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ANALYTICAL STUDY OF SITES EFFECT IN KOBE CITY DURING THE JANUARY 17, 1995 HYOGOKEN-NANBU EARTHQUAKE

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ABSTRACT

Analytical method was used to study the ground response at Sumiyoshi area in Kobe city during the Hyogoken-Nambu earthquake. A 2D FEM model was constructed based on results of previous studies about the soil structure. The strong ground motion recorded at Kobe University was used as an input motion. Due to uncertainties in the available data, two deep structure models one with inclined edge profile and the other with rectangular profile were analyzed and the inclined profile showed better agreement with the recorded strong ground motion. The effect of shallow structure was investigated by introducing two more models. Final analysis was made by using the inclined profile. Soil non-linearity was considered by the Equivalent Linear method. The obtained response showed good agreement with the damage distribution and explained the highest damage anomaly area of intensity VII in JMA scale. The effect of the sediment boundary edge, the shallow alluvium-diluvium boundary and the softer shallow layer were observed in amplification of the ground response in the heavily damaged area.

KEYWORDS

Site effect, Hyogoken-nambu earthquake, kobe, site response, non-linearity, 2D FEM, damage, deep structure, shallow structures.

INTRODUCTION

The Hyogoken-Nambu earthquake of January 17,1995(M=7.2, H=14.3 km) caused extensive damage in Kobe and surrounding areas . During this earthquake the damage that occurred in Kobe city was not uniform(BRI, 1995 and AIJ, 1995). Specially the intensity VII damage anomaly, which is the highest intensity in the Japan Meteorological Agency (JMA) scale, occurred within a narrow band of 1 km width and 20 km long. The above damage distribution patterns can not be explained by source and path effect only, though such effects have been reported to exist. (Kamae and Irikura, 1995). A close look at the damage distribution indicates a strong site effect . The strong ground motions recorded during the main event are not suitable enough to make detailed site effect study. After the main shock, an attempt was made to study site effects by using aftershock records, by systematically deploying seismometers on different formations (Iwata *et al.*, 1995 ; Kurita *et al.*, 1995) and by using microtremor measurements(Haile *et al.* 1995). Though partial success could be obtained, the differences in source, path, and strain levels between main-shock and aftershocks or microtremors poses limitations.

In this study an attempt was made to investigate the effect of site condition on ground response and damage distribution at Sumiyoshi area in Kobe city, by using various analytical method. Here the result of the 2D FEM is discussed. The analyzed site starts from the Rokko mountains, in the fault area, in the north and extends though rock outcrop sites, diluvial and alluvial deposits, and ends at the sea shore(Fig. 1). The shallow surface structure contains alluvial fan deposited by the Sumiyoshi river forming a strong irregularity in the shallow structures of about 20m depth on the average. In terms of damage distribution, the chosen site contains the non damaged area in the rock outcrops, and shallow diluvial formation, passes through slightly and moderately damaged area and heavily damaged sites. The intensity VII area crosses this site with a width of about 1 km (Fig.1). Besides encompassing wider damaged patterns, previous studies have been made in the area to determine both the deep and shallow soil structure. Aftershock observation and microtremor measurements were also made in the area providing further references. Though the above studies could not provide a very precise shallow and deep structure data, a reasonable information could be extracted to build an analytical model. In general in Kobe area reported investigations and studies both for shallow and deep soil structures indicate strong north-south directional variation and more uniformity in the east-west direction, justifying the use of 2D model spanning from the north to the south. But it should be noted that some local irregularities exist with 3D features, for example around the Kobe JMA, one of the strong ground motion observation stations. The 2D FEM was used for analysis and soil non-linearity was taken into account by the Equivalent Linear method. The strong ground motion recorded at Kobe university (KBU) was used as an input motion.

