Numerical Simulation of SH Seismic Waves Propagation Above Fault Zones – Application At Wadi Natash Area, Eastern Desert, Egypt-

M. Thabet
Geology Department, Science Faculty, Assiut University, Assiut, Egypt

ABSTRACT:
When sources are located in or close to fault zones, guided seismic head and trapped waves are generated which may be indicative of the structure of fault zones at depth. In this paper, SH seismic wave propagation is simulated using 2D finite element modelling above shallow irregular fault zone structures at Wadi Natash area in the eastern desert of Egypt. This area is characterized by significant linear heterogeneities in the subsurface sequence resulted from the presence of structural discontinuities represented by steeply dipping normal and reverse faults affecting both the massive basement and the overlying rocks. These 2D simulations were carried out using synthesized input ground motions with predominant frequencies ranging from 0.4 Hz to 25 Hz at 50m depth. The results of the 2D simulations using synthesized input ground motions with predominant frequencies ranging from 6.0 Hz to 9.6 Hz indicate that structural discontinuities of the fault zones affect significantly the trapping efficiency represented by high amplification. In contrast, the 2D simulations using synthesized input ground motion with predominant frequency less than 6.0 Hz and greater than 9.6 Hz could not produce trapped wave energy resulted in poor trapping behaviour. It is concluded that the resulted SH seismic wave trapping behaviour is a trade-off between the frequency of the incident SH seismic waves and the complex fault geometries without respect to the effect of varying the contrast between seismic wave velocity in the fault zone and the surrounding rock units.

Keywords: Numerical Simulation, Trapped Waves, Fault Structures

1. INTRODUCTION

Waveform modelling of fault zone trapped waves can improve the understanding of earthquake processes. Extensive 2-D studies of the dependency of fault zone wave motion on basic media properties and source receiver geometries (e.g., BEN-ZION, 1998; MICHAEL and BEN-ZION, 1998) show that there are significant trade-offs between propagation distance along the structure, fault zone width, impedance contrasts, source location within the fault zone, and quality factor. These trade-offs and additional sources of uncertainties make a reliable determination of site effects related to fault zone structure a very challenging endeavor. Ben-Zion *et al.* (2003) referred to trapped waves (motion amplification and long period oscillations) in fault zone stations due to sources not necessarily in the fault as 'fault zone-related site effects'.

In this paper, the fault zone is considered as layer discontinuity and represented as upward or downward shifting in the layer. Two dimension finite element simulations have been carried out at Wadi Natash area in the eastern desert of Egypt. The subsurface sequence at Wadi Natash area is characterized by the presence of complex structural features represented by steeply dipping normal and reverse faults affecting both the massive basement and the overlying sediments. Forward analyses have been performed to quantify the amplification of ground motion for coherent synthesized sources at 50m depth at Wadi Natash area. In general, trapping efficiency is expected to be resulted from the two dimension analyses.

2. DATA SETTING

Wadi Natash area represents one of the most important areas as future project, especially for mineral exploration. Figure 1a shows a location map of Wadi Natash area in the eastern desert of Egypt.

