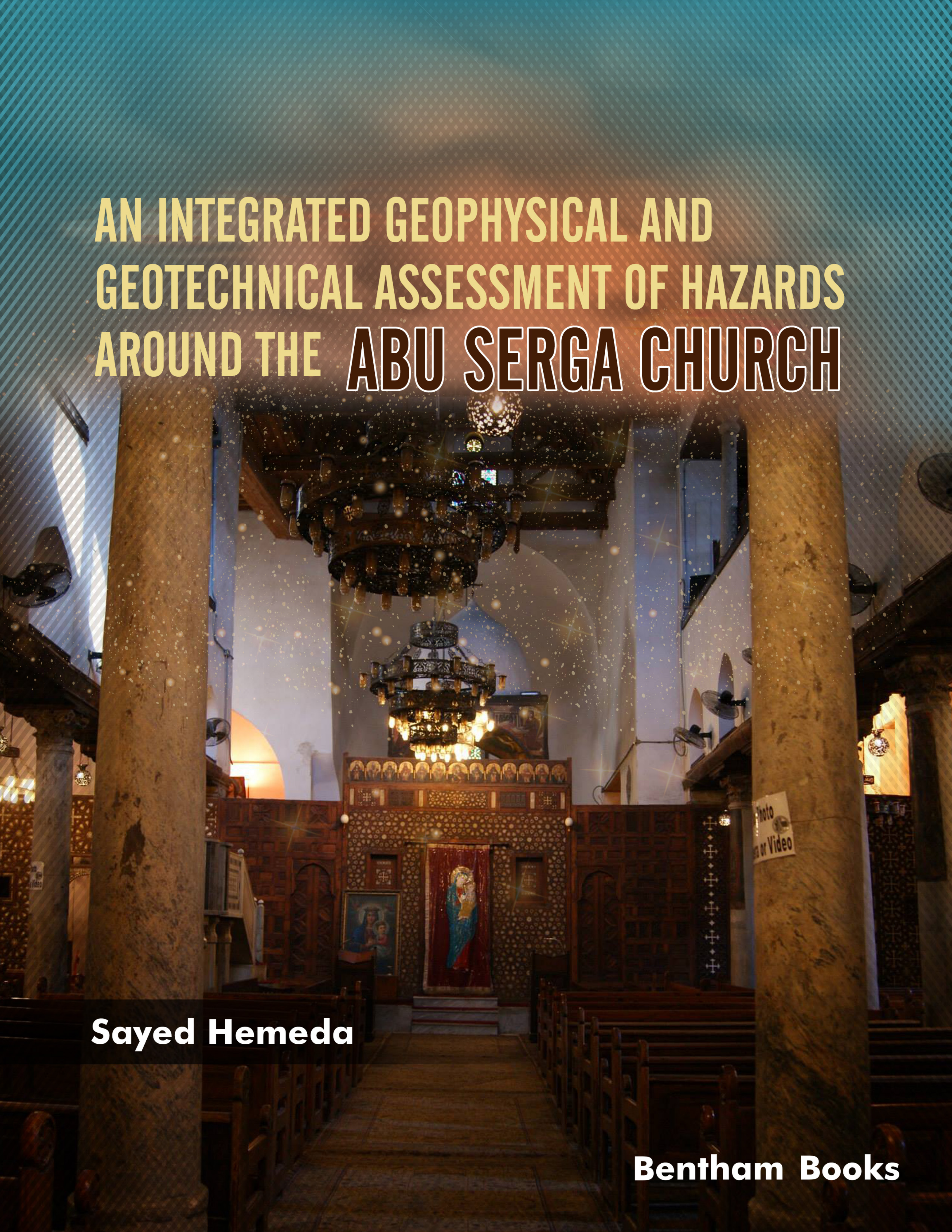
AN INTEGRATED GEOPHYSICAL AND GEOTECHNICAL ASSESSMENT OF HAZARDS AROUND THE ABU SERGA CHURCH



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An Integrated Geophysical and Geotechnical Assessment of Hazards Around the Abu Serga Church

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PREFACE

This book is of interest to practical geotechnical engineers and experts in the Conservation Engineering of the architectural heritage or built heritage. It discusses some contemporary issues related to **advanced geotechnical and geophysical techniques** in preservation projects which are critical components in conservation planning and management of built heritage and often require detailed management techniques and unique solution methods to address failures and remedial measures. The geotechnical engineering community continues to find improved testing techniques for determining sensitive properties of bearing soils and structures, including stress-wave based non-destructive testing methods and techniques. Also to improve the foundation retrofitting intervention; the design and implementation. To minimize failure during conservation and preservation projects. Contemporary issues and data may reveal useful lessons and information to improve restoration project construction management and minimize economic losses. This book discusses these aspects using appropriate methods in a simple way.

This book discusses many interesting topics in Geophysical and geotechnical engineering like, Modern Geotechnical Practice, Geotechnical Earthquake Engineering, Principals and Practice in Foundation Design, and 3D Modeling in Geomechanics, Geotechnical investigation for Preservation of Historical Buildings and Archaeological Sites.

This book brings together a small collection of chapters but covering Geotechnical problems and solutions from a broadest to a narrowest sense.

Using this opportunity, I would like to express my gratitude to the publishers (Benthan Scientific Publishers) for their efforts in making this book published.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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Declared none.

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CHAPTER 1

Introduction and Scope of Work

1. INTRODUCTION

Abu Serga Church in Coptic Cairo is one of the oldest Coptic churches in Egypt. The church was built in the 4th century and was probably finished during the 5th century.

Saints Sergius and Bacchus Church is traditionally believed to have been built on the spot where the Holy Family, Joseph, Mary, and the infant Jesus Christ, rested at the end of their journey into Egypt.

The church is of significant historical importance, and in fact, it is where many patriarchs of the Coptic Church were elected.

It was burned during the fire of Fustat, in the reign of Marwan II around 750. It was then restored during the 8th century and has been rebuilt and restored constantly since medieval times; however, it is still considered a model of the early Coptic churches. Again, the most precious and ancient of the icons are on the southern wall. A vast central hall is divided into three naves by two rows of pilasters.

The 12 October 1992 Dahshour earthquake south of Cairo, Egypt, was the most severe natural hazard to hit this area in more than 10 decades. The earthquake measured 5.3 in magnitude on the Richter scale (duration magnitude M_d due to the seismic station at Helwan). The P-wave magnitude (m_b) and the surface wave magnitude (M_s) determined from worldwide seismic records were equal to 5.9 and 5.3, respectively. The epicenter was about 18 km south of the center of Cairo, near the village of Dahshour, and located at an estimated depth of 25 km. Several aftershocks followed the main event and continued to occur during the month of November. One of Richter magnitude 4.2 occurred on 13 October another of magnitude 4.3 occurred on 22 October. On 5 November, three consecutive aftershocks ranging from 3.9 to 4.2 in magnitude occurred within half an hour, followed by several aftershocks of smaller magnitude.

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The present report helps in understanding the amount of hazards and risks that Abu Serga Church suffers. Abu Serga Church is located within Cairo city and is considered one of the oldest Churches found in Egypt. The church suffers moderate hazards but high risk; it is very important to assess the amount of engineering and seismic risk for this important archeological structure. For this, the amount of hazards were evaluated carefully using all available source of information, including review of the pieces of literature in and around Abu Serga church, earthquake catalogues, expected water table level, and seismic strength. A GPR survey was held at Abu Serga church to detect any suspected archeological remains under the church. Finally, the resonance properties and expected design response spectrum were determined for the Abu Serga Church.

Previously published geological maps and literature on the geology of the Cairo area have been integrated within a regional framework and tectonic context of the area under investigation. Having done that, fault intersection has been defined in the area in and around the church.

2. SCOPE OF WORK

The present study is an integrated geophysical work to determine the following points:

1. Determining the possibility of near-surface groundwater and its expected depth.
2. Determining the soil shear strength in terms of shear wave velocity versus depth.
3. Determining the amount of expected probabilistic seismic hazard in terms of expected peak ground accelerations for exposure time periods of 50 & 100 years.
4. Determining the soil and structure natural frequencies of vibrations.
5. Determining design response spectrum for Abu Serga church,
6. Making 2D geo-radar Multi-scanning for determining the possibility of old remains of any archaeologies features under the church.

Task 1- Study the soil saturation and expected water depth.

Task 2- Study soil strength in terms of shear wave velocity.

Task 3- Study the resonance properties of the church.

Task 4- Study the neotectonic and geohazards issues in Abu Serga church.

Task 5- Study of neotectonic and paleoseismic issues in Abu Serga church and the surrounding region, and give the expected amount of shaking in terms of

PGA. This is to address future surface and subsurface problems.

Task 6 - Regional tectonic framework study. This is to address fundamental problems or practical issues of tectonic evaluation and produce a seismic hazard model.

Task 7- Give the expected design spectrum based on the most important earthquakes that hit the region.

Task 8- Study the possibility of old archeological remains under the church.