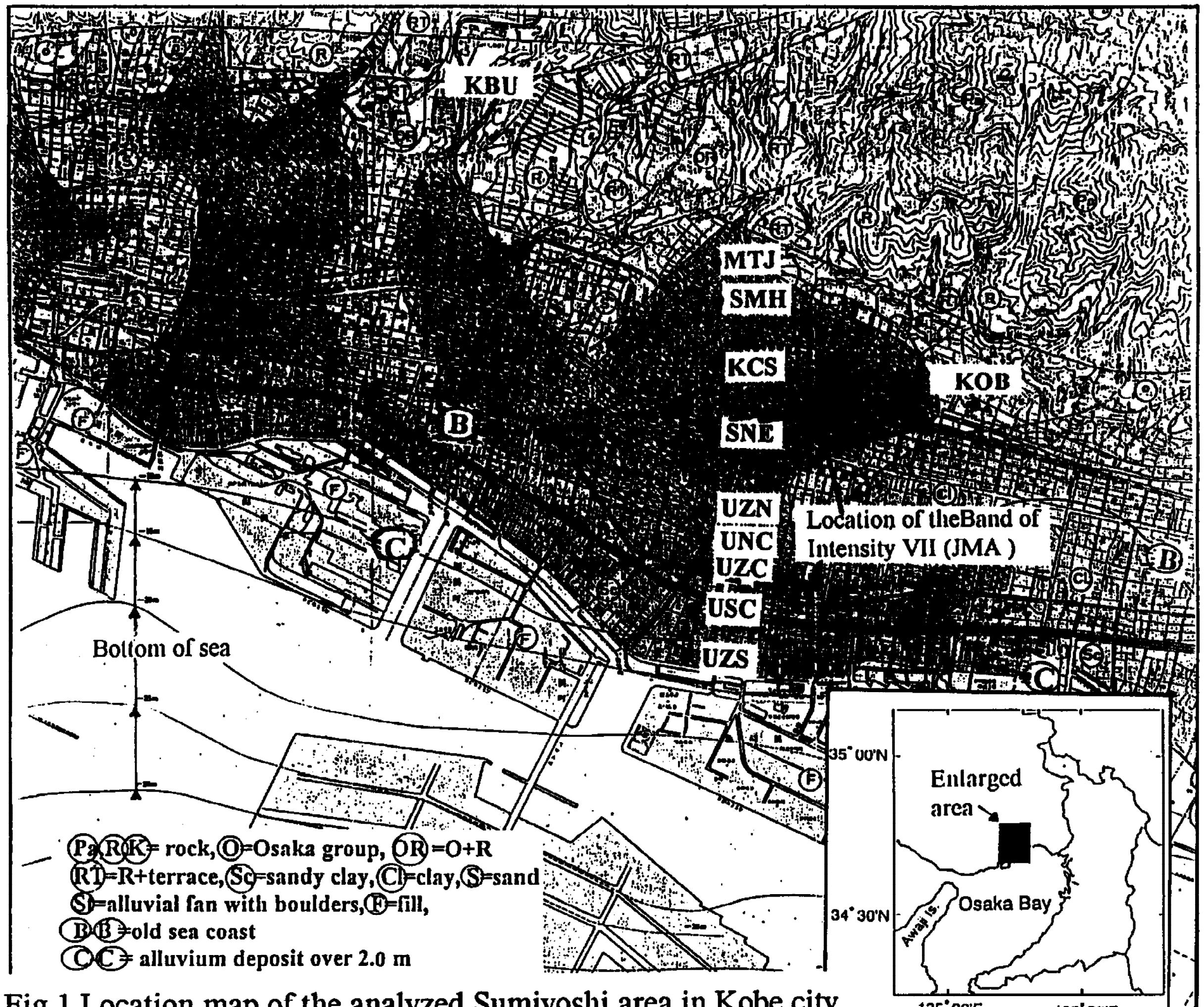


Fig.1 Location map of the analyzed Sumiyoshi area in Kobe city. and the selected characteristic points.

