ESTIMATION OF STRONG GROUND MOTION AND BUILDING DAMAGE IN THE 1995 HYOGO-KEN NANBU EARTHQUAKE

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SUMMARY

Much strong-earthquake data was recorded during the Hyogo-ken Nanbu Earthquake, but little was recorded for Chuo-ku, Nada-ku, Higashi-nada-ku, Ashiya-shi, and Nishinomiya-shi areas, where many buildings suffered severe damage. In this study, we simulated strong-earthquake motion for these areas and then determined the correlation between seismic level and building damage.

We simulated the strong-earthquake motion in the Sannomiya district in Chuo-ku by using a two-dimensional FEM (finite element method) soil model that included an observation point. The simulation results show that ground motion at the surface of Osaka-strata had peak acceleration exceeding 800cm/sec^2 and a peak velocity exceeding 120cm/sec, away from the Suwayama fault. The area where these maximum values occurred was 600m wide. The result also shows that the Motoyama-strata had a peak acceleration of 837cm/sec^2 and a peak velocity of 145cm/sec. For both the Sannomiya and Motoyama districts, the seismic intensity level derived from the simulated ground motion corresponds well to the areas of concentrated damage.

We also simulated the earthquake response of an eight-story reinforced concrete building (in Motoyama) whose actual damage included a collapsed first-story. The simulation results show that the maximum story-deformation angles for the upper second-story were about 2.7/100, compared with 1/200-1/50 estimated from the actual damaged building. When the maximum input acceleration was decreased to 60% of the simulated ground motion, the maximum story-deformation angle was about 1/200, and when decreased to 70%, the angle was slightly greater than 1/100. When this acceleration exceeded 70%, the deformation angle of the first story was significantly larger than for the other stories.

To simulate the building-damage level by using earthquake-response analysis, the input acceleration must be decreased to 70-80% from simulated ground-surface motion. This phenomenon may be caused by the interaction between the building and ground.

INTRODUCTION

Earthquake motions are influenced by position and destruction process of fault, direction, location of a building, ground property, and geographical features. Furthermore, seismic force that affects a building, is influenced by building foundation, structural form, and building specific characteristics.

Typical characteristics of earthquake motion in 1995 Hyougo-ken Nanbu earhquake are following.

Maximum acceleration has wide range as 300-800cm/sec^2. And velocity is much over 50cm/sec. In some places, recorded values are over 100cm/sec.

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1) An area of intensity 7 on the Japanese seismic scale specified by the Meteorological Agency is located middle position between Kobe coastline and Rokko foothills. Damaged buildings are concentrated in this area.
2) Characteristic ground condition of each area, such that sand gravel heaped up thickly, influences occurrence of building damages very much.

Much strong-earthquake data was recorded during the Hyogo-ken Nanbu Earthquake, but little was recorded for Chuo-ku, Nada-ku, Higashi-nada-ku, Ashiya-shi, and Nishinomiya-shi areas, where many buildings suffered severe damage. We simulate strong earthquake motions in these areas, then discuss the correlation between seismic intensity level, and building damage. And also we simulate the earthquake response of damaged building at Motoyama district in Higashi-nada-ku.

THE BUILDING DAMAGE RATIO

Investigation of damaged buildings grouped by building height and building use was reported [BRI 1996]. By height, buildings grouped into two types as low rise (below two stories) and medium/high rise (over three stories), and by use, grouped into five types as detached house, apartment house, commercial building, industrial facilities and all-purpose. We calculated damage ratio based on the report. Where, total collapse or seriously damaged are weighted 1.0, middle damaged are 0.5 and slight damaged or not damaged on outward appearance are weighted 0.0. Figure 1 shows the block areas those damage ratio of low rise buildings are over 30%. Figure 2 shows over 30% damage ratio of medium/high rise buildings. Where (a) is Chuo-ku Sannomiya area, and (b) is Higashi-nada-ku Motoyama area. Both areas are within the extent of about 2km width perpendicular to the fault.