3. METHODOLOGY & WORK PROCEDURE

In order to meet the above-mentioned objectives, the following work procedure was followed:

1- Reviewing available information, previous work, and maps (topographic, geologic, and seismicity data) related to Abu Serga church area and its surroundings.
2- Satellite images were geo-referenced, processed for structure analysis.
3- Analyzing and interpreting the collected data of resistivity imaging, refraction microtremors test, soil resonance test, and ground-penetrating radar data (GPR).
4- A field visit was conducted to verify the interpretation and gather detailed features, principally those that might affect the Abu Serga church area.
5- Collecting historical seismicity in and around Abu Serga church in the period 2200 BC. 1899 AD.
6- Collecting recent instrumental earthquake catalogue in the period 1899 AD. 2006 AD.
7- Performing regional seismic hazard analysis based on the most recent hazard parameters available in Egypt, such as PGA attenuation formulas, seismic source regionalization, recurrence relationships … *etc*.

Finally, based on the previously collected data, the amount of hazard at Abu Serga church is accessed assessed, and possible archeological features are given.

CHAPTER 2

Determining the S-Wave Velocity by Using Refraction Microtremors Technique

Abstract: The refraction microtremors technique is based on two fundamental ideas. The first one is that common seismic-refraction recording equipment, set out in a way almost identical to shallow P- wave refraction surveys, can effectively record surface waves at frequencies as low as 2 Hz (even lower if low-frequency phones are used). The second idea is that a simple, two-dimensional slowness-frequency (p-f) transform of a microtremors record can separate Rayleigh waves from other seismic arrivals and allow recognition of true phase velocity against apparent velocities. Two essential factors that allow exploration equipment to record surface-wave velocity dispersion, with a minimum field effort, are the use of a single geophone sensor at each channel, rather than a geophone "group array", and the use of a linear spread of 12 or more geophone sensor channels. Single geophones are the most commonly available type and are typically used for refraction rather than reflection surveying. The advantages of ReMi from a seismic surveying point of view are several, including the following: It requires only standard refraction equipment already owned by most consultants and universities; it requires no triggered source of wave energy, and it will work best in a seismically noisy urban setting. Traffic and other vehicles, and possibly the wind responses of trees, buildings, and utility standards, provide the surface waves. The present study uses the ReMi method to determine the S-wave seismic velocity with depth for Abu Serga church. This is important to determine the depth of the bedrock (any solid rock underlying the soil with S-wave >765 m/s, USGS, 190) as well as other engineering applications.

Keywords: Abu Serga church, Architectural Heritage Preservation, Cairo, Non-destructive Testing, Survey, ReMi Test.

1. DETERMINING THE S-WAVE VELOCITY USING REFRACTION MICROTREMORS TECHNIQUE

The present study uses the ReMi method to determine the S-wave seismic velocity with depth for Abu Serga church. This is important to determine the depth of the bedrock (any solid rock underlying the soil with S-wave >765 m/s, USGS, 190) and other engineering applications. The refraction microtremors technique is based on two fundamental ideas. The first is that common seismic-

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refraction recording equipment, set out in a way almost identical to shallow P-wave refraction surveys, can effectively record surface waves at frequencies as low as 2 Hz (even lower if low frequency phones are used). The second idea is that a simple, two-dimensional slowness-frequency (p-f) transform of a microtremors record can separate Rayleigh waves from other seismic arrivals and allow recognition of true phase velocity against apparent velocities. Two essential factors that allow exploration equipment to record surface-wave velocity dispersion, with a minimum of field effort, are the use of a single geophone sensor at each channel, rather than a geophone "group array", and the use of a linear spread of 12 or more geophone sensor channels. Single geophones are the most commonly available type, and are typically used for refraction rather than reflection surveying. The advantages of ReMi from a seismic surveying point of view are several, including the following:

It requires only standard refraction equipment already owned by most consultants and universities; it requires no triggered source of wave energy, and it will work best in a seismically noisy urban setting. Traffic and other vehicles and possibly the wind responses of trees, buildings, and utility standards provide the surface waves this method analyses (Louie, 2001; Pullammanappallil*et al.*, 2003).

2. THEORY

ReMi processing involves three steps: Velocity Spectral Analysis, Rayleigh Phase-Velocity Dispersion Picking, and Shear-Wave Velocity Modeling.

2.1. Velocity Spectral Analysis

The basis of the velocity spectral analysis is the p-tau transformation, or "slantstack," described by Thorson and Claerbout (1985). This transformation takes a record section of multiple seismograms, with seismogram amplitudes relative to distance and time (x-t), and converts it to amplitudes relative to the ray parameter p (the inverse of apparent velocity) and an intercept time tau. It is familiar to array analysts as "beam forming" and has similar objectives to a two-dimensional Fourier-spectrum or "F-K" analysis as described by Horike (1985). Clayton and McMechan (1981) and Fuis*et al.* (1984) used the p-tau transformation as an initial step in P-wave refraction velocity analysis. McMechan and Yedlin (1981) developed the p-f technique and tested it against synthetic surface waves and reverberations seen on controlled-source multichannel seismic records. Park*et al.* (1998) applied the p-f technique to active-source MASW records. All phases in the record are present in the resulting (p-f) image that shows the power at each combination of phase slowness and frequency. Dispersive phases show the distinct curve of normal modes in low-velocity surface layers: sloping down from high phase velocities (low slowness) at low frequencies to lower phase velocities (high slowness) at higher frequencies. Miller*et al*. (2000) examine p-f-domain power spectra of MASW records along a profile to define lateral variations in dispersion curves and thus in shear velocities. The distinctive slope of dispersive waves is a real advantage of the p-f analysis. Other arrivals that appear in microtremor records, such as body waves and air waves, cannot have such a slope. The p-f spectral power image will show where such waves have significant energy. Even if most of the energy in a seismic record is a phase other than Rayleigh waves, the p-f analysis will separate that energy in the slowness-frequency plot away from the dispersion curves this technique interprets. By recording many channels, retaining complete vertical seismograms, and employing the p-f transform, this method can successfully analyze Rayleigh dispersion where SASW techniques cannot.

2.2. Rayleigh Phase-Velocity Dispersion Picking

This analysis adds only a spectral power-ratio calculation to McMechan and Yedlin's (1981) technique for spectral normalization of the noise records. The ability to pick and interpret dispersion curves directly from the p-f images of spectral ratio parallels the coherence checks in the SASW technique (Nazarian and Stokoe, 1984) and the power criterion in the MASW technique (Park*et al*., 1999). Picking phase velocities at the frequencies where a slope or a peak in spectral ratio occurs clearly locates the dispersion curve. Picks are not made at frequencies without a definite peak in spectral ratio, often below 4 Hz and above 14 Hz where an identifiable dispersive surface wave does not appear. Often, the p-f image directly shows the average velocity to 30 meters depth, from the phase velocity of a strong peak ratio appearing at 4 Hz, for soft sites, or nearer to 8 Hz, at harder sites.

Picking is done along with a “lowest-velocity envelope” bounding the energy appearing in the p-f image. It is possible to pick this lowest-velocity envelope in a way that puts confidence limits on the phase velocities, as well as on the inverted velocity profile. Picking a surface-wave dispersion curve along an envelope of the lowest phase velocities having a high spectral ratio at each frequency has a further desirable effect. Since higher-mode Rayleigh waves have phase velocities above those of the fundamental mode, the refraction microtremor technique preferentially yields the fundamental-mode velocities. Higher modes may appear as separate dispersion trends on the p-f images if they are nearly as energetic as the fundamental.

Spatial aliasing will contribute to artifacts in the slowness-frequency spectral-ratio images. The artifacts slope on the p-f images in a direction opposite to normal-

CHAPTER 3

Electrical Resistivity Imaging for Investigating Aquifer Properties

Abstract: The paper presents the application of non-pervasive electrical resistance tomography (ERT) subsurface imaging surveys for the rehabilitation and strengthening of Abu Serga church in Cairo, Egypt. The use of several high-resolution geoelectrical methods derived from the field survey techniques proved to be very effective in the Non-Destructive Testing and survey of architectural heritage. In particular, the application of a tomographical approach allowed us to obtain subsurface images of the cross-sections of the bearing soil with complex layers and structures that clearly show the presence of eventual anomalies. Some experiments with geoelectrical tomographic techniques also gave very interesting results when working on historical buildings that seemed hostile to geoelectrics. This is very also interesting due to the velocity of the measurements and the data processing: this means short times and low costs.The use of micro-geophysical techniques offers many advantages with respect to some “classical” techniques under different angles: velocity of execution, non-pervasiveness and costs. The results of ERT are compared to ground penetrating radar (GPR) – they are just as detailed but are often easier to interpret at a lower cost.

Keywords: Abu Serga church, Cairo, Electrical Resistance Tomography (ERT), Architectural Heritage Preservation, Non-destructive Testing.

1. INTRODUCTION

Geophysical methods can assist the engineers in solving the problem through the detection of different physical properties of the soil by sending a physical property and receiving it again (such as current, sonic wave, EM wave *etc*.). Electrical Resistivity Tomography (ERT) is a technique that can detect and characterize layers by exploiting resistivity contrasts between different layers using electrical current.

The present report helps to investigate the expected ground water surface at Abu Serga church. Abu Serga church is considered one of the oldest churches located in Old Cairo district. ERT is a two-dimensional (2-D) model where the resistivity changes in the vertical direction, as well as in the horizontal direction along the

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survey line. ERT can help to monitor the soil properties the possibility of saltwater intrusion; it can also define the expected soil water salinity and aquifer properties.

