Blind Estimation of Recorded Seismic Ground Motion

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Summary This paper reports the results of a blind study made to estimate the seismic ground motions in an alluvial valley in Japan. Forty four teams of participants around the world were supplied data on the Ashigara valley and requested to make blind estimates of ground response, under a prerecorded earthquake motion, at various points in the valley. The authors submission and the overall collection of blind estimates are presented and discussed.

1. INTRODUCTION

The purpose of this work was to examine the accuracy of site response analyses and to evaluate the spread of results from different methods in use in the current state of practice. The participants were given detailed geological, seismological and geotechnical data on the valley, along with recorded time histories of motion for a very weak seismic event at various points in the valley. Using this information in the numerical model of their choice participants estimated the ground motion at various points in the valley to a recorded bedrock motion of considerably higher strength than the supplied weak motion data. More detailed information of the authors' analyses and numerical model is available in Larkin and Marsh (1991), Marsh (1992), and Marsh and Larkin (1992).

Ashigara valley lies 75 km to the SSW of Tokyo on Sagami Bay at the confluence of the Kari and Sakawa rivers. The adjacent Hakone volcano has a strong influence on the local geology.

2. GEOLOGIC AND SEISMOTECTONIC SETTING

The tectonic setting of the Ashigara valley and the neighbouring areas of Japan is complex, lying near the triple junction of the Philippine Sea Plate, the Eurasian Plate and the Pacific Plate. In the vicinity of the Ashigara valley itself the seismic and volcanic activities are high, with the Philippine Sea Plate and the Eurasian Plate colliding beneath the valley. It is thought that the Ashigara Valley is a sedimentary valley which has developed on a subsidence zone formed by the subduction of the Philippine Sea Plate. The valley is approximately 12 km long and 4 km wide and is formed on the alluvial plain of the lower Sakawa River. The area is bounded to the East and North by faults, and to the West by the Hakone volcano. Figure 1 shows a geological plan.

The bedrock in the area is thought to be old pyroclastic material from the Hakone volcano (named as Os-2). Above this material is a collection of silts, gravels, sands and loam. A schematic cross section at the KS2 site is shown in Figure 2. These conditions are typical of the valley. The site KR1 is at the head of the valley on hard rock, while the other two sites are situated on the alluvium. The depth of alluvium increases as the valley approaches the sea, being 80m at KS1 and 110m at KS2.

A very comprehensive site investigation was carried out at various points in the valley. The data collected was from down hole tests to determine compression and shear wave velocities, gamma-ray emission to yield densities and SPT tests to yield an estimate of the relative density and undrained shear strength. Laboratory tests were carried out on some materials to determine the dynamic properties. Both a resonant column device and a cyclic torsional shear device were employed to determine the shear modulus and damping over a reasonable range of strain. This data was presented to participants who were then given the option of using an interpretation of this information known as the standard geotechnical model or developing their own model from the data provided. These authors accepted the standard geotechnical model as did most participants.

3. RECORDED GROUND MOTION

The weak motion recorded was a fore-shock to the main event. The main event was a magnitude 5.1 event occurring at a depth of 13.6 km with an epicentral distance of 8 km. The fore-shock had a magnitude of 2.9 and was at a depth of 15.1 km. The recorded motions at station KR1 are shown in

