Site Condition Characteristics for Earthquake Disaster Mitigation at Kima Area, Aswan, Egypt

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Abstract

The Kima area is located in the southeastern part of Aswan city where the Aswan wastewater treatment plant and one of the giant factories in the Middle East for chemical and fertilization. The area is very close to the main active seismic zone in South Egypt, where November 7, 2010 earthquake (M 4.6) occurred. The earthquake was felt strongly and caused minor damage (cracks) to different buildings in the Kima area. This earthquake motivates us to perform the current study for earthquake disaster mitigation in this area. The main target of the study is the evaluation of the local soil conditions based on Multichannel Analysis of Surface Waves and Horizontal to Vertical Spectral Ratio seismic techniques. The outputs results include different parameters (Vs₃₀, the resonance frequency, the amplification factor, and the NEHRP site classification). The predominant NEHRP site class is class D occupying the middle part of the Kima area. The resonance frequency ranged from 0.62 to 13.8 Hz over all the investigated areas and has a small range close to the factory site (0.62–0.78 Hz).

Keywords: Kima; Frequency; Site condition; MASW; Microtremors

1. Introduction

Recently, after the occurrence of many large earthquakes caused a lot of damages in different parts in whole world, site characteristics study became one of the most valuable studies which has a significant effect on earthquake ground motion and on the degree of damage to structures. Long back, Milen (1898) studied the 1819 Japan earthquake and concluded that the sediments sites have higher ground motion than the hard rock. This conclusion acts as an indicator for the importance of the site characteristics studies which include the geotechnical parameters of rocks and unconsolidated deposits, the fundamental frequency, amplification factor, the shear wave velocity….etc. In earthquake engineering problems, one of the very significant parameters is the shear-wave velocity (Vs) especially in microzonation studies (Iwasaka et al., 1978; Anbazhagan and Sitharma, 2008; Ansal et al., 2009; Rahman et al., 2016). The pilot study area is Kima zone which is situated in the southeastern part of Aswan (Fig. 1) on the eastern bank of the River Nile. This area is a dense populated region with poor designed buildings and includes one of the biggest factories in the Middle East, Kima factory for chemical industries and fertilization. Also, inside this area the main wastewater treatment plant in Aswan is located. Because of the changes in the soil characteristics and the geometry, the spatial variability of the ground motion can be very significant over short distance and due to the location of DOI: 10.46717/igi.55.2B.2Ms-2022-08-18
Kima area very close to the principle seismic zone in South Egypt, it is very important to perform the ongoing research work for seismic hazard mitigation. The principle objective of the research is the studying the seismic site characteristics within Kima area based on the active Multichannel Analysis of Surface Waves (MASW) technique to build the subsurface Vs profile, $V_{s30}$ and NEHRP soil classification and the passive Horizontal to Vertical Spectral Ratio (HVSR) technique to calculate the resonance frequency and the amplification factor.

2. Geological Setting

Many researchers have previously described the geology of Aswan area (e.g. Said, 1962 and 1981; Issawi, 1968; Butzer and Hansen, 1968; El Ramly, 1973; El Shazly et al., 1974 and 1976, Klitzsch and Wycisk, 1987; Issawi and Jux, 1982; Barber and Carr, 1981). They are confirmed that the oldest sedimentary unit exposed is the Nubian Formation and unconformably lies over the Precambrian basement complex. The geological section of the area (Fig. 1) can be described as follows:

- The Precambrian rocks which are mainly granites and schist is locating on the east and west sides of the area.
- The Nubian sandstone of the Upper Cretaceous age overlies the Precambrian basement rocks with total thickness from ranging 20 to 85 m (Attia, 1954).
- In the middle part of the area, the Quaternary sediments exposed and are represented mainly by alluvial sands, gravel and clays as described from geological cross section of the drilled well in this part close to Kima factory with thickness of about 100 m (Mohamed et al., 2021b).

Fig. 1. Geological investigation of the pilot area and Aswan region, blue star is Kima factory site
3. Materials and Methods

To investigate S-wave velocity the essential parameter for seismic site characteristics and to calculate the fundamental frequency with its associated amplification factor (maximum amplitude) across the study area, MASW method (Park et al., 1999) and HVSR technique (Nakamura, 1989) were applied.

