SEISMIC BEHAVIOR OF SMALL-SCALE BASIN USING CENTRIFUGE TESTING

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ABSTRACT:

The lifeline facilities revealed high damage ratio in the vicinity of small-scale basin (scales in tens of meters). To explain the reasons of observed damage, the site response due to wave propagation in small-scale basin are numerically and experimentally investigated. A set of centrifuge tests is conducted on a simple small-scale basin model instrumented using 14 accelerometers. The accelerometers are placed at the base and top of the basin model in different distances and directions from the basin edge. The model is subjected to the different earthquake motions during centrifuge testing. Then, the site response at various locations is estimated using surface to base spectral ratio analysis in the frequency domain. The dominant frequencies and peak values vary significantly depending on the observation location to the basin edge. The amplification function within the basin edge show more peak frequencies with higher values than the others. The results of numerical analysis using 2D finite element computer program FILP agreed well with the experimental ones, certifying that the site amplification characteristics can be impacted by 2D effects of small-scale basin. The reasons are explained based on the coupling of shear waves propagating in different soil properties produced by 2D shape of small basin at close distance to the edge.

KEYWORDS:

Small-scale basin, geological irregularities, shear wave coupling, centrifuge test.

1. INTRODUCTION

The damage pattern in recent earthquakes shows the strong dependence of strong ground motion to the soil amplification characteristics, and especially to the 2D or 3D effects of subsurface geological irregularities at a site. Many populous cities are located on thick sedimentary layers that are laterally confined in a form of a basin or a valley. Therefore, the site amplification characteristics may not be properly expressed by a 1D soil amplification model. 2D or 3D effects of large-scale basins or valleys (scales in several kilometres) have been known to influence strong ground motion characteristics in the low frequency range (<1 Hz) (Graves, 1996; Kawase and Matsushima, 1998; Wald and Graves, 1998; Sato et al., 1999). However, there is no information on 2D or 3D effects of small-scale basins or valleys (scales in tens of meters), which could influence the ground motions with shorter wave length in the high frequency range (>1 Hz). For the first time, Ghayamghamian (2008) showed that the strong ground motion could be significantly influenced by 2D or 3D effects of small-scale geological irregularities in high frequency range. He found that the coupling of two shear waves propagating in areas with different soil properties in close proximity to the small basin edge could cause two peak frequencies or a split peak frequency in a site amplification function. This is verified by analyzing ground motion data in Sendai downhole array network and by conducting numerical analysis.

In this paper, we conduct centrifuge experiments on a small-scale basin model in order to provide more confirmation to analytical and numerical analyses already performed (Ghayamghamian, 2008). The basin model with 9 m high and 22.5 m length is made of dry sand with 100% density (very dense). Then, the basin is overlaid by deposits of dry sand with different densities of 80% (dense) and 50% (loose). The accelerograms are situated in various locations and depths along the basin model. The model is subjected to different near- and far-field input motions with various peak acceleration amplitudes on prototype scale. The site amplification function is computed using base to surface spectral ratio at different locations with respect to basin edge. Furthermore, the results are compared with those of numerical ones conducted by using 2D finite element FLIP computer program in order to examine the accuracy of the results.

2. CONFIGURATION OF CENTRIFUGE EXPERIMENTS

Experiments were conducted in a rigid wall container mounted on 2.5 m radius geotechnical centrifuge at the Disaster Prevention Research Institute, Kyoto University (DPRI-KU). Overall dimensions of the rigid container are 450 × 150 × 300 mm in length, width, and height, respectively (Fig. 1). A shake table unidirectionally driven by a servo hydraulic actuator is mounted on a platform and it was controlled through a laptop computer on the centrifuge arm. All the equipment to control the shake table was put together on the arm. The laptop computer was accessible during flight from a desktop computer located in the control room through a wireless LAN and "Remote Desktop Environment" of Windows XP (Microsoft 2003).

