PROBLEMS ENCOUNTERED WITH FIELD MEASUREMENTS FOR SITE-SPECIFIC SEISMIC RESPONSE

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ABSTRACT

This paper discusses problems encountered with field measurements made for development of seismic microzonation maps that contouring the site specific seismic response for a seismically active area. This Area is located in the far northwestern region of the Kingdom of Saudi Arabia. The field measurements included: (a) Conventional soil exploration borings with Standard Penetration Test (SPT), Cross-Hole (CH) and or Down-Hole (DH) measurements of shear wave velocity (SWV) profiles, and Non-invasive measurements of SWV. Comparisons and correlations of the results depicted the factors that probably affected the measurements related to different site conditions. Some of the major difficulties encountered with the field measurements were attributed to: a) drilling and casing of the boreholes, and non-uniform backfill between the borehole and its casing, b) Drilling of boreholes at increasing depths due to the unstable saturated sand conditions, c) existence of coral formations, d) influence of the water on the SWV where the water level is near the surface. In general, the SWV results of the different methods used in the study correlate well for most sites investigated where only minor problems occurred with the field measurements. Notwithstanding that, the experience gained from this study confirms that the field determination of soil profile class of individual site as per the current NEHRP provisions is very difficult or even prohibitive in some cases. It would therefore be significant evolution that more practical and economical solutions for the site–soil characterization are adopted in the future versions of the major international seismic codes.

KEYWORDS:
Seismic microzonation, seismic response, shear wave velocity

1. INTRODUCTION

This Paper discusses problems encountered with field measurements made for a national research project mainly aimed at developing seismic microzonation maps that contouring the site specific seismic response for City of Haql and its province Ad-Durra custom The location of the study area, as shown in Fig. 1, is in the far north-western region of the Kingdom of Saudi Arabia (KSA). The study region is classified as the most seismically active area in the KSA. The November 22, 1995, Gulf of Aqaba earthquake (M_D = 5.8) was the latest in the long historical evidences of several significant earthquake occurred in the area in the past (i.e. 1068, 1588, 1927). The damage of governmental buildings caused by this moderate-size earthquake (1) was a tragic demonstration of the warning that has been revealed by several studies conducted on the seismic hazard in the region. Probabilistic seismic hazard estimates of the region have been reported by several studies conducted in the KSA [2, 3, and 4]. The region is classified as the most seismic active area in the country. Peak ground acceleration (PGA) predicted for 10% probability of being exceeded in 50 and 100 years are about 0.2g and 0.3g, respectively.

2. SOIL PROFILE CLASSIFICATION

The National Earthquake Hazard Reduction Program (NEHRP) provisions, since 1994 [5], and subsequently, major building codes, based seismic site classification on geophysical and/or geotechnical investigations. The site categories are generally defined in terms of the mean shear wave velocity (V_S) in the upper 30 m of the soil profile based on the empirical relationship proposed by Borcherdt's [6]. (V_S) is considered as the main definition of the site categories and