MODELING AND ANALYSIS

In the absence of a more precise soil profile data like deep bore hole profile or result of intensive geophysical exploration, the results of previous studies were used to determine the deep structure profile. Bore hole data was used to decide the shallow structures. The deep velocity structure was determined based on explosive survey results (Murai, 1994), which suggests the existence of two distinct shear wave velocity structures of soil deposits. The top layer with S-wave velocity(Vs)=700m/s extends to -600m and the second layer with shear wave velocity of 1400 m/s extends from -600m to about -1500 m. The base with Vs=3300 m/s shows inclination at the edges and outcrops at Rokko mountain range. No information is given about the details of the inclination of the base. Using aftershock travel time analysis (Yamanaka and Aoi, 1995) gave a more detailed suggestion of 45° inclination up to 1 km distance from the edge and a gentler slope there after. The contour of the base layer and other intermediate layers for the whole of the Osaka basin area, including the site under consideration determined from reflection survey and microtremor array inversion analysis (Kagawa, 1994) also indicates a sloping base for all the layers. In deciding the deep structure model information that is consistent in all the three studies was selected, in some cases where difference is shown some judgment was used in selecting the most appropriate detail. For the shallow structure profile, the alluvium diluvium boundary was determined based on a report given by JSSMFE (1992). Bore hole profile data for the top 20 m including N values was provided by Kobe city office (1992). the N value was converted to Vs value by using the relation proposed by Ohta and Goto (1976) in Eq. 1

$$Vs' = 68.79 * N^{0.171} * H^{0.199} * E * F \qquad (1)$$

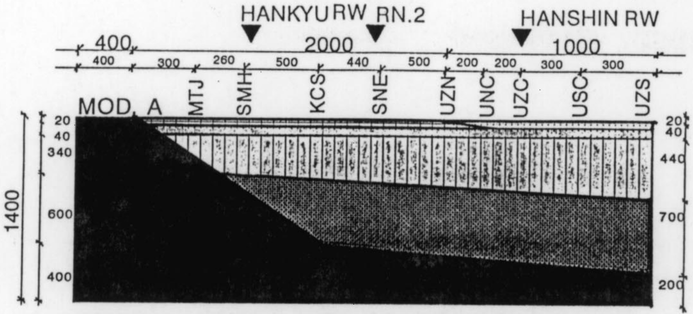
where Vs'= S-wave velocity (m/s)

E(epoch) is 1.0 and 1.303 for Alluvium and diluvium respectively

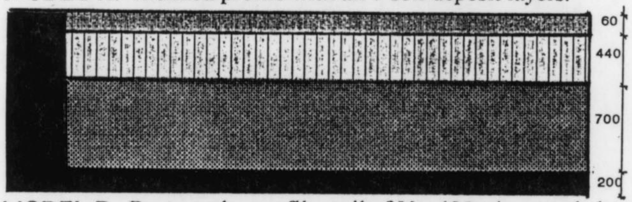
F(facies) is 1.0 , 1.086,1.066,1.135 and 1.448 for clay, fine sand,medium sand coarse sand, sand and gravel and gravel respectively

Because of computational and modeling convenience, the non-uniform shallow structure obtained from bore hole data was simplified, by taking average S-wave values for the alluvial and diluvial formations of top 20 m. Based on the above information and after some trial and error the 2D model shown in Fig 2.a was constructed. Other studies made to the east of Sumiyoshi area at about 2 km distance assumed a rectangular profile (Pitarka *et al.* , 1996; Kawase, 1996). The existence of such variation in a short distance indicates strong east-west directional variation or existence of a very local variation at some places. But since these profiles were determined based on inversion analysis which involves some assumptions, and this northern edge coincides with geological faults further complicating the nature of the structural discontinuity, exact determination of shape of the edge boundary becomes more difficult. To overcome such uncertainty, until more precise survey result is available, a rectangular edged model (model B, Fig.2b) and inclined edge (model C, Fig.2c) profiles were considered and response was computed for both cases. In both the above models used in comparison the shallow structure was not included to observe the effect of deeper structure more clearly. The computed result shows difference in the upper region of the profile in the diluvial formation and almost same response was observed around the alluvium-diluvium boundary and southwards. The acceleration response spectra obtained from both models is shown in Fig. 3, along with an observed ground motion record nearby in the area at (KOB) which is located at about equal distance from the edge with point MTJ (Fig. 1). The response of the inclined profile showed better agreement with the recorded motion. Therefore, in the subsequent analysis the inclined profile was used.

