The Dynamic Effect of Viscous Damping Factor of Yielding Domain on Bridge Pier

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SUMMARY:
The purpose of this study is to examine the effect of viscous damping factor *h* in yielding domain that gives for the dynamic response of bridge pier using single degree of freedom system. Using perfectly elasto-plastic model for analysis and changing *h* in yielding domain, an attempt was made to obtain the effect on demanding yield strength, cumulative plastic displacement and dissipated hysteretic energy. Since it was considered that the dynamic response of pier was related to properties in incident seismic waves, we conducted dynamic analysis using Type 1 and Type 2 in Level 2 earthquake motions. As a result, *h* in yielding domain had little effect to give the cumulative plastic displacement quantity for natural period, incident seismic wave and ductility factor. Also, the demanding yield strength and the dissipated hysteretic energy for natural period and incident seismic wave were little influenced, but the ductility factor was strongly affected.

Keywords: viscous damping factor, single degree of freedom system, Level 2 earthquake motion

1. INTRODUCTION

In Japan, the Great East Japan Earthquake occurred on March 11, 2011. More than eighty years have passed after “the Great Kanto Earthquake” in Tokyo Metropolis. It is surmised that in the near future any great earthquake at plate boundaries can occur in Off Tokai/Off Tonankai, or near-field earthquake can occur due to inland active fault in Tokyo and surrounding district. Earthquake disaster prevention of Tokyo Metropolis Government is becoming important from these things.

At present, there are about 1,200 bridges administered by Bureau of Construction of Tokyo Metropolis Government. If we try to conduct detailed dynamic analysis using FEM (Finite Element Method) for all existing bridges, immense budgets and time including talented people's reservation will be required. Hence, attention would be given to non-linear dynamic analysis of single degree of freedom system as a comparatively simple model to calculate the dynamic response of the structure for a great earthquake.

Restoring force models in consideration of characteristic of structure type is used for analysis, and seismic performance of structure is evaluated using the result. Dynamic analysis has been considering characteristics of structure type for restoring force model. However, viscous damping factor *h* using the analysis is often used in constant for elasto-plastic domain. Since the reason for this is made of several factors for the effect of *h*, the mechanisms have not completely been verified. Also, for non-linear dynamic analysis of single degree of freedom system, the effect of hysteresis damping is generally considered greater than one of viscous damping. One of the effects of viscous damping is radiation damping to the ground. However, in the case becomes non-linear, it has been pointed out that the radiation damping is not necessarily expressed in type of proportional to velocity (Akiyama, 1999).

The purpose of this study is to examine the effect of viscous damping factor in yielding domain h_p that gives for the dynamic response of bridge pier using single degree of freedom system. Using perfectly elasto-plastic model for analysis and three set of h_p, an attempt was made to obtain the effect on demanding yield strength, cumulative plastic displacement and dissipated hysteretic energy. Also, since it was considered that the dynamic response of the pier was related to properties in incident seismic waves, we conducted dynamic analysis using 18 earthquake motions of Type 1 and Type 2 in

Level 2 (Japan Road Association, 1996 and 2002).

2. METHOD

2.1. Incident seismic waves

The dynamic analysis using single degree of freedom system used 18 earthquake motions of Type 1 (plate boundary earthquake type) and Type 2 (inland direct strike earthquake type) in Level 2 (extreme earthquake motion) shown in design specifications for highway bridges (Japan Road Association, 1996 and 2002). Fig.4.1 shows the acceleration response spectra. Here, earthquake motion 1-1-1 noted in Fig.4.1 denotes that it is Type1, soil type1, incident seismic wave of case 1.

Relations of the acceleration response of Type 1 and Type 2 become against natural period T in approximately two seconds as shown in Fig.4.1. By assuming that the same yield strength of bridge pier is equal with respect to incident seismic waves of Type 1 and Type 2 in Level 2, it is thought that it appear linear domain and non-linear one at the same T. This is suggestive of the difference ductility factor. Hence, the dynamic analysis did not determine the yield strength of bridge pier and carried out the ductility factor μ constant.