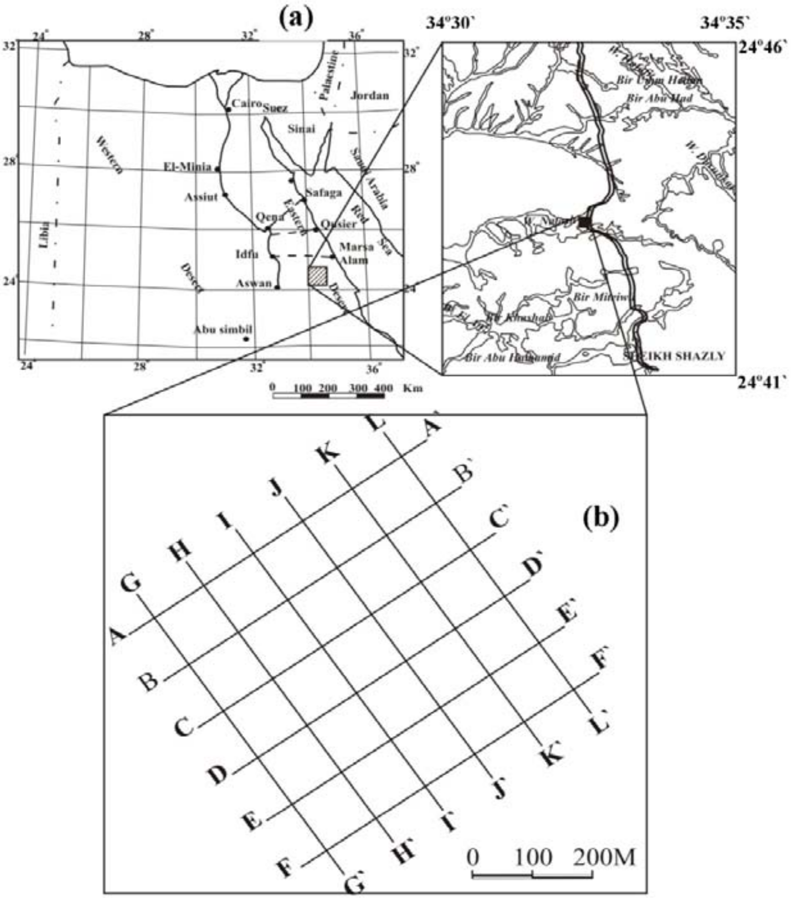

Figure 1. Location map of Wadi Natash area (a), distribution of 2D SH-wave velocity structures (El-Haddad, 2008) (b)

As shown in Figure 1b, detailed seismic investigations were done in an area of 600m x 600m dimensions of the flat Wadi Natash channel course (El-Haddad, 2008), that covered by the alluvial recent Wadi fill deposits.

The geology of the studied area is illustrated and shown in Figure 2. There are four major rock units are exposed at the studied area of Wadi Natash (Hashad, 1994 and Madani, 2000). These are, from oldest to youngest, as follows: 1) Basement rocks (oldest), 2) Abu Agag Formation, 3) Wadi Natash volcanics, and 4) Trachytic ring dykes (youngest). Precambrian basement rocks represent the oldest rocks exposed at the area and represented mainly by mafic to intermediate metavolcanics. They overlain unconformably by Turonian sandstone of Abu Agag Formation. The volcanic rocks exposed at Wadi Natash area form a dissected plateau with pronounced stratified appearance. They occur in the form of sill flows and ring dykes. The volcanic sequence consists of three distinct basal flows separated by two conglomeratic horizons. Four main volcanic flows (group I, group II, group III and group IV) separated by three erosional surfaces are recognized (Madani, 2000). These flows are extruded and cut by trachytic ring and semi –ring dykes (Madani, 2000).

In the present study, a set of twelve normal shallow 2D SH-wave velocity structures accompanied with their interpreted geoseismic sections (Figure 3 through Figure 4, El-Haddad, 2008) are used in the 2D forward modelling to calculate the seismic wave propagation. The SH-wave mode is an important and essential type of the shear wave, which is characterized by a horizontal particle motion (along the Y direction) perpendicular to both the direction of the measured profile and the incidence plane. Six of these sections are extended NNW-SSE parallel to the Red Sea and the others have a normal ENE - WSW direction (Figure 1b).

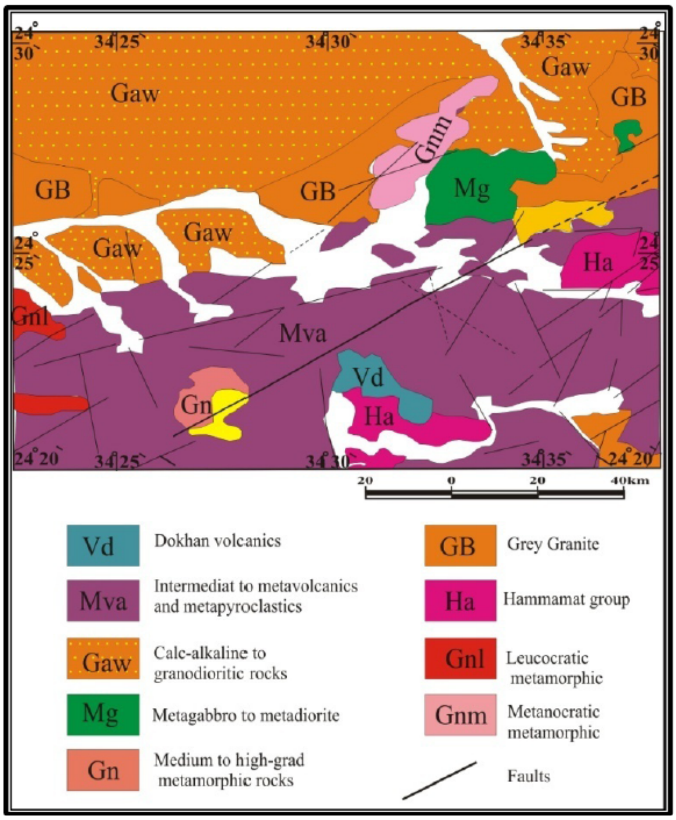

Figure 2. Geological map showing the different rock units and most of the significant fault trends in the studied area (modified after the EGPC and CONOCO, 1987)

3. METHODOLOGY

The numerical simulation process consists of two essential steps. Firstly, synthesizing input ground motions. Secondly, carrying out 2D simulations using all the twelve 2D SH-wave velocity structures. Those two steps are described in detail in the following two sections.

