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ASEISMIC DESIGN LEVEL USING RESPONSE SPECTRUM FOR WOODEN HOUSES

Koji Yamada[1]

ABSTRACT: Reviewed equations for horizontal resistant force of Japanese wooden houses are discussed in considering both the acceleration response spectrum with sharp peaks and the acceleration response spectrums of observed earthquake motion. This acceleration spectrum with sharp peaks is the sum of Minimum requirement spectrum and the order spectrum. The observed earthquake motions are divided into 2 groups. The one consists of Kobe JMA 1995, the motions distributed by BCJ. The other consists of 592 motions observed from 1996 to 2012 in Japan, their maximum acceleration are over 400 cm/s^2. The new horizontal resistant force is defined as the product of the coefficient of eccentricity ratio, the coefficient of a damping factor, and the coefficient of horizontal resistant force. This coefficient of horizontal resistant force is the function of the ductility factor, the natural period, the period of a response spectrum peak and its acceleration. The verification of the proposed coefficient of horizontal resistant force is checked by the ratio of the ductility factor subjected to input earthquake motions over the set ductility factor. As a result, the response analysis shows that the proposed equations give the safe side of the horizontal resistant force.

KEYWORDS: Acceleration response spectrum, Structural design, Base shear coefficient

1 INTRODUCTION

It is difficult to estimate input earthquake motions accurately in response analysis. Then the response spectra are used to define the input earthquake motions in structural design. In Japan, base shear coefficient is given in structural code. This base shear coefficient is related the acceleration response spectrum in [1]. Therefore, it is useful that the base shear coefficient is calculated from any acceleration response spectrum. In previous paper [2], new equations for base shear coefficient are discussed in considering the acceleration response spectrum with sharp peaks. The new base shear coefficient (Co) is defined as the product of the coefficient of eccentricity ratio(Fes), the coefficient of a damping factor(Fh), and the coefficient of horizontal resistant force(Ds). This coefficient of horizontal resistant force is the function of the ductility factor(μ), the natural period (Ts), the period of a response spectrum peak and its acceleration. This proposed base shear coefficient is discussed by the average of the maximum ductility factors by 10 input motions. In this paper, reviewed equations for horizontal resistant force of Japanese wooden houses are discussed in considering both the acceleration response spectrum with sharp peaks and the acceleration response spectrums of observed earthquake motion. The new horizontal resistant force is defined as the product of the coefficient of eccentricity ratio, the coefficient of a damping factor, and the coefficient of horizontal resistant force. This coefficient of horizontal resistant force is the function of the ductility factor, the natural period, the period of a response spectrum peak and its acceleration.

2 TARGET ACCELERATION SPECTRUM AND ANALYSIS SUPPOSITION

2.1 TARGET ACCELERATION SPECTRUM

The target acceleration spectra are shown in Fig.1. This acceleration spectrum is the sum of Minimum requirement spectrum and the order spectrum. The minimum requirement spectrum has the corner period (Tc), and the order spectrum has the peak periods(Ti).
The input earthquake motions are shown in Fig.2. There 10 input earthquake motions in each spectrum. Each input earthquake motion has random phase and 163.84 sec duration time. The minimum requirement spectrum has the 0.86 sec corner period and 1200gal constant acceleration spectrum region. The target spectrum A has both minimum requirement spectrum and 1400gal peak at 0.4sec natural period. The target spectrum B has both minimum requirement spectrum and 2000gal peak at 0.4sec natural period. The target spectrum C has minimum requirement spectrum, 1400gal peak at 0.4sec natural period and 1400gal peak at 1.2sec natural period. The input earthquake motions are multiplied 0.8 for response analysis of 1 DOF model.

