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DESTRUCTIVE POWER OF STRONG GROUND MOTIONS WITH HIGH LEVEL GROUND ACCELERATION

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ABSTRACT

Several earthquakes have occurred in which a very high peak ground acceleration (PGA) was recorded but damage of structures was not large. The destructive power of such strong ground motions was investigated. Elastic and inelastic response of single-degree-of-freedom systems under the input of such strong ground motions and those under the input of often-used strong ground motions were compared. It was found that the destructive power of such strong ground motions was smaller than that of the often-used strong ground motions in spite of their very high PGA. This means that PGA is not proper as an index for destructive power of strong ground motions. Strong ground motions measured in the 1995 Kobe earthquake which brought about extremely severe damage were also investigated in the same method. The destructive power of these motions was found to be incredibly large.

KEYWORDS

destructive power; peak ground acceleration; response drift angle; soil-structure interaction; inelasticity

INTRODUCTION

Several earthquakes have occurred in which a very high ground acceleration (PGA) was recorded but damage of structures was not large. For example, in old days, more than a 0.4g PGA was recorded in the 1962 Hiroo-oki earthquake, but almost no damage was found in the Kushiro Meteorological Agency building where the PGA was measured (Kanai *et.al.*, 1969). Recently, over 0.7g PGA was recorded in the 1993 Kushiro-oki earthquake, but damage of the Kushiro Meteorological Agency building where the PGA was measured were not so large (Sakai *et.al.*, 1993). And about 1.6g PGA was observed at Otobe-cho by an aftershock of the 1993 Hokkaido nansei-oki earthquake, but the damage of a school building where the motions were recorded was small (Kudo *et.al.*, 1994). Every time such an earthquake occurred, the strangeness of this phenomenon was discussed, but no convincing explanation was made.

In this study, the destructive power of such strong ground motions was investigated by comparing elastic and inelastic response of single-degree-of-freedom (SDF) systems under the input of such strong ground motions and those under the input of the often-used strong ground motions.

STRONG GROUND MOTIONS USED IN ANALYSES

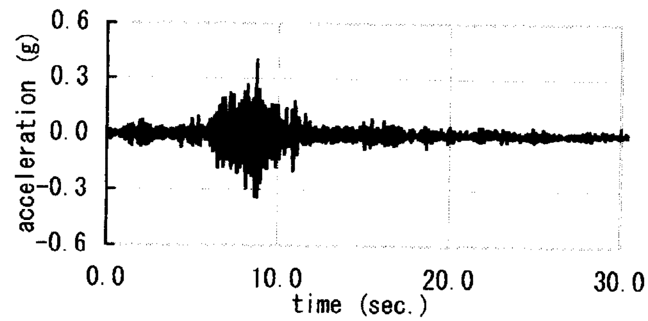
Strong ground motions used in the following analyses are shown in Table 1. Strong ground motions in which high PGA was recorded but damage of structures was not large are called 'high PGA motions' and others 'general motions' for simplicity. HRO, KSR and OTB are 'high PGA motions' and ELC, HAC and THU are 'general motions'. From Table 1, the PGA of 'high PGA motions' are much higher than those of 'general motions', but the damage by these 'high PGA motions' was not so large (Kanai *et.al.*, 1969, Sakai *et.al.*, 1993, Kudo *et.al.*, 1994).

Time history ground accelerations of 'high PGA motions' are shown in Fig. 1. This figure shows that very short period dominates in these motions and very high accelerations occurred not once but many times especially in the case of the KSR record.

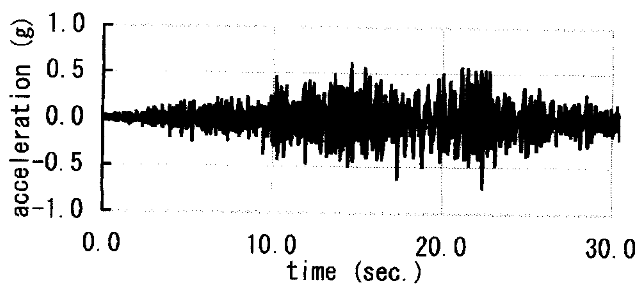
Table 1 strong ground motions used in analyses