3.1. Synthetic Input Ground motion Model

The stochastic model SMSIM (Boore, 2005) is used for synthesizing time histories of the input ground motions at 50m depth. The motions are generated at hard rock representing basement bedrocks. Nine input ground motions are generated with predominant frequencies 25Hz, 15Hz, 11Hz, 9.6Hz, 8.5Hz, 6Hz, 2Hz, 0.6Hz and 0.4Hz. Coherent input ground motions are assumed at each nodal point at 50m depth.

3.2. Two Dimension Simulations

The two-dimension (2D) forward analyses have been conducted using QUAD4M (Hudson *et al.*, 1994) code program. QUAD4M is an equivalent linear two-dimensional (2D) analyses code for time domain solution to dynamic soil response using finite element method.

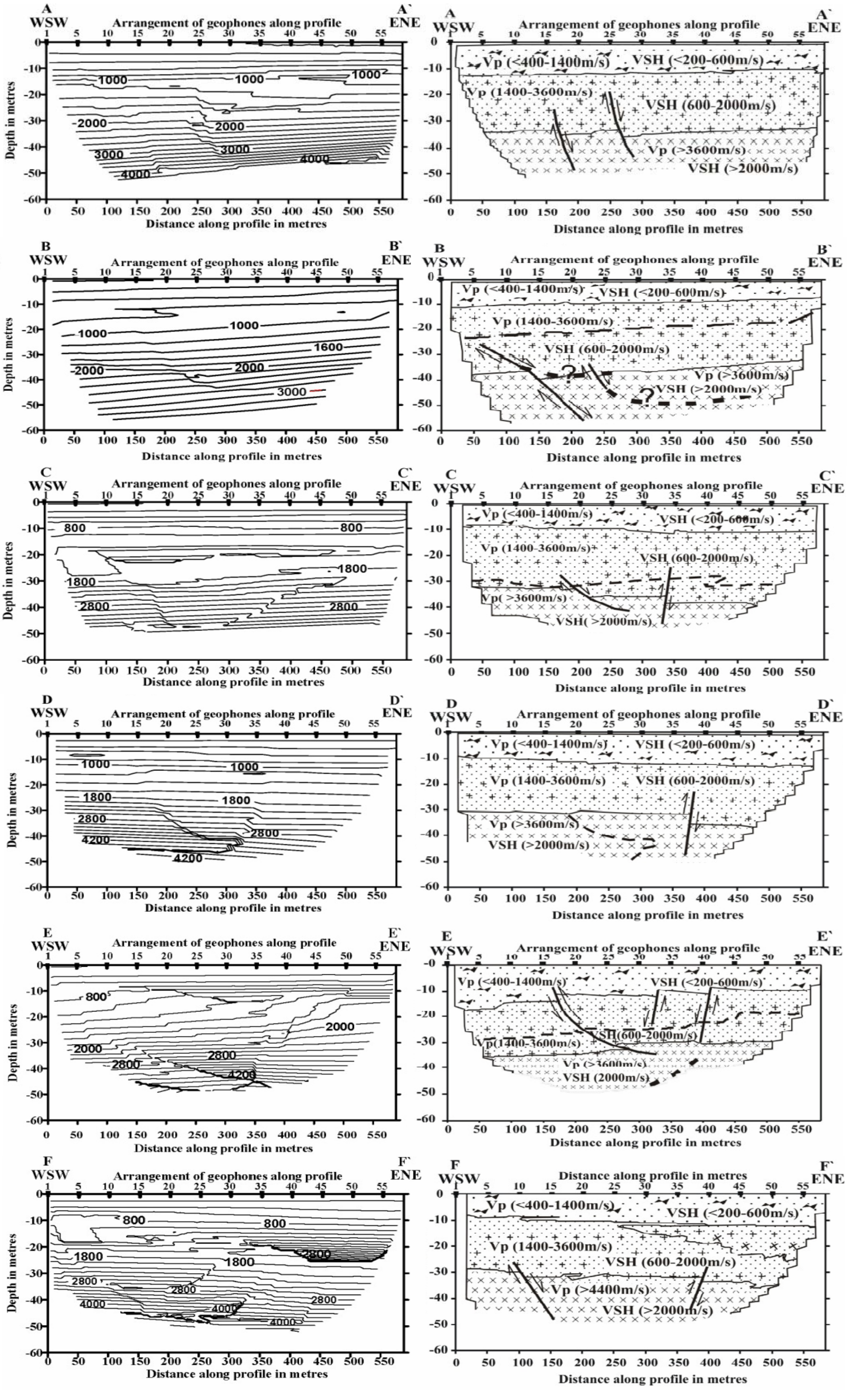

Figure 3. 2D SH-wave velocity structures and geoseismic sections for ENE - WSW profiles (El-Haddad, 2008)