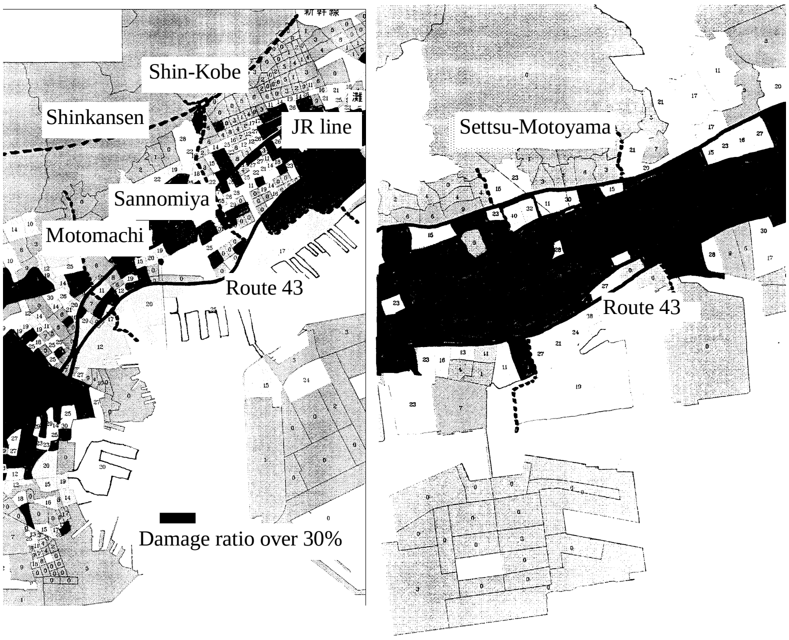


Figure 1: Damage ratio of low-rise buildings

The figures show tendency of building damage ratio as following.

In Chuo-ku Sannomiya area --- Damage ratio is higher in the extent of within 600m distance north and south from JR line. High damage ratio area of low-rise buildings is in the north side of high damage ratio area of medium/high rise buildings.

In Higashi-nada-ku Motoyama area --- Damage ratio is higher in the area between JR line and Route 43. Damage ratio of medium/high rise building is higher along the Route 2, the damage ratio is about half of damage ratio of low-rise buildings.

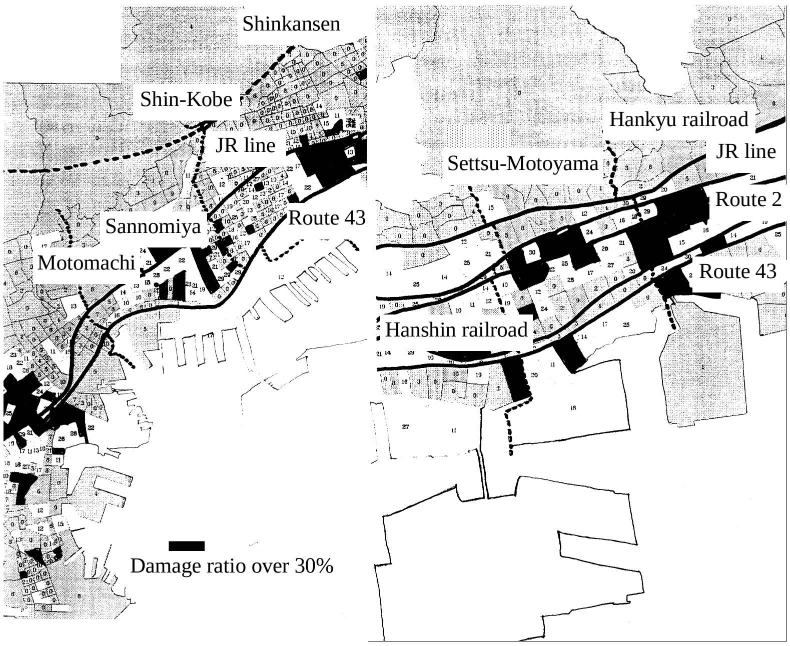


Figure 2: Damage ratio of medium/high rise buildings

ESTIMATION OF STRONG GROUND MOTION AND COMPUTED SEISMIC INTENSITY

Strong ground motion was recorded at Kobe Marine Observatory (KOB) by JMA87 type strong motion accelerometer. KOB is located in south side of Rokko fault system, and influenced by a sedimentary layer and geographical features [Kitagawa 1995]. Therefore, we were modeling soil section across the Rokko fault system include KOB in two-dimensional finite element method with energy transmitting boundary, and estimated a incident wave at bedrock (Vs=2.5km/sec) from transfer function at KOB. Using this bedrock motion wave as SV wave incident vertically, estimated the strong motion of each point, by two-dimensional soil model exposing surface of Osaka-strata covered from 160m north of Suwayama fault to center of Port-island include KOB and Sannomiya [Kawase 1995][Kawase 1996][Hayashi 1996]. Furthermore, it’s necessary to consider nonlinear behavior of surface layer for estimating strong motion of ground surface. Figure 3 shows soil model of Sannomiya section for analysis.

