(63) **Soil Amplification by Topographies During Hyogoken Nanbu Earthquake**

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INTRODUCTION: The Hyogo-ken Nanbu earthquake, occurred on January 17, 1995 with a magnitude of 7.2 on the Richter scale, due to a horizontal shift and vertical offset of about 1 m along a northeast trending fault extending from Awajishima to Kobe city. According to the Japan Meteorological Agency (JMA), the seismic intensity scale was partially VII in the most damaged area. The JMA seismic rank VII is given to the seismic areas where the housing collapse exceeded 30 % of the total numbers. The earthquake caused over 5,000 death and extensive property damage in a highly urbanized area of Japan.

The heaviest damages were centered to the areas along the Kobe coast but at some distance toward inland in a belt zone of width 300 to 500 m running East to West parallel to the Rokko mountains. In this belt zone, the quake devastated central Kobe, crushing buildings and homes, suspending train service and cutting electricity and water supplies. Collapse of about 600 m segment of Hanshin Expressway bridge truly surprised the Japanese civil engineering community. This elevated prestressed concrete bridge was constructed in 1968-1969 under older seismic provisions and designed against earthquakes by employing the seismic coefficient of 0.2.

Another heavy damage was centered in a certain area on the Sanyo Shinkansen Line near Shin-Kobe section at the east portal of the tunnel passing through Rokko mountains. Several spans of the elevated viaduct, built in 1960's, supporting bullet train tracks totally collapsed. For a length of 3 km, this viaduct was severely damaged with a number of the longer spans collapsing. In general, these collapses were due to shear failure of the supporting columns due to the high intensity seismic forces. However, the residential houses in the neighborhood have less damages.

The topographical feature of the most damaged areas consists of shallow depth, very soft alluvium with different configurations underlain by a very stiff base rock. This unusual configurations seem to be the most concerned with this damage features and strongly suggest that the local site topography has a significant effect on the soil response that may cause resonance for the aboveground structures response.

In this paper, the site investigations are performed in time domain for the above mentioned two damage sites. The hybrid technique is adopted for coupling of FEM for the irregular near field and BEM for the extended far field. Different types of input excitation are considered to get better explanation for this damage features. Detailed formulations can be found in the authors' previous work [1].

COMPUTER SIMULATIONS AND DISCUSSION

Kobe Site Model: The busy downtown Kobe area, stretching along the foot of the steep Rokko mountains in the West-East direction, is covered by soft alluviums which are accumulated on much stiffer deluviums. The deluviums are underlain by rocks. The depth of alluvium increases as the geography moves from the mountains to the sea. Fig. 1 gives a simplified model at one representative North-South section that includes the collapsed Hanshin expressway bridge. The depth along the seashore is about 20 m or more according to the geological map.

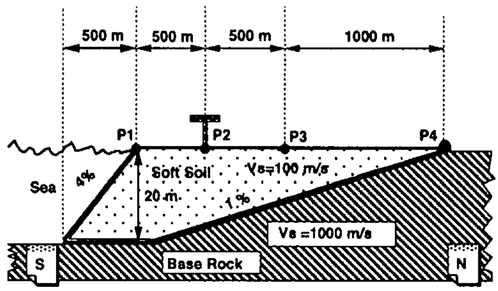


Fig. 1 Kobe Site Model for analysis

The ground motion recorded at the Kobe Marine Meteorological Observatory (herein abbreviated as JMA-Kobe) represents one of the strongest observed ground motion records with maximum acceleration of 820 gal at NS direction. The records at Kobe University basement (abbreviated as KBU) showed a maximum acceleration of 269.9 gal at the same direction with different characteristics. These two recorded accelerograms are shown in Fig. 2 and their Fourier transforms in Fig. 3. It can be noted that the large amplitudes come in the first several seconds of duration as clearly shown in Fig. 2. The Fourier transform of KBU records, supposedly showing the motions on rock site, indicates that it has more long period contents, while JMA-Kobe records shifted their period contents toward the shorter period range reflecting the site effects, as can be observed from Fig. 3.

Suppose that the KBU records is obtained on the free field or rock site, then one half of this record in intensity may be taken as an input motion in the far field for the analysis. The KBU recording was made in terms of velocity so that the associated acceleration and displacement are computed. The most important portion of the computed displacements (12 seconds in duration) are chosen for the incident wave at the far field of the model of Fig. 1. Here, the vertical SV wave incidence is considered for the NS directional motions. Another possible choice of the input motion may be obtained from the one dimension deconvolution procedures for the JMA-Kobe surface motion which was recorded on a relatively shallow alluvium site. The JMA-Kobe records are originally in acceleration so that the velocity and displacement are computed from it. It is concluded that the deconvoluted JMA-Kobe motions includes substantial short period motions below 1 second in contrast to the KBU record. Detailed information for deconvolution procedures is presented in Ref. [1]. These different input motions are used noting that they have the same maximum acceleration value.