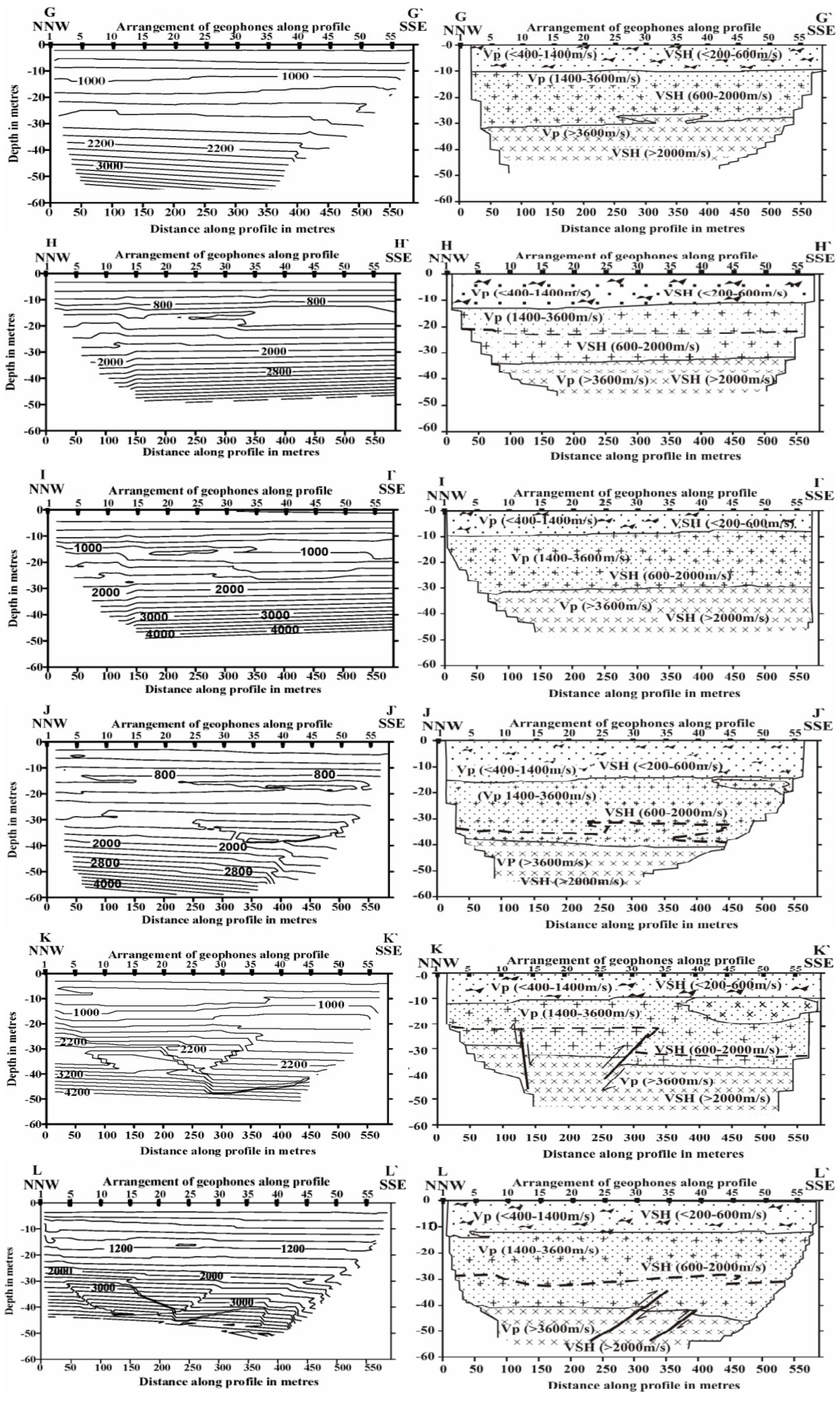

Figure 4. 2D SH-wave velocity structures and geoseismic sections for NNW-SSE profiles (El-Haddad, 2008)

Determining finite elements is a trade-off relation between the numbers of nodes and the slowest shear wave velocity throughout the entire domain. In the present 2D analyses, I used finite elements of the same size throughout the domain with the appropriate node spacing for the slowest SH shear wave velocity. This would be the most stringent option. Generally, the shear wave velocity at Wadi Natash area varies from approximately 4600 m/sec at the 50m depth to less than 200 m/sec at the surface. For simple mesh generation, EasyMesh code program is used as a 2D mesh generator for triangular finite elements. EasyMesh (Niceno, 2002) code program is a two-dimensional quality mesh generator. It generates two dimensional, unstructured, Delaunay and constrained Delaunay triangulations in general domains.