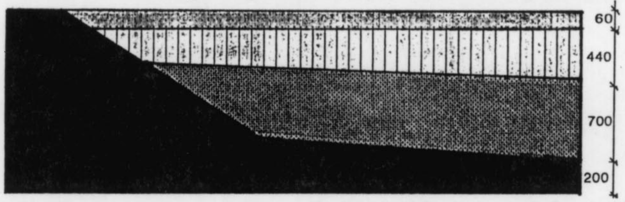
The record at Kobe University (KBU) was used as input motion. This motion was recorded inside a tunnel at the rock outcrop site in a hilly zone. Though this could be considered as most reliable record during this earthquake, to be used as an input motion, some soil structure effect from the tunnel and local topographic effect from the hills is expected. First the recorded ground motion was input on the rock outcrop at the northern end of the profile, and was deconvolved to the base. Then, as the source was very near to the site (northern edge of the profile coincides with the fault), the waves were propagated vertically upwards. The NS component was used in SV-wave analysis while the EW component was used in the SH-wave analysis.



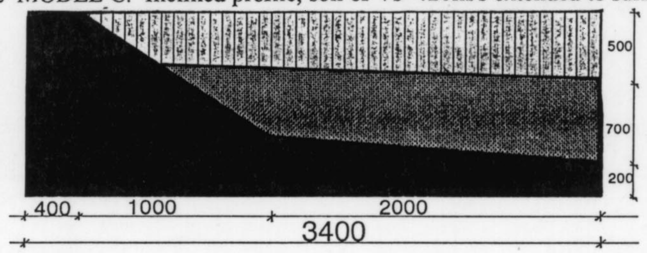
2.a MODEL A. Inclined profile with all 5 soil deposit layers.



2.b MODEL B. Rectangular profile, soil of Vs=420m/s extended to surface.



2.c MODEL C. Inclined profile, soil of Vs=420m/s extended to surface.



2.d MODEL D. Inclined profile, soil of Vs=700m/s extended to surface.

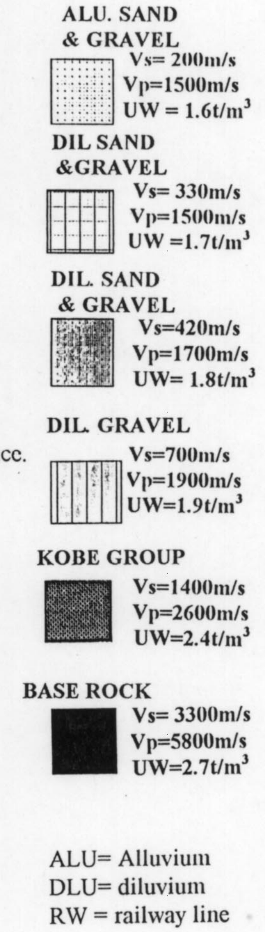


Fig 2. The different models used in analysis. The overall size of models and the location of points selected for response are same in all models

In the area four distinct velocity structures are identified overlaying the base in the vertical direction. Further introducing the alluvium-diluvium boundary splits the top layer in to two.(Fig 2.a.) In order to have a better understanding of the contribution of the shallow structures, two more models were introduced. Model C (Fig. 2.c) was obtained by removing the top 20 m and extending the velocity structure between -20m and -60 m to the surface. Model D (Fig. 2d) was obtained by removing the two top layers from 0m to -60m and replacing them with the velocity structure of the third layer with shear wave velocity of 700m/s. The three models were analyzed and the resulting responses were compared in an attempt to understand the influence of the top thin layers in the over all response. The results are presented in Figs. 4.a and 4.b for points KCS and UZS respectively. The results show that at KCS the response of models A and C are very similar as the top 20 m in the area do not have big velocity contrast with the second layer. The response of model D shows slightly less response. At UZS significant difference was obtained among the three in periods less than 1s. This difference could be understood as indicator of the contribution of the shallow structures considered in the respective models.