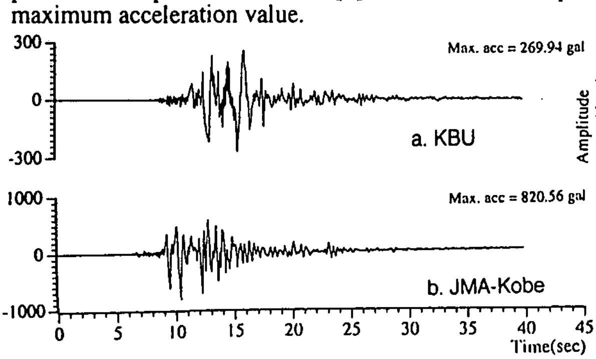


Fig. 2 Acceleration recoreds of the earthquake

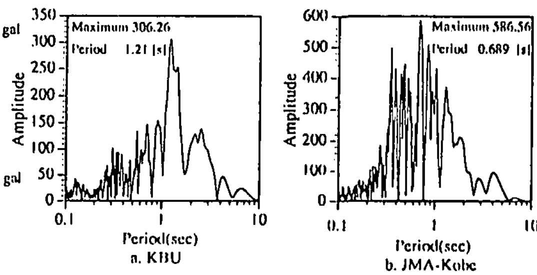


Fig. 3 Fourier transform of the accelerograms

The Max. horizontal response profiles due to different input motions are drawn in Fig. 4. Considering KBU record as input motion, it is clear that the large response amplification appears in the area closer to the seashore and a moderate amplification near the foot of the Rokko mountains. There is no high acceleration amplification in the seismic disaster belt zone at which heaviest damages have occurred to the residential houses and the expressway bridge as shown in Fig. 4.a. Since the surface acceleration is related to the seismic force acting on the aboveground structures, it may be stated that the use of the KBU record may not interpret the heavily damaged belt zone.

On contrast, the deconvoluted JMA-Kobe incident wave yield to different maximum acceleration response profile with the big amplification in the heavy damage area and the strong acceleration closer to the seashore. Relatively high velocity and displacement concentration has also occurred in the damage belt zone as shown in Fig. 4.b and Fig. 4.c respectively.

From the above trend of the maximum acceleration profiles along NS direction and the difference in the period contents between the two records, it may be stated that there exits two types of motions: long period motion (longer than 0.8 second) that is concerned with amplification near the sea shore and the short period motion that is concerned with the amplification in the heavily damaged area. Therefore, the artificial earthquake motions are simulated additionally by a combination of the five Ricker wavelets : one type is synthesized so as to meet the period contents in the range shorter than 0.8 seconds, and the other type has a longer period content. The maximum response profile due to these two types are also given in Fig. 4 for comparison with those due to KBU and the deconvoluted JMA-Kobe motions. It is interesting to note that the long period motions are related to the displacement and velocity responses whereas the short period motions are concerned with acceleration response at the heavy damage area. As far as to explain the strong acceleration amplification of the heavy damaged area, the short period

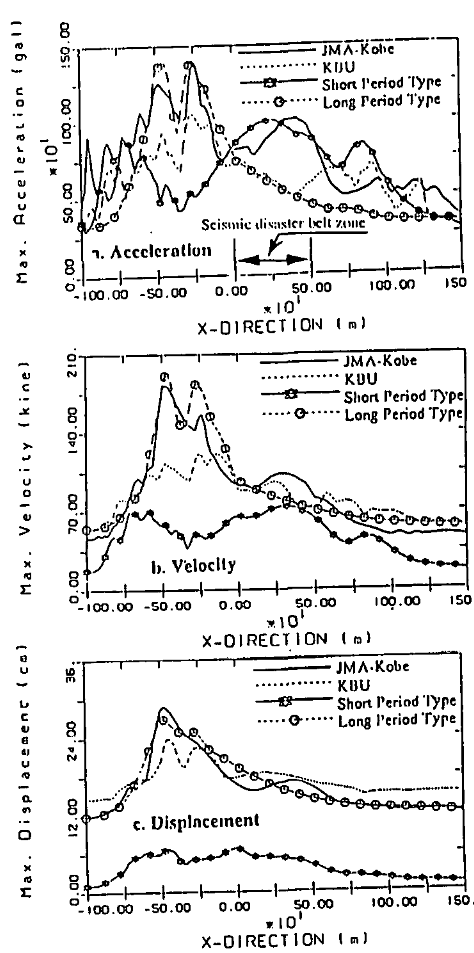


Fig. 4 Max. response profiels due to different input motions

type motions may be acceptable. In order to discuss the phase characteristics of the surface motions, the horizontal acceleration time history due to the deconvoluted JMA-Kobe record is depicted in Fig. 5. The horizontally propagating waves that are generated by the sharp edges and its interference with the vertically traveling waves, giving rise to amplified responses can be clearly observed. This phenomenon is termed here as "bump effect". This phenomenon can not be explained by the one-dimensional analysis[2].