The study demonstrates the efficiency of the electrical methods to map subsurface conductive zones. The results illustrate the potential of electrical resistivity methods to separate different layers and monitor the subsurface conditions based on electrical resistivity.

2. SITE NATURE

Abu Serga church is located within Cairo city, in a crowded area full of people and neighboring old churches and old temples such as the Jewish temple. The soil is covered with paved stones and asphalt, and this was a difficulty when electrodes were planted in the ground.

3. SUMMARY OF ELECTRICAL RESISTIVITY TOMOGRAPHY METHOD

Electrical resistivity tomography method (ERT) is a more accurate two-dimensional (2-D) model, where resistivity changes in the vertical direction, as well as in the horizontal direction along the survey line is imaged. It is assumed that resistivity does not change in the direction that is perpendicular to the survey line. In many situations, particularly for surveys over elongated geological bodies, this is a reasonable assumption.

In normal 1D resistivity measurements, a voltage is injected in the soil *via* two current electrodes, causing current to flow through the soil, and the voltage drop between the inner electrodes is measured using a sensitive voltmeter or complex geophysical instruments (Fig. **1**). The electrical resistivity is determined for a certain depth (this depth is a function of the spacing between electrodes) using equations like that present in Fig. (**1**).

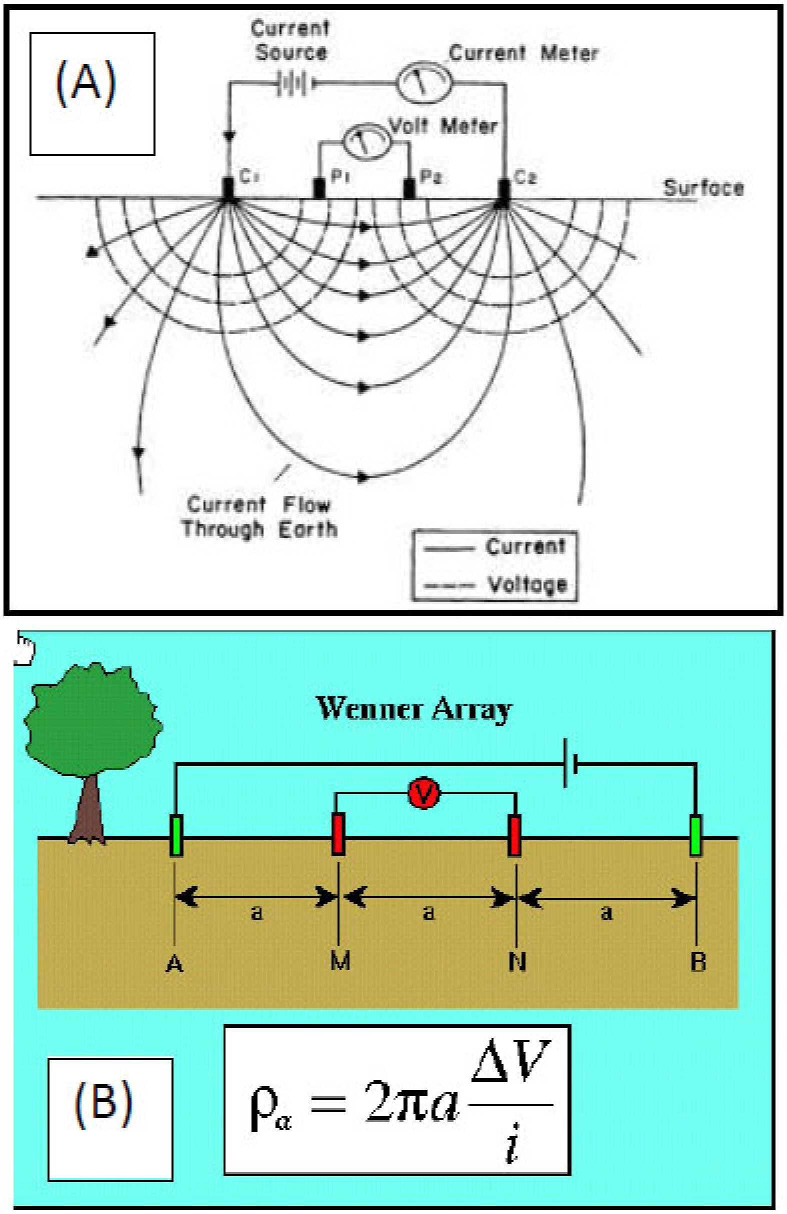

Fig. (1). Shape of injected current **(A)**, and example of equations used to determine soil electrical resistivity **(B)** in 1D method (Wenner array), Where **a** is the separation between electrodes, **ΔV** is the potential difference and **i** is the current injected in the soil.

In 2D ERT resistivity method, the previous normal 1D resistivity measurement is repeated several times at different places and different depths to make a complete image to the subsurface. This is done by shifting the measurements with distance

CHAPTER 4

Regional Seismic Hazard Analysis for Abu Serga Church

Abstract: Seismic hazard depicts the levels of chosen ground motions that likely will, or will not, be exceeded in specified exposure times. Hazard maps commonly specify a 10% chance of exceedance (90% chance of non-exceedance) of some ground motion parameter for an exposure time of 50 years, corresponding to a return period of 475 years. Such maps depict Peak Ground Acceleration (PGA) with a 10% chance of exceedance in 50 years for a firm soil condition. PGA, a short-period ground motion parameter proportional to force, is the most commonly mapped ground motion parameter because current building codes that include seismic provisions specify the horizontal force a building should withstand during an earthquake.

Keywords: Abu Serga church, Architectural Heritage Preservation, Cairo, Ground Motion, PGA, Survey.

1. INTRODUCTION

Seismic hazard depicts the levels of chosen ground motions that likely will, or will not, be exceeded in specified exposure times. Hazard maps commonly specify a 10% chance of exceedance (90% chance of non-exceedance) of some ground motion parameter for an exposure time of 50 years, corresponding to a return period of 475 years. Such maps depict Peak Ground Acceleration (PGA) with a 10% chance of exceedance in 50 years for a firm soil condition. PGA, a short-period ground motion parameter proportional to force, is the most commonly mapped ground motion parameter because current building codes that include seismic provisions specify the horizontal force a building should withstand during an earthquake.

Associated effects (*e.g.*, ground shaking, ground failure, surface faulting, tectonic deformation, and inundation) have always been a widespread threat to old, non-engineering or structures and facilities that don't take into account any seismic code. This is particularly due to the uncertainty level of ground motion that might produce damage. Earthquakes threats to human lives and important structures, *e.g.* power plants, have urged the need to quantitative estimate the hazard of earth-

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quake at a site, providing valuable guidance for informed decision-making on mitigating the earthquake threat.

In general, Egypt is suffering from moderate hazards. However, a tremendous amount of risk is coming from not applying an accurate UBC (uniform building code) until now. Although archeology is found in Egypt, such as Abu Serga church, no seismic code is applied before building these important monuments. Until 1992, very few strong motion records were available; no accurate seismic code for buildings was applied.

Apart from the numerous studies of local or regional scale, the comprehensive study of Gamal *et al.* (1996), has introduced 1st seismic hazard assessment study for Egypt. No elaborate probabilistic seismic hazard assessment by the official center of seismology in Egypt has been introduced yet.

All available models were reviled, checked and concluded to our present model to give a picture. However, the study is intended to serve as a reference for more advanced approaches, stimulate discussion and suggestions on the database, assumptions, and inputs, and pave the path for the probabilistic assessment of the seismic hazard in the site under study.

2. SOURCES OF INFORMATION

For the purpose of our hazard calculation in terms of PGA hazard parameter, the following data was utilized:

1. Geological and structural information from published papers and articles; Earthquake catalogues for the period 2800 BC - 1899 AC after Maamoun, 1979; Maamoun *et al*., 1984; Ben-Menahem, 1979; and Woodward - Clyde Cons., 1985.
2. Earthquake catalogues for the period 1900 - 2006 after Makropoulos and Burton, 1981; Maamoun *et al*., 1984; Ben-Menahem, 1979; Woodward - Clyde Cons., 1985; Riad and Meyers, 1985; Seismological Bulletin of Israel, 2003 - 2003; and NEIC 1995, 2006 and the Jordan seismological observatory 1993-2003 .
3. The Egyptian code for buildings, 1st copy, 2003.

3. SCOPE OF WORK

This study aims to conduct a probabilistic seismic hazard analysis for Abu Serga church and neighboring regions in terms of peak ground horizontal acceleration using the most recently developed attenuation relationships in Egypt. The seismicity database is compiled from numerous sources, and the tectonic setting of the region has been reviled and studied in detail. Utilizing these two major categories of information together with the selected attenuation relationship, the seismic source zones are determined, and PGA contour maps are produced for 50 and 100 years of exposure time.

4. TECTONIC AND SEISMTECTONICS OF EGYPT

The tectonic setting of Egypt is a consequence of the regional interaction between three main plates, namely the African, Eurasian and Arabian plates (Fig. **1** & **2**). Africa was found to move northward toward Eurasia, starting at Gibraltar, at the west, and extending eastward. This movement takes place along the plate boundary, which crosses North Africa, continues through or passes south of Sicily, and continues around the Adriatic Sea through Italy and Yugoslavia rather than crossing the entrance of the Adriatic directly into Greece.