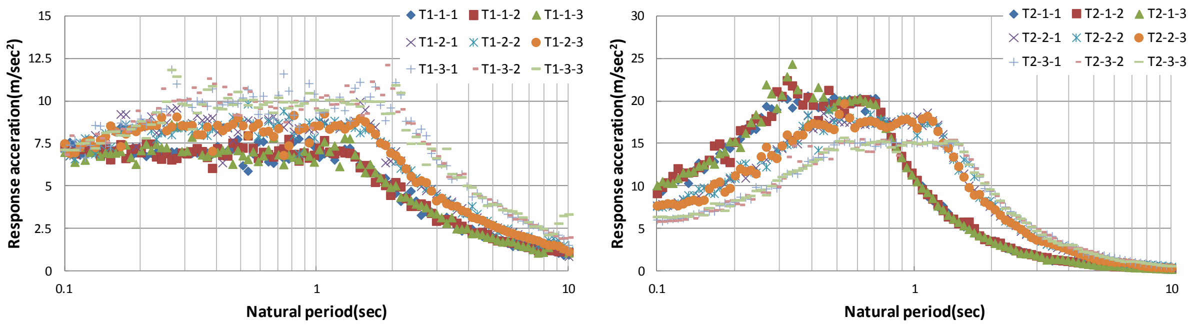

Figure 4.1. Response acceleration spectra of incident seismic wave

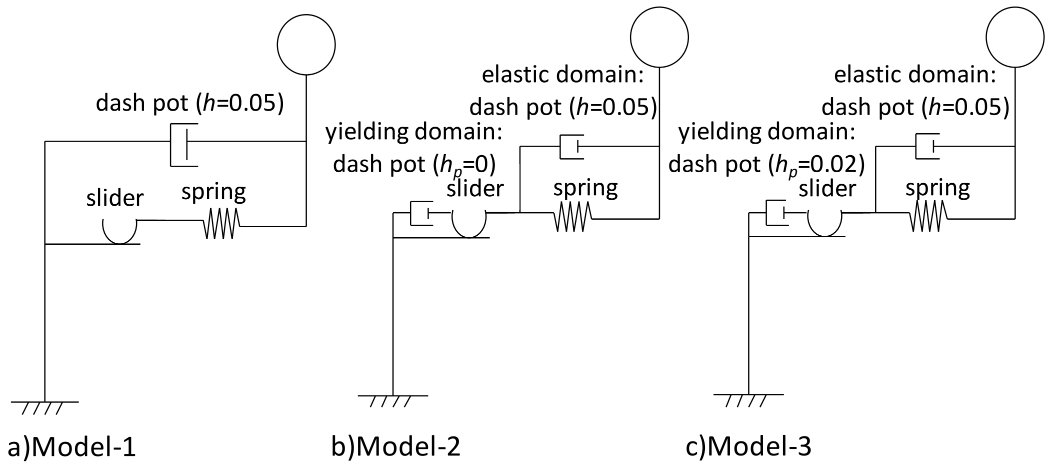

Figure 4.2. Analysis models

2.2. Analysis models

The purpose of this study is to examine the effect of the viscous damping factor in yielding domain h_p that gives for the dynamic response of bridge pier by the use of single degree of freedom system. As shown in Fig.4.2, the dynamic analysis was performed by the following models: (1) Model-1 assumed h=0.05 in elasto-plastic domain. (2) Model-2 assumed h=0.05 in elastic domain and h_p=0 in the yielding one. (3) Model-3 assumed h=0.05 in elastic domain and h_p=0.02 in the yielding one. The analysis derived the smallest required yield strength of bridge pier so that ductility factor (μ=2,4,6) became constant with T. The analysis carried out the calculation every 0.1 seconds in the range of 0.1-2 seconds in T.

Restoring force model used the perfectly elasto-plastic one. We adopted the mechanical model suggested by Iwan (Iwan, 1966) to express this restoring force. This model is comprised of the element which is directly connected to a spring and a slider. The characteristic is to give elastic energy and dissipated hysteretic energy analytically.

For restoring force reached yielding strength F_y, the slider calculates dissipated hysteretic energy E_p from F_y and quantity of displacement D_p. In the case of the dissipated hysteretic energy E_p with respect to incident seismic wave, this E_p is written as

$$E_p = F_y \times \sum D_p \tag{4.1}$$

Here $\sum D_p$ is the cumulative plastic displacement quantity.