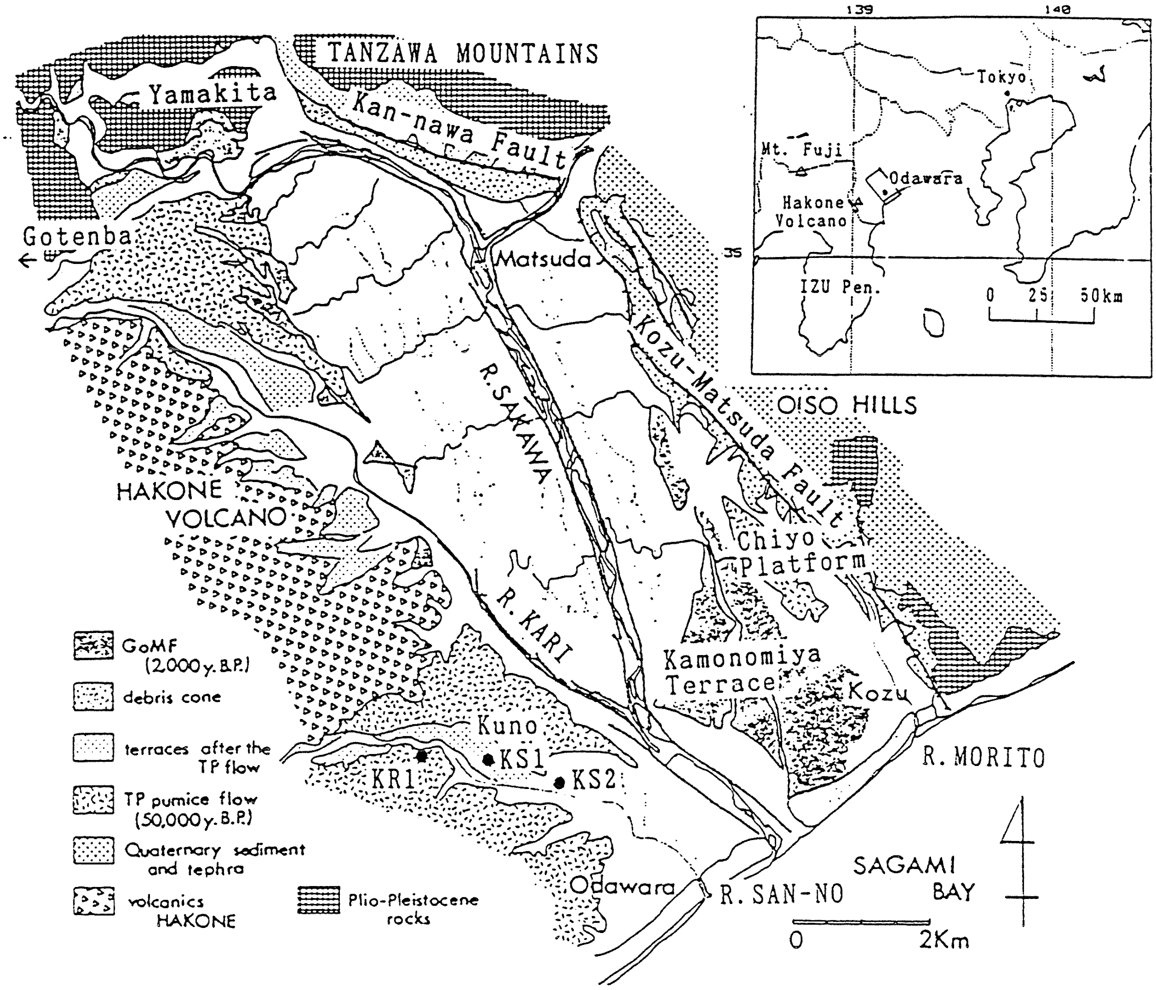

Figure 1. Geologic Map of the Ashigara Valley

Table 1. This data forms the input to the analyses to predict the motion at the two stations KS1 and KS2, and at a further deep station KD2. It is worth noting that even the strong event does not involve large accelerations. The maximum acceleration recorded was 0.15g in the NS direction during the main event. The smallest acceleration is .0022g recorded in the fore-shock.

With the weak motion event, as well as the observed ground motion at KR1, the observed ground motion at site KS1 was supplied to the participants.

Component of Motion	**Strong Motion Event Peak Accn. (m/s²)**	**Weak Motion Event Peak Accn. (m/s²)**
North-South	1.289	0.050
East - West	0.753	0.022
Up - Down	0.494	0.022

Table 1. Peak Accelerations at KR1

4. ANALYTICAL MODEL AND RESULTS

A two dimensional nonlinear finite difference program, TENSA, was used to model the valley in cross section. This program includes two separate solutions to compute the site response. The first solution incorporates the in plane components (cross section) of the ground motion, known as the PSV solution and ignores the out of plane components (long section). The second solution is used to model the out of plane components, this is known as the SH solution. Thus the 3 dimensional nature of the valley is modelled as being uncoupled in the in and out of plane domains. In the case of the out of plane solution the assumption is made that the valley is of infinite length.