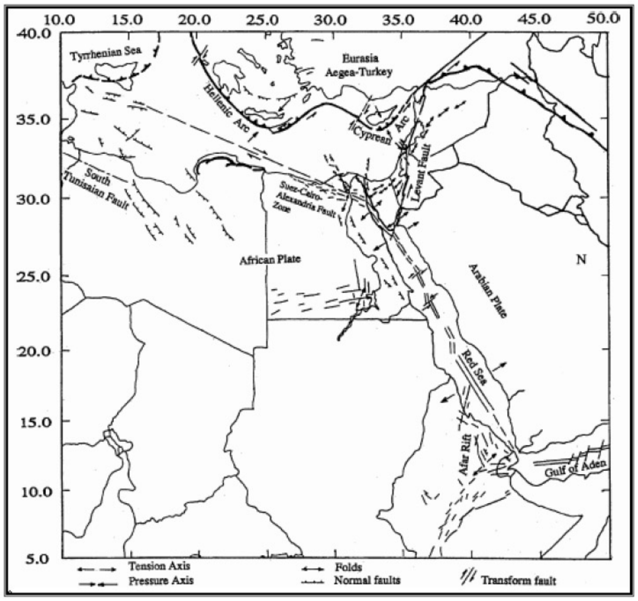

Fig. (1). Regional tectonic setting of Egypt and surrounding areas, modified from Abou Elenean, 1997; Sofratome Group, 1984; Ben-Avraham *et al*., 1987; Woodward-Clyde Consultants, 1985; Jarriage *et al*., 1990 and Mahmoud 2002.

CHAPTER 5

Seismic Hazard Analysis Theory and Methodology

Abstract: The probabilistic approach of earthquake hazard analysis aims at estimating the likelihood (probability) that any specified level of ground motion intensity will be attained or exceeded in an arbitrary future time period due to the trigger of earthquakes from potential seismic sources.

The analytical approach used to carry out probabilistic seismic hazard analysis is described in detail by Cornell, 1968; 1971; Esteva, 1969; Merz and Cornell, 1973; Cornell and Merz, 1975 and McGuire and Arabasz, 1990. The probabilistic seismic hazard assessment requires all the available information on seismicity and geotectonics of the examined region and regional attenuation characteristics of the ground motion as well as the adoption of a stochastic model for the forecasting of future earthquake occurrences.

Keywords: Abu Serga church, Ground Motion, Probabilistic Seismic Hazard Analysis.

1. PROBABILISTIC SEISMIC HAZARD ANALYSIS

1.1. Basic Concepts and the Seismic Hazard Models

The probabilistic approach of earthquake hazard analysis aims at estimating the likelihood (probability) that any specified level of ground motion intensity will be attained or exceeded in an arbitrary future time period due to the trigger of earthquakes from potential seismic sources.

Particular Site Intensity may occur because:

- An earthquake of that epicentral intensity occurred very close to the site.
- An earthquake of greater size occurred at some distance from the site but close enough that the natural attenuation of intensity with distance was sufficient to cause that particular site intensity.

The analytical approach used to carry out probabilistic seismic hazard analysis is described in detail by Cornell, 1968; 1971; Esteva, 1969; Merz and Cornell, 1973; Cornell and Merz, 1975 and McGuire and Arabasz, 1990.

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The seismic hazard analysis models presented there are called "***point - source models***" since they are based on the assumption that the energy released during an earthquake is radiated from the focus of the earthquake and the site ground motion is a function of the distance to the source; *i.e.,* the earthquake energy is assumed to propagate isotropically from the source. Although the assumptions may be acceptable for certain earthquakes and regions, they would not be valid for large events where the total energy released is distributed along the rupture zone. In such cases, the point-source model is an oversimplification which may lead to underestimating the seismic risk at sites near the fault; the error involved is, however, not excessively large in regions where the fault system is well defined and where the rupture (even during major earthquakes) is not expected to propagate outside the fault system under consideration (Der Kiureghian and Ang, 1977; Ben-Menahem *et al.,* 1982; Erdik *et al.,* 1985 and Bender, 1984).

The "***fault - rupture model***" developed by Der Kiureghian and Ang (1977) is based on the assumptions that the earthquake originates at the focus and propagates symmetrically on each side of the focus along a fault and the maximum intensity of the ground shaking at a site is determined by the rupture that is closest to the site; *i.e.,* the source is assumed to be in - line with the fault rupture resulting in a non - isotropic propagation of seismic energy.

Both of these models can be adequately represented by the so - called **"*Total Probability Theorem*"** (McGuire, 1976):

$$\mathbf{Pr[A] = \iint Pr[A|s, r]\ f_S\,(s)\ f_R\,(r)\ ds\ dr} \qquad \mathbf{(1)}$$

Where **A** represents the event that a specific measure of ground motion is exceeded at the site during an earthquake of a size **s** (magnitude or epicentral intensity) and distance **r** (fault, epicentral, or focal distance) and **S** and **R** are continuous random variables representing the earthquake size and distance. The probability of occurrence of **A**, **Pr[A]** is given by the integration of the conditional probabilities of **A** given **s** and **r**, times the independent probabilities of **s** and **r**, $\mathbf{f_S}$ **(s)** and $\mathbf{f_R}$ **(r)**, over all possible values of **s** and **r**. For the fault - rupture model, the s and f_S (s) terms include the information on and distribution of the rupture length and the rupture location at the source.

The probabilistic seismic hazard assessment requires all the available information on seismicity and geotectonics of the examined region and regional attenuation characteristics of the ground motion as well as the adoption of a stochastic model for the forecasting of future earthquake occurrences. The main evaluation steps in the state - of - the - art of the probabilistic seismic hazard analysis extensively discussed in Karnik and Algermissen (1975); Everenden (1982); Kiremidjian

(1982), and many others, may be summarized as follows:

- Acquisition of historic, macroseismic, and instrumental seismic data to form an integrated earthquake catalog.
- Regionalization of seismic sources based upon historical seismicity, the geologic evidence, tectonic province, geomorphic investigation, and other relevant data for identifying seismic sources.
- Assessing source seismicity for constructing the earthquake size recurrence relation and assessing the maximum magnitude for each individual seismic source.
- Determination of the regional ground motion attenuation formula to be used either through empirical data or by tectonic analogy with areas where strong motion data are accumulated.
- Deciding on a stochastic point process as the model of earthquake occurrences.

Numerous models for the forecasting of seismic hazards have been developed. The two major types of the stochastic model in common use are the Markov and Poisson processes. The simplest stochastic model for earthquake occurrences in the homogeneous Poisson process (Cornell, 1968; Shah *et al.,* 1975; and Der Kiureghian and Ang, 1977).

For earthquakes to follow the Poisson process, the following assumption is in order:

- Earthquakes are spatially independent.
- Earthquakes are temporally independent; and
- Probability that two seismic events will take place at the same location and at the same time approaches zero.

The first assumption implies that the occurrence of one event at a site does not affect the occurrences of the other events. The second assumption implies that the seismic events do not have memory in time. Although there are theories and pieces of evidence suggesting that in certain sources zones, earthquakes occur in regular, predictable cycles. Within limited time windows, however, random, unexpected occurrences of seismic events are assumed.

Gardener and Knopoff (1974) and Yocemen (1980) showed that a series of earthquake events are indeed Poissonian when aftershocks are moved further, the Poisson process indicates a constant hazard rate which is a completely descriptive phenomenon observed in seismic regions of relative uniformity of earthquakes. Another advantage of the Poisson process, besides its simplicity, is the fact that the seismic design decision should be more sensitive to the average number of

CHAPTER 6

Seismic Hazard Results for Abu Serga Church

Abstract: The following basic elements of modern probabilistic seismic hazard had been assessed to find the seismic hazard in Abu Serga church; the compilation of a uniform database and catalogue of seismicity for the historical (pre-1900), and instrumental periods (1900-today) in and around Abu Serga church. The creation of a master seismic source model to describe the spatial-temporal distribution of earthquakes, integrating the earthquake history with evidence from seismotectonic, paleoseismology, mapping of active faults. The evaluation of ground shaking as a function of earthquake size and distance, taking into account propagation effects in different tectonic and structural environments. The computation of the probability of occurrence of ground shaking in a given time period to produce maps of seismic hazard and related uncertainties at appropriate scales.

Keywords: Abu Serga church, Ground Motion, Seismic Hazards, Seismotectonics, Survey.

1. INTRODUCTION

We used the following basic elements of modern probabilistic seismic hazard assessment to find the seismic hazard in Abu Serga church:

1. *Earthquake Catalogue*: the compilation of a uniform database and catalogue of seismicity for the historical (pre-1900), and instrumental periods (1900-today) in and around Abu Serga church.
2. *Earthquake Source Model*: the creation of a master seismic source model to describe the spatial-temporal distribution of earthquakes, integrating the earthquake history with evidence from seismotectonics, paleoseismology, mapping of active faults.
3. *Strong Seismic Ground Motion*: the evaluation of ground shaking as a function of earthquake size and distance, taking into account propagation effects in different tectonic and structural environments.
4. *Seismic Hazard*: the computation of the probability of occurrence of ground shaking in a given time period to produce maps of seismic hazard and related uncertainties at appropriate scales.