On the other hand, when a structure generally becomes plasticity, it is considered that the effect of E_p increases, while one of dissipated viscous energy E_v decreases. Hence, since E_p is related to E_v, it is assumed that h_p influences F_y and $\sum D_p$.

In order to examine the effect of h_p, we were based on the dissipated hysteretic energy $E_{p,hp=0.05}$, the demanding yielding strength $F_{y,hp=0.05}$ and the cumulative plastic displacement quantity $\sum D_{p,hp=0.05}$ of Model-1 and considered it in Eqn.4.2.

$$\frac{E_{p,h_p=0}}{E_{p,h_p=0.05}} = \frac{F_{y,h_p=0}}{F_{y,h_p=0.05}} \times \frac{\Sigma D_{p,h_p=0}}{\Sigma D_{p,h_p=0.02}} \quad \text{(Ratio of Model-2 to Model-1)}$$

$$\frac{E_{p,h_p=0.02}}{E_{p,h_p=0.05}} = \frac{F_{y,h_p=0.02}}{F_{y,h_p=0.05}} \times \frac{\Sigma D_{p,h_p=0.02}}{\Sigma D_{p,h_p=0.05}} \quad \text{(Ratio of Model-3 to Model-1)} \tag{4.2}$$

Here $E_{p,hp=0}/E_{p,hp=0.05}$, $E_{p,hp=0.02}/E_{p,hp=0.05}$ is the dissipated hysteretic energy ratio, $F_{y,hp=0}/F_{y,hp=0.05}$, $F_{y,hp=0.02}/F_{y,hp=0.05}$ the demanding yielding strength ratio, and $\sum D_{p,hp=0}/\sum D_{p,hp=0.05}$, $\sum D_{p,hp=0.02}/\sum D_{p,hp=0.05}$ the cumulative plastic displacement quantity ratio.

3. RESULTS

About the demanding yielding strength ratio $F_{y,hp=0}/F_{y,hp=0.05}$, $F_{y,hp=0.02}/F_{y,hp=0.05}$, the effect of viscous damping factor in yielding domain h_p was recognized by incident seismic waves and target ductility factor μ in some natural periods as shown in Fig.5.1. $F_{y,h=0}/F_{y,hp=0.05}$ and $F_{y,hp=0.02}/F_{y,hp=0.05}$, except for these natural periods, were independent of natural periods and incident seismic waves and approximately showed a constant value. Therefore we averaged $F_{y,h=0}/F_{y,hp=0.05}$ and $F_{y,hp=0.02}/F_{y,hp=0.05}$ for μ=2,4,6, and compared the effect of μ in Fig.5.2.

$F_{y,h=0}/F_{y,hp=0.05}$ and $F_{y,hp=0.02}/F_{y,hp=0.05}$ showed a tendency in proportion to μ. As for the tendency, $F_{y,h=0}/F_{y,hp=0.05}$ was more remarkable than $F_{y,hp=0.02}/F_{y,hp=0.05}$. In addition, $F_{y,h=0}/F_{y,hp=0.05}$ increased more than 10% when μ=6. On the other hand, the standard deviation of $F_{y,h=0}/F_{y,hp=0.05}$ and $F_{y,hp=0.02}/F_{y,hp=0.05}$ showed a tendency to increase as μ increased. As for the tendency, $F_{y,h=0}/F_{y,hp=0.05}$ was more remarkable than $F_{y,hp=0.02}/F_{y,hp=0.05}$. However, when μ=6, $F_{y,h=0}/F_{y,hp=0.05}$ was around 0.03.

From these results, it turned out that the demanding yielding strength was influenced by ductility factor than natural period and incident seismic wave.