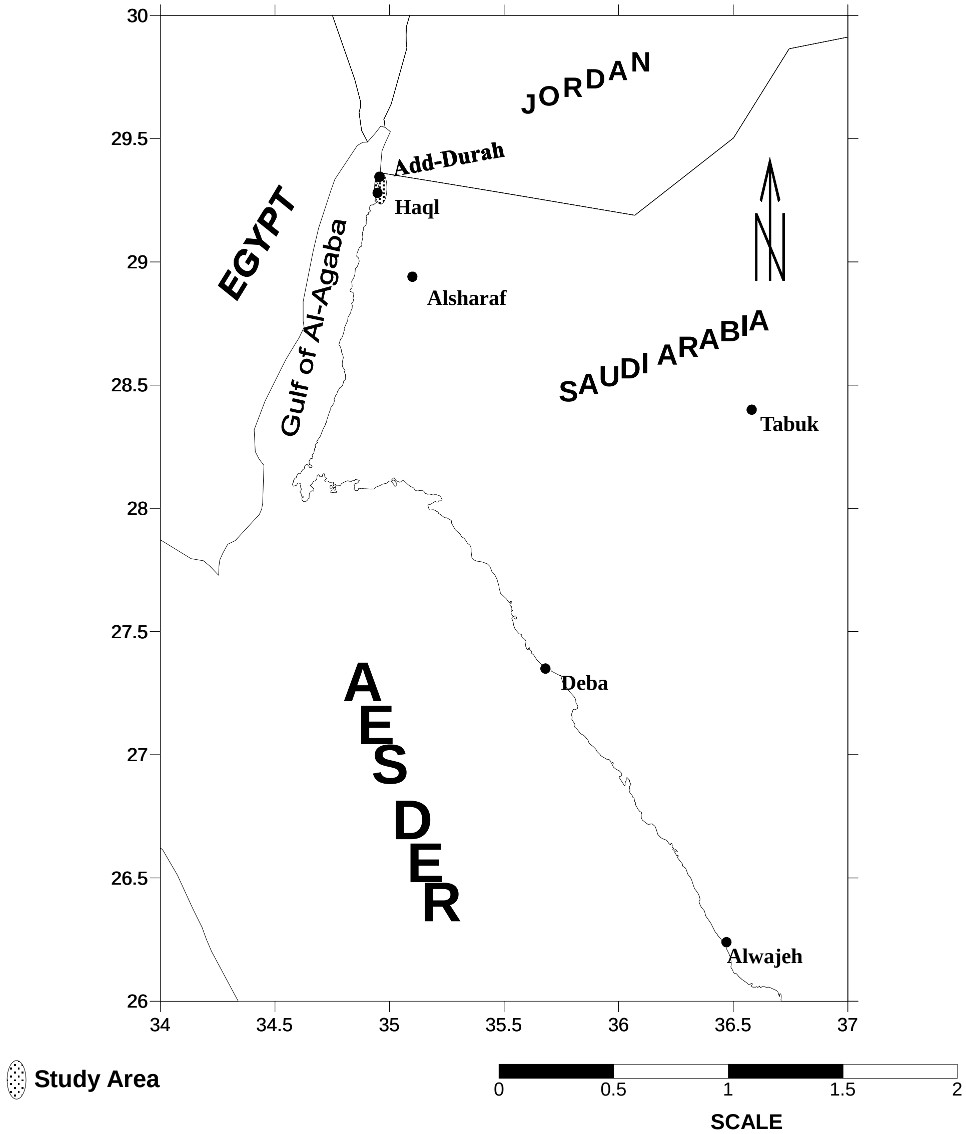

Figure 1 Geographical Location of the Study Area

shall be used if it is available. This method have been incorporated in NEHRP [7] provisions since 1994 with more detailed geotechnical definitions. In recognition of the fact that in some cases (V_S) is not available, alternative definition in term of the mean standard penetration resistant (N) and mean untrained shear strength (S_u) are included. The new site categories of NEHRP provisions were adopted in UBC97 [8] and have being adopted in the International Building Code (IBC) since 2000 [9]. Definitions of site classification parameters (V_S, N, and S_u) are prescribed in both IBC and NEHRP provisions. These definitions are applied to the upper 30 m of the site profile. If the site profile contains distinctly different soil layers, the site shall be subdivided into those layers. Each distinct layer shall be designated by a number that range from 1 to n, where there are a total of n distinct layers in the upper 30 m profile of the site. The site parameters then are computed as the average of the inverse of the layered values of the respective parameter. For instant, (V_S) is computed as follows:

$$V_s = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{v_{si}}} \quad (1)$$

Where, the symbol i refers to any one of the layers between 1 and n, v_{si} is the shear wave velocity (SWV) and d_i is the depth of the respective layer, in consistent units. The site classification parameters (N and S_u) are computed, similarly to V_S in Eqn.1, as the average of the inverse of the layered values of the respective parameter.

Rodriguez [10] provided a comprehensive overview of available geophysical methods for SWV profiling including advantages and disadvantages of each method. These methods can be classified to two major groups; drilling drop-hole based group (intrusive methods), and surface techniques based group (non-invasive methods). Intrusive methods such as Down-Hole (DH) and Cross-Hole (CH) SWV measurements, obviously, have several advantages. For instance, they allow one to determine SWV directly with higher precision and at the same time permit one to obtain geologic logs (texture, hardness, fracture spacing, age, and density) of formations. They also allow one to measure standard penetration resistance. However, in the current study test measurements of cross-hole SWV were conducted in selected sites (6 sites) of the study area to check the reliability of the final outcome of the study.

Non-invasive technique has long been recognized as a cost-effective approach to obtain SWV data essential for seismic response analysis including site amplification and liquefaction. The controlled-source surface wave's dispersion measurements (CXW) method may be regarded as a combination of the steady-state Raleigh waves and the spectral-analysis of surface waves, offering the advantages of most methods described in the literature [10]. This method is being used for site characterization in the USA, Japan, and other countries including the KSA, Al-Haddad et al. [11]. In the CXW method, a powerful electromagnetic exciter (the controlled-source) generates operator-selected, repeated surface vibrations that are recorded by two vertically oriented receivers placed at some known distance near the controlled source. Various modes of repeated source excitation might be used for accurate data averaging. The control unit of the system is used both as signal generator and as advanced signal analyzer.