ID	station	direction	earthquake	PGA*
HRO	Kushiro Meteorological Agency	EW	1962 Hiroo-oki	419
KSR	Kushiro Meteorological Agency	EW	1993 Kushiro-oki	711
OTB	Otobe cho	EW	1993 Hokkaido-nansei oki (aftershock)	1569
ELC	El-Centro	NS	1941 Imperial Valley	342
HAC	Hachinohe Kowan	EW	1968 Tokachi-oki	183
THU	Tohoku University	NS	1978 Miyagiken-oki	259

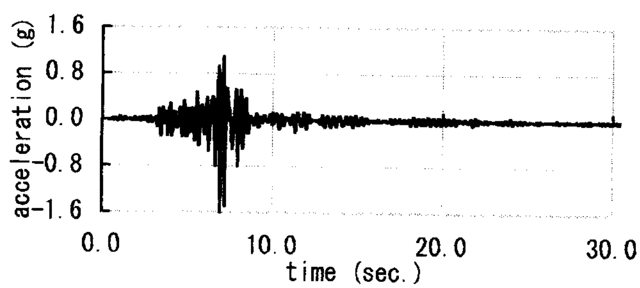
*PGA: peak ground acceleration (cm/sec.^{2})



(1) HRO



(2) KSR



(3) OTB

Fig. 1 Time history ground accelertion

ELASTIC RESPONSE ACCELERATION SPECTRA

Elastic response acceleration spectra with a damping factor of 5% are shown in Fig. 2, comparing 'high PGA motions' with 'general motions'. Solid lines and dotted lines mean 'high PGA motions' and 'general motions', respectively. Response accelerations of 'high PGA motions' have very sharp and high peaks in the short period region around 0.3 sec., but these radically become smaller for longer period. Response accelerations of 'high PGA motions' are smaller than those of 'general motions' for above the 0.7 sec. period.

ELASTIC RESPONSE DRIFT ANGLE SPECTRA

Elastic response drift angle spectra with damping factor of 5% are shown in Fig. 3. Solid lines and dotted lines mean 'high PGA motions' and 'general motions', respectively as in Fig. 2. Damage of buildings should be estimated not by response acceleration but by regulated response displacement, thus Fig. 3 shows

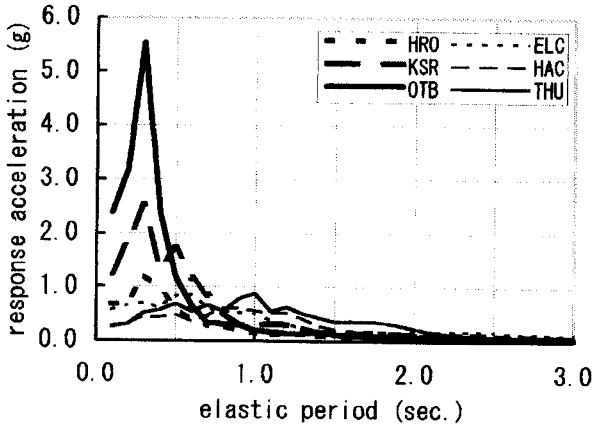


Fig. 2 Elastic acceleration spectra

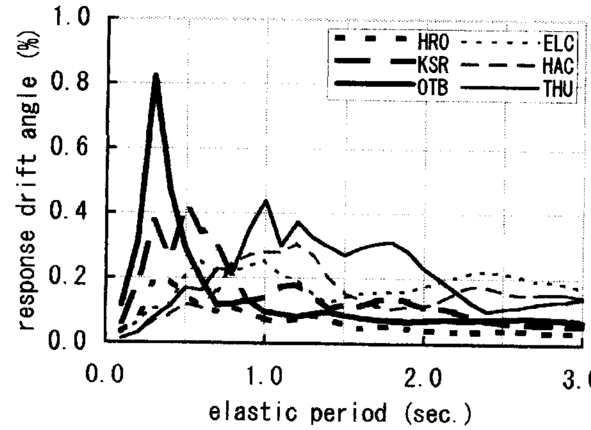
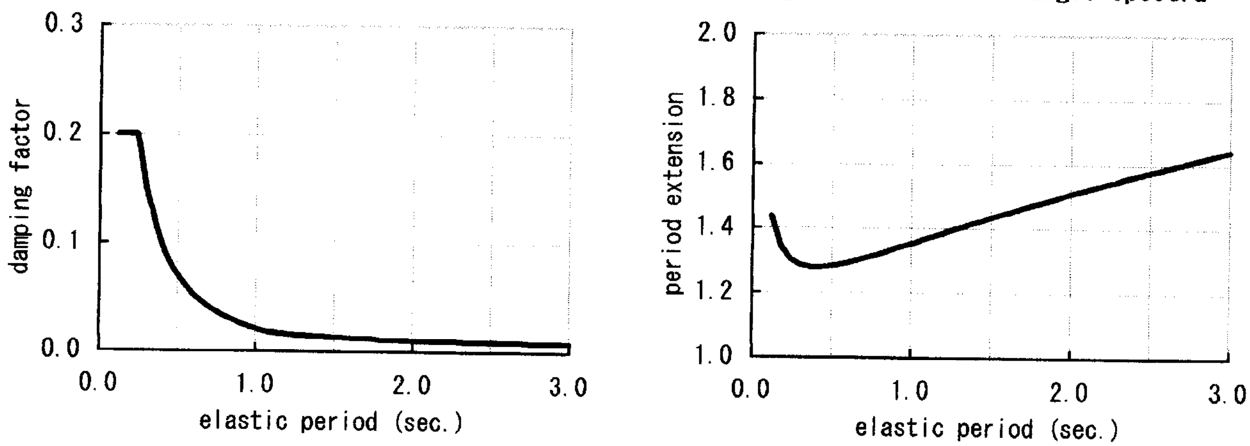