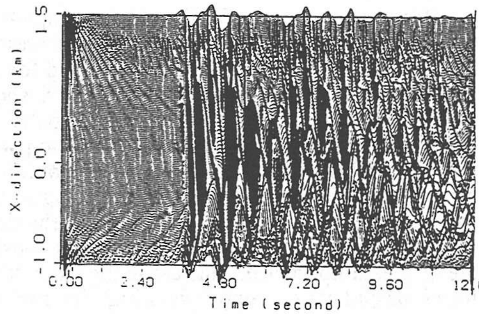


Fig. 5 Acceleration time history du to (JMA-Kobe)

Now suppose that the predominant period of the alluvium at different locations can be estimated by the simple formula as a SDOF system, then the predominant periods of the seismic disaster belt zone varies between 0.4 and 0.6 second, although the two dimensional motions have more complicated period contents because of the bump effect due to the wave interferences. This fact derives that the soil came into resonance at the respective characteristic period at different locations leading to higher surface response amplification. Unfortunately, the natural periods of the residential houses in the disaster area and the expressway bridge are supposed to vary between 0.4 and 0.6 second leading to the resonance of these structure response.

Shinkansen Site Model: One of the most damaged structures is the railway viaduct constructed for the bullet train along Sanyo Shinkansen Line at Osaka-Kobe Portion. Three spans of the viaduct are totally collapsed within a distance between Muko River and Rokko Mountain. According to the geological map of this area, the soil conditions consist of a thin very soft surface layer (depth of 6 -10 m) with irregular subsurface underlain by stiff to very stiff soil or base rock. From the soil profile and the bore hole data at the collapsed bridge site, the shear wave velocity of the surface layer varies between 80 and 100 m/s while the stiff soil or the base rock has the shear wave velocity varies between 800 and 1000 m/s. Based on these data, the dimensions and the soil profile of the analyzed site are shown in Figure 6.

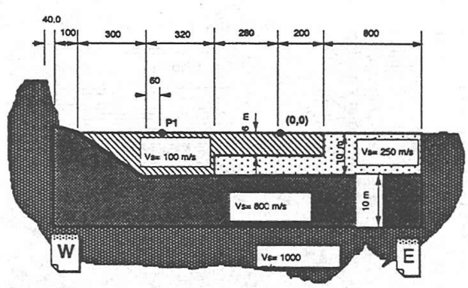


Fig. 6 Shinkansen Site Model for analysis

As there is no ground motion recorded near this site, the artificial earthquake input motion should be used. First, in order to investigate the soil behavior and the wave propagation pattern inside the soft soil the surface response due to SV single Ricker wavelet is considered. The predominant period of the soft soil layer with a depth of 10 m is 0.4 sec. (f=2.5 Hz). Fig. 7 depicts the comparison between the maximum acceleration response due to incident wavelet with predominant frequency of 1.5 Hz and 2.5 Hz. The maximum horizontal response values are highly amplified at the frequency of 2.5 Hz even for the portion having only 6 m depth soft soil and the distribution of the maximum response along the surface is drastically changed. Fig. 8 displays the time history of horizontal acceleration this case. The resonance inside the 10 m depth soft soil portion, the long duration and the horizontal propagation of the surface wave generated by the soft soil edges can be clearly observed.

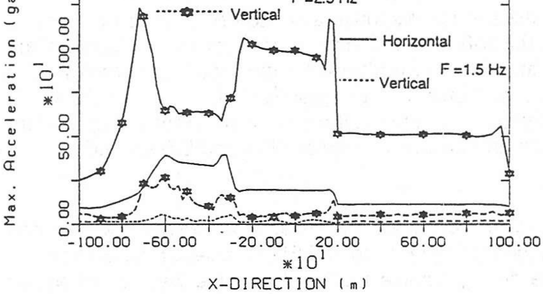


Fig. 7 Max. Surface Acceleration Comparison

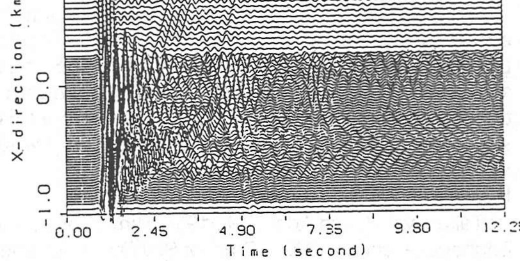
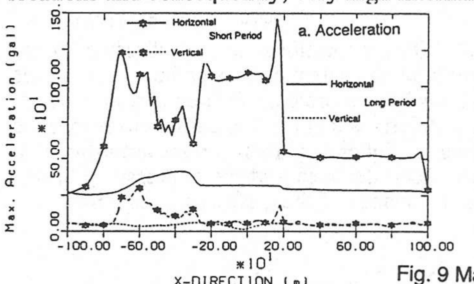