After making the above preliminary analysis using linear stress strain relationship to decide the most appropriate model and understanding the relative contribution of each layer, model A was considered as the most appropriate model and analysis was made by considering non-linearity of stress-strain relationship by the Equivalent Linear method. Some mesh refinement was also made to accommodate the reduction in shear wave velocity due to non-linearity.

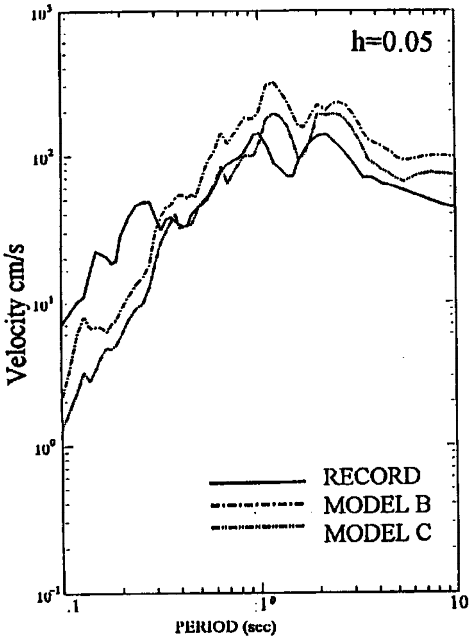


Fig.3. Velocity response spectra for models B and C at MTJ compared with the recorded strong ground motion at KOB.

DISCUSSION OF RESULTS

The results of the analysis for the final model are shown for characteristic points selected in terms of locations in different soil formations. The acceleration time history for the 9 selected points is shown in Fig. 4. The minimum response was shown for sites MTJ and SMH, an increase shows at KCS and SNE, and further increase appears at UZN and UNC. Points UZC, USC and UZS decreases gradually. It is understood that the increase which started from KCS is due to the effect of the 2D deep structures. The extra amplification and elongation of the strong portion of the motion at UZN and UZC indicated by arrow are combined effects of deep structure and shallow inclined alluvium-diluvium boundary. Decrease to the south of UZC could be attributed to two factors. One is that the effect of the deep inclined base and the shallow alluvium and diluvium boundary decreased as we move further south. The fact that models B and C gave similar response in this area further confirms this fact. The second factor for this decrease is understood to be due to the non-linearity which is more dominant in the softer alluvium formation.