In both analyses the soil is modelled as a nonlinear hysteretic material using an incremental plasticity model for the stress - strain properties. The hysteresis loops are modelled using a hyperbolic model for the backbone curve. The data required for this rheological formulation is the low strain shear wave velocity, the low strain compression wave velocity, the density and the shear strength. Both programs are modified versions of the original programs written by Joyner (1972).

Finite difference meshes were constructed for the cross sections at the sites KS1 and KS2. The cross section at both these sites contained 10 material types with a range of shear wave velocities between 65 m/s for alluvial humus near surface soil to 950 m/s for the deep pyroclastic material. The compression wave velocities ranged between 400 m/s to 2300 m/s for the same material. The undrained shear strengths used in the model ranged between 12 kPa for the near surface humus to 500 kPa for the deep sands and gravels. More details of these complex sites can be found in Marsh (1992).

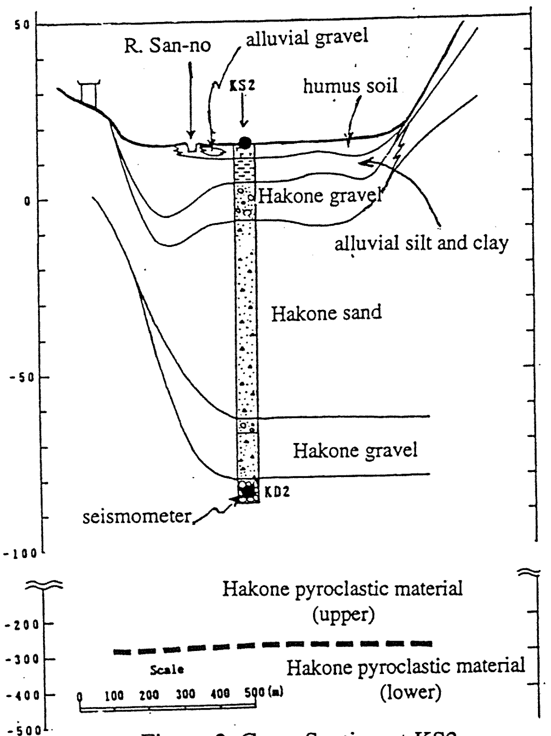

Figure 2. Cross Section at KS2

After initial computations had been made for the weak motion event at KS1, it was found that the predicted peak accelerations and velocities were in general less than the observed values which were supplied to the participants. This is likely to be because of the sloping nature of the longitudinal axis of the valley which can not be modelled by the two dimensional analysis. The sloping bedrock may reflect additional energy into the site at KS1, explaining the higher recorded values. To adjust for this effect the shear and compressional wave velocities of the underlying bedrock were increased. The shear wave velocity was changed from 950 m/s

	Observed Accn. (m/s^2)	Predicted Accn. (m/s^2)	Observed Velocity (m/s)	Predicted Velocity (m/s)
SH	0.074	0.059	0.0025	0.0014
PSV HORIZ	0.085	0.096	0.0023	0.0023
PSV VERT	0.075	0.034	0.0014	0.0007

Table 2. Peak Value Comparisons at KS1

to 2000m/s and the compression wave velocity from 2200m/s to 4600 m/s. Increasing the velocities had the desired effect of reducing the difference between observed and calculated accelerations and velocities. Table 2 shows the comparison of the observed and calculated values for the weak motion event at KS1 after the calibration.

This benchmarking of the computations to observed data was only possible for the weak motion event at KS1. The strain levels that are invoked in such analyses are very small and are confined to the elastic range of the nonlinear soil model. With a hysteretic model there is no damping over this range of strain, however the method is still helpful in refining the variables used in the analysis.

Following the initial calibration, the remainder of the analyses were performed. This involved predicting the ground motion at KS2 and KD2 in the weak motion event, and at KS1, KS2 and KD2 in the strong motion event. The blind predictions were then compared to the observed ground motions.