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2. EARTHQUAKE CATALOGUE

In the present work, a modified and updated earthquake catalogue for Egypt and surrounding areas affecting Abu Serga church has been prepared to provide a base for the purposes of determination of the seismic source regions in Abu Serga church and surrounding areas for the assessment of the frequency-magnitude characteristics of the earthquakes in these seismic sources.

This earthquake data is mainly based on the following catalogues:

- For the period 2200 B.C-1900: Maamoun,1979; Maamoun *et al*., 1984 ; Ben-Menahem 1979 and Woodward-Clyde consultants, 1985 (Fig. **1**).
- For the period 1900-2006: Makropoulos and Burton, 1981; Maamoun *et al*., 1984 ; Ben-Menahem 1979; Woodward-Clyde consultants, 1985; Riad and Meyers, 1985; Shapira, 1994 and NEIC, 2006; Seismological Bulletin of Israel, 2003 and bulletin of Jordan seismological observatory 1998-2003 (Fig. **2**).

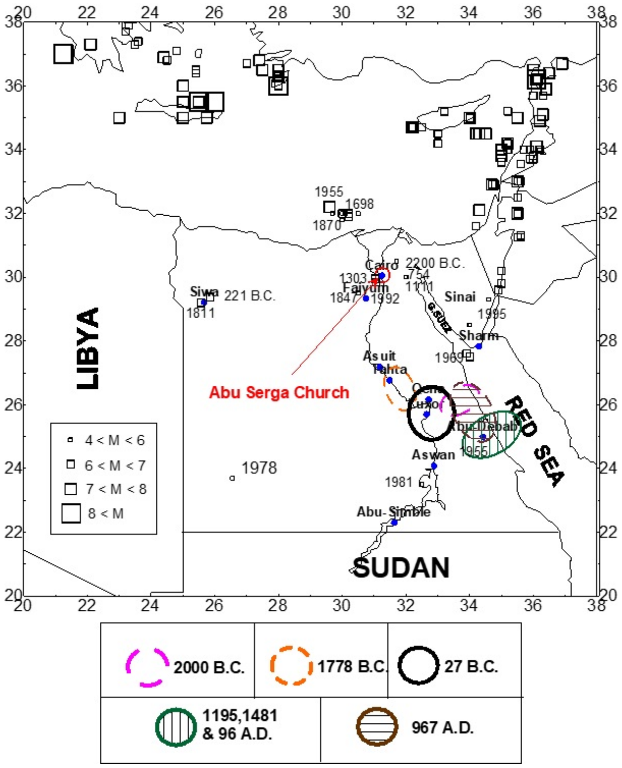

Fig. (1). Important and historical Earthquakes Occurred in and around the Abu Serga church area in the Period (2200 B.C - 1995).

3. HISTORICAL SEISMICITY

Fortunately, Egypt possesses a great earthquake catalogue that goes as far as ancient Egyptian times. The pharaohs left us a detailed description of earthquakes that we can put a seismicity maps for some earthquakes that go to the 4000 years ago. Fig. (**1**) shows the most important historical seismicity around Abu Serga church.

(Integrated from, Maamoun, 1979; Maamoun *et al*., 1984; Ben-Menahem 1979; Woodward-Clyde consultants, 1985; Makropoulos and Burton, 1981; Riad and Meyers, 1985; NEIC and USGS 2006; Seismological Bulletin of Israel, 2003; and Bulletin of Jordan seismological observatory 1998-2003).

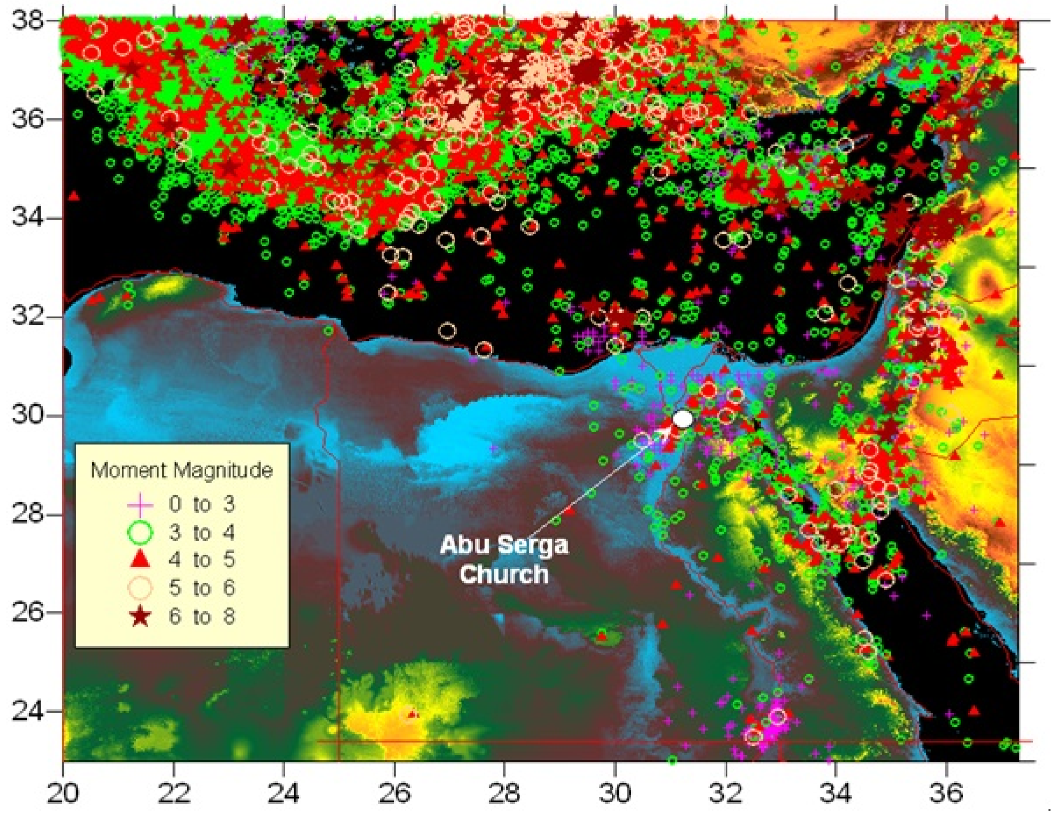

Fig. (2). Historical and recent Seismicity in the Period 2200 B.C - 2006 AD in and around Abu Serga church Area.

4. MAXIMUM INTENSITY AFFECTING ABU SERGA CHURCH

In Studying the Hazard from earthquakes at Abu Serga church, it is usual practice

CHAPTER 7

Soil and Structure Response for Abu Serga Church

Abstract: Abu Serga church is located in the Coptic section of Old Cairo area. It is considered the oldest Coptic Church found in Egypt that represents the cultural heritage of outstanding universal values. It suffers multiple environmental, geotechnical and earthquake hazards.

The integrated geotechnical and geophysical investigation techniques were done to assess the seismic and other geo-environmental hazards and risks that Abu Serga church suffers from in the present and future. This knowledge is required to protect the building against seismic events. Abu Serga church suffers high risk in terms of seismic and environmental hazards. The main purposes of the present study is to: 1) Assess the level of seismic and other geo-environmental hazards at Abu Serga church. 2) Understand the nature of damage to this historic building caused by the recent earthquakes. 3) Offer technical support and advice on the restoration and repairs of the damaged structure. 4) Build up knowledge and case studies towards the restoration and repairs and survey the historic structure's damage state.

However, Abu Serga church is the oldest Coptic church that was constructed with little or no seismic considerations that represent the most enormous risk to most communities. These significant historical buildings must be assessed, their level of risk determined, and unacceptable risks reduced. This paper focuses on the issues associated with detailed risk and hazard assessment procedures for retrofitting architectural heritage. Many forms of evaluation and related procedures for the assessment of seismic risk for historical buildings have been discussed.

This study suggest a moderate level of earthquake activity at Abu Serga church, and this is in a good agreement with the fact that “Egypt is a part of the stable African Shield”, but the existence of old structure such as the Abu Serga church may reduce the ability to resist any earthquake shaking. This pilot study is essential with respect to the continuous efforts to preserve and restore cultural heritage worldwide.

Keywords: Abu Serga church-Cairo, Geophysical Campaign, Geotechnical, Microtremors, Natural Frequency, PGA, SHA.

1. INTRODUCTION

It is a well-documented phenomenon that local site conditions can amplify earthquake ground motion (*e.g.*, Milene, 1898; Kanai, 1951, Brocherdt, 1970; Aki, 1988). When earthquakes emerge from the base of more competent rocks

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into the less competent fragmented rocks (the soil or the uppermost nearly 100 m), it could change dramatically. This near-surface impedance contrast affects the frequency-amplitude content of earthquake ground motion. It can also change one of the most important parameters controlling the damage of earthquake ground motion, which is its duration. The nature of the soil is forcing the earthquake to be changed depending on its own resonance properties.

An example of this phenomenon is illustrated during the 1985 Michoacan, Mexico, earthquake (M=8). This event, although felt with little or no resulting damage on a volcanic rock site, after a few km, the ~0.5 HZ fundamental vibration mode of the Mexico City Lake-bed zone, caused severe structural damage, and more than 10,000 people were killed (Anderson *et al*., 1986).

