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EXTREMELY LARGE POTENTIAL DESTRUCTIVENESS OF THE GROUND MOTIONS MEASURED IN THE 1995 KOBE EARTHQUAKE IN JAPAN

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ABSTRACT

The destructiveness of strong ground motions measured in the 1995 Hyogoken-nanbu earthquake was investigated. Elastic and inelastic responses of single-degree-of-freedom systems under the input of these ground motions and those by other strong ground motions were compared. It was found that the strong ground motions measured in the 1995 Hyogoken-nanbu earthquake had much larger destructive power than any other strong ground motions. The destructive power of these motions was higher than estimated from their peak ground acceleration.

KEYWORDS

the 1995 Hyogoken-nanbu earthquake; destructive power; peak ground acceleration; response drift angle

INTRODUCTION

The 1995 Hyogoken-nanbu earthquake which occurred on January 17 in 1995 with a magnitude of 7.2 brought about the severest damage since the 1923 Kanto earthquake in Japan. More than 6000 people were killed and more than 100,000 houses and buildings were severely damaged.

In this study, the destructiveness of strong ground motions recorded in Kobe by the 1995 Hyogoken-nanbu earthquake was investigated by comparing elastic and inelastic responses of single-degree-of-freedom (SDF) systems under the input of these ground motions with those by other strong ground motions.

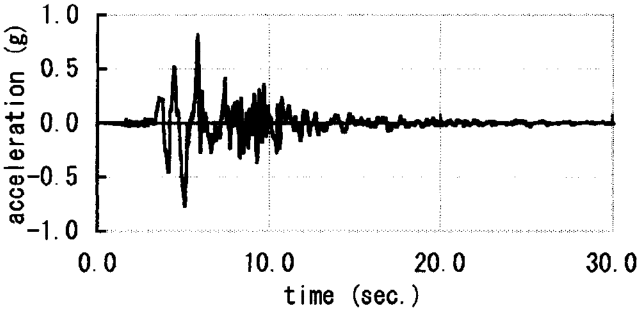
STRONG GROUND MOTIONS RECORDED IN THE 1995 HYOGOKEN-NANBU EARTHQUAKE

Some strong ground motions recorded in the 1995 Hyogoken-nanbu earthquake (Kobe earthquake) are shown in Table 1. This shows that very high peak ground accelerations (PGA) were recorded, but higher PGAs were recorded in the 1994 Northridge earthquake. Time history ground accelerations of strong ground motions recorded at Osaka Gas Fukiai station (FKI) and Kobe Port 8th bank (KBP), for example, are shown in Fig. 1. This figure shows that very high accelerations occurred many times and considerably long period dominated. Elastic response accelerations with a damping factor is 5% by motions in Table 1 are shown in Fig. 2. These are very high and don't reduce in the long period region, especially in the case of motions FKI and KBP.

Table 1 strong ground motions recorded in the 1995 Hyogoken-nanbu earthquake

ID	station	direction	PGA*
FKI	Osaka Gas Fukiai Station	NS	802
KBM	Kobe Ocean Meteorological Agency	NS	818
KBP	Kobe Port 8th bank	NS	686
KBU	Kobe University	EW	301
KBS	NTT Kobe-ekimae-sc	NS	331
SKB	Kansai Electric Power Shin-Kobe substation	EW	584

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



(1) FKI

(2) KBP

Fig. 1 Time history ground acceleration

STRONG GROUND MOTIONS USED IN ANALYSES

To estimate the destructive power of records measured in the Kobe earthquake, elastic and inelastic earthquake response analyses by SDF systems were performed. Some of the Kobe earthquake motions and other strong ground motions are used as input ground motions. The destructive power of records measured in the Kobe earthquake is estimated by comparing responses of the Kobe earthquake motions with other strong ground motions. Strong ground motions used in analyses are shown in Table 2. Motions KBM, FKI and KBP are selected from the Kobe earthquake motions in Table 1.