A cross-section of the small-scale basin constructed with 100% density (very dense) dry sand is depicted in Figure 2. The basin is overlaid by deposits of dry sand 80% (dense) and 50% (loose) densities. Silica sand No. 7 ("Soma" sand No. 7) with emax = 1.20, emin = 0.70, and D50 = 0.13 mm, and Dr=100% was used for base of small basin. Furthermore, the silica sand No. 7 with Dr=80% and silica sand No. 5 with emax = 1.013, emin = 0.76, and D50 = 0.50 mm were employed for deposits overlaid the basin. The model was instrumented with fourteen accelerometers (SSK, A6H-50) at base and surface. All the electric data were recorded by digital data recorders (TML, DC-104R) mounted on the centrifuge arm. The data were recorded with 5 kHz sample frequency.

The model was subjected to two input motions recorded during Bam earthquake (2003), Iran, and Miyagiken-Nanbu (1998) earthquake, Japan. Ten tests were conducted by changing the maximum amplitude of the input acceleration for investigating 2D site effects with non-linear behavior of soil deposits. However, the model was not experienced non-linear soil behavior even up to large amplitude due to high density of the sand

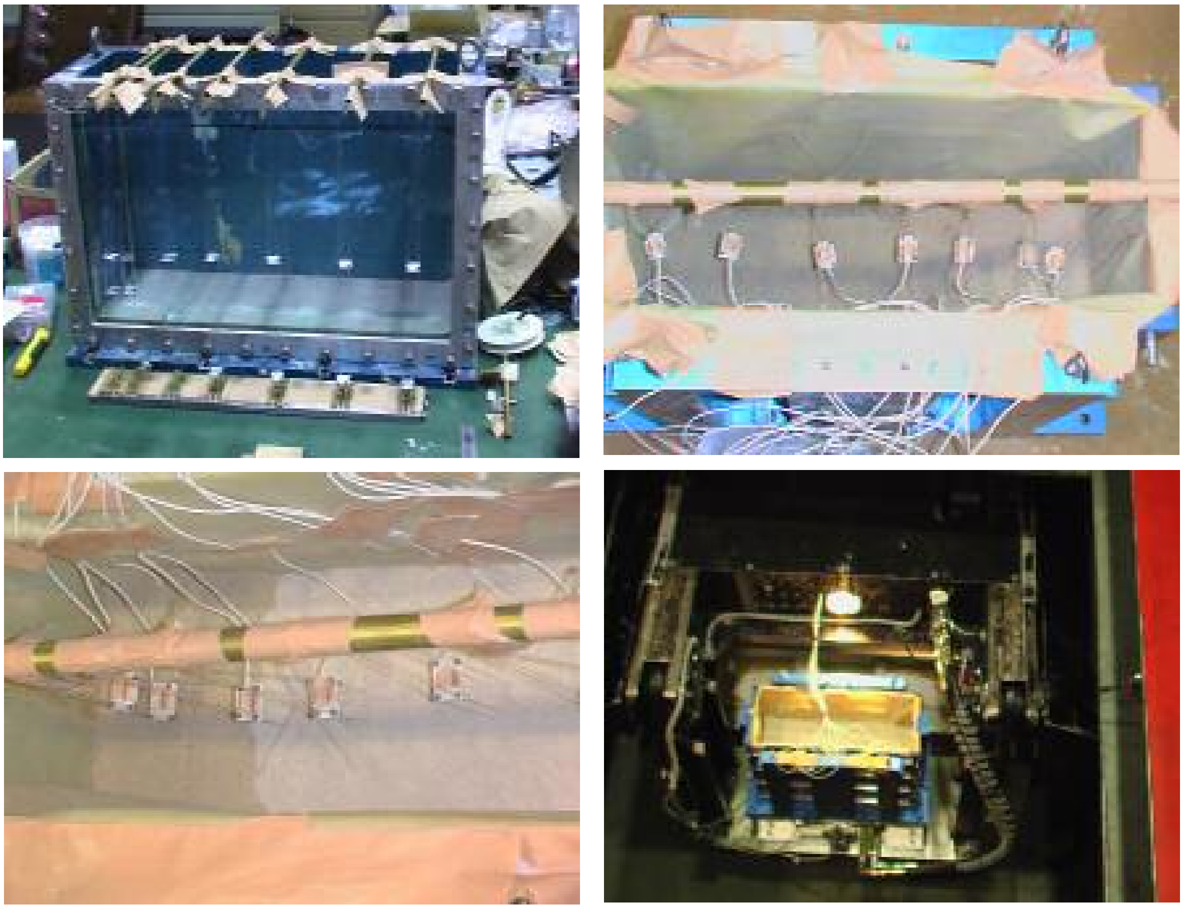

Figure 1 The container and the configuration of accelerometers at the base and surface of the model constructed using dense sands with different densities.