3. FIELD WORK PROGRAM

In this paper mainly problems encountered during the field measurements at Add-Durra custom are highlighted and discussed. Figure 2 shows the sites of the field measurements conducted in Ad-Durra custom. The fieldwork and mobilization can be summarized as follows:

1. Conventional soil exploration was performed by borings with Standard Penetration Test (SPT) and soil sampling for laboratory tests. At several sites borings were drilled and cased for CH wave propagation measurements.

2. Non-invasive measurements of Rayleigh wave's propagation were performed using the (CXW) method, to obtain shear wave velocity (SWV) profiles (Vs) to 30 m depth.

3. Using cased boreholes, CH-SWV measurements were performed and complemented with some down-hole measurements, to obtain shear and compression wave velocities.

4. PROBLEMS AND DISCUSSION

The major problems encountered in this research project can be summarized as follows:

1. The high costs of mobilization, and drilling and casing the boreholes for CH and/or DH measurements of SWV. Furthermore, the cost increases in vey great manner with the borehole depth. For instant, the cost of a CH test was higher than the cost of a CXW test by factor of 5, and 8 for depth of 30 m and 60 respectively.

Figure 2 Locations of the Field Tests in Add-Durra

2. Difficulty of preparation of the boreholes for the SWV tests due to highly unstable soil. The soil at the sites is mostly clean sand, that were highly unstable during drilling, especially those encountered under the water table. These conditions were further aggravated by frequent micro-tremors in the study area making the casing and backfilling of the borehole very difficult. In addition, some voids could have been left around the casing, as most likely the backfill compaction around the casing remained irregular. This problem was more noticeable in the boreholes where the cases were installed by hollow-stem augers than that in the boreholes cased by water-well truck mounted boring machines.

3. At several sites, the water backflow rate filling the borehole was too high and did not allow enough time to keep the borehole dry during the measurements.

4. In several near-shore sites, the CXW analysis was difficult due to presence of shallow higher SWV layers of coral and compacted superficial layers. In these sites the CXW dispersion curves couldn't be well defined, as the SWV of the superficial layers was significantly higher than that of the underlying soil. This made the dispersion curves affected by the contributions from higher vibration modes of surface waves propagating through the higher velocity superficial layers.

At this point, it is of interest to present examples of comparative results obtained from the different types of testes at specific sites. The factors that likely affected the measurements, interpreted results, and the respective site conditions are discussed in the following:

4.1 Site A-5

The boreholes at this site were performed with a hollow stem auger. Results from this site are given in the Fig. 3. This figure shows a reasonable correspondence between the CH, and CXW measurements for depths between 6 and 17 m, except for CH readings at 7 and 10-12 m that shows lower SWV. At depths of less than 5 m there is an apparent higher velocity layer shown by the CXW results, but it is less defined in the CH measurement. From the site observations it is expected that there is a layer of coral near the surface. The CXW measurements were performed in two perpendicular directions. Both directions showed a high velocity. The CH also shows lower SWV values in the deep part of the boreholes compared to the CXW measurements. Boring logs show that the drilling was increasingly difficult with depth due to the unstable saturated sand conditions under the water table. These conditions likely resulted in caving loosened soil pockets around the borehole. The differences between the estimated SWV values and the associated site-classes from the two methods can bee seen in Fig. 3.

4.2 Site A-12

The boreholes at this site were performed with a water-well boring rig with a diameter of 400 mm. Therefore, the hole had to be backfilled as the casing was of 76 outer diameter. This had likely affected the respective CH results due to velocity change adjacent to the casing over the thickness of the void-laden borehole backfill, which was significant relative to the test distance of 3.0 m between the boreholes. The Figure 4 shows the results of CXW and CH tests. It can be seen that the general trend of CH data is consistent with the CXW interpretation. There are however certain measurements in the CH profile indicating low SWV values. Also, measured CH data do not clearly indicate a higher velocity layer near the surface, as deduced from the measured dispersion curve. It is possible that there are inter-bedded lower velocity layers around 15, 20 and 25 m depth that are relatively thin and cannot be interpreted from the CXW data, and that are not thick enough to have a significant effect on the dispersion curve. However, it may also be possible that such low velocity layers do not exist and that they show in the CH data only due to backfilling problems. The differences between the estimated SWV values and the associated site-classes from the two methods can bee seen in Fig. 4.