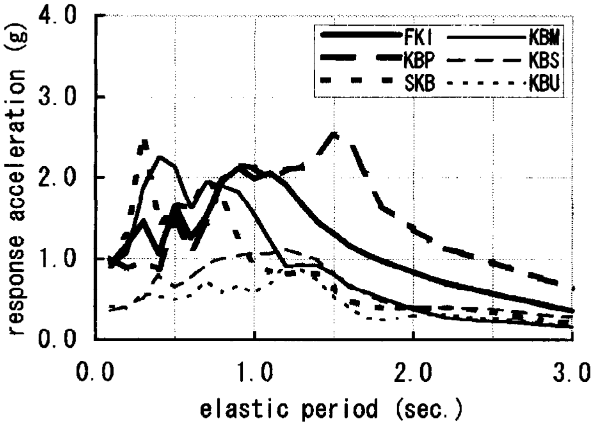


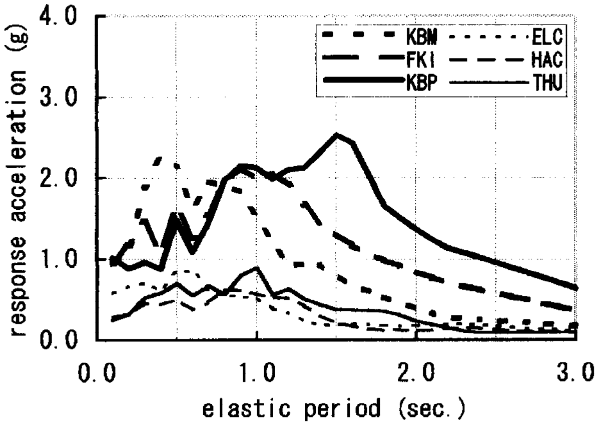
Fig. 2 Elastic acceleration spectra by records in the 1995 Hyogoken-nanbu earthquake

Table 2 strong ground motions used in analyses

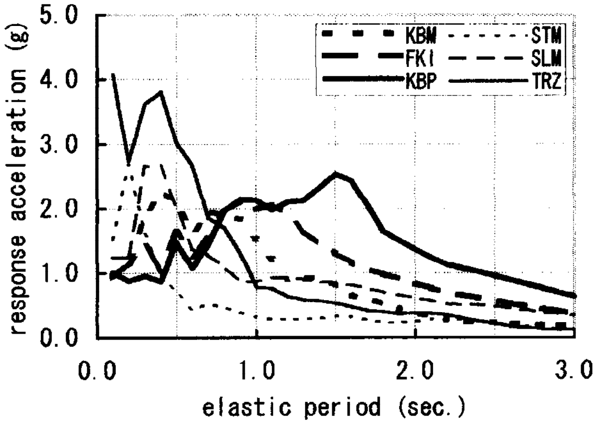
ID	station	direction	earthquake	PGA*
KBM	Kobe J.M.A.	NS	1995 Hyogoken-nanbu	818
FKI	Osaka Gas Fukiai Station	NS	1995 Hyogoken-nanbu	802
KBP	Kobe Port 8th bank	NS	1995 Hyogoken-nanbu	686
ELC	El-Centro	NS	1941 Imperial Valley	342
HAC	Hachinohe Kowan	EW	1968 Tokachi-oki	183
THU	Tohoku University	NS	1978 Miyagiken-oki	259
STM	Santa-Monica	EW	1994 Northridge	866
SLM	Sylmar	EW	1994 Northridge	827
TRZ	Tarzana	EW	1994 Northridge	1744
CDA	CDAF	EW	1985 Mexico	95
TLB	TLHB	NS	1985 Mexico	136
SCT	SCT1	EW	1985 Mexico	168

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

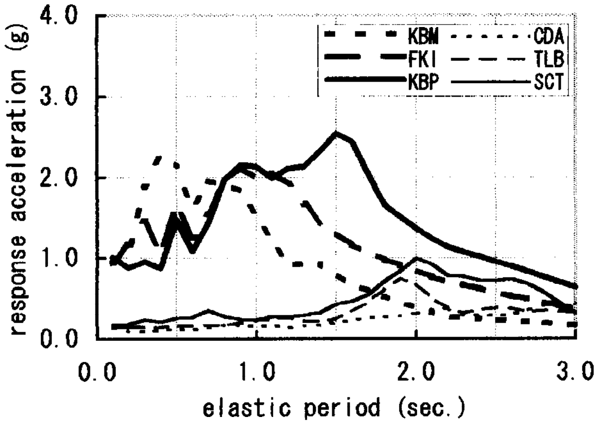
Three groups of strong ground motions are chosen to compare their responses with those by the Kobe motions. The first group is the motions often-used in earthquake response analyses. These are ELC, HAC and THU. The second group is the motions in the 1994 Northridge earthquake with very high PGA. These are STM, SLM and TRZ. The third