3.1. Multichannel Analysis of Surface Waves Method

MASW is well-known as a valuable non-invasive seismic technique to estimate shear-wave velocity for site characterization. It is faster, less expensive and more accurate for information about soil dynamic properties (Xia et al., 1998, 1999, 2000a, 2000b; Park et al., 1999; Miller et al., 1999; Louie, 2001; Anbazhagan et al., 2009; Karastathis et al., 2010; Raef et al., 2015; Rahman et al., 2016).

3.2. HVSR Technique

Nakamura (1989) technique which called the HVSR is a very widely used method in site characterization studies to determine resonance frequency and its associated maximum amplitude (amplification factor). Nakamura (1996) concluded from his extensive studies that the HVSR technique is providing reliable estimation of the fundamental frequency and corresponding amplification. Bard (2000) based on microtremor studies, reviewed the site characterization problem and inferred that the technique is inexpensive and a simple experimental application for response studies. In urban areas with high noise level such as Kima, the microtremor method is very useful due to its stable response curve for site characterization. Nakamura H/V ratios proved by many pioneers (Duval et al., 1995; Field and Jacob, 1995; Seekins et al., 1996; Lachet et al., 1996 and Riepl et al., 1998) that are much more constant than raw noise spectra. During the last decade, the approach became one of the valuable applied methods in Egypt for site characterization. The technique was applied by many investigators (Mohamed and Fat-Helbary, 2010; Mohamed et al., 2013, 2015, 2020, 2021a, 2021b; Abdel-Hafiez and Toni, 2019; Abudeif et al., 2019; Fat-Helbary et al., 2019; Meneisy et al., 2020) in many new and important projects across the Egyptian territories and gave good and acceptable results.

4. Data Acquisition and Analysis

MASW method for data acquisition can be divided into active and passive technique. In our study, the active MASW method was applied to acquire shear wave velocity (Vs) utilizing 24 geophones (4.5 Hz) line up in a straight line and placed vertically on the ground with 2 m geophone interval and connected to geometrics Strata Visor-NZ seismograph. A sledgehammer of 10 kg was used as a dynamic source for generating surface waves at 21 selected sites (Fig. 2) with forward, middle and reverse shot points with 5 m offset. The data were collected using a 1-ms sampling rate and a 1000-ms recording length. Seisimager/SW (2006) software used for the acquired MASW data processing and interpretation to compute the Vs by generating the dispersion curve at each measured site.

For HVSR technique, the ambient measurements were collected in 34 different sites over the study area (Fig. 2) using Trillium 120s velocity sensor. The number of the measured points is bigger than the MASW sites with different locations because the H/V acquisition can be conducted in a very small site not like the MASW which needs accessible wide area. The ground vibrations data is recorded continuously for two hours at each site. The data collection following the Site EffectS assessment using Ambient Excitation (SESAM, 2004) European project guidelines and recommendations for data acquisition. The acquired data were analyzed using the Geopsy software to compute the resonance frequency and its maximum H/V amplitude (amplification factor).
5. Results and Discussion

To produce the 1-D velocity profile, the Vs at Kima area was analyzed depending on Seisimager/SW software (2006). MASW lines show the distribution of the shear wave velocity from the surface of the ground down to 30 m depth. A direct signal of the bearing capacity and its soil rigidity is the shear wave velocity (Kramer, 1996).

Generally, two layers of different soil shear wave velocity rigidity were found in the most of MASW profiles (Fig. 3). The low Vs values (138-962 m/s) are represented in the surface layer with depth ranges from 0 to 10 m (Fig. 4). The second layer has relatively moderate shear wave velocity from 206 to 1278 m/s (Fig. 5) and the third (bedrock) layer has high velocity value (357-1550 m/s).