Fig. 3 Elastic drift angle spectra



(1) Equivalent damping factor

(2) Equivalent period extension

Fig. 4 Equivalent damping factor and period extension to consider soil-structure interaction

more actual damage than Fig. 2. Response drift angles were calculated by Eq.(1), assuming elastic period of a building is given by Eq.(2).

$$da = d/H = 0.02d/Te \quad (1)$$

$$Te = 0.02H \quad (2)$$

da: response drift angle,d: response displacement, H: whole height of a building (m),
Te: elastic period of a building (sec.)

In Fig. 3, the response value of 'high PGA motions is not so sharp compared to Fig. 2, but the peak in the short period is still sharp in the case of the motion OTB.

ELASTIC RESPONSE DRIFT ANGLE SPECTRA CONSIDERING SOIL-STRUCTURE INTERACTION

To get actual and accurate responses of buildings by a strong ground motion, soil-structure interaction should be considered, because responses of buildings are considerably reduced by soil-structure interaction, especially for short period buildings.

A method shown in (Architectural Institute of

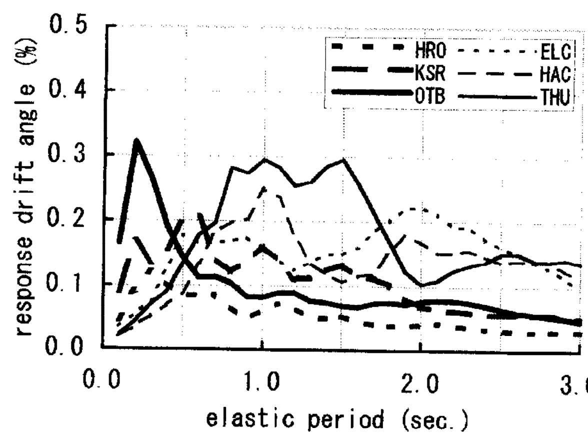


Fig. 5 Elastic drift angle spectra considering soil-structure interaction

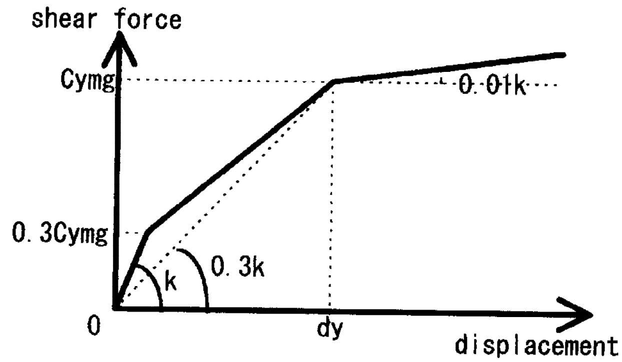
Japan, 1992) was used to consider soil-structure interaction. The method is to use an additional equivalent damping factor and a period extension. The damping factor and period of a system are given in Eq.(3) and (4), respectively,

$$h = h0 + heq \quad (3)$$
$$T = Et * Te \quad (4)$$

h: damping factor, h0: building damping factor (=0.03)
heq: additional equivalent damping factor by soil-structure interaction
T: elastic period considering soil-structure interaction (sec.)
Et: period extension by soil-structure interaction, Te: elastic period of a building (sec.)