A comparison of observed and predicted peak accelerations and velocities in the strong motion event is shown in Table 3 for the three components of motion at the sites KS1,KS2,KD2. East refers to the out of plane solution (SH), North refers to the horizontal component of the in plane (PSV) solution and Up refers to the vertical component of the in plane solution. In general the agreement is close. The greatest differences occur in the case of the KS1 site, as was the case with the low strain calibration work.

Site	Observed Accn. (m/s^2)	Predicted Accn. (m/s^2)	Observed Velocity (m/s)	Predicted Velocity (m/s)
KS1 East	2.478	1.895	0.0738	0.0789
KS1 North	2.014	2.960	0.0889	0.1540
KS1 Up	2.992	1.181	-	0.0391
KS2 East	1.063	0.875	0.1065	0.0926
KS2 North	2.214	2.015	0.2193	0.1794
KS2 Up	0.638	0.724	-	0.0328
KD2 East	0.437	0.739	0.0138	0.0182
KD2 North	1.104	1.261	0.0577	0.0610
KD2 Up	0.315	0.354	-	0.0155

Table 3. Peak Values in Strong Motion Event

KD2 is situated at depth at the KS2 site, being 10 m above the level of the input motion, and is thus situated in similar material to the under lying basement material. These factors mean that even allowing for radiation of energy from the valley the motion will be similar to the input motion at KR1. The agreement between observed and calculated motion at KD2 is very good, even given the considerations above.

In the frequency domain the requested information from participants was:

(i) Ratios of Fourier Amplitude Spectra relative to KR1.
(ii) Pseudo-velocity response spectra (5% damped)

Some of this information is shown in Figures 3 to 7. Fourier amplitude spectra in the strong motion event for the North component at KS2 is shown in Figure 3 and the East component at KD2 in Figure 4. The agreement in frequency content at KS2 is clear. The plots for KD2 confirm that the calculated ground motions are closer to the recorded motions at KR1 than the observed motion at KD2. This is due to the method of applying the input motion.