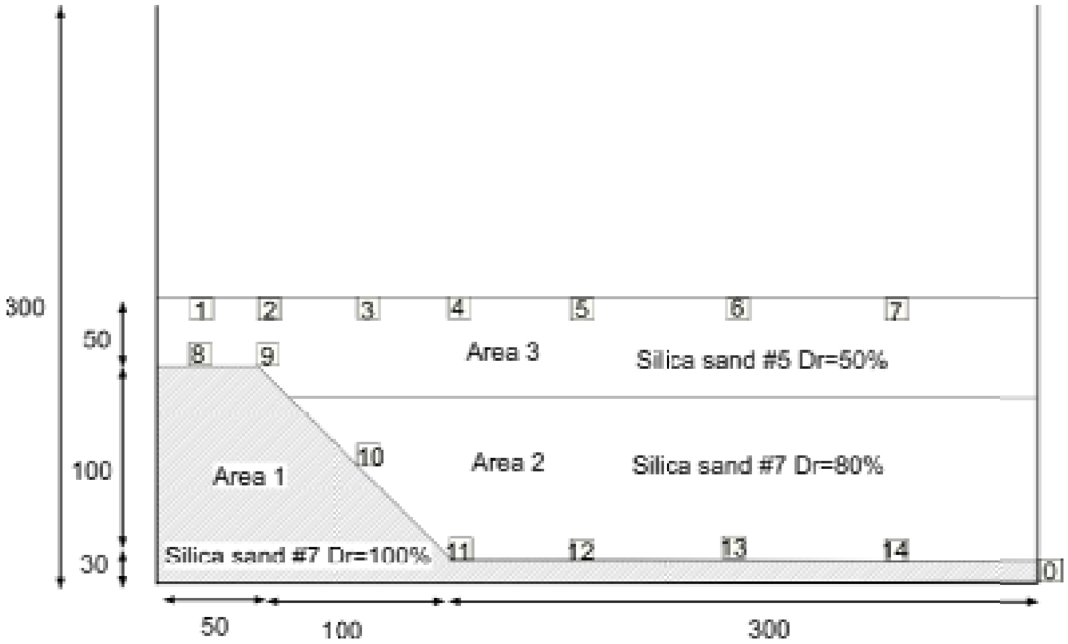

Figure 2 A cross-section of the small-scale basin constructed by dry sands with different densities and location of accelerometers at the base and surface of the model.

deposits. The acceleration recorder 5 was dead during the experiments and its data can not be used in the analysis. Figure 3 shows an example of the recorded motions at base and top of the model for input motion recorded during Miyagiken-Nanbu (1998) earthquake. From this figure, the recorded motions at the base show almost the same characteristics with no 2D effect, as expected. Meanwhile, the recorded motion at surface show large amplitudes in high frequency range mostly due to amplification of higher frequencies by the dense deposits (with dominant frequency larger than 5 Hz as will be discussed later) overlaying the small basin. Unfortunately, the visual inspection of 2D effect of small basin in acceleration time histories is difficult to trace due to large amplitude of low frequencies in comparison with high frequencies in input motion. However, this can be better observed by comparison among estimated site amplification function in frequency domain at different recorded locations, which will be discussed in the next section.