The additional equivalent damping factor and the period extension used in these analyses are shown in Fig. 4. These values are in the case of a building whose plan size is 50m x 12m, the ground motion input direction is transverse and an equivalent ground shear wave velocity is 100 (m/sec.).

Elastic response drift angle spectra considering soil-structure interaction are shown in Fig. 5. Compared to Fig. 3, the peak values by 'high PGA motions' are considerably reduced in the short period region. The peak values of 'high PGA motions' are almost the as same as those of 'general motions' in spite of much difference in PGA.



Cy:base shear coefficient, m:mass of system, g:gravity, k:elastic stiffness, dy:yielding displacement

Fig. 6 Skelton curve of hysteresis model

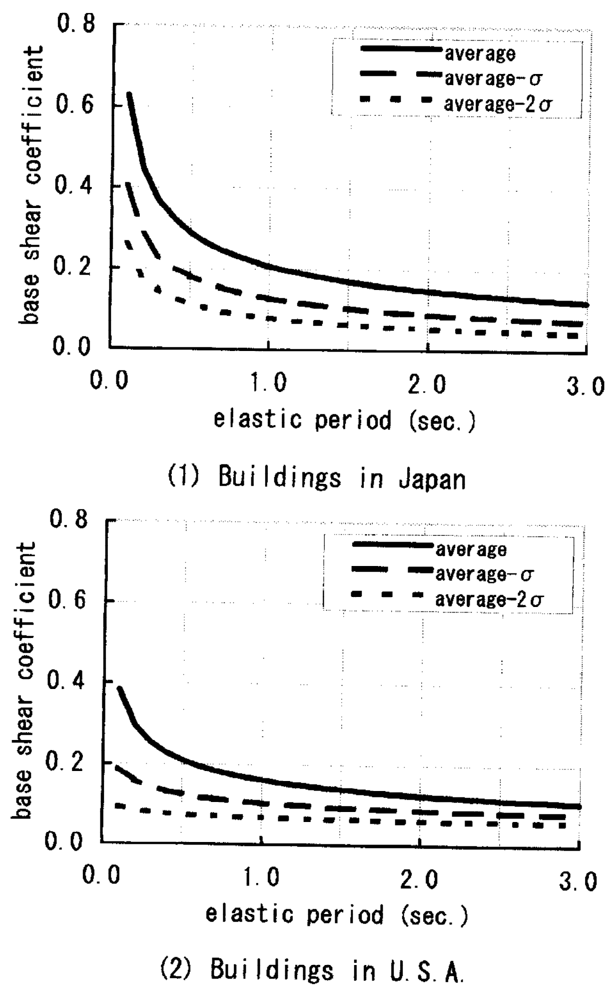


Fig. 7 Base shear coefficient distrubution

INELASTIC RESPONSE ANALYSES

Next, in addition to soil-structure interaction, the inelastic behavior of a building is considered. That is, inelastic earthquake response analyses considering soil-structure interaction were performed. The method to consider soil-structure interaction is the same as the elastic response analyses. In order to consider the inelastic behavior of systems, the Takeda model (Takeda *et. al.*, 1970) is used as the hysteresis model of a system assuming reinforced concrete buildings. The skeleton curve of the hysteresis model is shown in Fig. 6.

A response drift angle is used as an index to express damage of buildings instead of a response ductility factor. Response ductility factor is not proper for an index to express the damage of a building, because the apparent yielding displacement dy is very small and not actual for very short period buildings. For example, in the case of a one story building with story height 3.0(m), that has elastic period Te = 0.06(sec.) from Eq.(2), assuming that α y (ratio of yield