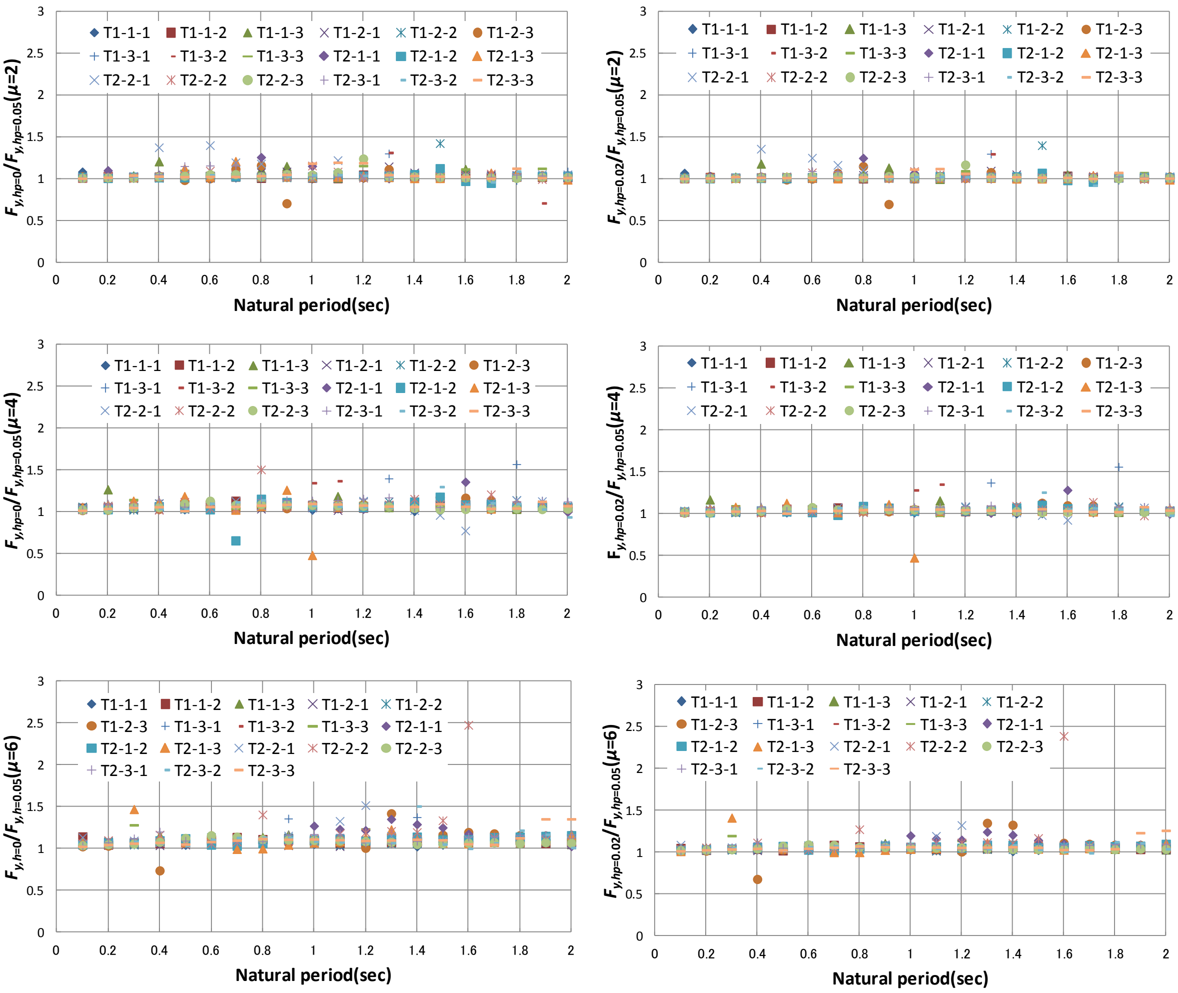

Figure 5.1. Demanding yielding strength ratio of incident seismic waves

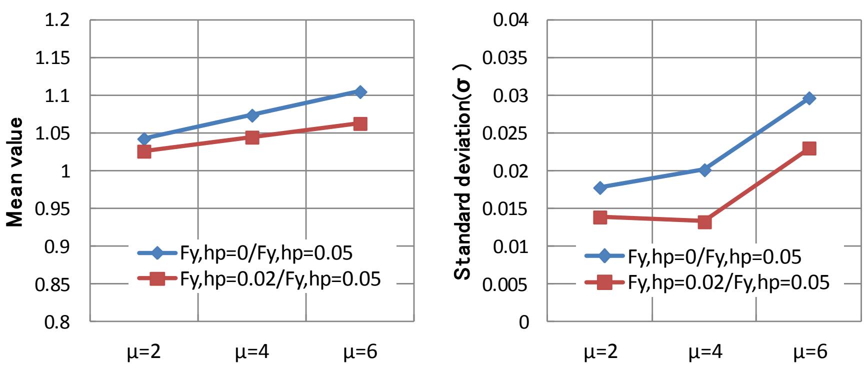

Figure 5.2. Mean value and standard deviation of demanding yielding strength ratio