3. SITE AMPLIFICATION FUNCTION

The identification of site amplification function was carried out by calculating surface to base spectral ratios in the frequency domain. In spectral ratio analysis, the autospectrum was calculated for the time windows of surface and base accelerograms. The spectra were smoothed using a rectangular averaging window having a bandwidth of 0.3 Hz. Then, the ratio of the two smoothed spectra was calculated. Successive smoothing was applied two times to the raw spectra. This number was chosen empirically by visually examining the spectral shape. Figure 4 shows the calculated spectral ratios between the surface and base accelerograms at various tests at different locations of the small basin model. In this figure, the peak frequency around 17 Hz can be observed at locations 1 and 2. This is due to wave propagation in soil deposits with shear wave velocity of 170.5 m/s. This shear wave velocity is estimated using the empirical relations for sand among density, effective stress ($\sigma_v^{'}$), N value (below count SPT value) and shear wave velocity (v_s) as:

$$D_r = 208\sqrt{\frac{N}{\sigma_v^{'} + 69}} \qquad \text{and} \qquad v_s = 80N^{1/3} \tag{3.1}$$

Considering the thickness of the deposit in the left hand side of the edge to be 2.5 m (scaling factor 50), the dominant frequency ($f=v/4h$) is estimated to be 17.5 Hz that is almost equal to the estimated dominant frequency in amplification functions at locations 1 and 2. At locations 3 and 4, the soil profiles are changed as can be seen in Figure 3. Therefore, the dominant frequencies at locations 3 and 4 show the values of around 11 and 5 Hz, respectively. Meanwhile, the 2D shape of small basin causes the coupling of shear waves propagating in different media around small basin edge (Ghayamghamian, 2008). This will produce the complicated amplification functions with many resonance peak frequencies and varying amplification values at locations in