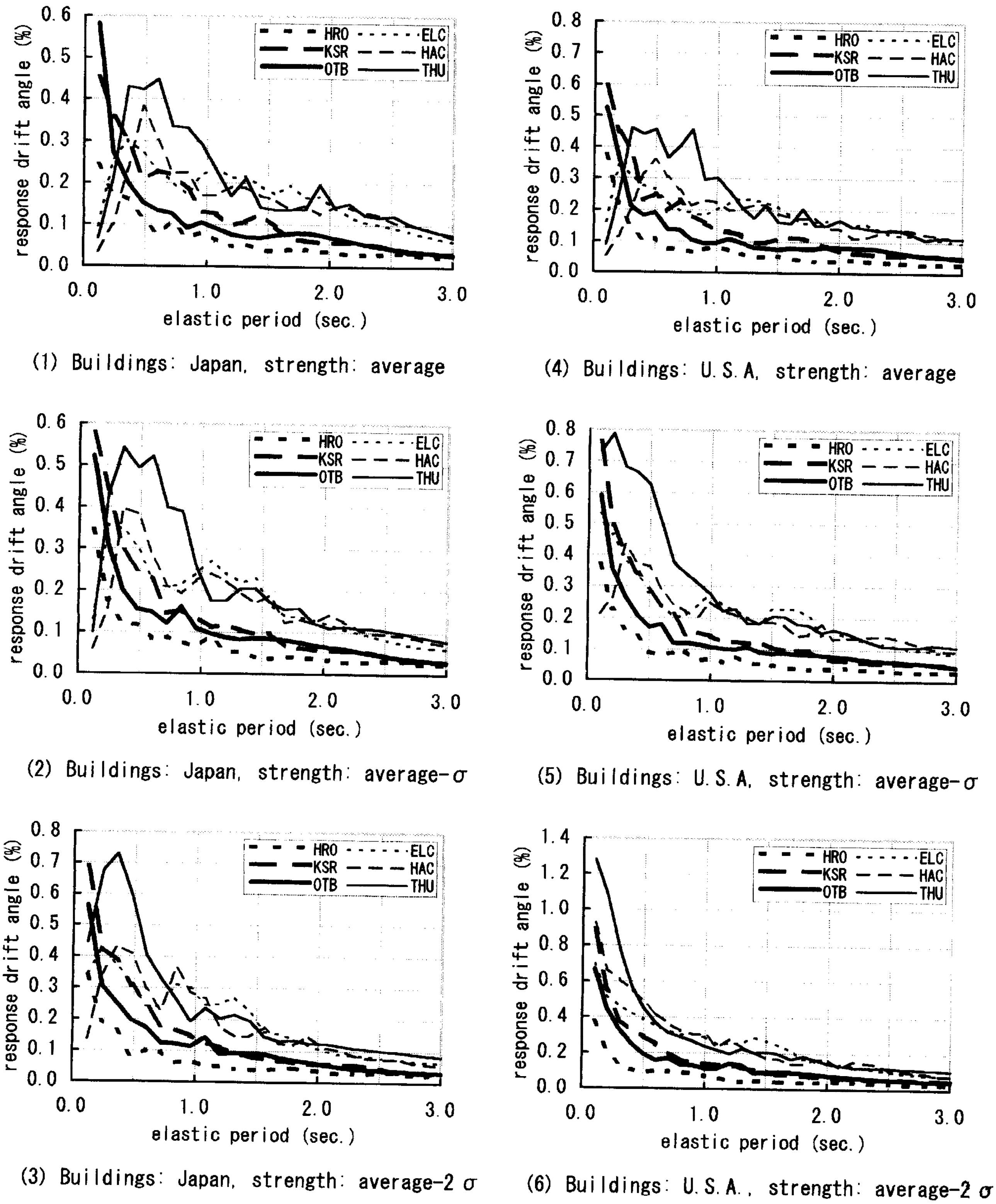


Fig.8 Inelastic drift angle spectra considering soil-structure interaction

point stiffness to initial elastic stiffness) =0.3 and base shear coefficient Cy = 0.3, yielding displacement dy comes to $Cymg/\alpha yk = CygTe^2/4\pi^2\alpha y = 0.09$ (cm), that is, yielding drift angle is dy/H = 1/3353. This is not actual. Response drift angles in inelastic analyses are calculated also by Eq.(1).

As for the strength of buildings, Is distribution investigated by research on RC buildings in Shizuoka prefecture, Japan (Nakano, 1988) and strength distributions statistically calculated from data on (Sozen, 1989) were used as Japanese and U.S.A. buildings strength distributions, respectively. This is considering the fact that short period buildings have a larger base shear coefficient than long period buildings. Is means the product of the base shear coefficient and the ductility of a building. To get base shear coefficient distributions, the ductility is assumed to be 1.5. Base shear coefficient distributions used in the analyses are shown in Fig. 7. Three lines means average, average-σ and average-2σ distributions, where σ is standard deviation, assuming base shear coefficients follow the logarithmic normal distribution (Nakano, 1988). The strength of buildings in Japan is considerably larger than in U.S.A.