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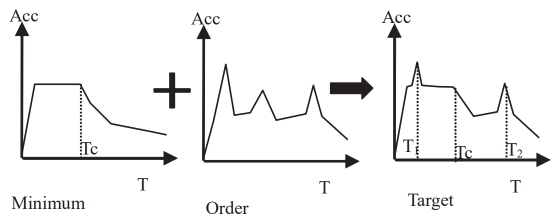
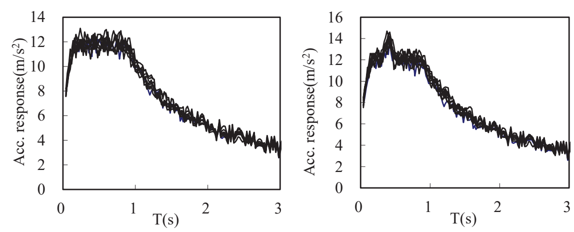
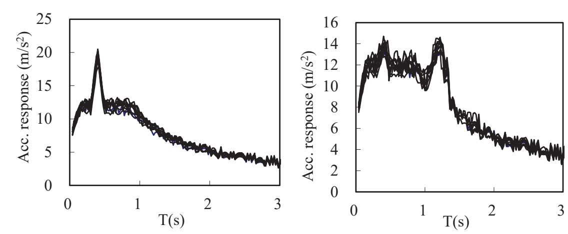


Figure 1: *Acceleration response spectrum for structural design*



a) Minimum requirement *b) Target spectrum A*



c) Target spectrum B *d) Target spectrum C*

Figure 2: *Acceleration response spectrum of input earthquake motions(h=0.05)*

2.2 OBSERVED EARTHQUAKE MOTIONS

The observed earthquake motions are divided into 2 groups. The one consists of Kobe JMA 1995, the motions distributed by BCJ. The other consists of 592 motions observed from 1996 to 2012 in Japan, their maximum acceleration are over 400 cm/s^2.

2.3 PROPOSED BASE SHEAR COEFFICIENT

The proposed base shear coefficient (Co) in Eq.(1) is defined in [2] as the product of the coefficient of eccentricity ratio(Fes), the coefficient of a damping factor(Fh), and the coefficient of horizontal resistant force(Ds). This coefficient of horizontal resistant force is the function of the ductility factor(μ), the natural period (Ts), the period of a response spectrum peak and its acceleration in Eq.(3) - (7). Three restoring force characteristics are considered in this paper(Fig.3). The coefficient is the bearing force of Bi-linear component over the whole bearing force. The parameters of restoring force characteristic are the natural period(T) and the bearing force(Co). The natural periods are set from 0.2 to 3.0sec. The bearing force is calculated by Eq.(1) - (7). The damping factor(ho) is 0.05 basically, are 0.02 and 0.10 for parameter analysis.

$$C_o = F_{es} F_h \overline{D_s} \tag{1}$$

$$F_h = \sqrt{\frac{1+\alpha h_o}{1+\alpha h_{eq}}} \tag{2}$$

$$\alpha = 25$$

$$\overline{D_s} = D_{si} C_{oi} \tag{3}$$

$$C_{oi} = 0.816 * Acc(T) / 980 \tag{4}$$

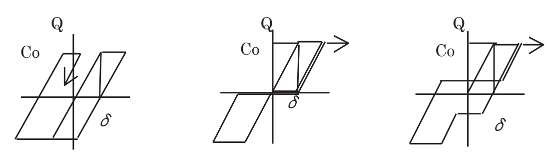
For Minimum requirement

$$D_{sc} = \begin{cases} \dfrac{1}{\sqrt{2\mu-1}} + \beta \dfrac{T_c - T}{T_c} & T \le T_c \\ \dfrac{1}{\sqrt{2\mu-1}} \dfrac{T_c}{T} & T > T_c \end{cases} \tag{5}$$

For customer order requirwement

$$D_{si} = \begin{cases} \dfrac{1}{\sqrt{2\mu-1}} + \beta \dfrac{T_i - T}{T_i} & T \le T_i / 0.8 \\ 0 & T > T_i / 0.8 \end{cases} \tag{6}$$

$$\beta = \begin{cases} 0.1 & Bi-linear \\ 0.5 & Slip \\ 0.5 - 0.4\gamma & Composite \end{cases} \tag{7}$$



a) Bi-linear b) Slip c) composite

Figure 3: *Restoring force characteristic*

Hence, the restoring force characteristic of a wooden house is shown in Fig.4. It seems like the composite type. The calculation value of β is 0.47, I suppose β as 0.5. The natural period of a wooden house is supposed as 0.4 sec. The adequacy of the proposed base shear coefficient at 1/120 rad is checked up by the ductility factor subjected to input earthquake motions over the set ductility factor (μ). Hereinafter, the ratio of the ductility factor subjected to input earthquake motions over the set ductility factor (μ) is called the ductility factor ratio.