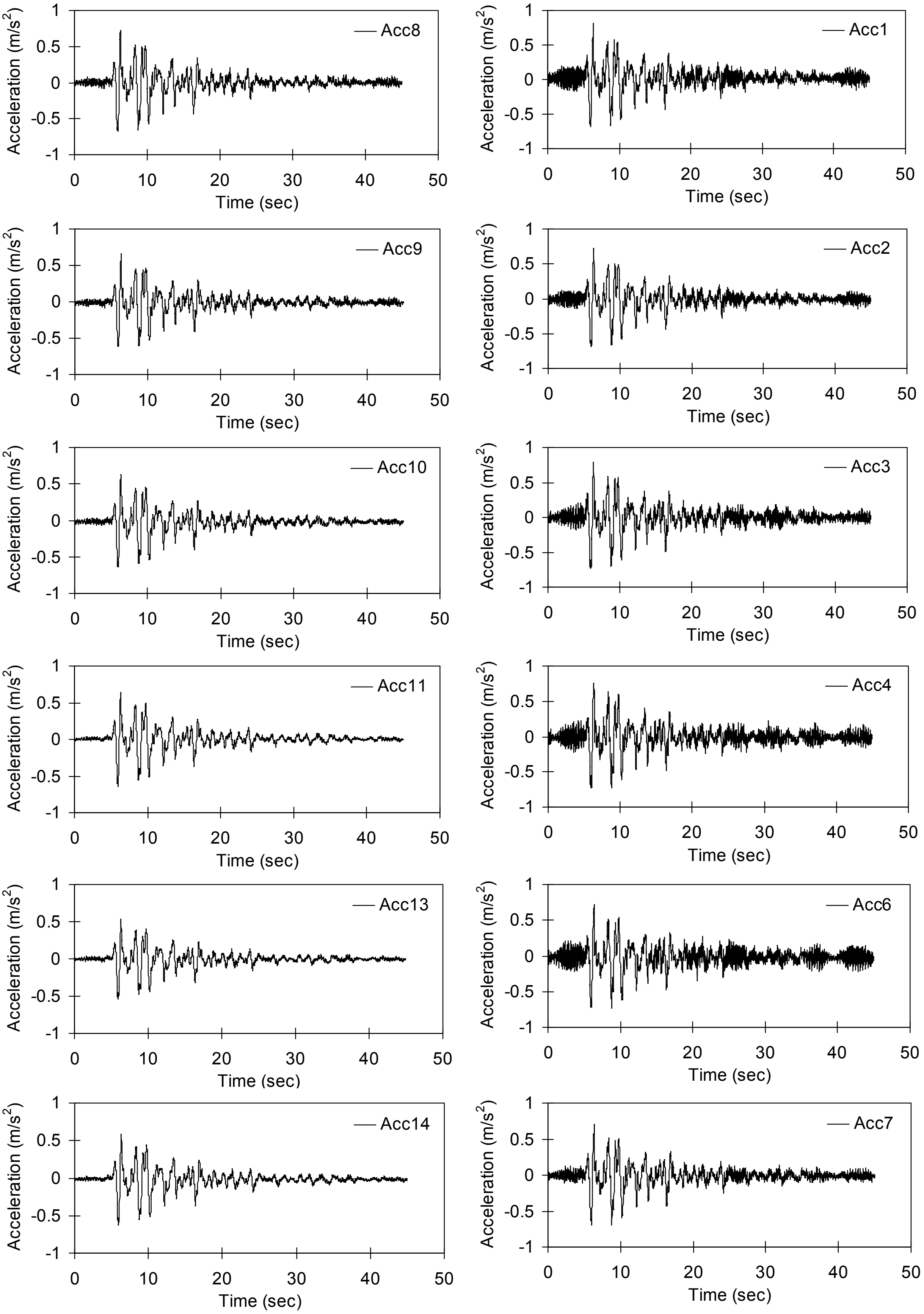

Figure 3 Recorded motions at base and surface in various locations of small basin model.