Inelastic response drift angles considering soil-structure interaction are shown in Fig. 8, comparing 'high PGA motions' with 'general motions'. In this figure, responses using Japanese and U.S.A. building strength distribution are on the left and right side, respectively. In each side, three figures mean responses by average, average-σ and average-2σ building strength distributions in Fig. 7 from top to bottom. The difference of lines on same figures means the difference of records.

Comparing Fig. 8 with Fig. 5, the spectra move toward the short period, because of period extension by inelastic behavior of systems. The region in which the responses of 'high PGA motions' are larger than those of 'general motions' becomes narrow. The responses of 'high PGA motions' are smaller than those of 'general motions' except in the case of very short period. This tendency is more distinguished for lower strength distribution whose response drift angle spectra correspond to actual damage by an earthquake, because buildings with low strength are actually damaged by an earthquake. That means that the destructive power of 'high PGA motions' are smaller than that of 'general motions' in spite of their very high PGA.

DESTRUCTIVE POWER OF MOTIONS IN THE 1995 KOBE EARTHQUAKE

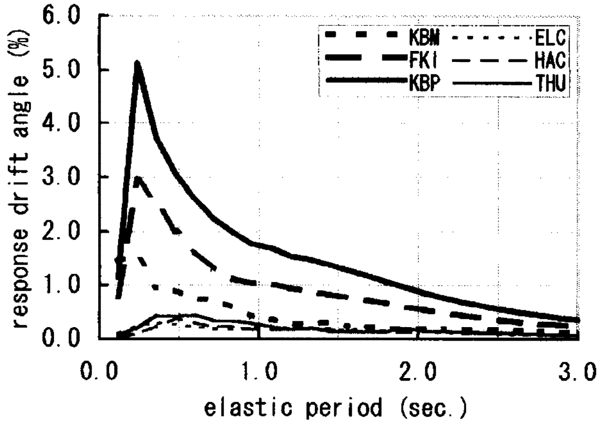
The destructive power of strong ground motions with high PGA but not so much actual building damage was proved to be small above, but the destructive power of any strong ground motion with high PGA is not small, of course. Finally, the destructive power of motions by the 1995 Kobe earthquake which brought about extremely severe damage was investigated. The input ground motions of the 1995 Kobe earthquake used in this analysis are shown in Table 2.

Table 2 strong ground motions recorded in the 1995 Hyogoken-nanbu earthquake used in this analysis

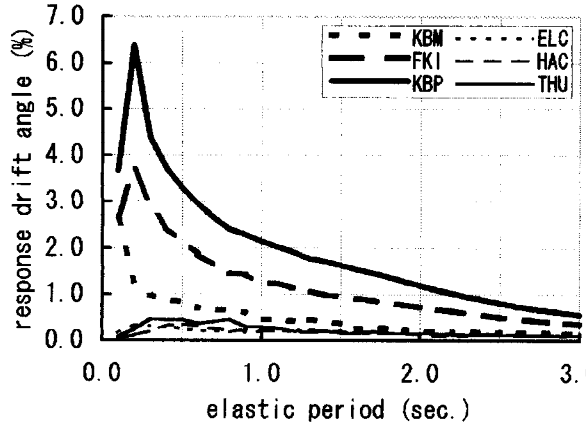
ID	station	direction	PGA*
KBM	Kobe Ocean Meteorological Agency	NS	818
FKI	Osaka Gas Fukiai Station	NS	802
KBP	Kobe Port 8th bank	NS	686

*PGA: peak ground acceleration (cm/sec.^{2})

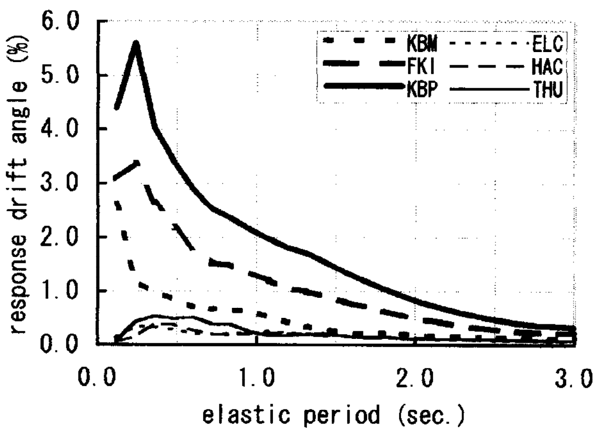
Inelastic response drift angles considering soil-structure interaction are shown in Fig. 9 just the same way as Fig. 8, comparing motions in the 1995 Kobe earthquake with 'general motions'. The destructive power of motions by the 1995 Kobe earthquake is incredibly large. This also shows the propriety of the method in this study.



