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SEISMIC CAPACITY OF EXISTING REINFORCED CONCRETE BUILDINGS

by

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ABSTRACT

This report describes the seismic capacity of existing reinforced concrete buildings in Japan, comparing with that of damaged buildings due to recent severe earthquakes. Statistical data used herein are seismic capacity of existing reinforced concrete buildings in Shizuoka Prefecture, both before and after strengthening. From probabilistic point of view, damage ratio due to severe earthquake and effects by strengthening are also estimated.

INTRODUCTION

A large number of reinforced concrete (R/C) buildings designed by seismic codes have been constructed in Japan. However, recent earthquake damages suggest us that some of them have not sufficient seismic capacity. In Shizuoka Prefecture, where a severe earthquake is predicted to occur in near future from a seismological point of view, the seismic capacity of more than 3,000 public buildings has been evaluated and some of them have already been strengthened or demolished.

This paper will focus on 1) seismic capacity of buildings damaged due to recent severe earthquakes in Japan, 2) seismic capacity of existing buildings both before and after strengthening, 3) relationship between the decision criteria and the seismic capacity of damaged and existing buildings, and 4) applicability of probabilistic approach to estimate the effects by strengthening and the earthquake damage ratio.

SEISMIC CAPACITY OF EXISTING AND DAMAGED BUILDINGS

Fig.1 shows the distribution of seismic capacity of 1,615 existing R/C buildings in Shizuoka Prefecture, where Is-indices by the second level

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non-linear earthquake response analysis in consideration of ground acceleration level, soil condition, and type of failure, in which 5% probability of failure was accepted as a risk level. Consequently, a building with Is-index listed in Table 1 may avoid damage in 95% probability. Table 1 indicates that Is-index larger than about 0.6 should be required in order to survive a severe earthquake, the intensity of which is nearly equal to Tokachi-Oki or Miyagi-Ken-Oki Earthquake[4]. This value is approximately upper bound of E_T-index shown in Fig.3.

It should be noted that the earthquake intensity during both Tokachi-Oki Earthquake and Miyagi-Ken-Oki Earthquake is assumed about 0.23g. In Fig.4, the damage ratios to 0.36g and 0.45g earthquake calculated by Eqs.(1) and (2), where the mean value of p_{ET} is multiplied in proportion to the ground acceleration level, are also illustrated.

SEISMIC CAPACITY OF STRENGTHENED BUILDINGS AND ITS EFFECTS

Fig.5 shows the distribution of Is-indices of 242 strengthened buildings in Shizuoka Prefecture, comparing with that of existing buildings shown in Fig.1. Most of them are three or four storied school buildings. In order to estimate the effects by strengthening, the distribution of Is-indices and the damage ratio after strengthening are calculated with assumption that 1) the distribution of Is-indices can be approximated by a log-normal probability density function as shown in Fig.5, and 2) the mean value and the standard deviation of Is-indices of strengthened buildings remain constant even if the number of strengthened buildings are increased. The distribution of Is-indices after strengthening, therefore, can be defined as ;

$$p_{Rs}(x) = p_{Is}(x) - Rs \cdot p_{BS}(x) + Rs \cdot p_{AS}(x) \quad \cdots\cdots \quad (3)$$

where,
- $p_{Rs}(x)$: distribution of Is-indices for total buildings including strengthened buildings
- $p_{Is}(x)$: distribution of Is-indices for unstrengthened buildings (curve 1)
- $p_{BS}(x)$: distribution of Is-indices for strengthened buildings before strengthening (log-normal fn.)
- $p_{AS}(x)$: distribution of Is-indices for strengthened buildings after strengthening (log-normal fn.)
- Rs : strengthened ratio; i.e. ratio of number of strengthened buildings to that of total buildings
- x : Is-index

Fig.6 shows the distribution of Is-indices corresponding to strengthened ratio Rs equal to 10%, 20%, 30%, 40%, respectively, which screening procedure[1] to both directions of each building are plotted. Most of them are three or four storied school buildings, designed and constructed before the code revision in 1970. As shown in the figure, the distribution of the Is-indices may be approximated by a log-normal probability density function (curve 1).

The hatched area in Fig.1 shows the histogram of Is-indices of moderately or severely damaged buildings due to 1968 Tokachi-Oki Earthquake or 1978 Miyagi-Ken-Oki Earthquake. In this figure, a modification is employed so that the number of damaged buildings become 10% of the total number of buildings, because damage ratios due to these two earthquakes were approximately 10%[2),3)].

Fig.1 indicates the probabilistic feature of the decision criteria for screening sound buildings. Fig.2 shows a schematic expression of the Is-index of both existing and damaged buildings. The shape of Fig.1 is quite similar to Fig.2(b). If the required seismic capacity E_T-index is deterministic, the damage ratios in the past two earthquakes would be greater than 10%.