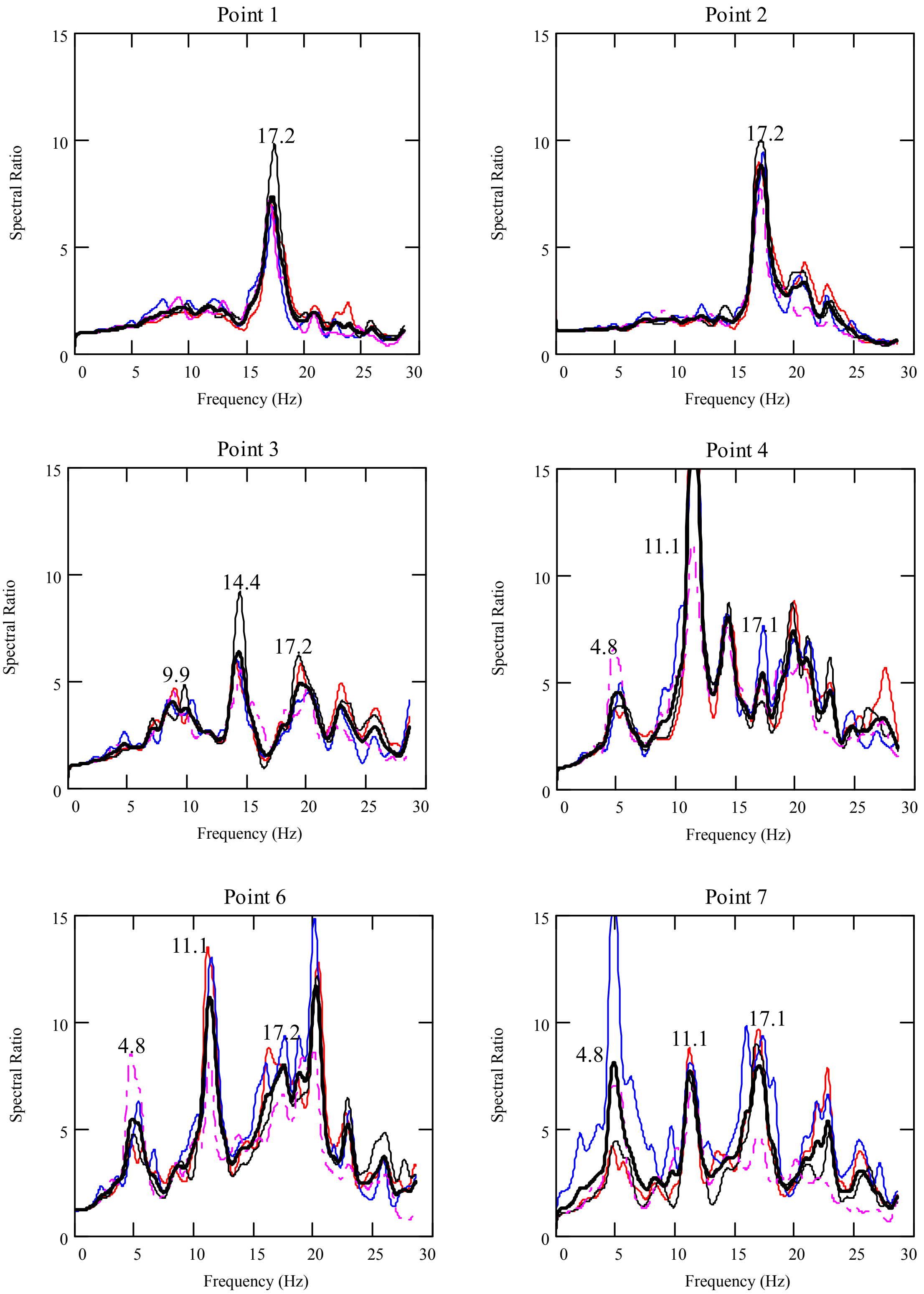

Figure 4 The estimated amplification functions at different location with respect to small basin edge using spectral

close proximity to the basin edge. The appearance of three peak frequencies at about 5, 11, and 17 Hz in amplification functions at locations 6 and 7 also validates the coupling of shear waves propagating with different velocities around small basin edge. As getting far from the edge, the amplitude of coupled resonance frequencies decrease and gradually fade away.

4. NUMERICAL ANALYSIS

Ghayamghamian (2008) carried out numerical analysis on small scale basin using finite element computer program FLIP (Iai et al., 1992). The small scale basin with the shape same as the one employed in the experiment was assumed and excited by an earthquake motion. The motions at base and surface elements along the small basin were obtained. Then, the site amplification function was calculated using the same fashion explained for the experimental data in centrifuge testing. Therefore, the numerical analysis results were not shown here due to space limitations and the readers are referred to the paper by Ghayamghamian (2008) for study of the numerical analysis. Although, the soil properties of overlying deposits were different from those used in the experiments, the estimated amplification functions from the numerical analysis (Figs 4 and 5 in Ghayamghamian, 2008) agreed well in trend with the experimental results. This confirm the shear wave coupling around the small basin edge, and emphasizes more to the 2D effects of small-scale basin and its influence on site amplification characteristics.

5. CONCLUSIONS

The 2D effects of small-scale basin were experimentally examined by using centrifuge test. The obtained results confirmed that the site amplification characteristics in high frequency range (>1 Hz) can be influenced by 2D shape of small-scale basin (scales in tens of meters) at close distance to the edge. The results also compared with the numerical analysis conducted using finite element computer program FLIP and found to be in good agreement with experimental ones providing more supports to the 2D effects of small-scale basin. Furthermore, the outcome validates the influence of site amplification characteristics in high frequency range by the 2D effects of small scale basin (or small-scale geological irregularities), which is a consequence of the coupling among shear waves propagating with different velocities in close proximity to the basin edge. This may also explain the observed high damage to the life lines or bridges located around the edge of small basins or subsurface geological irregularities with thickness of about tens of meters. The outcome also shows that the 2D effects of small scale geological irregularities need to be noticed and carefully treated for the design of critical facilities or important structures.

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