Abu Serga church local soil conditions and structure response are very important for ground motion change. Generally, the soil found at Abu Serga or in Old Cairo is famous for the existance existence fill and rocks that are famous for little or no grond motion amplification.

2. AIM OF THE STUDY

The study aims to determine the natural frequency of vibration of the soil present at Abu Serga and the Natural frequency of vibration of the Church itself. Also, it determines the amplification factor for the church to be able to deal with the PGA emerging from the bedrock.

3. INSTRUMENTS AND DATA ACQUISITION

A high dynamic range Seismograph (Geometrics ES-3000- Fig. **1**) mobile station with triaxial force balance accelerometer (3 channels), orthogonally oriented, was used. The mobile station was used to record the horizontal components in longitudinal and transverse directions in addition to the vertical components with the sensors having natural frequencies of (4 HZ).

Fig. (1). High dynamic range ES-3000 Geometrics mobile station and Triaxial geophone used 4 HZ to drive soil and structure response of Abu Serga church.

4. THEORY OF MICROTREMORS

Microtremors are omnipresent low amplitude oscillations (1-10 microns) that arise predominantly from oceanic, atmospheric, and cultural disturbances. It may be composed of any seismic wave type. We have two main types of microtremors, Local cultural noise coming from urban disturbances and long period microtremors originated from farther distances (*e.g.*, Oceanic disturbances). Although Microtremors are used widely now in recent studies to drive soil response (*e.g.*, Shapira *et al.*, 2005), there is still a big contradiction between the correct types of noise that should be used. While some deal with the longer period microtremors originated from farther distances (oceanographic disturbances) excluding urban excited sites where high degree of local cultural noise exist (*e.g.* Field *et al.*, 1990), others considered the traffic and cultural noise not affect microtremors response. Moreover, they considered the excited soils (sometimes by a helicopter) to give even more convincing site responses. They found good agreement between soil responses excluded from excited soils compared with those derived from strong-motion recorded data (Mucciarelli, 1998). Mucciarelli, 1998, constricted to microtremors generated by winds or coming out from asphalt (asphaltic waves) and considered them as false effects and should be removed. The implicit assumption of early studies was that microtremor's spectra are flat and broadband before they enter the region of interest. When microtremors enter the soil, it changes and resonates depending on the nature of the material, shape, and other soil characteristics.

Kanai 1957, first introduced the use of microtremors, or ambient seismic noise, to estimate the earthquake site response (soil amplification). After that, lots of people followed this work but from the point of soil amplification of earthquake energy for different frequencies (*e.g.*, Kanai and Tanaka 1961 and Kanai 1962, Kagami *et al.*, 1982 and 1986; Rogers *et al.*, 1984; Lermo *et al.*, 1988; Celebi *et al.* 1987).

The soil response derived using microtremors is very complex. In almost all cases, the very calm sites during the night or early hours of the morning successfully drive the site response. This is because traffic affects the site response and sometimes hides the original soil response. Moreover, the higher the traffic noise, the higher the amplitude of the amplification of these sites. Moderate soil excitation leads to identify all soil resonance peaks (fundamental and all other harmonics); however, it sometimes inserts resonance peaks not related to the soil but mainly to the source of the noise itself "*e.g.*, traffic".

CHAPTER 8

Ground Penetrating Radar for Archeological Investigation

Abstract: The results of an integrated geophysical survey at the archaeological site of Abu Serga church, Cairo, Egypt, are presented and discussed. The aim was to investigate the ground conditions of the Church of Abu Serga (St. Sergius), Cairo's oldest. The Church was built in the 4th century, located at Qasr el-Shama in old Cairo in Egypt. In particular, the objective is to study the subsurface geological structures at the church's location and detect and possibly map any ancient remains concealed under the monument. The survey was conducted using two geophysical methods: the ground-penetrating radar (GPR), a fully non-destructive method, and the electrical resistivity tomographies (ERTs). The usefulness of combining conventional geophysical mapping techniques and high resolution imaging methods in delineating shallow targets of archaeological interest at such complex archaeological sites is studied. Ground penetrating radar time slices and 3D electrical tomography depth slices were used for the verification of specific anthropogenic anomalies, which were detected on the geophysical maps Processing of geophysical maps included filtering with the gradient and first derivative operators in the space domain and the upward continuation and Butterworth filters in the wave number domain. The integration of the geophysical measurements revealed that the present Crypt is not the original holy Crypt. The anomalous reflector is detected at a depth of about 5 m below the sanctuary floor, in the form of buried ceiling of the original Crypt. The present Crypt is just a small low subterranean church belong to the 2nd century. High resistivity anomalies and distinct GPR signals were also observed deeper in the inner parts of the church. They are attributed to possible remains of ancient walls and surrounding tunnels or other man-made structures concealed under the monument's floor. The geophysical survey at Abu Serga church also demonstrates that the general features of the foundation soil are heterogeneous with the abundance of fractures; the water table is very high at 1.5m below the sanctuary floors. The benefits of combined geophysical surveys in the case of archaeological investigations at complex sites are highlighted.

Keywords: Abu Serga church, Electrical Resistivity Tomography, Geophysical Survey, Ground Conditions, Ground Penetrating Radar, Non-destructive Testing.

1. INTRODUCTION

The ground penetrating radar (GPR) has been used in this study to detect the possibility of old archeological features under Abu Serga Church. GPR is a

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continuous non-destructive prospecting tool that is proven to be useful for various problems, especially in archeological investigations. It is appropriate where large dielectric contrast exists between nearby sources; this contrast in electrical properties shows the subsurface clearly.

GPR uses the electromagnetic waves to detect targets in subsurface media. In many aspects, GPR is the electromagnetic equivalent to seismic reflection surveying and can employ similar data processing and display techniques that are already highly developed. The basic principle of using electromagnetic waves is that signals of relatively short wavelength can be generated and radiated into the soil and other geologic materials to detect anomalous variations in the dielectric properties of the medium.

2. SUMMARY OF THE METHOD

The GPR equipment used to measure subsurface conditions normally consists of a transmitter and receiver antenna, a radar control unit, and suitable data storage and display devices (Fig. **1**).

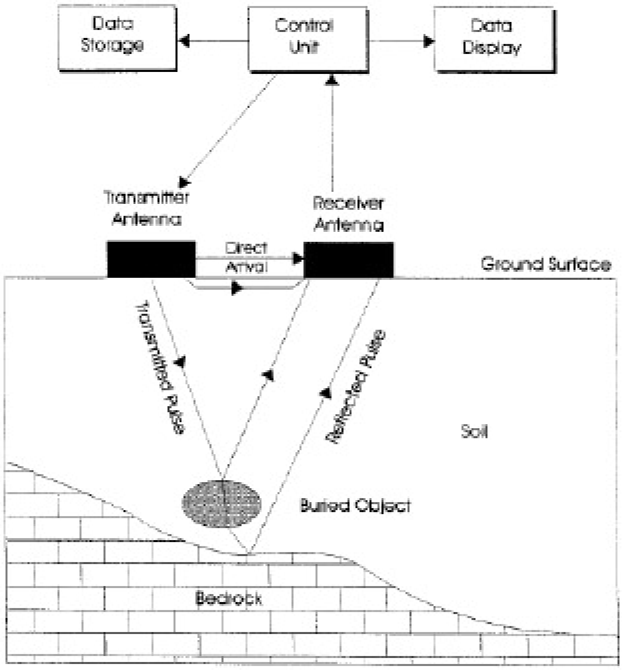

Fig. (1). Schematic diagram showing components of the ground penetrating radar.(ASTM D6432-99 2005).

A circuit within the radar control unit generates a train of trigger pulses that are sent to the transmitter and receiver electronics. The transmitter electronics produce output pulses that are radiated into the ground from the transmitting antenna. The receiving antenna detects the EM waves that are reflected from interfaces at which the EM properties of the material(s) change. These signals are sent to the control unit for amplification. As the antenna(s) are moved along a survey line, a series of scans is collected and positioned side by side to form a profile of the subsurface (Fig. **2**).

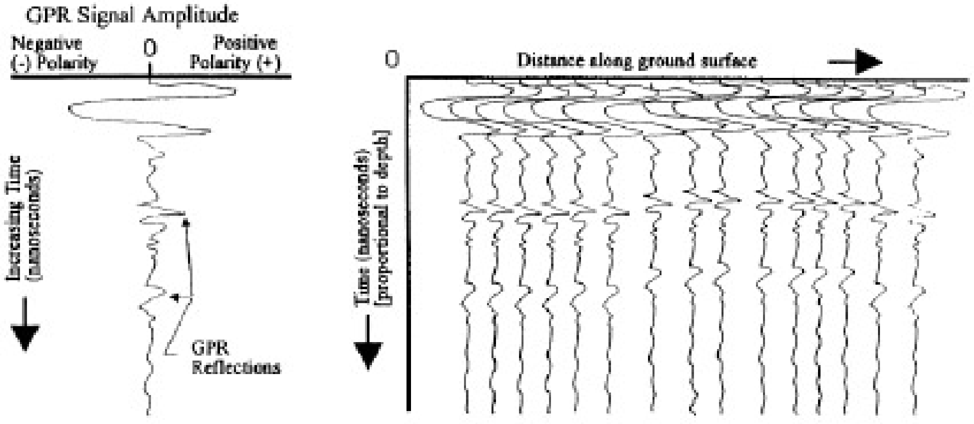

Fig. (2). Schematic diagram showing a typical radargram and a Series of traces collected at specific distances to form a GPR profile line or cross-section.