Defining p_{Is} and p_{ET} which represent the probability density functions of Is-index and E_T-index, respectively, the damage ratio **V** (ratio of damaged buildings to total buildings) is expressed in the following general formula;

$$\mathbf{V} = \int_0^{\infty} p_{Is}(x) \cdot [1 - \int_0^{x} p_{ET}(r)dr]dx \qquad \text{.................... (1)}$$

Setting

$$v(x) = p_{Is}(x) \cdot [1 - \int_0^{x} p_{ET}(r)dr] \qquad \text{...................... (2)}$$

the term of v(x) may be considered to represent the distribution of Is-indices of damaged buildings shown in Fig.1. Substituting the function p_{Is} in Fig.1 approximated by a log-normal probability density function (curve 1) and the relative frequency of Is-indices of damaged buildings shown as hatched part in Fig.1 into Eq.(2), we obtain the probabilistic distribution of E_T-indices (p_{ET}) as shown in Fig.3.

Assuming the normal distribution, we obtain the probability density function of E_T-indices as shown in Fig.3 (curve 2). The curve 3 in Fig.1 is obtained by Eq.(2), where function p_{Is} in Fig.1 (curve 1) and function p_{ET} in Fig.3 (curve 2) are used. Table 1 shows an example of E_T-indices required in the lowest seismic zone in Shizuoka Prefecture, where the predicted acceleration to building base is approximately twenty three percent of the gravity (0.23g). These values in Table 1 are obtained by indicates the distribution shifts to the larger value in Is-index and the peak value also shifts around 1.0 with increase of strengthened buildings.

The damage ratios were estimated by the following two different procedures ;

First, a) the failure probability $[1-\int p_{ET}(r)dr]$ of buildings with the same Is-index is constant to the same ground acceleration level, whether the buildings have been strengthened or not. Replacing $p_{Is}(x)$ in Eq.(1) with previously defined $p_{Rs}(x)$ in Eq.(3), the damage ratio **V**, therefore, can be calculated as ;

$$\mathbf{V} = \int_0^{\infty} p_{Rs}(x) \cdot [1-\int_0^{x} p_{ET}(r)dr]dx \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (4)$$

Secondly, b) the strengthened buildings shall never suffer from earthquake damage. By modifying the term v(x) in Eq.(2), the damage ratio **V**, therefore, can be calculated as ;

$$\mathbf{V} = \int_0^{\infty} [v(x)-Rs \cdot p_{BS}(x)]dx \ ; \quad [v(x)-Rs \cdot p_{BS}(x)] \geq 0 \quad \cdots\cdots \quad (5)$$

The results are shown in Fig.7. The two procedures a) and b) are considered to represent the lower and upper bound of effectiveness by strengthening, respectively. Fig.7 shows that when Rs=40%, the damage ratio becomes almost zero to 0.23g earthquake, but still remains more than 20% to 0.45g earthquake.

CONCLUDING REMARKS

1) E_T-indices in Table 1 approximately corresponds to the upper bound of distribution of E_T-indices in Fig.3 obtained by the seismic capacity relationship of existing and damaged buildings.
2) It may be possible to estimate the damage ratio to different level of ground acceleration with the modification of function p_{ET} in the Eq.(1), because the mean value of p_{ET} may be proportional to the level of ground acceleration.
3) It is possible to estimate the effects by strengthening applying probabilistic procedures.
4) Relationship between the strengthened ratio and the damage ratio can be estimated by the proposed method in this paper.