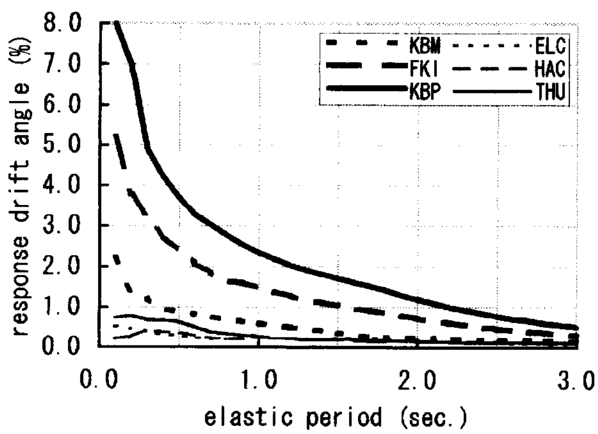
(1) Buildings: Japan, strength: average



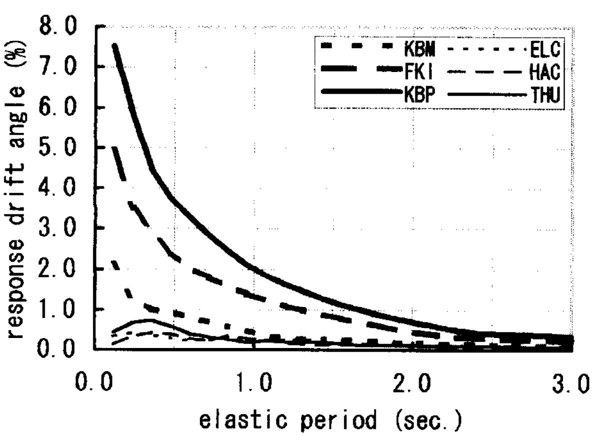
(4) Buildings: U.S.A, strength: average



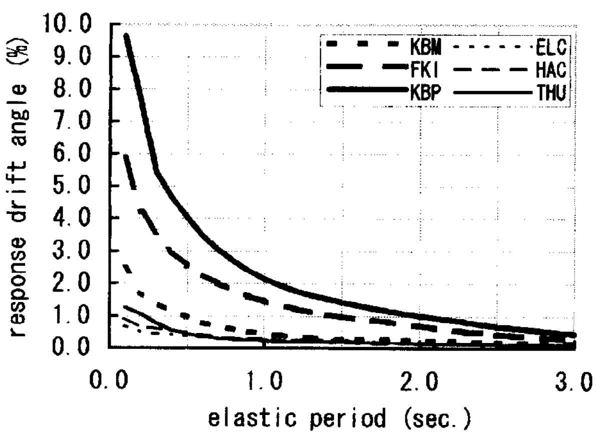
(2) Buildings: Japan, strength: average-σ



(5) Buildings: U.S.A, strength: average-σ



(3) Buildings: Japan, strength: average-2 σ



(6) Buildings: U.S.A., strength: average-2 σ

Fig.9 Inelastic drift angle spectra considering soil-structure interaction comparing motions in the 1995 Hyogoken-nanbu earthquake with often-used motions

CONCLUSION

The destructive power of strong ground motions with high peak ground acceleration (PGA), but not so much actual building damage was investigated. Response drift angles of single-degree-of-freedom systems by such motions and those by often-used motions were compared.

It was found that the destructive power of such strong ground motions was small in spite of their very high PGA, if soil-building interaction and inelastic behavior of buildings are considered. This means that PGA is not proper as an index for destructive power of strong ground motions.

Strong ground motions measured in the 1995 Kobe earthquake which brought about extremely severe damage were also investigated in the same method. The destructive power of these motions was found to be incredibly large.

ACKNOWLEDGMENT

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