(1) Comparison with often used records

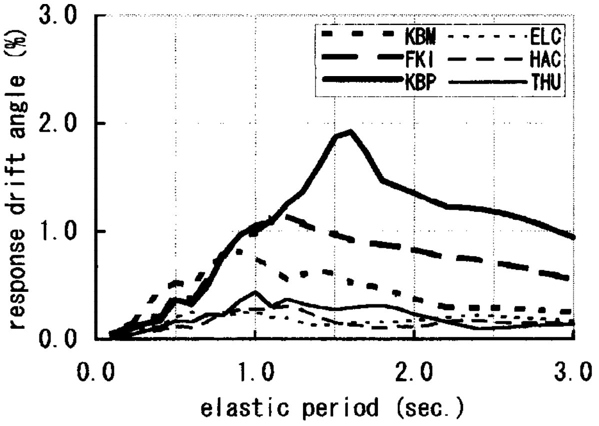


(2) Comparison with the 1994 Northridge records

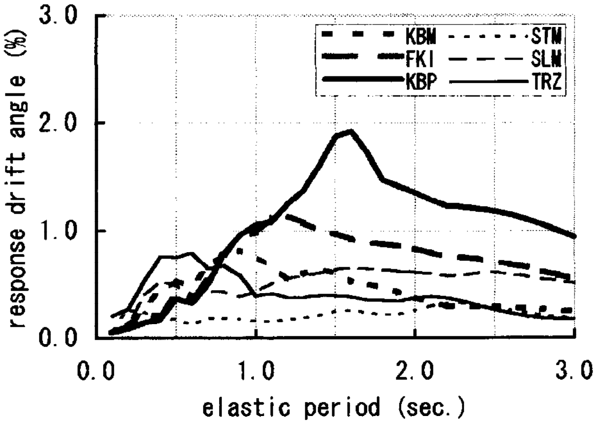


(3) Comparison with the 1985 Mexico records

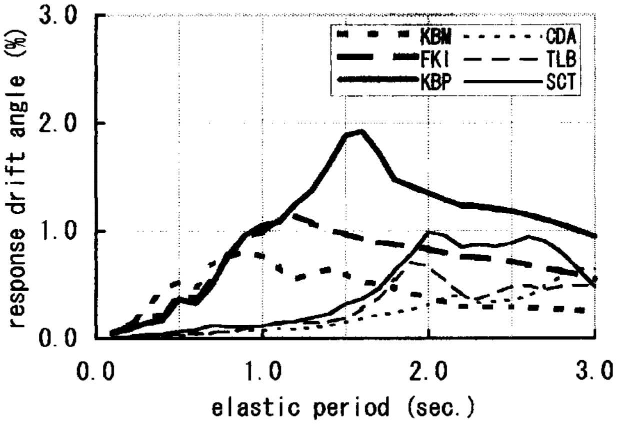
Fig. 3 Elastic acceleration spectra



(1) Comparison with often used records



(2) Comparison with the 1994 Northridge records



(3) Comparison with the 1985 Mexico records

Fig. 4 Elastic drift angle spectra

group is the motions in the 1985 Mexico earthquake which brought about as severe damage as the Kobe earthquake. Table 2 shows that PGAs of the motions of the Kobe earthquake are very high, but PGAs by the motions of the 1994 Northridge earthquake are larger than those of the Kobe earthquake.

ELASTIC RESPONSE ANALYSES

First, Elastic response analyses by SDF systems are performed. Elastic response acceleration spectra with a damping factor of 5% are shown in Fig. 3, comparing the Kobe records with the other three groups of records. Compared to the often-used records, the elastic response accelerations of Kobe records are larger in any period region. Compared to the 1994 Northridge records, the elastic response accelerations by the Kobe records are larger above the 0.7 sec. period region, but smaller below the 0.7 sec. period region. Compared to the 1985 Mexico records, the elastic response accelerations of Kobe records are larger even in the long period region.

Elastic response drift angle spectra with a damping factor of 5% are shown in Fig. 4. Damage of buildings should be estimated not by response acceleration but by regulated response displacement, thus Fig. 4 shows more actual damage than Fig. 3. Response drift angles were calculated by Eq.(1), assuming elastic period of a building is given by Eq.(2).

$$da = d/H = 0.02d/Te \tag{1}$$

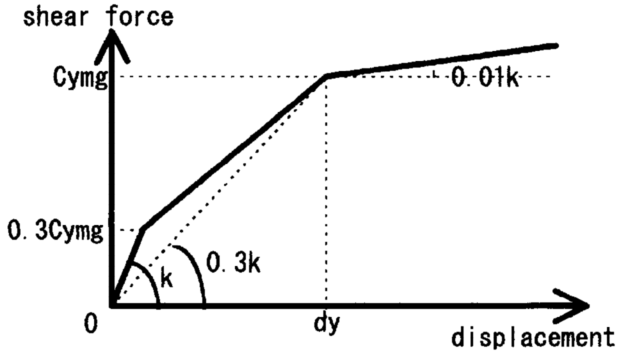
$$Te = 0.02H \tag{2}$$

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

Fig. 4 shows that the Kobe records have extremely large destructive power compared to the other records. It is distinguished especially between 1.0 sec. and 2.0 sec. period.