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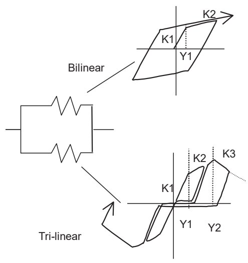


Figure 4: Restoring force characteristic of a wooden house

3 VERIFICATION

3.1 VERIFICATION OF PROPOSED BASE SHEAR COEFFICIENT ON TARGET ACCELERATION SPECTRUM

Firstly, the proposed base shear coefficient is checked by input earthquake motions in Fig.2. The ductility factor ratio is shown in Fig.5. The ductility factor ratio is between 0.2 and 0.4. These ductility factor ratios are too small for a design code. The new equations are proposed in Eq.(8) and (9).

For Minimum requirement

$$\begin{aligned} \overline{D_s} &= D_{sc} C_{oc} \\ C_{oc} &= 0.816 * Acc / 980 \\ D_{sc} &= \begin{cases} \dfrac{1}{\sqrt{4\mu - 1}} + \beta \dfrac{T_c - T}{T_c} & T \le T_c \\ \dfrac{1}{\sqrt{4\mu - 1}} \dfrac{T_c}{T} & T > T_c \end{cases} \end{aligned} \tag{8}$$

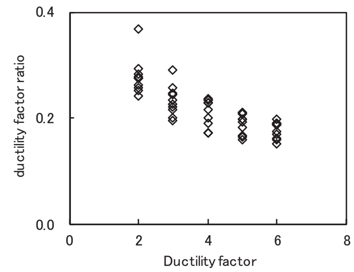
For customer order requirement

$$\begin{aligned} \overline{D_s} &= D_{si} C_{oi} \\ C_{oi} &= 0.816 * Acc / 980 \\ D_{si} &= \begin{cases} \dfrac{1}{\sqrt{4\mu - 1}} + \beta \dfrac{T_i - T}{T_i} & T \le T_i / 0.8 \\ 0 & T > T_i / 0.8 \end{cases} \end{aligned} \tag{9}$$

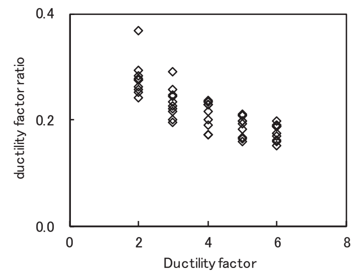
The ductility factor ratio in Eq.(8) and (9) is shown in Fig.6. These new equations have an improvement in the range of the ductility factor ratio against in Fig,5.

3.2 VERIFICATION OF PROPOSED BASE SHEAR COEFFICIENT ON OBSERVED EARTHQUAKE MOTIONS

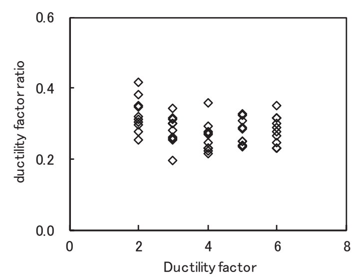
Next, the proposed base shear coefficient is checked by observed earthquake motions. The damping ratios are supposed as h=0.05, 0.10 and 0.20 because of using seismic energy dissipation systems. The ductility factor ratio is shown in Fig.7. The damping ratio is set in proportion to the secant stiffness at 1/120 rad. The ductility factor ratios of some samples are over 1.0. Nevertheless, almost all ductility factors are less than 1.0. proposed equations give the sufficient base shear against earthquakes.