4. RESULTS AND DISCUSSION

The results of the present research work could be classified in three main categories. These categories are classified according to the predominant frequencies of the synthetic input ground motions that are used in the 2D simulations. The results are shown as the maximum spectral accelerations at the surface nodal points along the twelve profiles that cover the whole Wadi Natash area. These maximum spectral accelerations determined at frequencies that are corresponding to their predominant frequencies of the input ground motions. In the following sections, results are shown and discussed in detail.

In Figure 5, the locations of the faults in the studied area are shown. These faults are interpreted from the geoseismic sections in Figure 3 and Figure 4. Fault location map in Figure 5 is an important tool in interpreting the trapping behaviour of the seismic *SH*-waves that will be discussed later in the following sections.

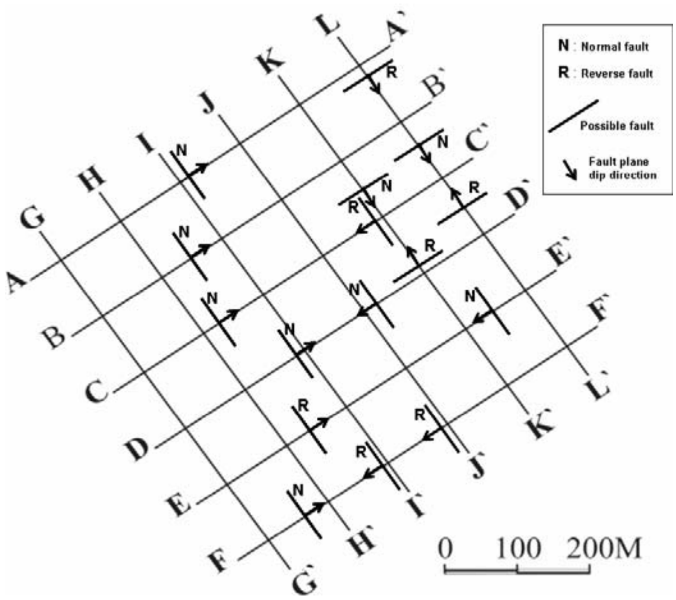

Figure 5. Fault location map interpreted from 2D *SH*-wave velocity structures

4.1. High Frequency Simulations

The simulations were conducted using synthesized input ground motions with predominant frequencies 11Hz, 15Hz, and 25Hz. As shown in Figure 6(a), slight amplification could be detected in the central and eastern parts of the studied area. In Figure 6(b), there is no significant amplification could be observed in the studied area, except in the northern borders of the studied area. Limited amplification is resulted in the western south part of the studied area, as shown in Figure 6(c). As a result, trapping efficiency due to complex fault structures in the studied area could not be reproduced obviously in this high frequency band.