INELASTIC RESPONSE ANALYSES

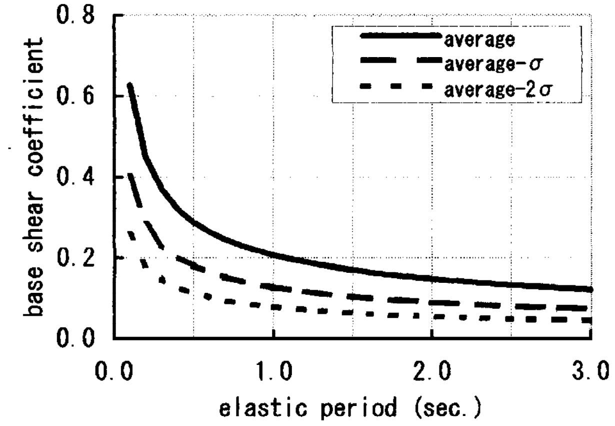
Next, earthquake response analyses for when the hysteresis characteristics of systems are inelastic were performed. The Takeda model (Takeda *et. al.*, 1970) is used as the hysteresis model of the system assuming reinforced concrete buildings. The skeleton curve is shown in Fig. 5.



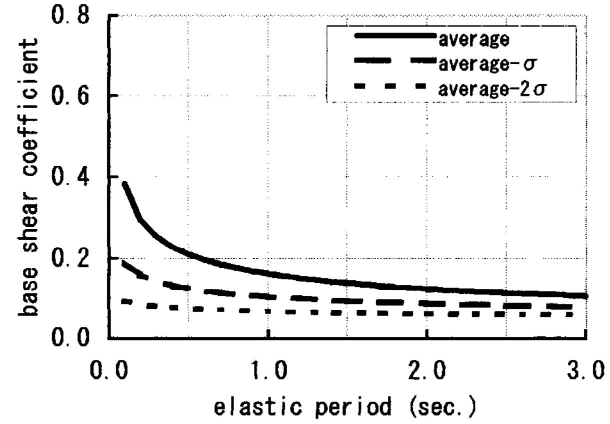
Cy: base shear coefficient, m: mass of system,
g: gravity, k: elastic stiffness,
dy: yielding displacement

Fig. 5 Skeleton curve of hysteresis model

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 a damage of a building, because an apparent yielding displacement dy is very small and not actual for very short period systems. 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 = 0.3 and base shear coefficient Cy = 0.3, yielding displacement dy comes to Cymg/ α yk = CygTe^2/4 π^2 α y = 0.09 (cm), that is,

