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Evaluation of local site effect in the western side of the Suez Canal area by applying *H/V* and MASW techniques

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ABSTRACT

The soft sediments are one of the most important factors responsible for the amplification of the seismic ground motion in an area of study. Three components, single-station microtremor measurements were performed at 61 sites along the Suez Canal to estimate the fundamental frequencies of the soil and corresponding *H/V* amplitude ratios by using the horizontal-to-vertical spectral ratio (HVSR) method. We have applied the investigations of the shear wave velocity for supplementing the existing seismic microzonation of the Suez Canal. The multichannel analysis of surface wave (MASW) tests were done along the Suez Canal in the three cities, Suez, Ismailia, and Port Said using 24 channels digital engineering seismograph with 4.5 Hz geophones from September 2014 to January 2015 to get the shear wave velocity V_{S30}. The SeisImager/SW software was used for analyzing the data, and 1D-shear wave velocity model have achieved for each site. The *HVSR* curves show that the fundamental frequency values are ranging from 0.57 to 1.08 Hz, and *H/V* amplitude ratios are ranging from 4.05 to 6.46. The average values of V_{S30} are (548, 301), (241, 319), (194, 110, 238) for Suez, Ismailia, and Port Said respectively. The average of shear wave velocity up to 30 m depth is estimated and used for site classification based on the National Earthquake Hazard Reduction Program (NEHRP) classification. The majority of the sites was classified as Class D (stiff soil) except one site at Port Said city is classified as Class E (soft soils), and another site in the Suez city is classified as Class C (hard rock).

1. Introduction

The Suez Canal is located in the northeastern part of Egypt. It is the most commercially used, and the longest excavated waterway in the world (Fig. 1) rivaled only by the Panama Canal in Panama. The Suez Canal is an inland coastal-ocean saltwater body that links the Red Sea in the south with the Mediterranean Sea in the north. It mostly transmits a desert environment and is bound by sand banks, except the northern 60 km where extensive wetlands bordered it. The canal conditions such as poor construction quality and the presence of the soft soil conditions may increase the damage ratio in a scenario of major earthquake occurrence in the study area. Therefore, the construction of important buildings in the Suez Canal corridor needs suitable construction methods for these geotechnical conditions. In regions that have low seismicity, it would be necessary to wait for a long time to get a complete data set. Therefore, due to this reason, the use of ambient noise is becoming popular as an excellent alternative technique for determining the fundamental frequencies of the soil and corresponding *H/V* amplitude (Bard, 1998).

The study area is affected by moderate seismic activities due to its closeness to the junction of the Red Sea and the movement along the Gulf of Suez and the Gulf of Aqaba-Dead Sea transform fault system. The area is also affected by the Suez-Cairo Shear Zone (wadi Hagul Seismic Source); the seismicity emanates from northeast Cairo (Abu-Zaabal area) due to the relative motion between three plates (Eurasia, Africa, and Arabian plates). This area has experienced damage from local earthquakes between 1955 and 2007 (e.g., the Mediterranean offshore 1955 Alexandria earthquake, Ms = 6.8, the 1969 Shadwan earthquake, Mw = 6.9; the 1995 Gulf of Aqaba earthquake, Mw = 7.2; the 1996 Cyprus earthquake, Mw = 6.8, and the 2007 Wadi Hagul earthquake with $M_L = 3.8$.

In general, the softness of the surface layer not only amplifies ground motion at certain frequencies but also extends the duration, which may cause further damage during earthquakes. The identification of the fundamental frequencies of soil deposits is gaining

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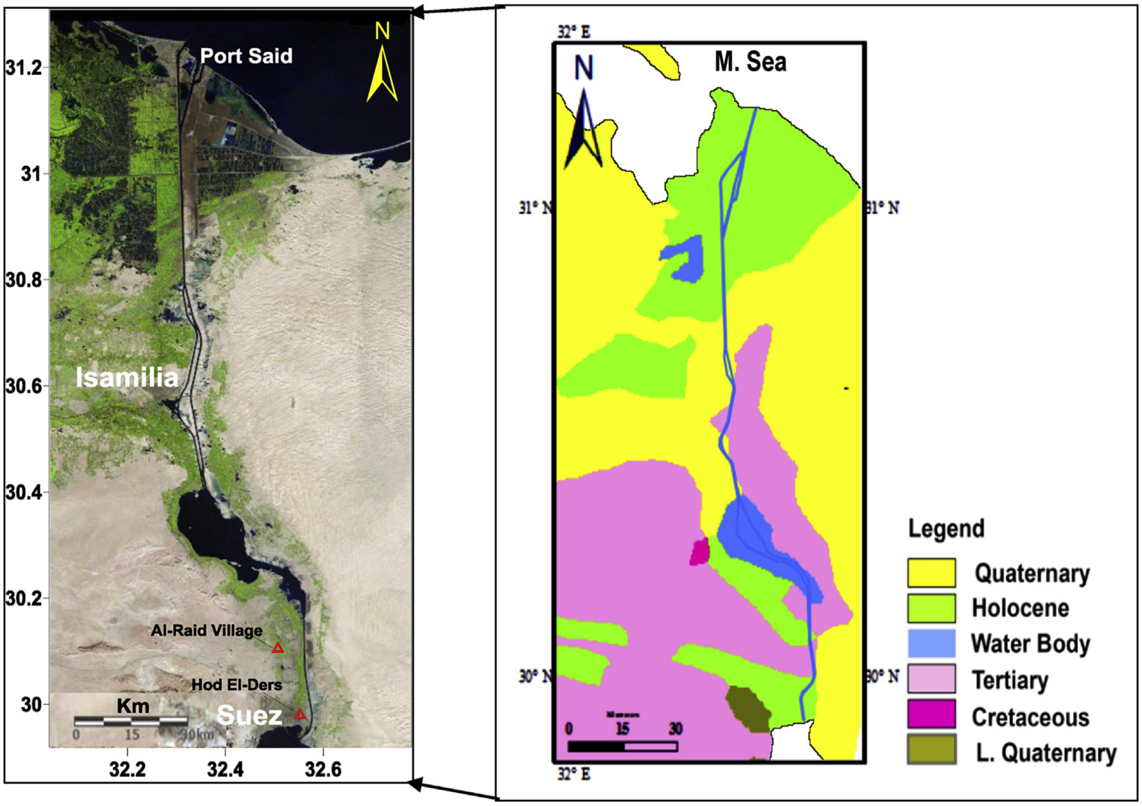