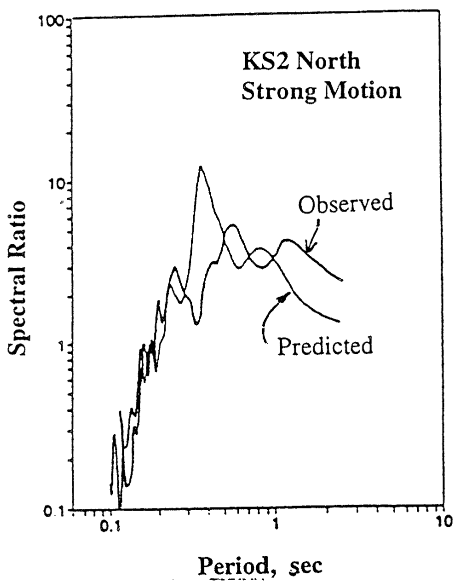

Figure 3. Fourier Spectral Ratios at KS2, North Component

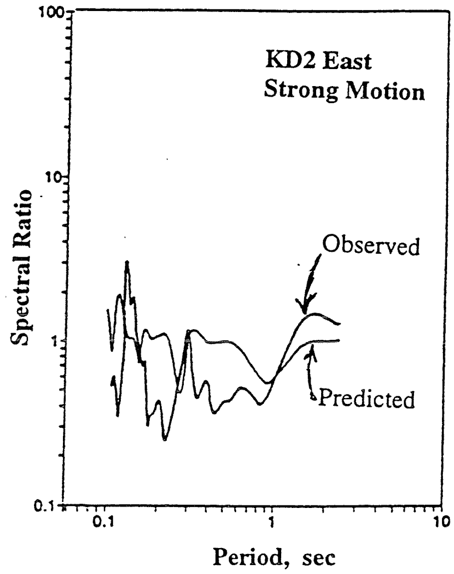

Figure 4. Fourier Spectral Ratios at KD2, East Component

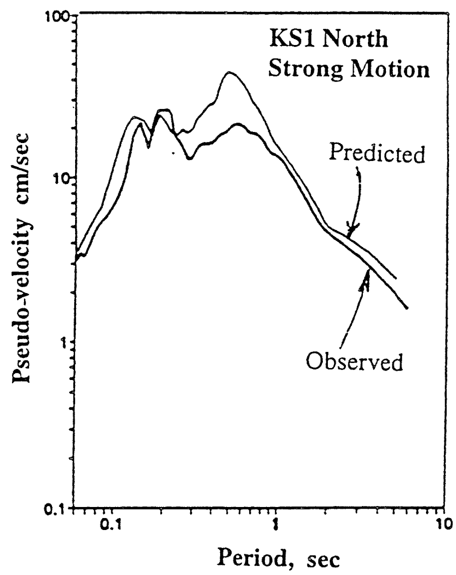

Figure 5. Velocity Response Spectra at KS1, North Component

Pseudo-velocity response spectra are shown in Figures 5 to 7. The agreement of all results is seen to be close, particularly the result for KS2. The greatest difference is seen to be the KS1 case at periods around 0.5 seconds. For this site the observed and computed maximum accelerations are different by approximately 50%. In general however the agreement across the full range of frequencies is seen to be close.

Response spectra were calculated for the weak event and showed good agreement with the recorded data for both the in plane and out of plane solutions. The area of greatest difference was in the area of high frequency response where the analytical method over predicts the response due to the very low damping present in the model. The agreement was better at the KS2 site implying that the finite difference model was a closer approximation to reality for this site.

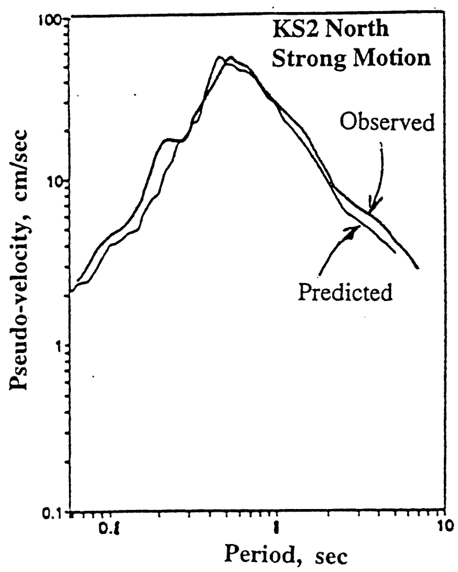

Figure 6. Velocity Response Spectra at KS2, North Component

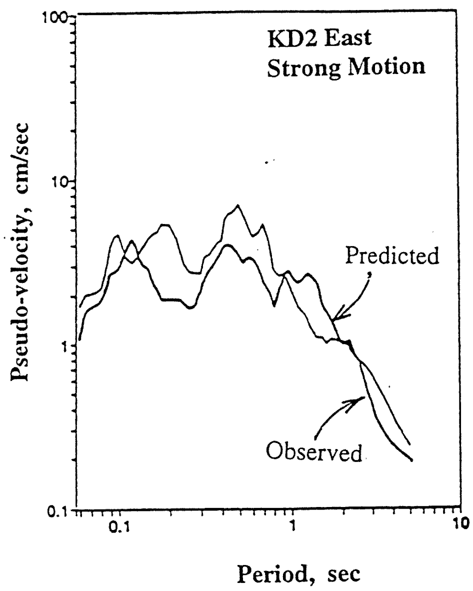

Figure 7. Velocity Response Spectra at KD2, East Component

5. COMPARISON WITH MEAN PREDICTED VALUES FROM ALL PARTICIPANTS

In this section the predicted results of all participants in the study are presented and comparisons made with the submission of these authors. The comparisons are made with mean calculated peak accelerations and velocities at the three sites. Figures are also given showing the scatter of spectral ratios and pseudo-velocity response spectra.

It should be noted that the participants used a range of analytical methods. These included one dimensional equivalent linear (frequency domain), one dimensional nonlinear, two dimensional equivalent linear (frequency domain) and two dimensional nonlinear. The method most favoured by participants was the one dimensional equivalent linear method, which is generally regarded as the state of practice technique. It should be noted that not only are there different methods but some participants used something other than the "standard geotechnical model" to decide the material parameters for use in the analysis.