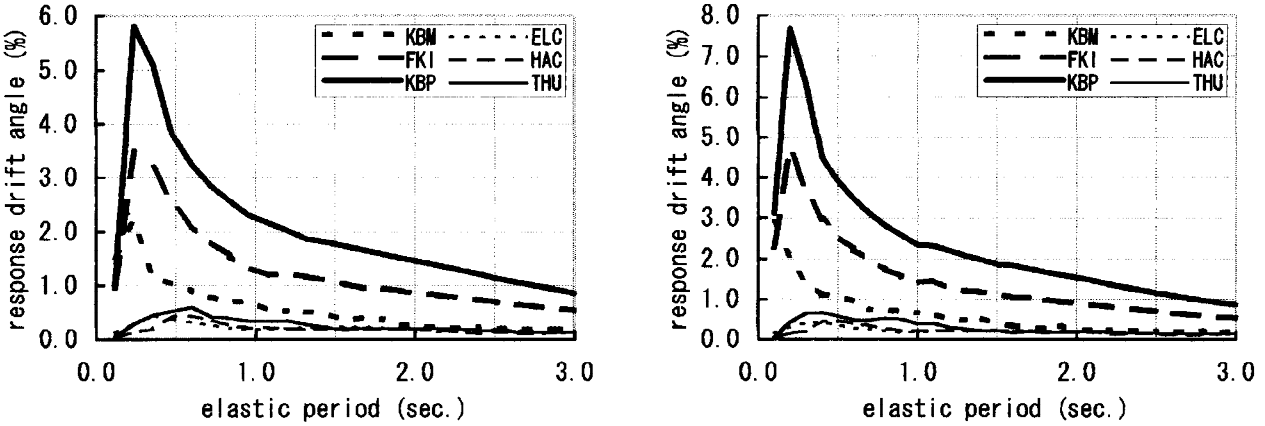


(1) Buildings in Japan

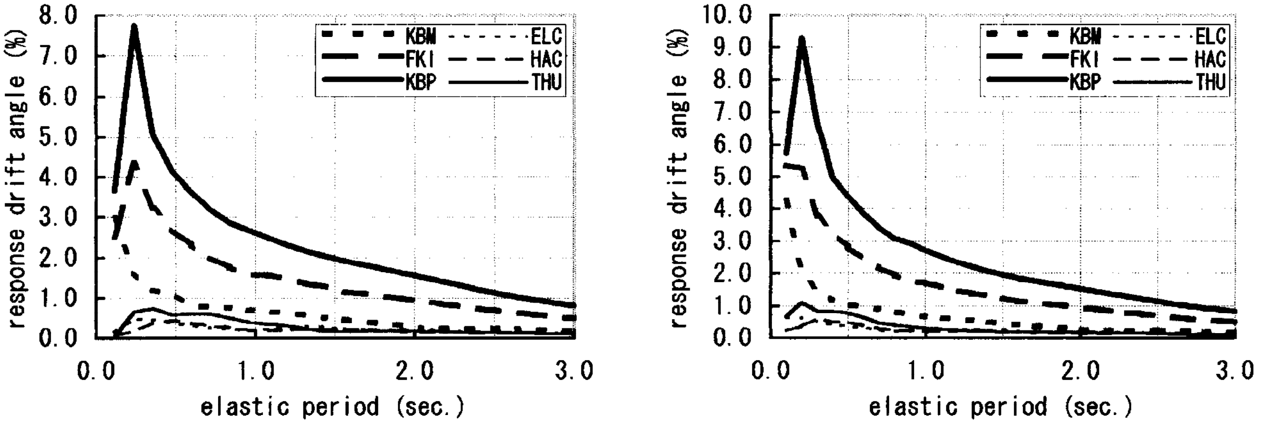


(2) Buildings in U.S.A.

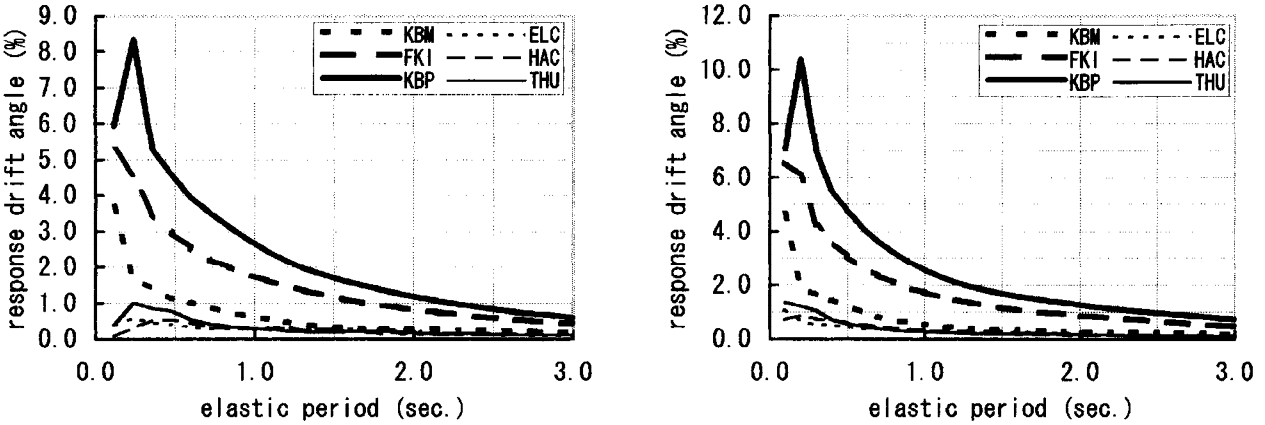
Fig. 6 Base shear coefficient distrubution