About the cumulative plastic displacement quantity ratio $\sum D_{p,hp=0}/\sum D_{p,hp=0.05}$, $\sum D_{p,hp=0.02}/\sum D_{p,hp=0.05}$, the effect of h_p was recognized by incident seismic waves and μ in some natural periods as shown in Fig.5.3. These natural periods were in accord with those of the demanding yielding strength ratio. However, the tendency of fluctuation was suitable for objection.

$\sum D_{p,hp=0}/\sum D_{p,hp=0.05}$ and $\sum D_{p,hp=0.02}/\sum D_{p,hp=0.05}$, except for these natural periods, approximately showed a constant value without depending on natural periods and incident seismic waves, similar to the demanding yielding strength ratio. Also, as a result of having averaged $\sum D_{p,hp=0}/\sum D_{p,hp=0.05}$ and $\sum D_{p,hp=0.02}/\sum D_{p,hp=0.05}$ for μ=2,4,6, $\sum D_{p,hp=0}/\sum D_{p,hp=0.05}$ and $\sum D_{p,hp=0.02}/\sum D_{p,hp=0.05}$ were hardly influenced by the value of h_p as shown in Fig.5.4. In addition, $\sum D_{p,hp=0}/\sum D_{p,hp=0.05}$ and $\sum D_{p,hp=0.02}/\sum D_{p,hp=0.05}$ approximately exhibited 1.0. On the other hand, the standard deviation of $\sum D_{p,hp=0}/\sum D_{p,hp=0.05}$ and $\sum D_{p,hp=0.02}/\sum D_{p,hp=0.05}$ showed a tendency to decrease as μ decreased. However, when μ=2, $\sum D_{p,hp=0}/\sum D_{p,hp=0.05}$ was around 0.041.