The results show better agreement of the authors' computed values with the observed values at KS2 and KD2 compared with the mean computed values, than at KS1. In most cases the agreement is better than that of the mean computed values. The agreement is thought to be due in the main to a two dimensional method of analysis.

The scatter in the Fourier amplitudes and velocity spectra from all participants is shown in Figures 8 and 9. The observed motions are also marked. The scatter is seen to be large in both the Fourier amplitudes and the velocity spectrum. A statistical summary of the data from all participants is shown in Figure 10. The data submitted by the authors is also shown. Generally the authors values compares better than the mean of the results of the participants.

6. CONCLUSIONS

The study undertaken was an excellent opportunity to investigate the various analytical methods of calculating ground response to earthquake motion. A wide variety of methods were employed by the 44 participating groups.

The method used by these authors was calibrated by using the results of a very weak motion recorded in the valley. Changes were made to the initial properties of the valley to ensure better agreement with the recorded motion. This resulted in a reasonable degree of agreement between the recorded and calculated results.

In general for the main event the calculated results agreed very well with the recorded data. Calculated peak accelerations and velocities, acceleration and velocity time histories, Fourier spectral ratios and pseudo-velocity response spectra were all in good agreement with the recorded data. The agreement was better at KS2 and KD2 than at the KS1 site, suggesting that the two dimensional approximation and material properties chosen for KS2 were a better fit to reality than those at KS1.