(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

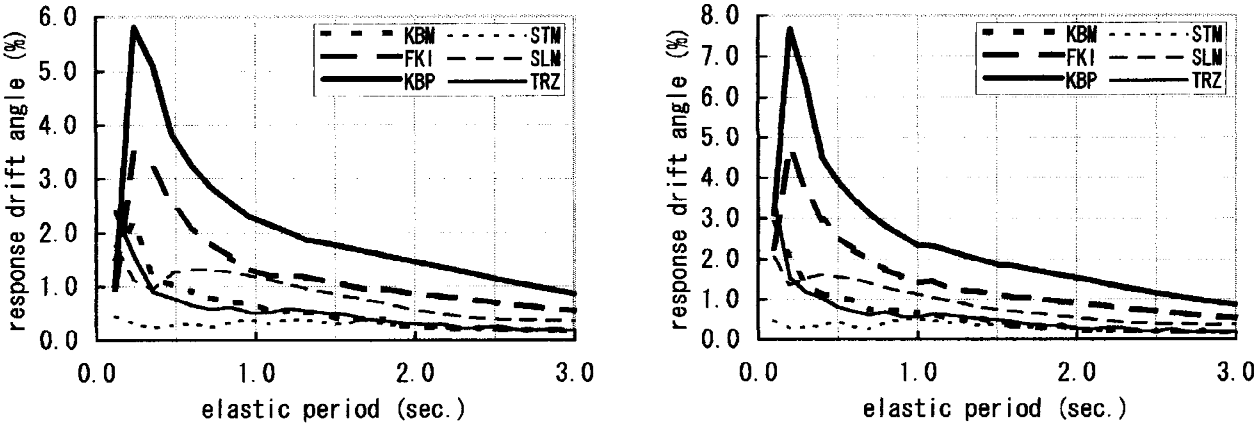


(3) Buildings: Japan, strength: average-2σ (6) Buildings: U.S.A., strength: average-2σ

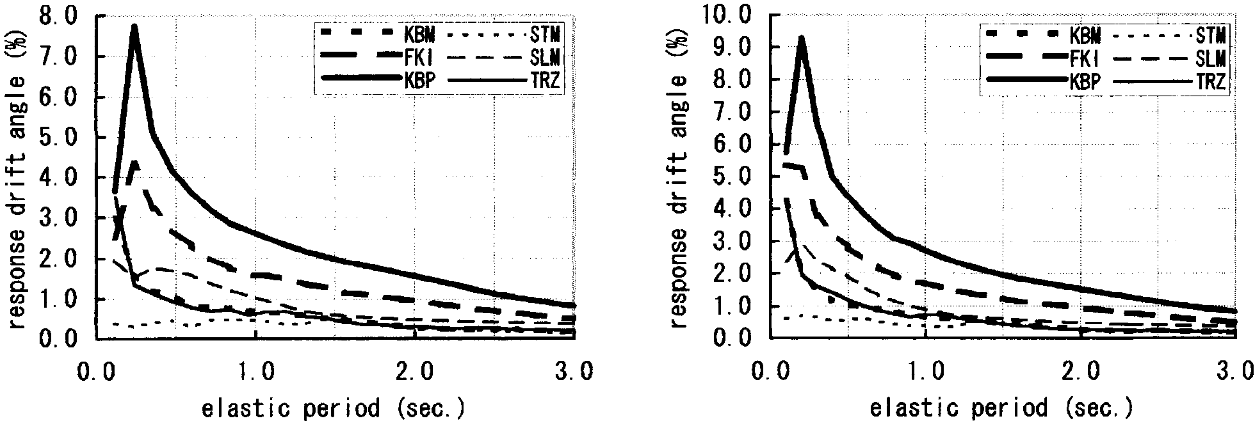
Fig. 7 Comparison with often-used records by inelastic response drift angle spectra

yielding drift angle is dy/H = 1/3353. This is not actual. Response drift angles in inelastic analyses are calculated also by Eq.(1).