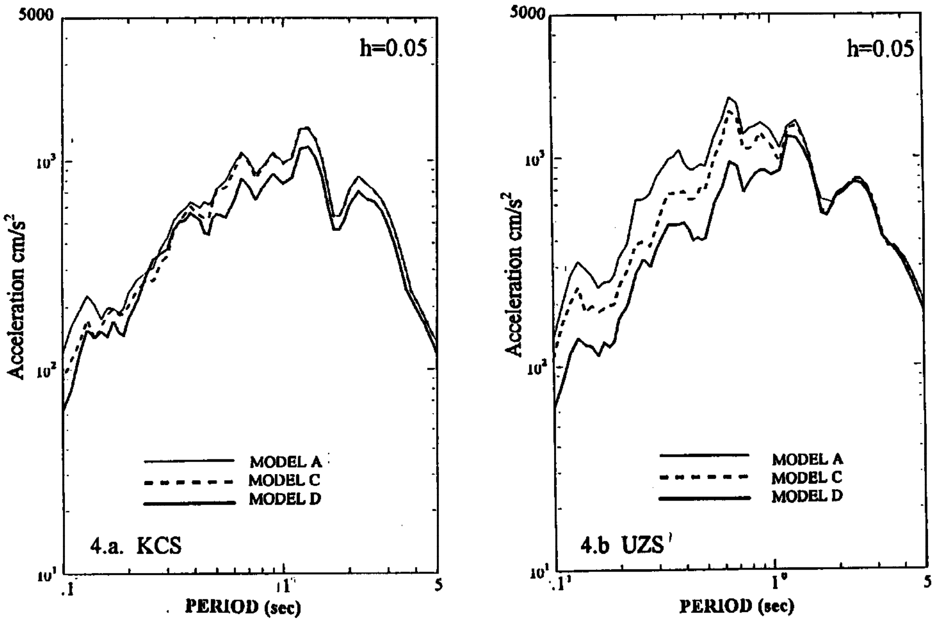


Fig 4. Acceleration response spectra of models A, C and D compared at points KCS and UZS

The acceleration and velocity response spectra, plotted for every other point to make tracing of curves more easier, are presented in Figs. 6a and b. While both figures show similar tendency, the response in the shorter period less than 1s is more clearly observed in the acceleration response spectra, while the response in the longer period is more clear in the velocity response spectra. In the acceleration response spectra MTJ located on a rock site overlain by a very shallow soil shows the minimum response. Sites KCS and UZN showed the maximum response in the shorter period less than about 0.6s, the response for UZN showed more response value further up to 1s with a distinct peak at 0.9s. At periods longer than 1s bigger response was obtained for UZC and UZS in the alluvial formation, as could be observed more clearly from the velocity response spectra (Fig. 6). In the period range longer than 1s, double peak appeared for all sites around 1-1.2s and between 2-3s, but different amplifications were observed as we move southwards towards deeper and softer formations.