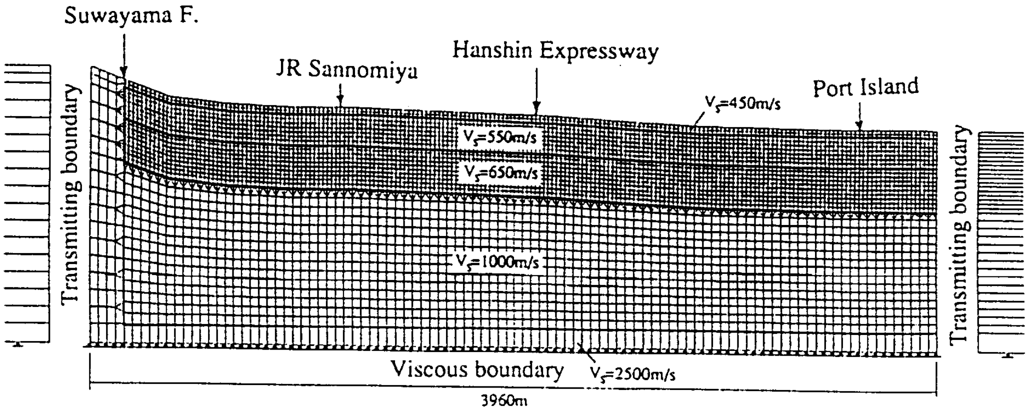


Figure 3: **2-D FEM soil model (Sannomiya section)**

Maximum acceleration of bedrock motion wave is 335cm/sec^2, maximum velocity is 55cm/sec, and direction of maximum principal axis is N32W, these show good correspondences with recorded wave data at Kobe University, where 293cm/sec^2, 55cm/sec and N14W.

Figure 4 (a), (b) shows maximum acceleration and maximum velocity on the surface of estimated by the soil model. Where, triangle mark shows maximum value of recorded wave data in the maximum principal axis direction at Kobe port and Port Island (POI), and circle mark shows estimated maximum response value at ground surface considering surface layer behavior. From the figure, the acceleration and the velocity have a peak at 740m away from Suwayama fault (900m on the soil model). Where, maximum acceleration is 1200cm/sec^2 and maximum velocity is 150cm/sec. There is an area across in width of 600m with center of the peak, where maximum accelerations or velocities exceeding 800cm/sec^2 or 120cm/sec respectively. At the seaside, 2000m away from fault, both maximum acceleration and maximum velocity are convergent. Those values are agreement with the value, 600 cm/sec^2 and 100cm/sec, that was calculated by one-dimensional analysis.

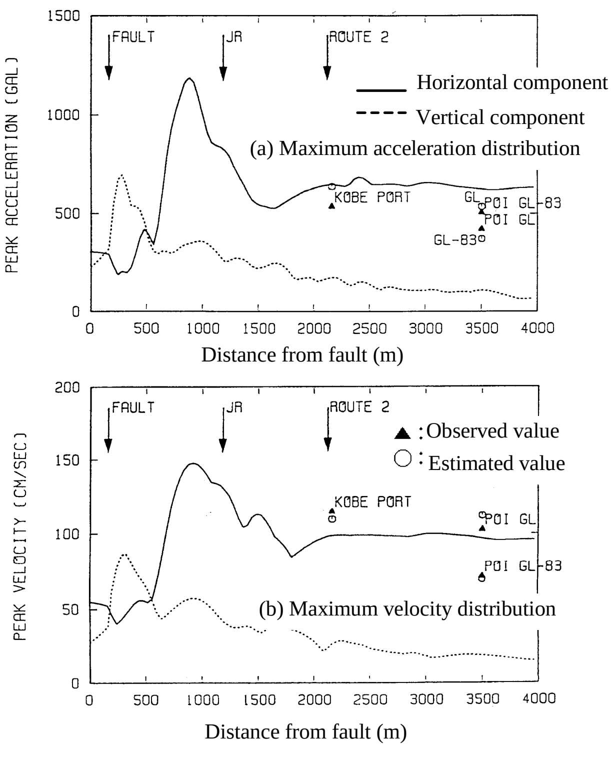
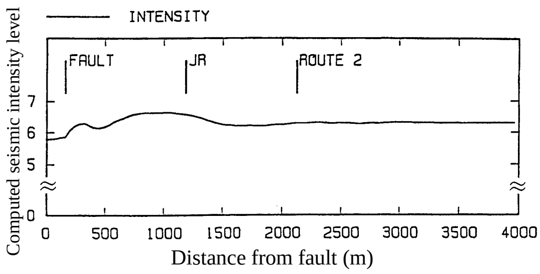