![Fig. 2. Location of the measured sites, blue circles for MASW, red triangles for HVSR and blue star is Kima factory site](image)

Depending on the results, the Vs of the upper 30 m depth (Vs30) that is used for soil classification by National Earthquake Hazards Reduction Program (NEHRP, 2001) was computed with the following equation:

\[
Vs30 = \frac{30}{\sum_{i=1}^{N} \frac{d_i}{v_i}}
\] (1)

Where di and vi refer to the thickness (in meters) and the shear wave velocity in m/s of the ith Formation or layer, respectively. N denotes to the number of layers within 30 m. The calculated shear wave velocities for the top most 30 m (Vs30) almost vary from 208 to 1258 m/s (Table 1). Based on NEHRP (Table 2), the predominant site class is D (180<Vs30<360) found in the middle part of the investigated area where the Quaternary sediments have more than 100 m thickness followed by site class C (360<Vs30<760) on both sides of the area, while site class B (760<Vs30<1500) is representing only in site 32 (Figs. 6&7). The geology and soil characteristics of the measured sites are reflecting by the H/V response curves derived from the microtremor measurements along the study area. The H/V curves are having more or less flat curves with rock outcrops while in areas with thick sediments have a peak curve with high amplification at low frequencies. From the H/V results (Table 3), the tested
sites in the middle part close to Kima factory where a thick layers of sand have low frequency values started from around 0.62 to 1.1 Hz. While the eastern and western parts of the area have high frequency values from 4.2 to 8.65 and from 10.04 to 13.8 Hz respectively and some sites with basement rocks at the surface have flat H/V curves without noticeable peaks. The resonance frequency and the maximum amplitude (amplification factor) through the study area are represented in 2D maps (Figs. 8&9). From these maps, it was recognized that the frequency has its low value at the central part of the area (0.622 Hz) while the highest frequency value found on the western part of the area (13.8 Hz).

Fig. 3. An example of the 1D velocity model at the area

Fig. 4. The distribution of the Vs at the surface layer, blue star is Kima factory site.
Fig. 5. The distribution of the shear wave velocity at the second layer, blue star is Kima factory site.

Table 1. The $V_{S30}$ and NEHRP site classification across the area

| Site No. | Latitude  | Longitude | $V_{S30}$ m/s | NEHRP site class |
|----------|-----------|-----------|---------------|-----------------|
| 1        | 24.063445 | 32.919597 | 325           | D               |
| 2        | 24.067332 | 32.919167 | 283           | D               |
| 3        | 24.072397 | 32.918679 | 280           | D               |
| 4        | 24.067615 | 32.923974 | 313           | D               |
| 5        | 24.073403 | 32.92349  | 286           | D               |
| 6        | 24.076992 | 32.918088 | 312           | D               |
| 7        | 24.07508  | 32.913367 | 298           | D               |
| 8        | 24.071527 | 32.914336 | 291           | D               |
| 11       | 24.058575 | 32.920545 | 402           | C               |
| 12       | 24.060959 | 32.924785 | 543           | C               |
| 13       | 24.045273 | 32.916741 | 308           | D               |
| 15       | 24.047359 | 32.919589 | 300           | D               |
| 16       | 24.053859 | 32.921406 | 437           | C               |
| 18       | 24.085203 | 32.916253 | 208           | D               |
| 25       | 24.049175 | 32.912822 | 322           | D               |
| 26       | 24.054192 | 32.909888 | 485           | C               |
| 27       | 24.057995 | 32.908768 | 433           | C               |
| 29       | 24.058036 | 32.926109 | 758           | C               |
| 30       | 24.048782 | 32.922822 | 680           | C               |
| 32       | 24.065911 | 32.905759 | 1258          | B               |
| 33       | 24.067626 | 32.91089  | 610           | C               |
Table 2. Site characteristics of NEHRP based on $V_{s30}$ (BSSC, 2001).

| Soil Profile type | Rock/Soil Description                  | $V_{s30}$ (m/s) |
|-------------------|----------------------------------------|-----------------|
| A                 | Hard Rock                              | >1500           |
| B                 | Rock                                   | 760-1500        |
| C                 | Very dense soil/soft rock              | 360-760         |
| D                 | Stiff soil                             | 180-360         |
| E                 | Soft soil                              | <180            |
| F                 | Special soil requiring, site specific evaluation | -               |

Fig. 6. The distribution of the $V_{s30}$ at the study area, blue star is Kima factory site