Fig. 1. Location and Geologic Map of the study area show three provinces (Suez, Ismailia, and Port Said) compiled from Landsat 8 OLI (The Operational Land Imager) Triangular red symbols are Hod El-Ders site and Al-Raid Village at the Suez city. (Modified from the U.S. Geological Survey's World Energy Project, 1997–2000, Feliks et al., 2002). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

increasing importance for seismic site effect assessment because it carries implicit information about the bedrock depth and shear wave velocity of the soils, which is related to soil shear stiffness. Site amplification is considerably an effect on the building response, especially in the near field and large scale earthquakes (Polat et al., 2009). According to the frequency range in nature; the natural frequencies of high storey buildings (3–10 floors) range from 1 to 3 Hz, while the natural frequencies for low storey buildings (1–3 floors) range from 3 to 10 Hz, and the natural frequency of very high storey buildings (10–50 floors) range from 0.1 to 1 Hz (Mandal et al., 2005).

The MASW is a newly method. It was developed by Miller et al. (1999) and Xia et al. (2000) to estimate the shear wave velocity profile (i.e., Vs versus depth) from the surface wave energy by analyzing Rayleigh-type surface waves on multichannel recordings. The surface wave measurements were carried out around the area and processed using the 1D multichannel analysis of surface waves to get the shear wave velocity profiles through two main steps; the first is the calculation of the dispersion curves and the second is the estimation of the shear wave velocity profiles from the inversion of these dispersion curves. The shear wave velocity V_{S30} in the upper 30 m of sediments is a very significant parameter to evaluate near-surface stiffness and for characterizing the given site (Stokoe et al., 1994). This parameter is important to derive the resistant structural design for the earthquakes (Kanai, 1983).

The National Earthquake Hazard Reduction Program (NEHRP, 2003) provides a classification of the given sites based on V_{S30}. This code was developed after strong earthquakes occurred in the USA, Japan, Europe and in other countries. In this study, the effects of local site conditions were determined by conducting HVSR measurements along the Suez Canal. HVSR peak frequencies of the soil and HVSR peak amplitude values were calculated, and the site Classification is determined based on V_{S30}.

2. Geologic and tectonic setting

The study area and its surroundings occupies a semi-flat terrain from the north to the south, except the area to the south where topography rises defining the southern mountains as in Gabal Geniefa, which rises on average to 234 m above sea level and Gabal Shabraweet, which rises on average to 226 m above sea level. Many wadis drainage channels in the study area are filled by alluvial deposits. The most important wadis are; Wadi El Ashara, Wadi Yasara, Wadi Al Agrama, and Wadi El Tumilat (Mohamed and Hamdy, 2012).

The Suez Canal area is classified into three provinces; i) the southern province includes the Suez city and Bitter Lakes area, it represents a part of the transitional zone between the Gulf of Suez rift and the unstable shelf of the northern part of Egypt (Omaran, 1989; Geriesh, 1989). This province is covered by sedimentary rocks belonging to the Cretaceous, Middle Eocene to Late Eocene, Oligocene, Early Miocene, Middle Miocene, Late Miocene and Pleistocene-Holocene ages (Fig. 1). The Pleistocene-Holocene sediments (Quaternary) are composed mainly of sandy clay and clay deposits around marshes and sabkhas, gravels, gypsum, beach ridges, beach sand, alluvium and sand dunes.

ii) The central province includes Ismailia City and El-Temsah Lake along the coast of the Suez Canal. El-Temsah Lake formed in a depression in a fault trough (http://www.intechopen.com/books/advances-in-geoscience-and-remote-sensing/environmental-hazards-in-the-el-temsah-lake-suez-canal-