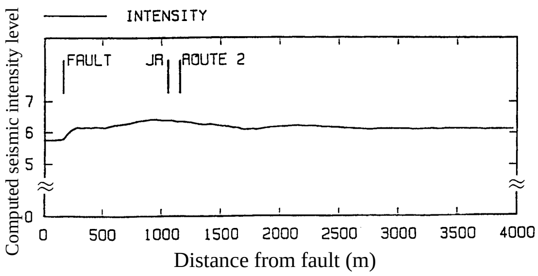
Figure 4: Maximum acceleration and maximum velocity along Sannomiya section

Figure 5(a) shows distribution of computed seismic intensity derived from response acceleration wave at surface of Osaka-strata. The area where computed seismic intensity is over 6.5, shows good correspondence with the area of intensity 7 on the Japanese seismic scale, where over 30% buildings were collapsed just after the earthquake.

Meanwhile, we analyzed Higashi-nada-ku (Motoyama section) by similar model. On this occasion we used observed wave data at Kobe University as bedrock incident wave in consideration of fault position, collapse process and direction. Figure 5(b) shows distribution of computed seismic intensity derived from response acceleration wave at surface of Osaka-strata in Motoyama section. In comparison with value of Sannomiya section, altogether, amplitude of acceleration is lower, and there is no area where computed seismic intensity is over 6.5. However, high intensity area has good correspondence with an area damaged by an earthquake. Furthermore, it's necessary to analyze by one-dimensional model with considering nonlinear behavior and liquefaction of surface for estimating strong motion of ground surface.



(a) Along Sannomiya section



(b) Along Motoyama section

Figure 5: **Computed seismic intensity**

ESTIMATION OF GROUND MOTION AT HIGASHI-NADA-KU

We estimated the ground motion at Higashi-nada-ku by one-dimensional nonlinear analysis considering liquefaction of surface layer using observed data at Kobe University as bedrock incident wave, soil model include the area at where eight-storied reinforced apartment building, that is object of analysis, was stood [Kawase 1995][Hayashi 1996].

Table 1 shows maximum accelerations and maximum velocities in Motoyama.

Table 2 is soil structure that was made by boring data at nearest point to eight-storied reinforced apartment building in obtainable soil data. Figure 6 shows computed acceleration waveform at ground surface.

Table 1: Estimated maximum accelerations and maximum velocities in Motoyama.

Depth	Direction	Maximum acceleration (cm/sec^2)	Maximum velocity (cm/sec)
GL 0m	**NS**	837	146
	EW	486	80
GL –10.7m	**NS**	694	136
	EW	384	74

Table 2: Soil structure in Motoyama site.

No.	Depth (m)	Major soil character		P wave velocity (km/sec)	S wave velocity (km/sec)	Density (t/m^3)
1	0.0-2.0	silty sand	alluvium	1.50	0.200	1.80
2	2.0-6.0	sand gravel		1.50	0.200	1.95
3	6.0-9.0	sand gravel		1.20	0.350	1.95
4	9.0-13.0	gravel mixed cohesive sand	diluvial clay Mal2	1.20	0.350	1.95
5	13.0-	sand gravel	diluvial sand gravel (upper Osaka-strata)	1.90	0.450	1.90