Fig. 8 Acceleration time history (f=2.5 Hz)

Based on the above finding, the earthquake-like motion in the far field is represented by a consequent series of five Ricker wavelets of two different types, long period and short period type, similar to Kobe model. The response analysis is performed for both types as the maximum amplitude is set to be 150 gal for input acceleration in the far field. Figure 9 shows that the maximum surface response due to short period type is highly amplified with drastically spatial variation along the surface. The response due to long period type input has very smooth spatial variation with the maximum values that are very close to the free field response. The surface horizontal acceleration time histories for both types are shown in Fig. 10. The strong amplification, resonance and the big phase difference in case of short period type input are depicted in Fig. 10.a, while the almost free field behavior can be observed clearly from Fig. 10.b for the long period input. As well as the extended structure is considered, the spatial and time variation of the surface response are of great importance. This cause the extended structure to be subjected to different excitations at different locations and consequently, very high internal stresses and strains at the weak viaduct columns.



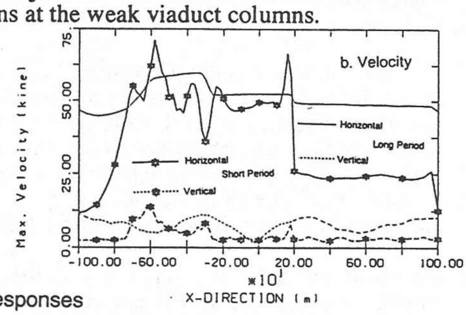
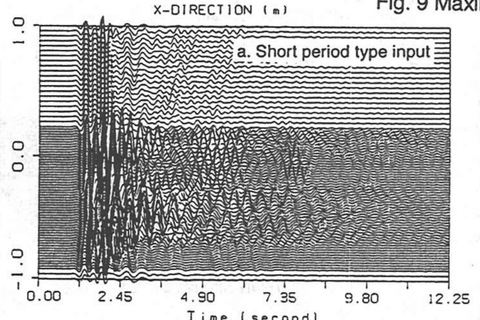


Fig. 9 Maximum Surface Responses



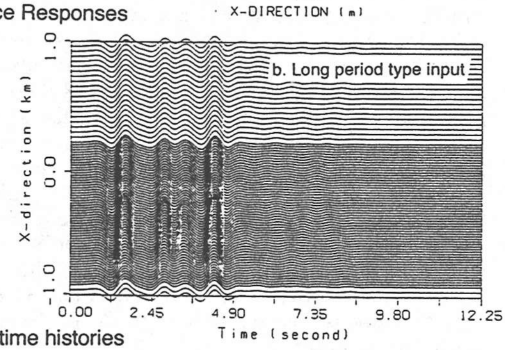


Fig. 10 Hl. acceleration time histories

Another important factor is the period content of the surface response. Figure 11 shows the Fourier transform spectrum of the response at point P1 as defined in Fig. 6. The very high maximum amplitude occurred at period of 0.407 sec. which is the predominant period of the soft soil layer. This period may coincide or very close to fundamental period of the bridge structure at this site leading to the high possibility of the structure response resonance. These findings can explain why the damages happened to the extended bridge while the other type of nearby structures have not suffered from sever damages.

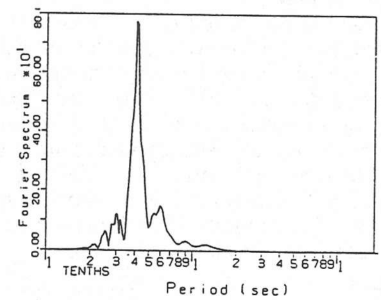


Fig. 11 Period Content at point P1

CONCLUSIONS: The soft soil strongly amplified the surface response and modified its critical period during the Hyogo-ken Nanbu Earthquake. Coupling of the soft soil and structures responses resonance are the crucial factor for the heavy damages at Kobe area and Sanyo Shinkansen Line viaduct. Therefore, the site conditions and the soil-structure interaction must be considered in the practical analysis and design of the aboveground structures. The findings from this study give an important warning concerning the modern structures located in Kobe city area especially whose natural periods lie between 0.4 and 0.6 second.

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