3. PRINCIPLES AND MODE OF OPERATION OF GPR

The GPR technique is similar in principle to seismic reflection and sonar techniques, where GPR systems radiate pulses of high-frequency electromagnetic energy (10 - 1000 MHz) into the ground from a transmitting antenna. When the radiated energy encounters an inhomogeneity in the electrical properties of the subsurface, part of the incident energy is reflected back to the radar antenna, and part is transmitted through the inhomogeneity, (Fig. **1**).

The GPR data are presented as a two-dimensional depth profile along the scanned traverse line. The horizontal axis represents the horizontal distance along the profile line, and the vertical axis represents the two-way travel time measured in nano-seconds. The two-way travel time is the time of travel of the electromagnetic waves from the transmitter to the discontinuity surface, for example, and back to the receiver.

CHAPTER 9

Design Response Spectrum for Abu Serga Church

Abstract: The response spectra for the Faiyum earthquake were selected as the best earthquake for the most effective zone near Abu Serga church to construct the design response spectrum for the church. The original acceleration time history was recorded 10 km away from Abu Serga church over the bedrock of Cairo city at Mokattam area (about 10 Km from Abu Serga church). This is considered to be the first response spectrum done for all earthquakes that ever affected Egypt. Fortunately, this earthquake is regarded as one of the most important earthquakes that affected Egypt in the last 100 years. The maximum acceleration response spectrum maintained for Abu Serga church for the church's fundamental resonance frequency, which is 5.5 HZ, is about 100 cm/sec^2 for 5% damping. As for the other resonance peaks for the 2nd wooden floor and the roof, nearly the same spectral acceleration occurs (0.1 g).

Keywords: Abu Serga church, Acceleration, Geophysical survey, Ground conditions, Response Spectra.

1. INTRODUCTION

The response spectrum is a very important engineering quantity defined using original ground motions. Engineers have developed this kind of spectrum, which has proven very useful in designing and analyzing structures. This response approximates the structure's elastic response to earthquake ground motion as a simple oscillator whose fundamental or natural period is the same as structure (damped oscillator performance).

Although Egypt lacks in ground motion records, we have reviewed all available strong motion records available beside Abu Serga church. We took benefits from the records of the important earthquakes that affected Egypt in the last 100 years near Abu Serga church, the Faiyum, 1992 earthquake. We have calculated its acceleration response spectrum to show the expected design response spectrum for Abu Serga church. Although such spectrum is considered one of the few rare response spectra for any earthquake that ever stroked Egypt, lots of valid conclusions based on this record are concluded. This will assess the final expected acceleration for Abu Serga Church.

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2. RESPONSE SPECTRA

Response spectra are widely used in engineering seismology research to define the frequency-dependent effects caused by earthquake source and transmission path. The earth tends to act like a low pass-filter on propagating seismic waves. That is, the high-frequency spectral components are attenuated more rapidly than low-frequency components. The response spectrum technique, proposed by Benioff, 1934 and Boit, 1943, is a method for determining the maximum amplitudes of the response of a simple damped, harmonic oscillator (a narrow band filter) when excited by a given ground-motion time history.

The spectral characteristics of ground motion are generally displayed as response spectra; structural engineers for the study of building response prefer this form. This was based on the phenomenon that structures are oscillating systems with well-defined periods of vibration, and their response is strongly dependent on spectral composition and duration of ground motion. Simple systems such as a viscous damped pendulum or mass-spring systems have been successful for modeling true structures (Blume *et al*., 1961).

The various types of responses are:

1. Psedu absolute acceleration (PSAA)

2. Pseudo relative velocity (PSRV)

3. Absolute acceleration (AA)

4. Relative velocity (RV)

5. Relative displacement (RD)

PSAA: Is the measure of maximum elastic spring force per unit of mass.

PSRV: Is the maximum velocity relative to its base the center of mass of the simple resonant structure.

AA: Is the true absolute acceleration of oscillator

RV: Is the true relative velocity of oscillator

RD: Is the maximum value of relative displacement of the simple system during vibratory motion

PSAA is actually quite close to AA, but PSRV can be quite different from RV.

3. COMPUTATION OF RESPONSE SPECTRUM

Different authors have shown the computation of response spectrum for single degree of freedom simple structure, like simple-one story building and multi-story buildings, by solving the equation of motion using natural structure frequency, damping ratio of structure and ground acceleration (*e.g.* Housner, 1959).

The computation of the displacement response spectrum or deformation is based on the well-known equation (1) (Chopra, 1981; Fig. **1**):

$$U(t) = -\frac{1}{\omega_D}\int_0^t U_g(\tau).\exp[-\xi\omega(t-\tau)].\sin[\,\omega_D(t-\tau)].d\tau \qquad \textbf{(1)}$$

Where:

$U(t)$: Deformation response history

$U_g(\tau)$: Earthquake ground acceleration

ξ : The damping ratio of the structure

ω : The natural circular frequency of vibration

ωD: The natural circular frequency of vibration of damped structure (=$\omega\sqrt{1-\xi^2}$)

A plot of maximum values of response quantity as a function of natural vibration frequency of structure (natural period or natural frequency of structure), will give the displacement response spectrum (Fig. **1**).

The pseudo-velocity response spectrum and pseudo-acceleration response spectrum are derived by multiplying the displacement response spectrum obtained in Fig. (**1**), by ω and ω2 respectively. The three quantities of response spectrum are related to the power of vibration period and can be represented on a so-called TRIPARTITE or four-way logarithmic plot from which all three spectral quantities can be read (see Fig. **7**).

CHAPTER 10

3D Finite Element Coupled Analysis Model for Geotechnical and Complex Structural Problems of Historic Masonry Structures: Conservation of Abu Serga Church, Cairo, Egypt

Abstract: This research presents the damage mechanism of a historical masonry architecture induced by differential settlement based on 3D FE analysis. The study aimed to investigate the behavior of fully-saturated soft clays subjected to self-weight loading from an old masonry structure of Abu Serga church, the oldest church in Cairo. The church was built in the 4th century and was probably finished during the 5th century, located in misr alqaddima area in Cairo. The church gains its high prestige to having been constructed upon the Holy crypt of the Holy Family where they stayed during their sojourn in Egypt. The main objective of the present study is to accurately record and analysis the geotechnical problems and induced structural failure mechanisms observed and calculated in the field, experimental and numerical studies. The land area is also susceptible to floods. Numerical analysis for such geotechnical problems is largely expected to contribute to the conservation of cultural heritage.

The present research presents an attempt and pilot study to design the PLAXIS 3D FE model to simulate ground problems and distort and analyze the stress of the complex structure of the Abu Serga church, which is loaded on a plane level. Plastic modeling or Mohr Coulomb model in advanced soil was used during the various stages of numerical analysis. Results are recorded and discussed with respect to the stress and volumetric behavior of soil. Finally, the study represents the design studies and implementation of the inter-organizational retrofitting intervention and strengthening project for the oldest Coptic Church in Egypt.

Keywords: 3D Constitutive models, FE PLAXIS 3D, Geotechnical modeling, Historic structures, Problematic soils, Soil problems, Soil settlement, The oldest Coptic Church, Vertical displacement.

1. INTRODUCTION

Historical monuments are invariably exposed to the influence of the geological environment. Given the lifespan of such structures, several dynamic geological processes (weathering/erosion, surface movements and earthquakes) usually have a dramatic impact on the integrity of the monuments.

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The protection of monuments requires special approaches in terms of adaptation of the engineering interventions to the historical environment and the lifetime of such interventions.

The significant cost and implicit long-term effectiveness of engineering schemes for the protection of historical monuments necessitate integrated approaches requiring ongoing validation of the design. The co-operation between the designer and the contractor during construction and long-term performance monitoring are key components for the success of such undertakings.

Structural damage to the architectural heritage is often caused by the displacement of the earth's soil, its differential settlement, its rotation, or any other effect of the interaction between the structure and the soil. Although it is necessary to examine both the shear resistance and the underlying settlements of any structure, the research is very limited and focuses on mechanisms of failure of superstructures only [1-7].

To determine the magnitude of stresses, analyze the deformation and settlement of the soft silty clay soil and the superstructure response, an analytical coupled model of geotechnical and structural engineering is presented in detail. Geotechnical numerical modeling of complex soil structure problems requires advanced three-dimensional advanced soil models. PLAXIS 3D (PLAXIS v.b, 2018) was used to calculate the soil settlement due to consolidation and the impact of its accompanying pressures and stresses on the superstructure. It is a program produced for the geotechnical construction plan and inquired about it and was used late as part of the structural and geotechnical survey. The Mohr-Coulomb model is used for both static assembly and rigidity inspection. The code contains a useful methodology for the programmed batching drive, called Load Advancement, which we used here [8-10].

Constitutive models are the key-stone for understanding the mechanical behavior of soils and carrying out numerical predictions by means of the FE method [11, 12].