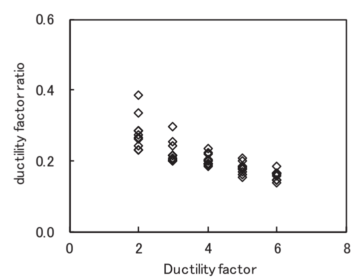
a) Minimum requirement



b) Target spectrum A

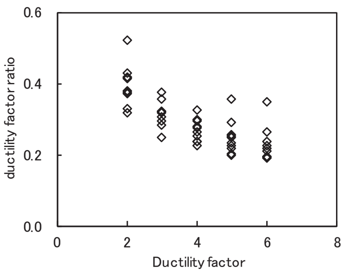


c) Target spectrum B

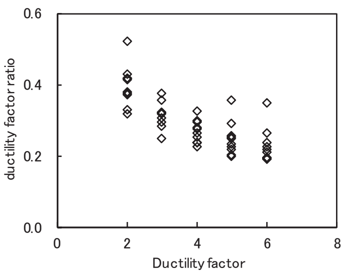


d) Target spectrum C

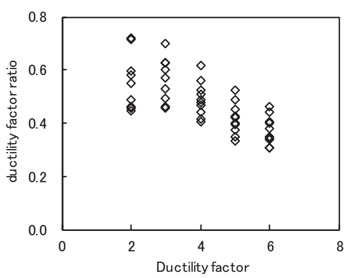
Figure 5: Ductility factor ratio subjected to earthquake motions in Fig.2 (h=0.05)



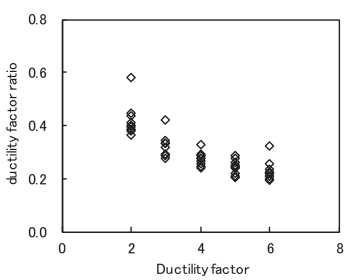
a) Minimum requirement



b) Target spectrum A



c) Target spectrum B

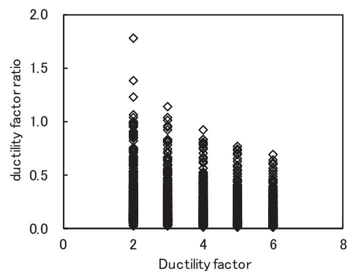


d) Target spectrum C

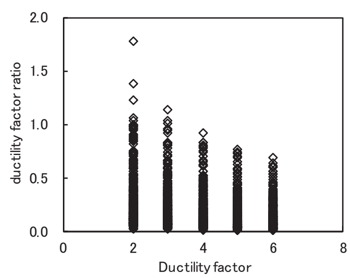
Figure 6: *Ductility factor ratio subjected to earthquake motions in Fig.2 (h=0.05)*

4 VERIFICATION OF PROPOSED BASE SHEAR COEFFICIENT WITH SEISMIC ENERGY DISSIPATION SYSTEM

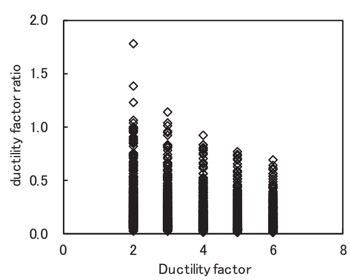
The damping ratio in Fig. 7 is a simple supposition. So the result of Fig. 7 is not applied to actual seismic energy dissipation systems. In this section, a hysteresis damping system and a velocity proportional viscous damping system with relief valve are supposed as actual seismic energy dissipation systems. The hysteresis damping system has the bi-linear restoring force characteristic in Fig. 8. Its yield displacement is 0.5cm and its yield strength is 8kN. The viscous damping system is the brace system, whose 1st damping coefficient is 4 kN/(cm/s), whose 2nd damping coefficient is 0.04 kN/(cm/s), whose relief velocity is 0.9sm/s, and whose stiffness is 20kN/cm. These seismic energy dissipation systems are supposed to be set at 1st floor because the almost Japanese wooden houses collapse at their 1st floor. Their demand in a house is calculated from both of the difference between the set damping ratio value and structural damping ratio 5%, and the 1 loop energy dissipation at 1/120 rad of slope by relative storey displacement of the energy dissipation systems.



a) h=0.05



b) h=0.10



c) h=0.20

Figure 7: *Ductility factor ratio subjected to observed earthquake motions*

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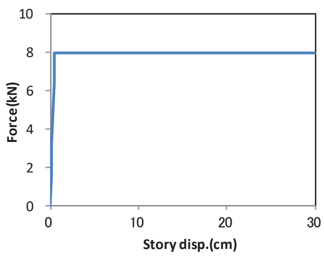