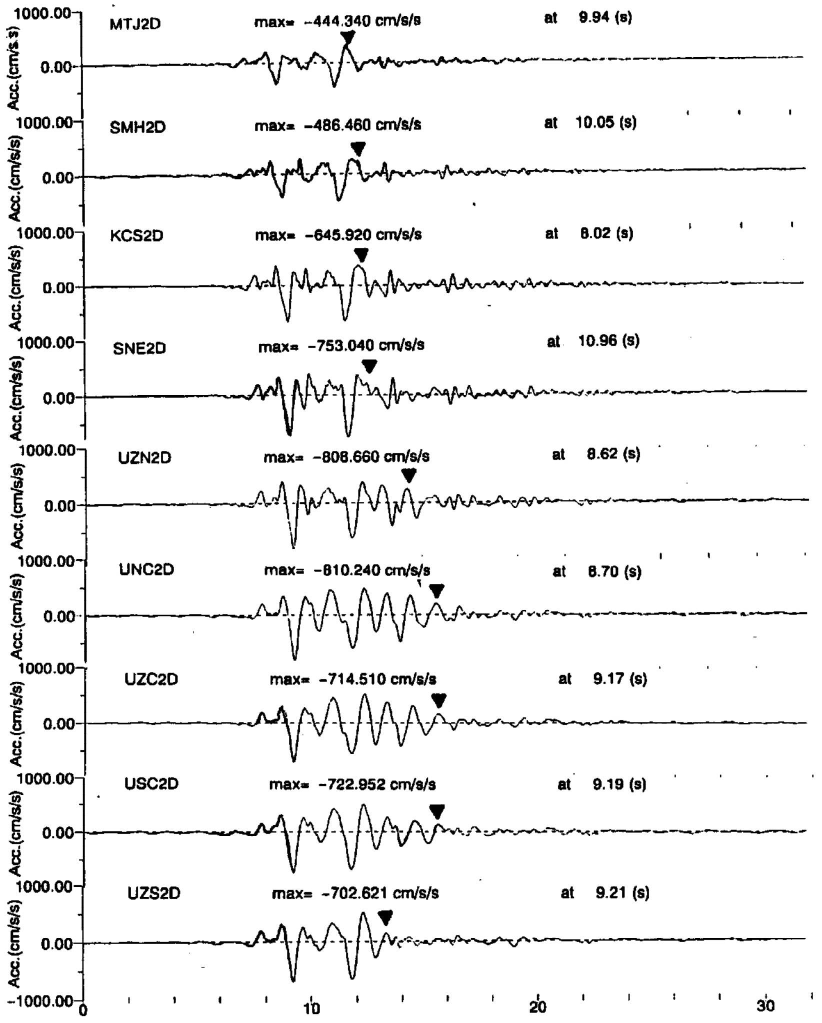
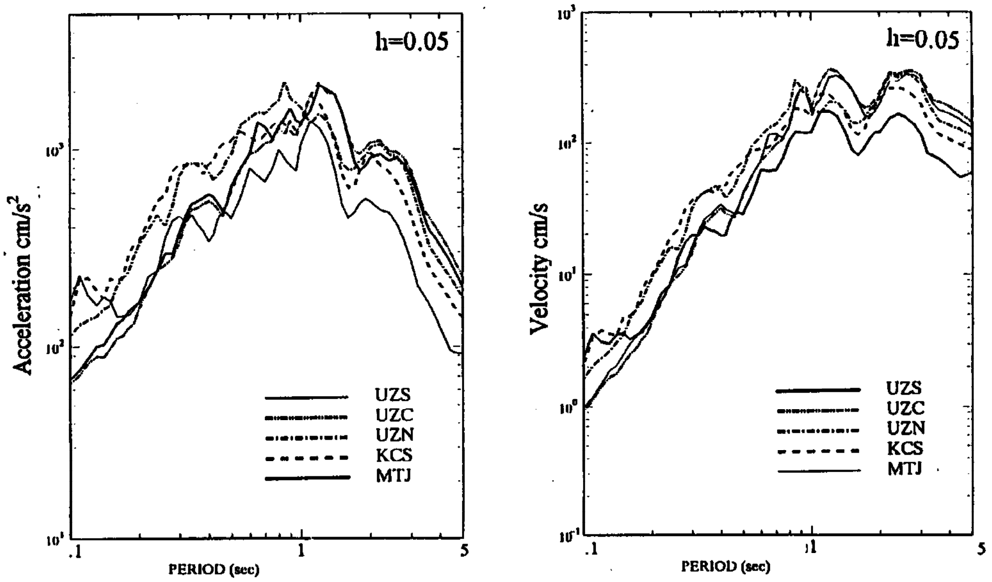


Fig. 5. Acceleration time history of the 9 selected characteristic points shown in Figs. 1and 2.



6.a. Acceleration response spectra

6.b. Velocity response spectra

Fig. 6. Acceleration and velocity response spectra of every other point for which the time histories are shown in Fig. 5.

CONCLUSIONS

1. The existence of the shallow structures up to 60m has shown influence on response in the short period range less than 1s. But strong influence was observed in the alluvium due to the top 20m softer soil.
2. The influence of the sloping edge boundary between the base and deposit at the northern end has amplified the response between KCS and UZC.
3. The alluvium-diluvium boundary further amplified the response between UZN and UZC.
4. In this analysis the area with maximum response both in the time history and spectral amplitude in the period shorter than 1s coincide with the area of maximum damage intensity of VII. The heavy damage in the area could be attributed to items 1, 2 and 3 mentioned above.
5. The site selected in this study did not show sign of liquefaction or strong permanent land failure, but as the adjacent areas around UZS were extensively liquefied during the strong ground motion , At this analysis using the effective stress analysis is more appropriate.
6. In this study, the average soil structure was taken for the top 20m, while bore hole profile data indicates strong variation. A study taking into account these detailed variations will produce a better result.

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