5. CONCLUSIONS

Considering the conditions of testing and the limitation of the test methods, CH, and CXW data are consistent at the sites where only minor problems occurred with the boreholes' casings and backfilling. SWV data at very low strains is sensitive to testing procedures and soil conditions. There is a range of variation that defines the reliability of the SWV estimate. This range should be considered in the site response evaluations. Even under best possible test conditions, it is unreasonable to define a unique SWV profile for a given site. For this reason the site response analysis performed for this project was based on SWV ranges for the different, representative soil types. At the sites where there were problems with boreholes casing and backfilling, measured CH data was affected and SWV values were underestimated. When preparing boreholes for CH or DH testing it is important

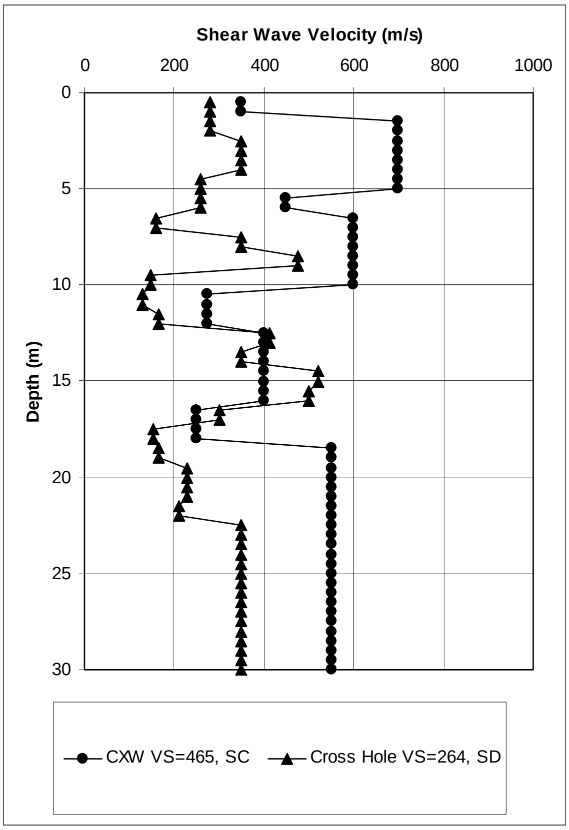

Figure 3 Comparison between SWV Profiles of CH and CXW Methods at Site 5

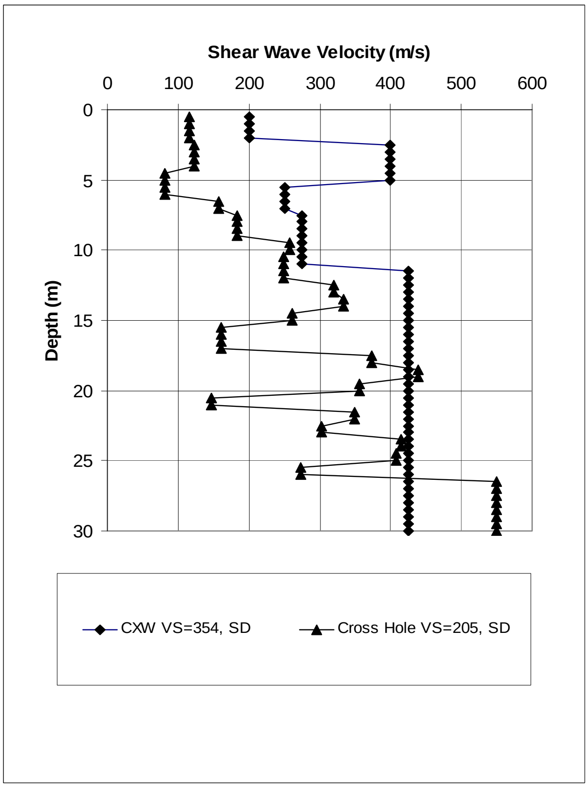

Figure 4 Comparison between SWV Profiles of CH and CXW Methods at Site 12

to achieve good fit of the casings with the surrounding soil in the boreholes. Borehole diameter should not be too large relative to casing diameter. If uniform compacted backfill cannot be achieved, it is preferred to apply pressurized grout to backfill the borehole-casing spacing. In future projects related to this work, it is advisable to perform complete DH measurements (both V_p and V_s) in sites where CH tests are performed, preferably at both boreholes. This DH data are valuable for CXW interpretation and CH calibration. However, because of the requirement of drilled holes, these methods are much more costly (at least by a factor of 5) compared to any surface measurement technique. These costs make direct SWV methods (such as down-hole and cross-hole) impractical in seismic microzonation studies that cover large areas and many different sites especially for depths reaching of 30 m. It is also important to plan fieldwork schedule for future projects allowing for adequate time to identify and resolve on site any measurement problems similar to the ones were encountered in this study.

Logically, not all problems that may be encountered in field measurements of seismic site-specific response are discussed. Notwithstanding that, the experience gained from this study confirms that the field determination of soil profile class of individual site as per the NEHRP [7] or IBC 2006 [9] provisions is very difficult or even impractical in some cases. This not only because of high cost and difficulties inherent required field tests, but more than any thing ells these tests involve geotechnical and geophysical measurements need to be conducted by experienced and well-equipped staff. It would therefore be significant evolution if more practical and economical solution for the site –soil characterization is adopted in the future versions of the major international seismic codes.

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