rows (c,d)paralel to (x-x) direction are designed.

During a seismic action for example in x-x direction using the forces equilibrium can be writen:

$$m.\ddot{u} = - k.u + F \qquad (1)$$
$$m.\ddot{u} + ku = mcg.coswt \qquad (2)$$
$$\ddot{u} + p^2 u = cg. coscwt \qquad (3)$$

A diffitanttial equation is found. The general solution of this equaton is:

$$U = A.cospt + B.sint + cg. \frac{Coswt}{\frac{p(1-w^2)}{p^2}} \qquad (4)$$

In this equation (A,B) parameters can be found using limit conditions of the system (t = 0 ,v= o ü = 0) and the equation can be writen,

$$u = cg. \frac{1}{\frac{p^{(1-w^2)}}{p^2}} . (coswt-cospt) \qquad (5)$$

In this equation: W: weight of the building,m= W/g: the mass of building, g: gravity acceleration, u: motion in (x-x) direction, ü: acceleration, of the building mass (m), K: total elastic coefficient of the pile rows (a,b)in (y,y) direction, F = mcg coswt: equivalant seismic force, c: earthquake coefficient. w: pulsation of seismic vibration and $p^2 = k/m$ are shown .

Using the formula (5); the seismic effect on the pile system (xp = K.u) can be calculated. According to these conclusions, it can be possible to reduce the seismic effect on the building. using a favorable system of piles embedded in soil, which can absorb the greatest part of the seismic energy.

CONCLUISONS

1 According to the observations and analitical investigations made on the dome buildings of Istanbul which had no damages during historical earthquakes, with intensities greather 6 (in M.M. Scale) lead to the following concusions:

1.1 The element and components of the structures have a large ductility and a great seismic energy absorbtion ability.

1.2 In the domed buildings, there exist axisymetry. The arches carrying the central dome have the same rigidity.

1.3 The distrubution of rigidity in plan and in elevation is uniform.

1.4 The plane rigidity center and gravity center coordinates coincide approximatly at the same point.

1.5 The stresses in the structural elements are all compression.

2.The analitical investigations made using the Turkish seismic code, show that all buildings which have tension streesses had been cracked, collapsed several times by the earthquakes in the history. These edifices are now still under the risk of further earthquake damages.

3.Taking in consideration to the damages of historical earthquakes in Istanbul the prevention systems as presented here for historical buildins which are the summit of the mankind can be designed, against the hazardous future earthquakes.

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