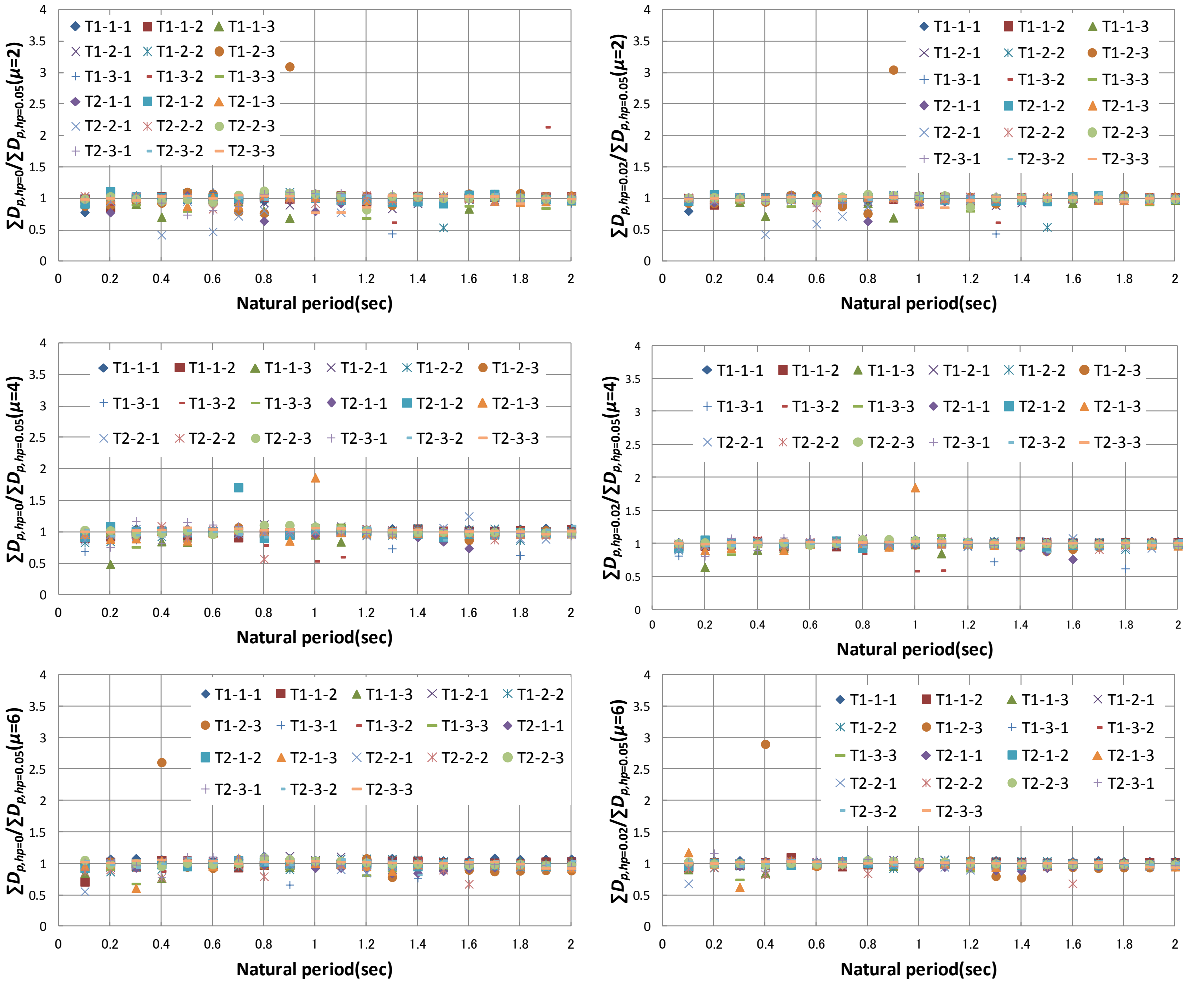

Figure 5.3. Cumulative plastic displacement quantity ratio of incident seismic waves

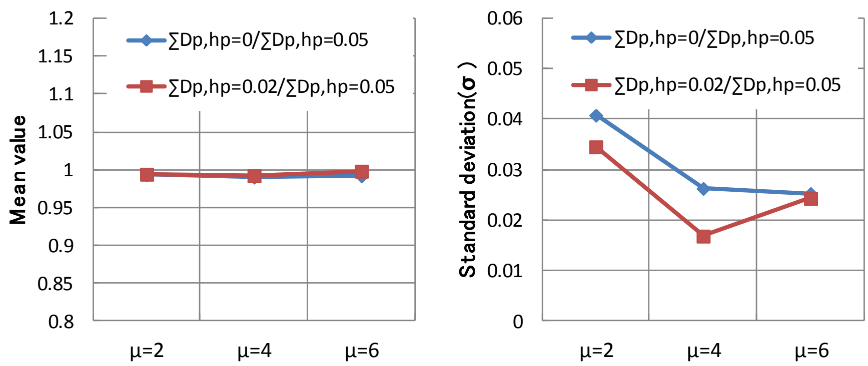

Figure 5.4. Mean value and standard deviation of cumulative plastic displacement quantity ratio

In the above-mentioned result, it turned out that the cumulative plastic displacement quantity had little effect on natural period, incident seismic wave and ductility factor.

The dissipated hysteretic energy ratio $E_{p,hp=0}/E_{p,hp=0.05}$, $E_{p,hp=0.02}/E_{p,hp=0.05}$ is calculated in Eqn.4.2. About $E_{p,hp=0}/E_{p,hp=0.05}$, and $E_{p,hp=0.02}/E_{p,hp=0.05}$, the effect of h_p was recognized by incident seismic waves and μ in some natural periods as shown in Fig.5.5. These natural periods were in accord with those of the demanding yielding strength ratio and the cumulative plastic displacement quantity ratio. Also, the tendency of fluctuation was strongly influenced towards the cumulative plastic displacement quantity ratio than the demanding yielding strength ratio.