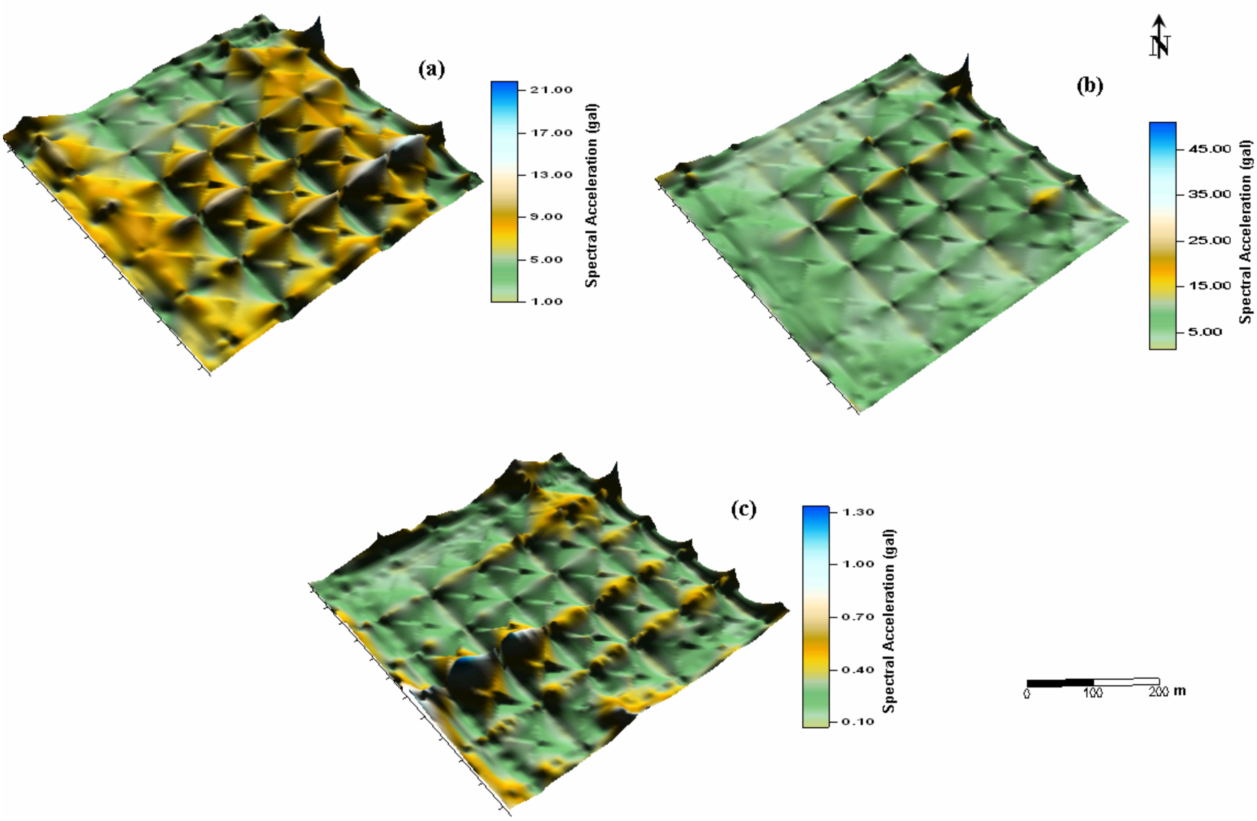

Figure 6. Maximum spectral acceleration at surface using 11Hz (a), 15Hz (b), and 25Hz (c) input motions

4.2. Medium Frequency Simulations

The simulations were conducted using synthesized input ground motions with predominant frequencies 6Hz, 8.5Hz and 9.6Hz. As shown in Figure 7(a, b and c), high amplification occupies the entire east northern and western parts of the studied area, whereas slight amplification is resulted in the central area.

This high amplification means that seismic waves of frequency band ranging from 6Hz ~ 9.6Hz could trap seismic waves efficiently within fault structures. Therefore, trapping efficiency of seismic waves within the faulted-basin-like structure at the east northern parts of Wadi Natash area could be described as highly positive trapping behaviour or amplification trapping behaviour. Obvious regression in the high amplification peaks that are locating in the central parts of the studied area could be related that complex fault structures in Wadi Natash area could not reproduce the amplification of SH-waves.

4.3. Low Frequency Simulations

The simulations were conducted using synthesized input ground motions with predominant frequencies 0.4Hz, 0.6Hz and 2Hz. High deamplification is dominated at the center of the studied area, as shown in Figure 8(a, b and c). This high deamplification means that long period seismic waves could not propagate efficiently in fault structures. Therefore, trapping efficiency of seismic waves within the faulted-basin-like structure at the center of Wadi Natash area could be described as negative trapping behaviour or deamplification trapping behaviour.