Figure 8: *Characteristic of hysteresis damping system*

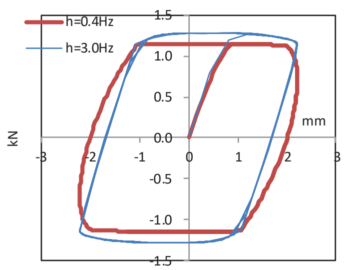
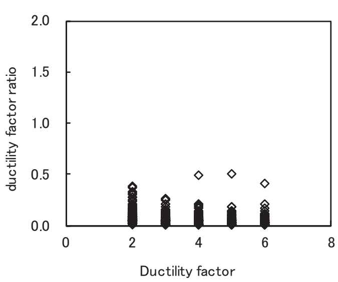
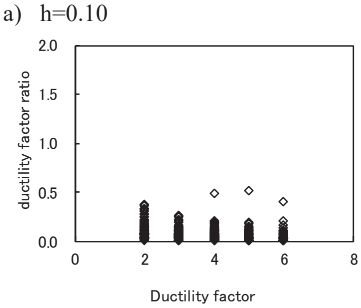


Figure 9: *Characteristic of viscous damping system*

The results are shown in Fig. 10 and Fig. 11. The result on the viscous damping system (Fig.11) is similar to the result in Fig. 7. But the result on the hysteresis damping system (Fig.10) shows that the ductility factor ratio in Fig. 7 is smaller than that in Fig.10.



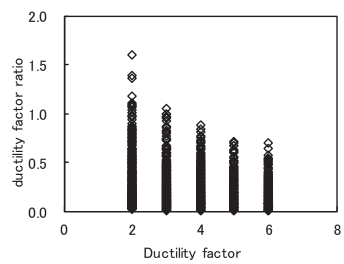
a) h=0.10



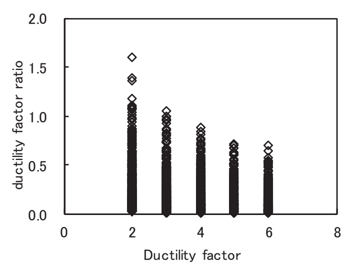
b) h=0.20

Figure 10: *Ductility factor ratio subjected to observed earthquake motions with hysteresis damping system*

The reason is that the consideration of a hysteresis damper is only 1 loop energy dissipation. There is no consideration on its strength. The adequate method to consider the strength of a hysteresis damper is to change β in Eq. (8) and (9). The change of β needs the calculation on the effect of the strength of a hysteresis damper. It is cumbersome procedure. In this paper, a next simple method is proposed. The method is the increase of the 1 loop energy dissipation. The result on double count of 1 loop energy dissipation is shown Fig.12. This figure shows that the ductility factor ratio is a little larger than that in fig.7. But the proposed method is in safe side on structural design.



a) h=0.10

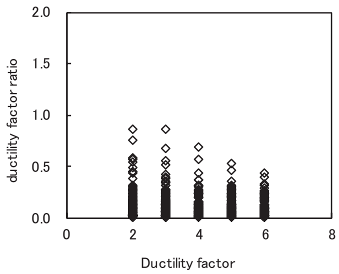


b) h=0.20

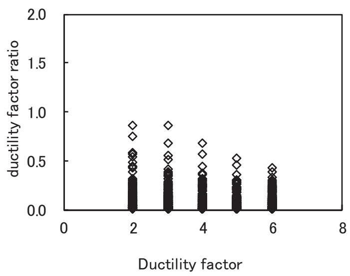
Figure 11: *Ductility factor ratio subjected to observed earthquake motions with viscous damping system*

5 CONCLUSIONS

In this paper, new equations for horizontal resistant force of Japanese wooden houses are discussed in considering both the acceleration response spectrum with sharp peaks and the acceleration response spectrums of observed earthquake motion. The new horizontal resistant force is defined as the product of the coefficient of eccentricity ratio, the coefficient of a damping factor, and the coefficient of horizontal resistant force. This coefficient of horizontal resistant force is the function of the ductility factor, the natural period, the period of a response spectrum peak and its acceleration. As a result, the response analysis shows that the proposed equations give the safe side of the horizontal resistant force.



a) h=0.10



b) h=0.20

Figure 12: *Ductility factor ratio subjected to observed earthquake motions with hysteresis damping system whose energy dissipation is counted double.*

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