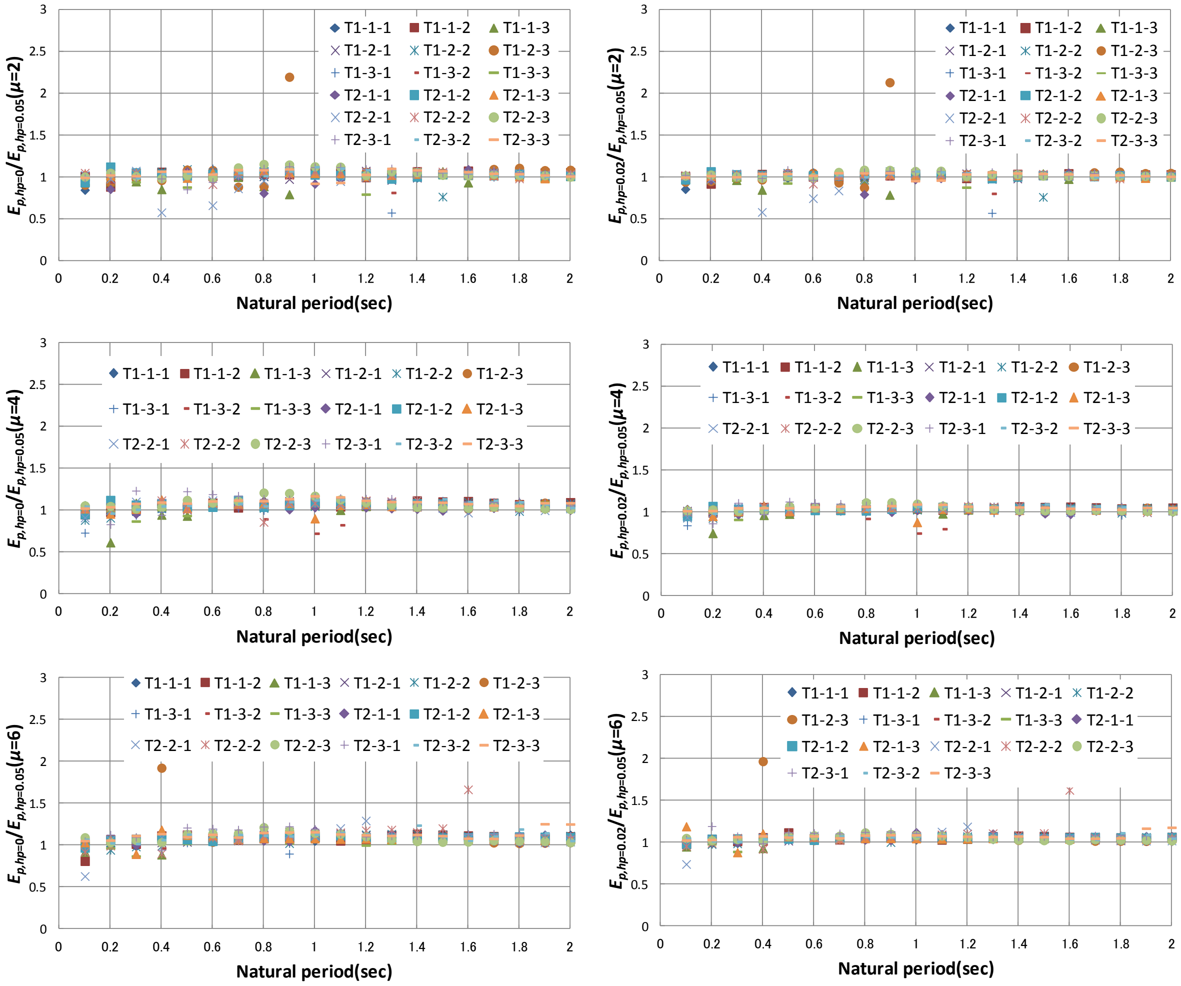

Figure 5.5. Dissipated hysteretic energy ratio of incident seismic waves

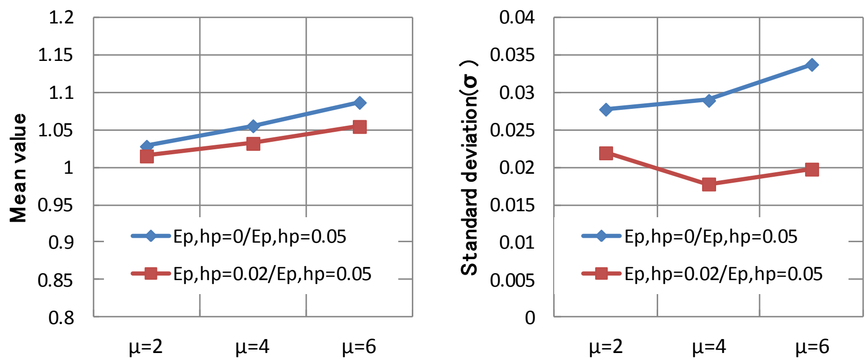

Figure 5.6. Mean value and standard deviation of dissipated hysteretic energy ratio

$E_{p,hp=0}/E_{p,hp=0.05}$, and $E_{p,hp=0.02}/E_{p,hp=0.05}$, except for these natural periods, were independent of natural periods and incident seismic waves and approximately showed a constant value, similar to the demanding yielding strength ratio and the cumulative plastic displacement quantity ratio. Therefore we averaged $E_{p,hp=0}/E_{p,hp=0.05}$, and $E_{p,hp=0.02}/E_{p,hp=0.05}$ for μ=2,4,6, and compared the effect of μ in Fig.5.6. $E_{p,hp=0}/E_{p,hp=0.05}$, and $E_{p,hp=0.02}/E_{p,hp=0.05}$ showed a tendency in proportion to μ. As for the tendency, $E_{p,hp=0}/E_{p,hp=0.05}$ was more remarkable than $E_{p,hp=0.02}/E_{p,hp=0.05}$. In addition, $E_{p,hp=0}/E_{p,hp=0.05}$ increased more than 8% when μ=6. On the other hand, the standard deviation of $E_{p,hp=0}/E_{p,hp=0.05}$, and $E_{p,hp=0.02}/E_{p,hp=0.05}$ was little affected by μ. When μ=6, $F_{y,h=0}/F_{y,hp=0.05}$ was around 0.034 at the maximum.

In the above-mentioned result, it turned out that the dissipated hysteretic energy was influenced by ductility factor than natural period and incident seismic wave.

4. DISCUSSION

The purpose of this study is to examine the effect of viscous damping factor in yielding domain that gives for the dynamic response of bridge pier using single degree of freedom system.

As a result, the viscous damping factor in yielding domain had little effect to give the cumulative plastic displacement quantity for natural period, incident seismic wave and ductility factor. Also, the demanding yield strength and the dissipated hysteretic energy for natural period and incident seismic wave were little influenced, but the ductility factor was strong affected.