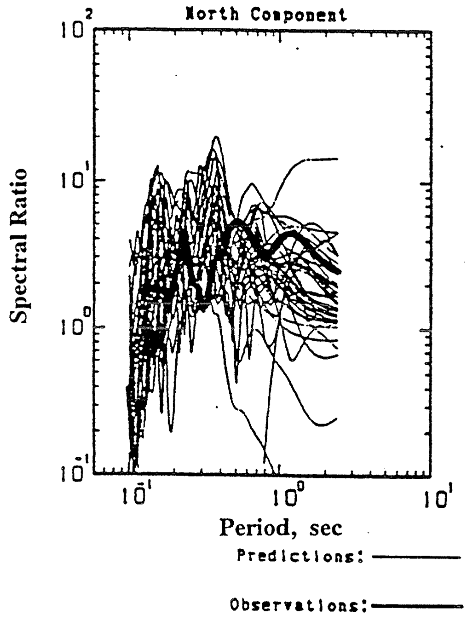

Figure 8. All Fourier Spectral Ratios at KS2, North Component

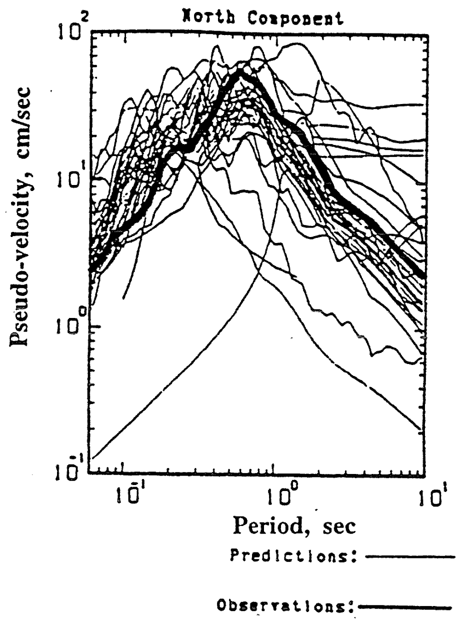

Figure 9. All Velocity Response Spectra at KS2, North Component

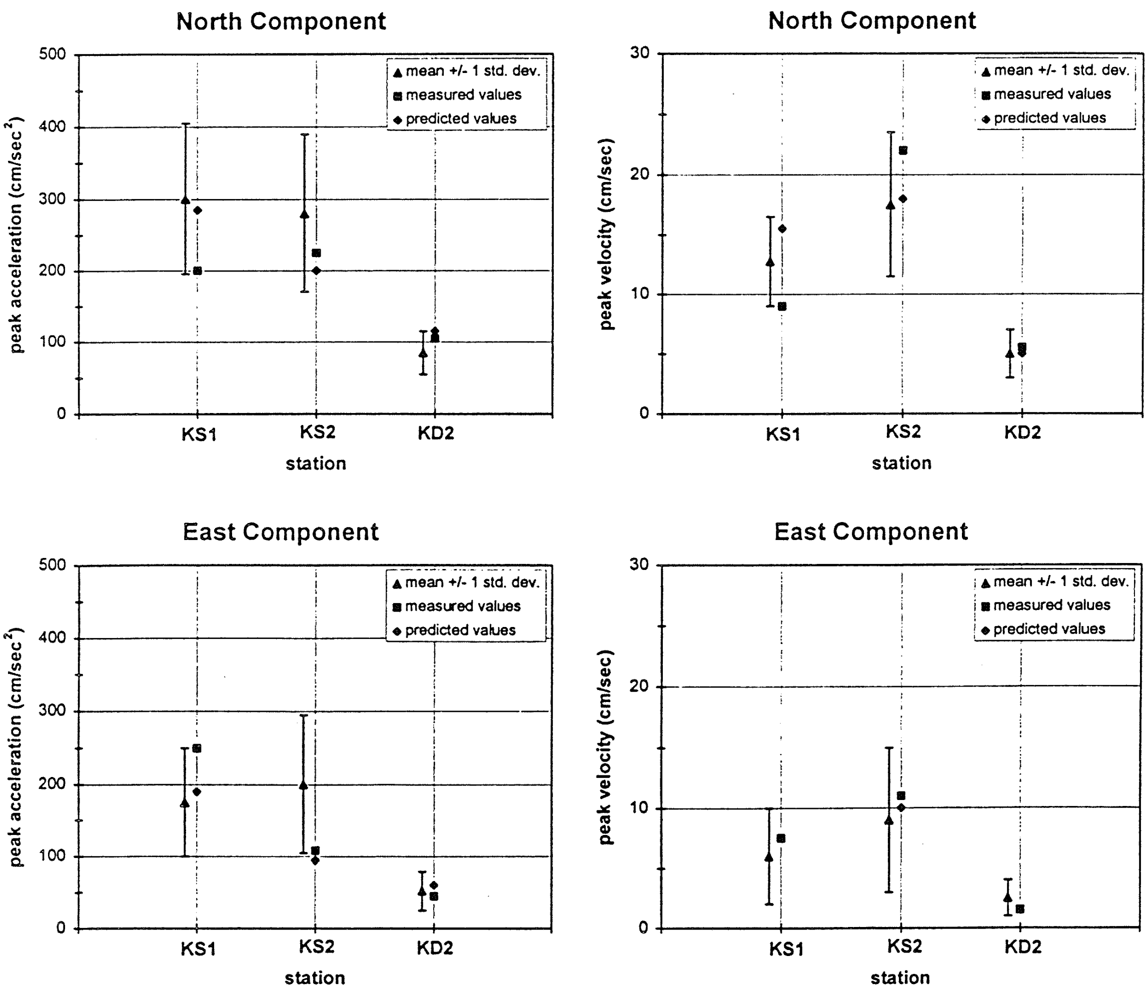

Figure 10. Comparison of Peak Values with All Predicted Results, Strong Motion Event

The results calculated by these authors were also compared to the mean values of all participants. In general the authors results were in better agreement with the observed ground motions than the mean of the accumulated data from all participants. The study suggested there is merit in two dimensional solutions for valleys, particularly where there is a complex array of materials in the cross section.

This study demonstrates that provided care is taken with models developed specifically for nonlinear ground response it is possible to predict the general characteristics of earthquake ground response. While specific features of the motion are not exactly comparable the model used was successful in most cases in capturing the most important features of surface seismic motion relevant to design.

It cannot be hoped to closely simulate all features of ground response using a two dimensional model for what is a complex 3D situation. Even when using two dimensional solutions our ability to model the nonlinear response on a computer usually is not matched by the knowledge of the details of the heterogeneous nature of the site. Further work is required to identify the important out of plane features that effect ground response followed by a need to develop methods of accommodating these effects.

7. REFERENCES

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