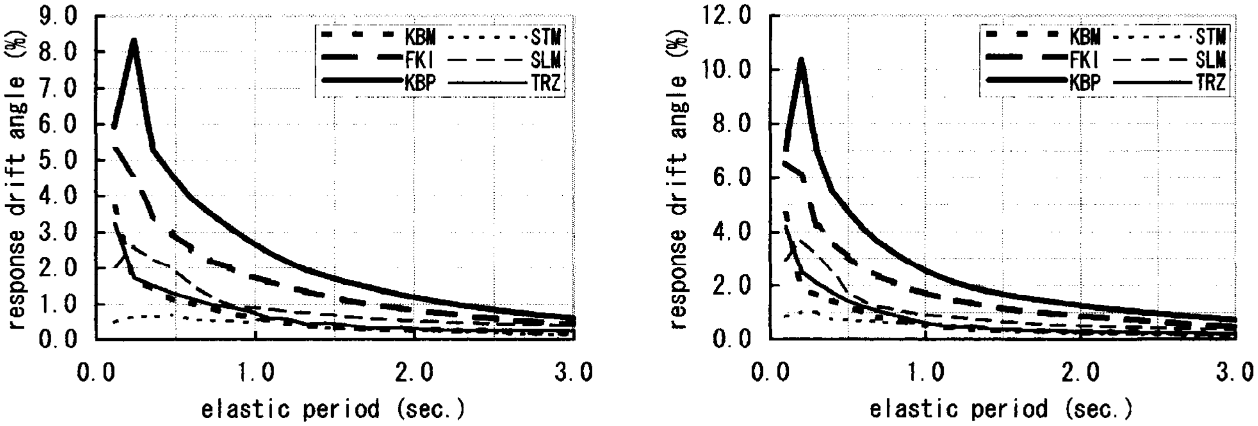
As for the strength of buildings, Is distribution investigated by a research on RC buildings in Shizuoka prefecture, Japan (Nakano, 1988) and strength distributions statistically calculated from data on (Sozen, 1989) were used for Japanese and U.S.A. buildings strength distributions, respectively. This 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



(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

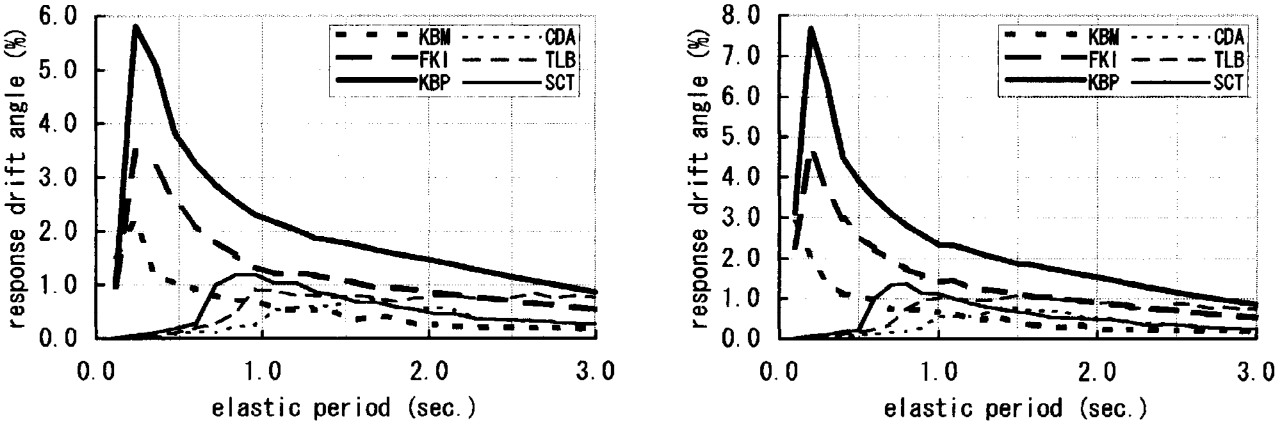


(3) Buildings: Japan, strength: average-2 σ (6) Buildings: U.S.A., strength: average-2 σ

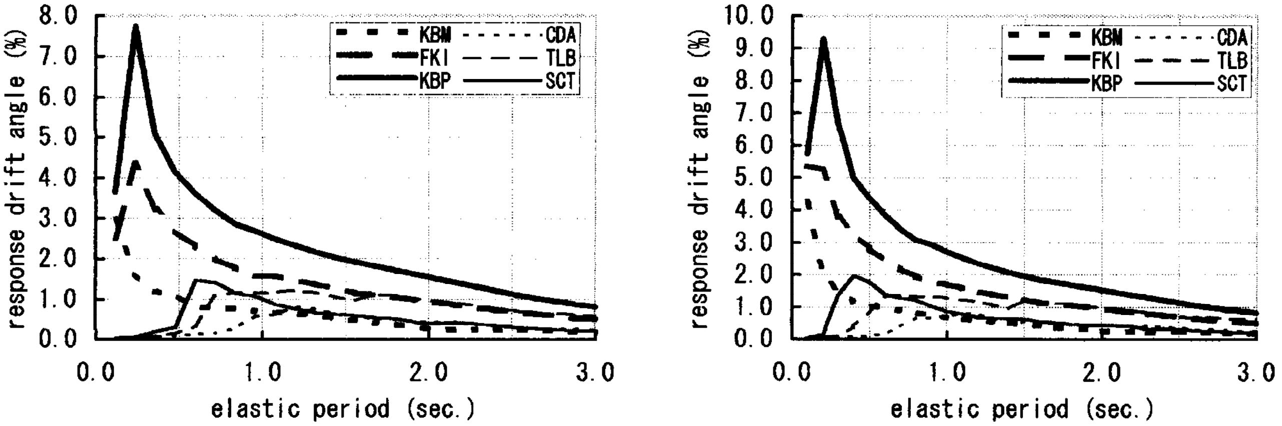
Fig. 8 Comparison with the 1994 Northridge records by inelastic response drift angle spectra