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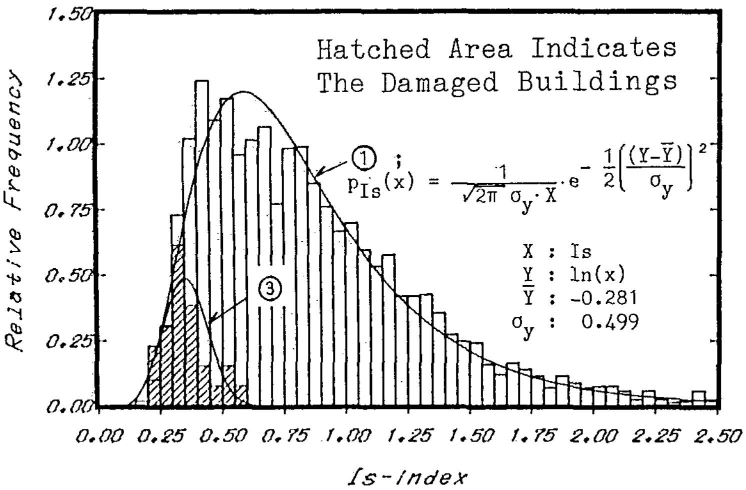
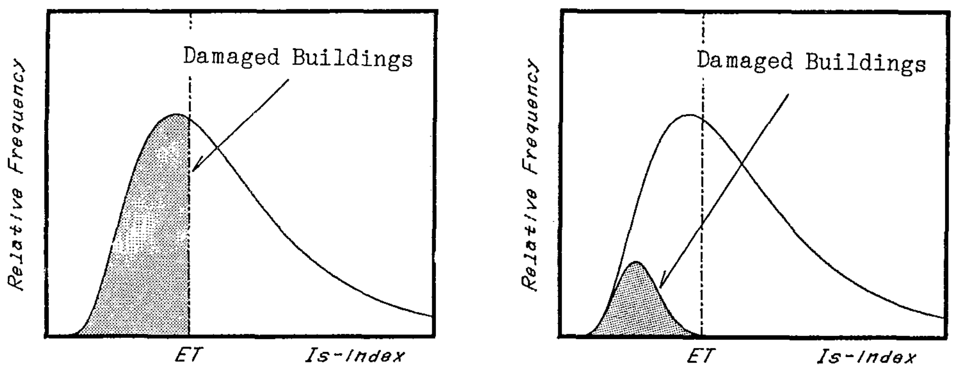