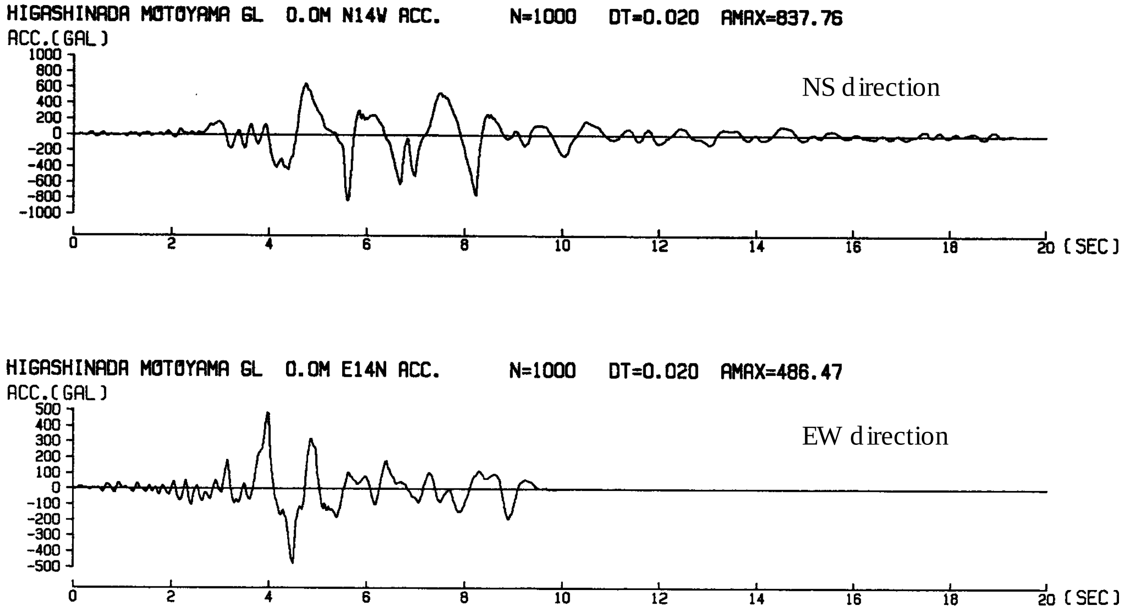


Figure 6: Computed earthquake waves at Motoyama

DAMAGE APPEARANCE AND ANALYSIS MODEL OF EIGHT-STORIED APARTMENT BUILDING

The said building was designed in conformity to the present design standard. And it lacked walls in first story as shown in Figure 7.

Estimate maximum response deformation angle from damage appearance:
The building damage was concentrated at first story, and its residual deformation is estimated at 70-80cm because collapsed column was get out of position about the column width. Deformation angles upper second story are following, those are estimated form damage appearance at A-E frame. Second and third stories are 1/100-1/50, fourth and fifth stories are 1/100, sixth and seventh stories are 1/200 and eight story is 1/400 [BRI 1995][Sugita 1983].

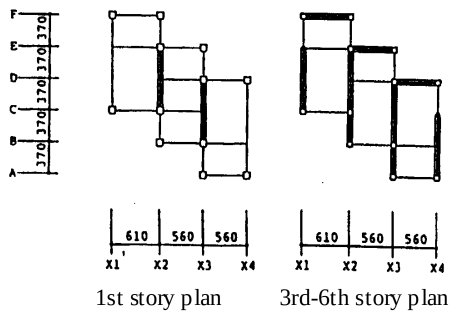


Figure 7: Typical plan of target building

Analysis condition and analysis model:
Analysis model : Tree-dimensional frame model assuming that each floor is rigid. Foundation support conditions are two cases. Case (a) is fixed support, and case (b) is considering interaction effect between building and ground by sway rocking (linear) model.
Column and girder member model : Using rigid plasticity end model. Shear stiffness is linear, but when shear force exceeds ultimate shear strength, make bending hinge at both ends forcibly.
Wall member model : Using wall element model.
Material strength : Using design strength.
Column and girder bending strength : Calculate by common use formula. Bending strength of column is calculated in each step to consider axial force fluctuation affected by loading.
Wall bending strength : Using *e*-functional method at wall plate part without incidental columns. Incidental column effect is considered by axial stiffness and axial strength of the incidental columns.

Column, girder and wall shear strength : Calculate by Arakawa's mean formula. Declining strength after yield is ignored.
Stiffness and damping ratio of sway and rocking : Calculate by formula from reference [Inoue 1987].

Figure 8 shows the analysis model. Nonstructural wall is considered in the model.

Table 3 shows first period of the model. And table 4 shows deformation component of sway, rocking and building of first eigenmode.