distributions, the ductility is assumed to be 1.5. Base shear coefficient distributions used in the analyses are shown in Fig. 6. Three lines means average, average-σ and average-2 σ 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.

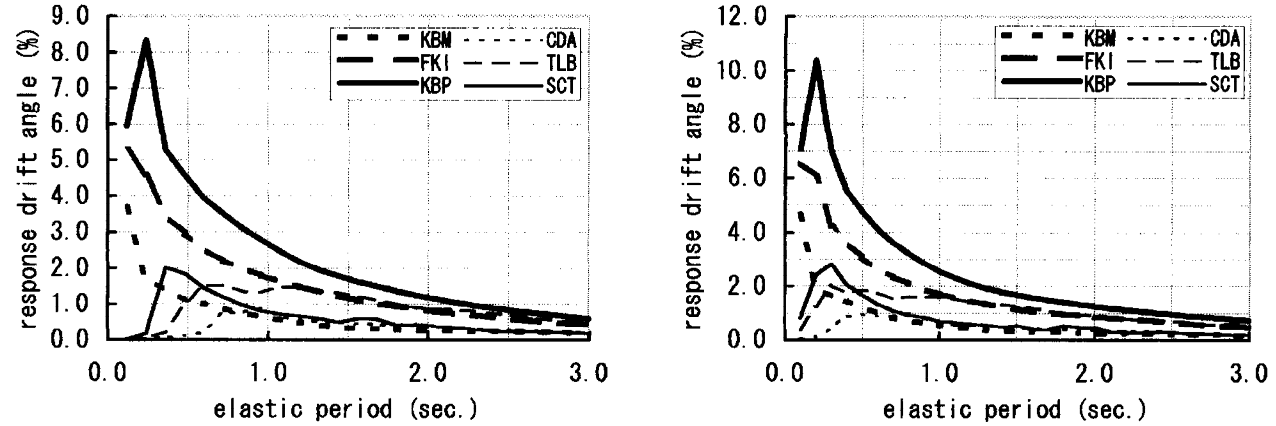
Response drift angles are shown comparing the Kobe motions with the often-used records, the 1994 Northridge records and the 1985 Mexico motions, in Fig. 7,8, and 9, respectively. In each figure, responses



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

Fig. 9 Comparison with the 1985 Mexico records by inelastic response drift angle spectra

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. 6 from top to bottom. The difference of lines on the same figures means the difference of records.

First, comparing Fig. 7,8 and 9 with Fig. 4, the region between 1.0 and 2.0 sec. where the Kobe records have extremely high destructiveness in Fig. 4 moves to below 0.5 sec. because of period extension by inelastic behavior of buildings. And the difference between the Kobe records and others becomes larger. Comparing the case of Japanese building with American ones, the responses difference is not so large for the difference of strength between them. It is expected by the property of displacement conservation by Newmark (Newmark *et. al.*,1960).

Comparing response drift angles from the Kobe records with others, in almost every case, response drift angles by the Kobe records are much larger than those of others. These are larger even than those of the 1994 Northridge records in spite of the PGAs of the Kobe records being smaller than the Northridge ones. These are larger than the 1985 Mexico records even in the long period region. The difference between them is larger for smaller strength distribution. Response drift angle spectra for building with small strength correspond to actual damage by an earthquake, because buildings with low strength are actually damaged by an earthquake. In short, the destructiveness of the Kobe records are much larger than any other motions.

CONCLUSION

The destructiveness of strong ground motions measured in the 1995 Hyogoken-nanbu earthquake was investigated by comparing elastic and inelastic responses of single-degree-of-freedom systems under the input of these ground motions with those by other strong ground motions.

It was found that the strong ground motions recorded in the 1995 Hyogoken-nanbu earthquake had much larger destructive power than any other strong ground motions. The destructive power of the Kobe motions is larger even than that of the 1994 Northridge records in spite of PGAs of the Kobe records being smaller than the Northridge ones and larger than that of the 1985 Mexico records even in the long period region.

ACKNOWLEDGMENT

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