Fig. 7. Soil classification map of the investigated area, blue star is Kima factory site
Table 3. Results of the H/V technique in Kima area

| Site No. | Latitude      | Longitude     | Frequency ($F_o$) | Amplitude ($A_o$) |
|----------|---------------|---------------|-------------------|-------------------|
| 1        | 24.063445     | 32.919597     | 4.38              | 0.693             |
| 2        | 24.067332     | 32.919167     | 4.3               | 0.622             |
| 3        | 24.072397     | 32.918679     | 5                 | 0.685             |
| 4        | 24.067615     | 32.923974     | 2.7               | 1.44              |
| 5        | 24.073403     | 32.92349      | 2.9               | 0.639             |
| 6        | 24.076992     | 32.918088     | 3.2               | 0.675             |
| 7        | 24.07508      | 32.913367     | 5.1               | 0.812             |
| 8        | 24.071527     | 32.914439     | 2.8               | 0.647             |
| 9        | 24.071559     | 32.91058      | Flat curve        | Flat curve        |
| 10       | 24.048668     | 32.915151     | 2.9               | 0.821             |
| 11       | 24.058575     | 32.920545     | 3.5               | 6.64              |
| 12       | 24.060959     | 32.924785     | 3.4               | 6.61              |
| 13       | 24.045273     | 32.916741     | 5.1               | 0.8               |
| 14       | 24.044682     | 32.912277     | 2.6               | 1.13              |
| 15       | 24.047359     | 32.919589     | 2.4               | 1.1               |
| 16       | 24.053859     | 32.921406     | 3.8               | 4.2               |
| 17       | 24.078992     | 32.923431     | Flat curve        | Flat curve        |
| 18       | 24.085203     | 32.916253     | 2.5               | 0.618             |
| 19       | 24.079671     | 32.912219     | Flat curve        | Flat curve        |
| 20       | 24.077971     | 32.910287     | Flat curve        | Flat curve        |
| 21       | 24.074981     | 32.910244     | Flat curve        | Flat curve        |
| 22       | 24.067556     | 32.914963     | 5.4               | 0.75              |
| 23       | 24.080414     | 32.916329     | Flat curve        | Flat curve        |
| 24       | 24.063675     | 32.925472     | 3.5               | 8.65              |
| 25       | 24.049175     | 32.91281      | 4.9               | 0.797             |
| 26       | 24.054192     | 32.909888     | Flat curve        | Flat curve        |
| 27       | 24.057995     | 32.908768     | Flat curve        | Flat curve        |
| 28       | 24.061757     | 32.907952     | Flat curve        | Flat curve        |
| 29       | 24.058036     | 32.926109     | 2.7               | 0.615             |
| 30       | 24.048782     | 32.922822     | Flat curve        | Flat curve        |
| 31       | 24.084327     | 32.913985     | Flat curve        | Flat curve        |
| 32       | 24.065911     | 32.905759     | 2.8               | 13.8              |
| 33       | 24.067626     | 32.91089      | 3.1               | 10.04             |
| 34       | 24.059264     | 32.914819     | 5.5               | 0.76              |
Fig. 8. The frequency distribution over the study area, blue star is Kima factory site.

| Frequency (Hz) | 32.905 | 32.91 | 32.915 | 32.92 | 32.925 |
|---------------|--------|--------|--------|--------|--------|
| Amplitude     |        |        |        |        |        |
| Km            | 0.2    | 0.5    | 0.75   | 1      |

Fig. 9. The maximum amplitude (amplification factor) distribution across the area, blue star is Kima factory site.
6. Conclusions

The utilized techniques (MASW and HVSR) are the most approved approaches in the site characterization studies. The methods are applied along the selected sites over the area, where some sites are occupied by both techniques and the others are measured by the HV method only depending on the surveyed areas where the investigated part is located inside a dense dwelling zone where there are no wide areas for MASW survey. From the site characteristics study in Kima area, it can be concluded that the middle part of the investigated region has alluvial thick sediments with low shear wave velocity, low frequency and high amplification factor. The eastern and western parts of the area lying on compacted and basement rocks and this is confirmed and coincident with the geological setting of the area where the eastern and western parts have low amplification, high frequency with high shear wave velocities and shallow thickness of the surface sediments layer. The site class D is a predominant soil classification across the area and is concentrated at the central part of the area. This sector is a more hazardous zone in the area and will have a direct impact on the strong ground motion. The investigation’s outputs are very important for decision-makers and should take into consideration for design in this area of earthquake disaster mitigation.

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