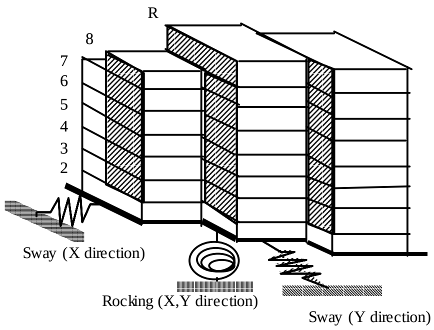


Figure 8: Analytical Model

Table 3: 1st Period (sec)

Direction	Base fixed model	Sway rocking model
X	0.38	0.41
Y	0.20	0.29

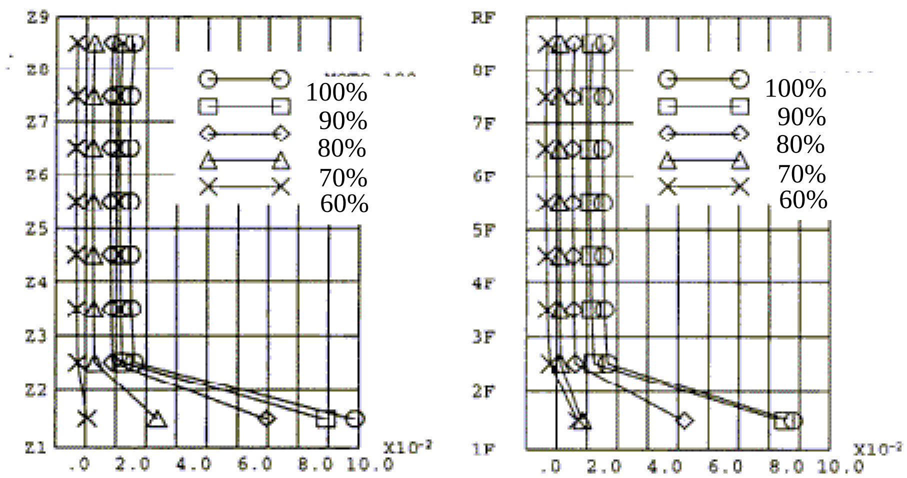
Table 4: Deformation component of sway, rocking and building

	X direction	Y direction
Sway	4.2	11.0
Rocking	12.7	60.7
Building	83.1	28.3

RESPONCE ANALYSIS WITH VARYING LEVEL OF ESTIMATED GROUND MOTION

To two case models, (a) fixed base model, (b) sway rocking model, above-mentioned in 5., we inputted estimated ground motion at ground surface of objective area proposed in 2. Maximum acceleration of input motion was varied from 100% to 60%. And we inputted NS direction component and EW direction component simultaneously.

Figure 9 shows maximum response deformation angle. Figure 9 (a) is result of fixed base model. Deformation angles upper second story are almost constant in regard to varied ground motion, those are about 1/200 when decrease rate is 60%, a little over 1/100 as 70%, and about 2.7/100 in case of 100% input. Deformation of first story is increase significantly than other stories when decrease rate was exceeded 70%. We inferred that input level was 70% of estimated ground motion from damages upper second story. Concentration of deformation at first story seems small, but considering that analysis cannot simulate collapse process exactly such as strength declining after yield, we inferred that effective input level to this building was 70-80% of estimated ground motion.



(a) Fixed base model (b) Sway rocking model

Figure 9: Maximum story deformation angle

The decrease of input ground motion is inferred that maximum acceleration of effective input to building was decreased by interaction effect between ground and building, from relation between predominant period of ground in elastic, that is about 0.3sec, and natural period of building on fixed base, that is about 0.4sec. Figure 9 (b) shows maximum story deformation angle considered interaction between ground and building as linear sway rocking model. Response value on sway rocking model inputted 80% decrease rate is correspond to value on fixed base model inputted 70%. The reason for considering decease rate in sway rocking model may be ignoring nonlinear behavior of soil and geometrical interaction.

CONCLUSIONS

1. The simulation results of strong ground motion in damaged area suggest that the seismic level derived from simulated ground motion based on observed records generally correspond well to the observed building damage. However, there is difference between computed seismic intensity level and building damages according to location. Because of left subject as uncertainties in soil model form or coefficients, it's necessary to examine in detail further.
2. Actual damage of eight-storied reinforced concrete building was simulated successfully by decreasing maximum acceleration of ground surface earthquake motion to 70-80%. The earthquake motion was estimated by using observed record at Kobe University as bedrock incident wave.
3. Decrease in estimated ground motion may be caused by decrease in input to building basement from ground surface or interaction effect owing to inertia force.

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