Fig. 1 : Distribution of Is-Index for Existing And Damaged Buildings



(a) ET-Index Is Deterministic

(b) ET-Index Is Probabilistic

Fig. 2 : Distribution of Is-Index For Damaged Buildings

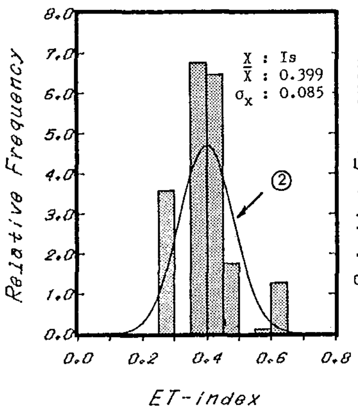


Fig. 3 : Distribution of ET-Index

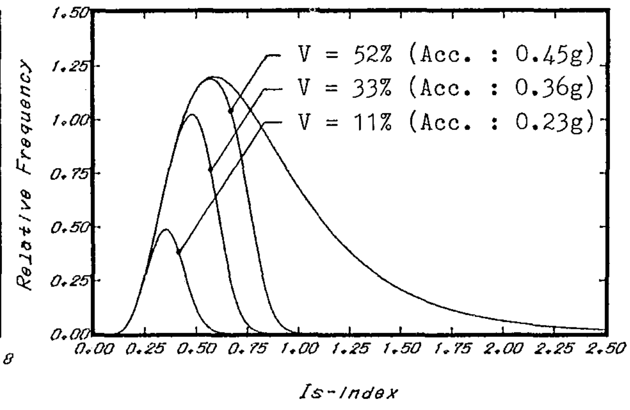


Fig. 4 : Damage Ratio V

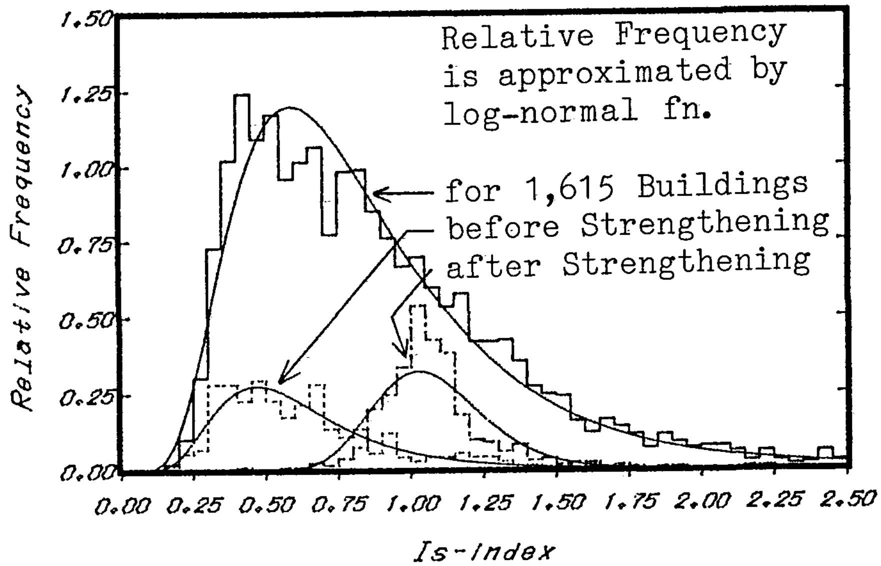


Fig.5 : Distribution of Is-Index For Strengthened Buildings

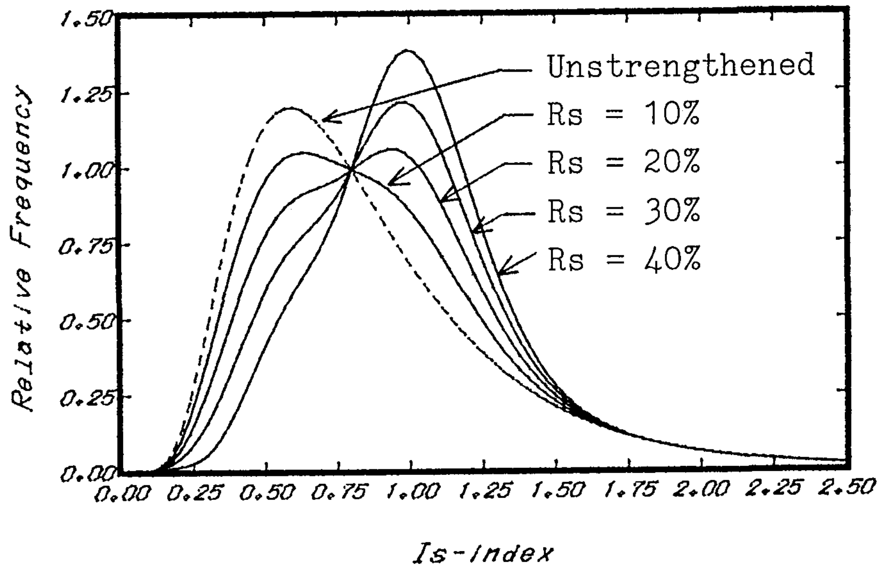


Fig.6 : Distribution of Is-Index After Strengthening

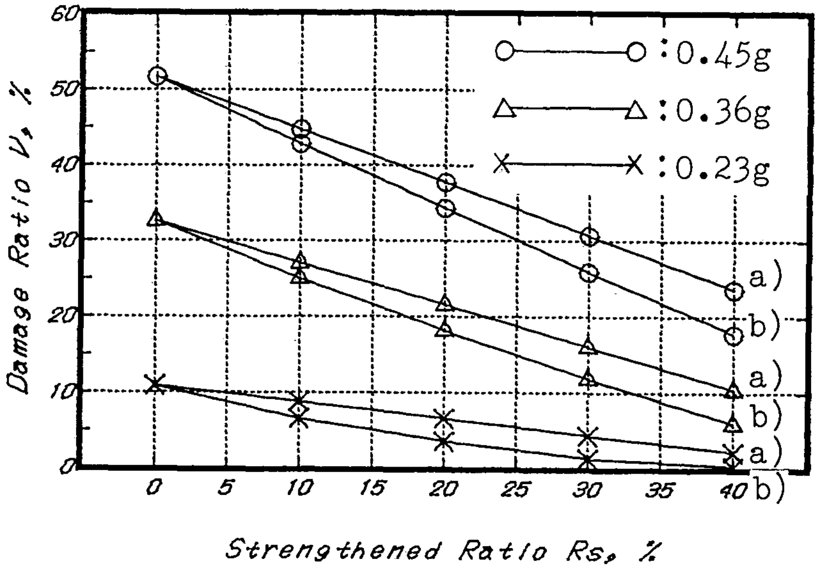


Fig.7 : Strengthened Ratio vs. Damage Ratio

Table 1 : E_T-Indices for Maximum Ground Acc. of 0.23g Earthquake[4)]

N \ T_G	0.3 sec.	0.4 sec.	0.5 sec.	0.6 sec.	0.7 sec.	0.8 sec.
1	0.80 (0.70)	0.70 (0.70)	0.65 (0.65)	0.60 (0.60)	0.55 (0.55)	0.50 (0.50)
2	0.70 (0.60)	0.70 (0.60)	0.65 (0.60)	0.60 (0.60)	0.55 (0.55)	0.50 (0.50)
3	0.65 (0.60)	0.65 (0.60)	0.65 (0.60)	0.60 (0.60)	0.55 (0.55)	0.50 (0.50)
4	0.60 (0.55)	0.60 (0.55)	0.60 (0.55)	0.60 (0.55)	0.55 (0.55)	0.50 (0.50)
5	0.60 (0.55)	0.60 (0.55)	0.60 (0.55)	0.60 (0.55)	0.55 (0.55)	0.50 (0.50)
6	0.60 (0.50)	0.60 (0.50)	0.60 (0.50)	0.60 (0.50)	0.55 (0.50)	0.50 (0.50)

N : Number of Stories T_G : Predominant Period of Ground
Values in parentheses are for ductile buildings