Since the 1970’s, there are extensive studies on an elastic-plastic model about saturation soil under dynamic loading. Building model under monotonic loading and using relatively complicated hardening law, such as the model based on the Cambridge model by Carter [13], the Desai model with a single yield surface built in 1984 [14]. The dynamic model is based on other types of plasticity theory, such as the multi-surface model built by Provest, Mroz, Norris and Lenkiewicz [15,16], the secondary loading surface model built by Hashiguchi in 1993, the plasticity model of sand based on multi-mechanism conception under cyclic loading by Kabilamany, Pastor and Zienkiewicz, [17,18].

The evaluation methodology which has been followed for the structural rehabilitation of Abu Serga church (which is located in the old Cairo area in Cairo) comprised the following phases/actions, as summarized in Table **1**.

The methodology established for the study of historic masonry structures was assessed in terms of their reliability, accuracy, and effectiveness by comparing analytical results with experimental and empirical data [19, 20].

2. GEOTECHNICAL CONDITIONS AND MONITORING

The subsurface conditions of the Abu Serga church consist of multi-layers of thick, soft clay mixed with variable sand. The delicate sandy layers are shown to the middle at a depth of 6 meters below the floor level of the chapel. The subsurface water appears at a depth of 1.8 m [21]. Fig. (**1**) shows the ERT-3 reflection model on the main street of Mar Girgis, at the height of 5 m above the level of the ground floor of the church.

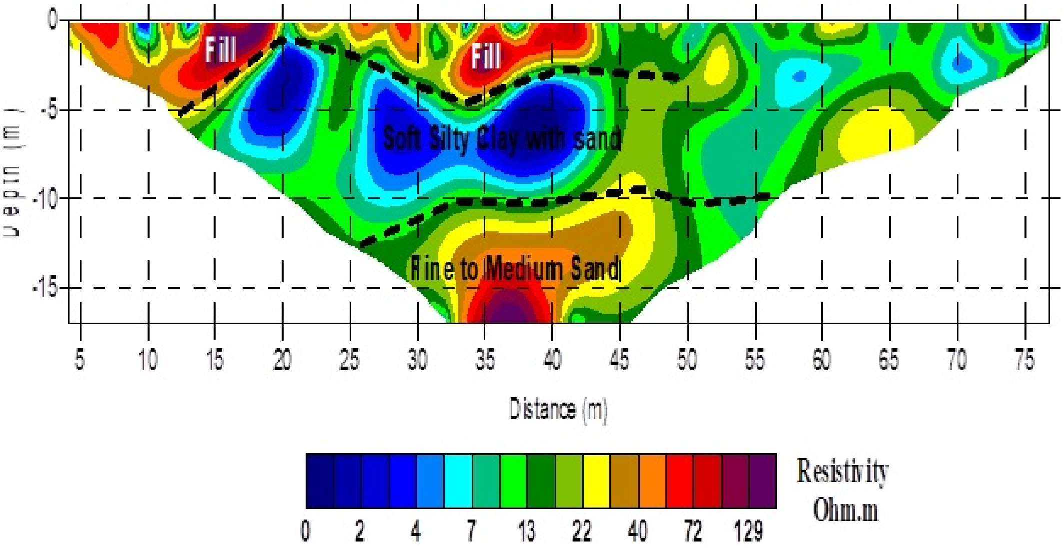

Fig. (1). ERT 2D model for profile ERT-3 at Abu serga church.

The geotechnical investigations were carried out on the extracted soil samples. Data was collected from five (5) (boreholes), four (4) (PCPT/CPT), and eighteen (18) Undisturbed Samples (US). The results of laboratory tests were selected over eleven (11) grain size distributions, five (5) oedometer tests, three (3) direct shear tests, six (6) triaxial CU + u tests, and five (5) triaxial UU tests. The geotechnical testing has been carried out in the soil mechanics laboratory of the Faculty of Engineering, Cairo University.

CHAPTER 11

Conclusions

The current work helps the amount of hazards and risk Abu Serga church suffers. Abu Serga church is located within Cairo city and is considered one of the oldest Churches found in Egypt. The Church suffers moderate hazards but high risk in terms of seismic hazards and other hazards.

Refraction microtremors test was applied to 11 tests in and around the Abu Serga church to detect the shear strength in terms of S-wave velocity and detect the average depth of the bedrock. The test was done using normal p-wave geophones and normal refraction equipment (Louie 2001).

The test was done using 30 records of 20 seconds, each cultural noise coming from culture disturbances inside sandbags and leveled 14 Hertz p-wave geophones. Using multichannel analysis of surface waves (MASW) using Refraction Microtremors technique described by Louie, 2001, a total of six tests inside the church and another 5 tests outside the church were used to detect the average s-wave velocity within the Abu Serga church.

The conducted ReMi profiles ReMi-1 to ReMi-6 inside the church, show a shear-wave velocity of about 1000 m/s for an average depth of about 3.5 m (Figs. **24** to **29** in Chapter 2). While outside Abu Serga church, the S-wave velocity detected is about 900 m/s for an average depth of about 6.5 m (Figs. **30** to **34** in Chapter 2). This is most probably due to the change in the ground level, which is higher outside the church with about 2-4 m.

The bedrock velocity is thus 4-6 m at Abu Serga church site (USGS, 1980 take the S-wave velocity of > 765 m/s to be the velocity of the bedrock).

The electrical resistivity imaging study shows the soil at Abu Serga church to be of relatively inhomogeneous composed mainly of the following units:

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1- A first layer composed of fill that extends to a depth of **5 m** and possesses average resistivity of about 70-250 Ohm.m with distinctive **hot colors (yellow to Purple)**.
2-The second layer is composed of soft silty clay (as described by the client) mixed with sand in some places, starting from an average depth of **5m** and extended to **10 m** depth with low electrical resistivity between **2-25 Ohm.m** with distinctive **blue color.**
3- The third layer is composed mainly of sand; it extends to a depth of **10-15 m** and has average resistivity between 30-129 Ohm.m.

Based on the electrical resistivity measured, the soil show inhomogeneous effects. Some parts show very high resistivities extend to 900 Ohm.m, and other parts show very low resistivity, less than 2 Ohm.m. The high and low resistivity zones are found in the form of pockets. Very high resistivities were attributed to the existence of voids or cavities in the soil or archeological features abundant in these sites. While very low resistivity values less than 2 Ohm.m. are attributed to the existence of saline source, which could be the effect of saline drainage water which is abundant in this area.

Based on the resistivity values, the expected groundwater level is expected to be at a depth between 3-5 m showing electrical resistivity of $\leq$ 8 Ohm.m, which could be the resistivity of brackish or saline water. The aquifer found at Abu Serga church is thus of low resistivity high salinity nature.

For Assessments of seismic hazards, a seismic source regionalization methodology was utilized assuming that in the future, the location of major seismic activity will be limited to the boundary and intraplate tectonics of the micro-plates as it has been over the course of the recorded history, regardless of the times at which these boundaries were locked for considerable periods. The peak ground acceleration attenuation relationships used in this study are the mean maximum horizontal accelerations over the bedrock. With soil deposits of soft- and medium-stiff sands and clays of appreciable depth, the ground accelerations will be considerably modified and should be taken into consideration.

Although the variability of the attenuation relations, maximum magnitude, recurrence relationships, and even the border of the seismic source zones should undoubtedly be considered for the site-specific seismic hazard assessment of susceptible structures such as Abu Serga church, it is not thoroughly accounted for in such general regional seismic hazard assessments.

The maximum magnitudes assigned to each seismic source zone have been based only on the historical recordings within each source zone. It should be noted that higher maximum magnitudes can affect the iso-acceleration contours of these maps.

RECURRENCE OF EARTHQUAKES AT ABU SERGA CHURCH

The recurrence of earthquakes is very important for determining future plans for sensitive structures like archeological sites. We have calculated the return period for Magnitudes M ≥ 5, M ≥ 6, and M ≥ 7 for the most affecting zones at Abu Serga church:

The Southern Pelusium Zone

The return period in years for the southern Pelusim Zone is as follows (Fig. **4** in Chapter 6):

Table. The estimated return periods of earthquakes in the region per year.

Magnitude	M ≥5	M ≥6	M ≥7
Return Period/years	**33**	**229**	**1550**

The clustering and distribution of earthquakes in and around Abu Serga church have introduced the idea that two intersected active seismic trends intersect at Abu Serga church.This was proposed by Kebeasy (1990). This presents an important remark that if **two active trends intersect at Abu Serga church** area, the hazards and threats in Abu Serga church will be more enormous. However, no support is given to this from seismotectonic or seismic plate boundaries for these suggestions.

This study suggest a moderate level of earthquake activity at Abu Serga church and this is in good agreement with the fact that " **Egypt is a part of the stable African Shield"**, but the existence of old structure such as the Abu Serga church may reduce the ability to resist any earthquake shaking.

Although it was difficult to get and gather the kind of data needed to construct hazard maps in Egypt because of the lack of data and no cooperation between agencies, we succeeded in generating two important maps. These are the "**Maximum Intensity Zonation Maps** for Abu Serga church and the "**Iso-Acceleration Contour Maps for Abu Serga church**". To a great extent, these maps succeed in forming a general picture of the amount of hazard that Abu Serga church is subjected to.

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SUBJECT INDEX

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