Generally, when a structure generally becomes plasticity, it is considered that the effect of the dissipated hysteretic energy E_p increases, while the one of dissipated viscous energy decreases. Therefore we examined the effect of the viscous damping factor in yielding domain using the perfectly elasto-plastic model of single degree of freedom system.

We will attempt to perform similar examination about the complicated skeleton curve such as Takeda model used with concrete structures.

When the yield strength of bridge pier is low level compared to acceleration of incident seismic wave, it is predicted that the dynamic response of the pier increases up. In this case, consideration should be given to the setting of the viscous damping factor in yielding domain.

5. CONCLUSIONS

In conclusions, we have obtained the following from the analysis:

(1)It turned out that the demanding yielding strength was influenced by ductility factor μ than natural period and incident seismic wave. Also, the demanding yielding strength ratio showed a tendency in proportion to μ and increased more than 10% when μ=6. Hence, consideration should be given to the setting of the viscous damping factor in yielding domain.

(2)It turned out that the cumulative plastic displacement quantity had little effect on natural period, incident seismic wave and ductility factor.

(3)It turned out that the dissipated hysteretic energy was influenced by μ than natural period and incident seismic wave. Also, the dissipated hysteretic energy ratio showed a tendency in proportion to μ and increased more than 8% when μ=6. Hence, consideration should be given to the setting of the viscous damping factor in yielding domain.

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