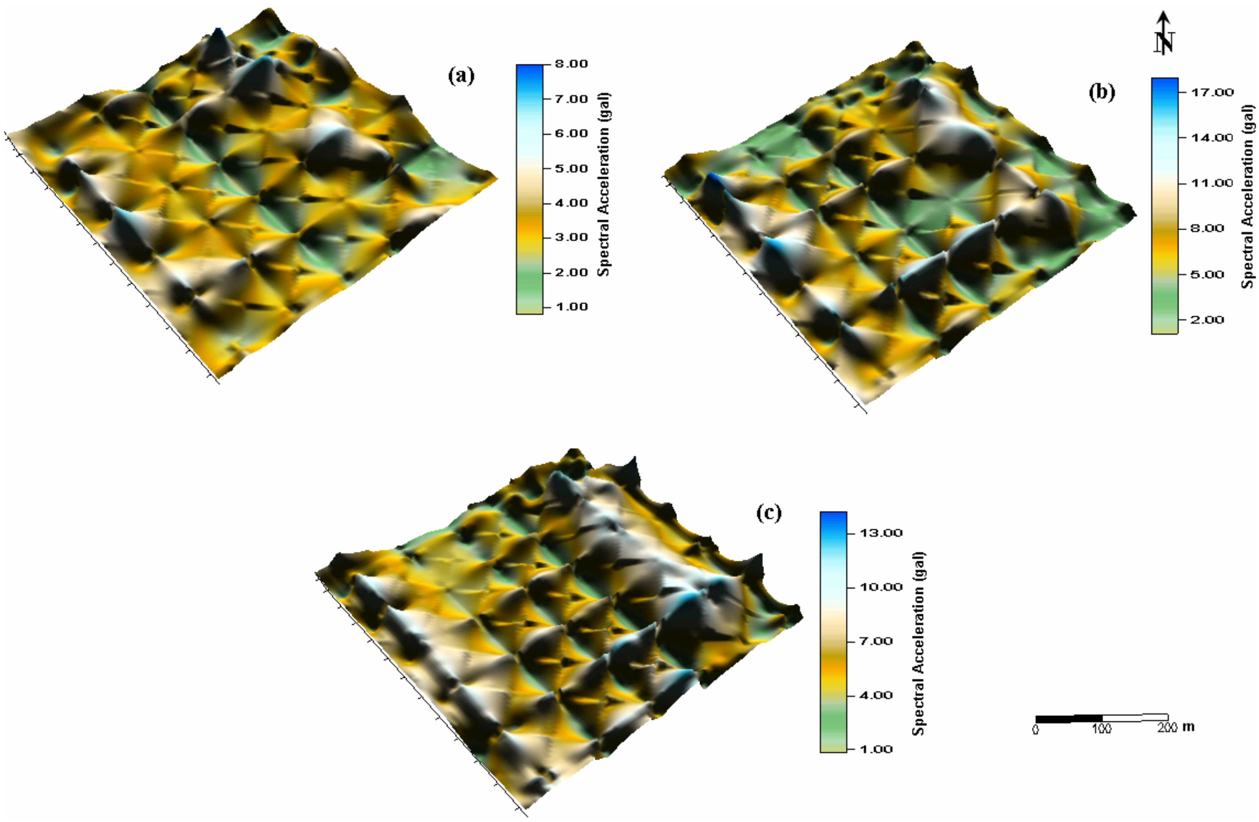

Figure 7. Maximum spectral acceleration at surface using 6Hz (a), 8.5Hz (b), and 9.6Hz (c) input motions

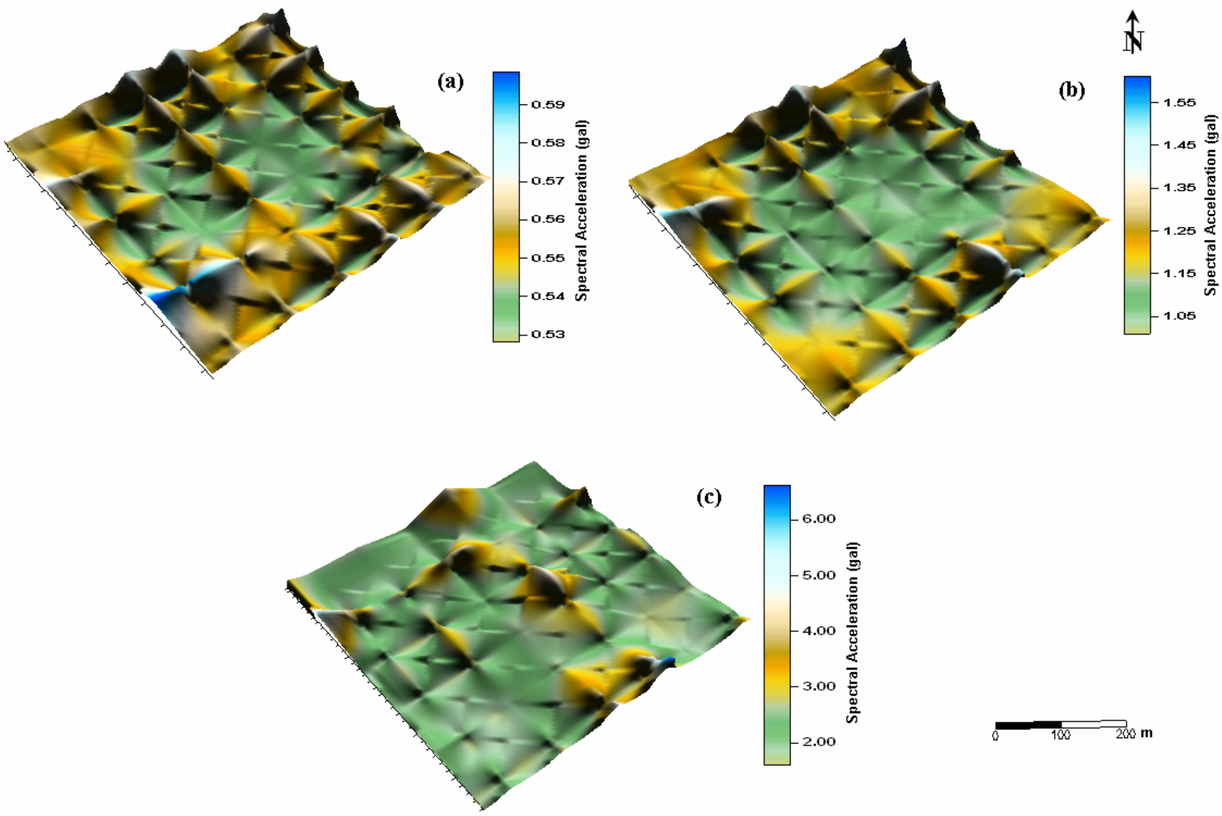

Figure 8. Maximum spectral acceleration at surface using 0.4Hz (a), 0.6Hz, and 2Hz (c) input motions

5. CONCLUSIONS

In the present study, 2D finite element simulations have been carried out along twelve profiles at Wadi Natash area. Wadi Natash area is located in the Eastern Desert of Egypt. This area is characterized by significant linear heterogeneities in the subsurface sequence resulted from the presence of structural discontinuities represented by steeply dipping normal and reverse faults affecting both the massive basement and the overlying rocks. Nine synthetic seismograms with different predominant frequencies ranging from 0.4Hz to 25Hz were used as input ground motions at 50m depth. The resulted 2D simulations using synthetic input ground motions with predominant frequencies ranging from 6Hz to 9.6Hz could produce high amplification in the east northern and western parts of Wadi Natash area due to the trapping efficiency. The resulted 2D simulations using synthetic input ground motions with predominant frequencies ranging from 0.4Hz to 2Hz and greater than 9.6Hz could not produce guided wave energy in the overlying fault zone layers. As a result, poorly trapping efficiency is dominated in the center of Wadi Natash area when using synthetic input ground motions with predominant frequencies ranging from 0.4Hz to 2Hz and greater than 9.6Hz. The discussed 2D simulations indicate that the material discontinuities of the fault zone affect significantly the trapping efficiency within a specified band of predominant frequencies of synthetic seismograms, that could be related to fault zone width and fault zone narrowing with depth.

AKCNOWLEDGEMENT

I deeply acknowledge Prof. Assem El-Sayed El-Haddad (Geology Dept., Science Faculty, Assiut University, Assiut, Egypt) for providing valuable data of detailed 2D SH-wave velocity structures and interpreted geoseismic sections at Wadi Natash area.

REFERENCES

Ben-Zion, Y. (1998). Properties of Seismic Fault Zone Waves and their Utility for Imaging Low Velocity Structures. *J. Geophys. Res.* 103, 12567-12585.

Ben-Zion, Y., Peng, Z., Okaya, D., Seeber, L., Armbruster, J. G., Ozer, N., Michael, A. J., Baris, S., Aktar, M. (2003). A Shallow Fault Zone Structure Illuminated by Trapped Waves in the Karadere- Duzce Branch of the North Anatolian Fault, Western Turkey. *Geophys. J. Int.* 152: 699–717.

Boore, D. M. (2005). SMSIM- Fortran Programs for Simulating Ground Motions from Earthquakes (Version 2.3). U.S. Geological Survey-Open File Report, A, 80-96.

EGPC, and CONOCO, (1987). Geological Map of Egypt (Scale 1:500,000). Cairo, Egypt.

El-Haddad, A.E. (2008). Detection of Ground Water Level in Fractured Basement Using Seismic Velocity Measurements in Wadi Hafafit Area, Eastern Desert, Egypt. *J. Appl. Geophys.*, 7(1), 339-360.

Hashad, M.H. (1994). Geochemical Characteristics and Petrogenesis of Phonolitic Plugs Associated With Wadi Natash Volcanic Rocks. M.E.R.C. Ain Shams University-Earth Science. 8, 131-145.

Hudson, M., Idriss, I. M., Beikae, M. (1994). QUAD4M- A Computer Program to Evaluate The Seismic Response of Soil Structures Using Finite Element Procedures and Incorporating a Compliant Base. National Science Foundation, Washington, D. C., 1-72.

Madani, A. A. (2000). Geological Studies and Remote Sensing Application on Wadi Natash Volcanics, Eastern Desert of Egypt. M.Sc. Thesis, Faculty of Science, Cairo University, Egypt.

Michael, A. J. and Ben-Zion, Y. (1998). Inverting Fault Zone Trapped Waves with a Genetic Algorithm. *EOS Trans. Am. Geophys. Union,* 79, F584.

Niceno, B. (2002). EasyMesh- A Two-Dimensional Quality Mesh Generator (Version 1.4). Trieste University, Italy.