OPTIMUM CONNECTION PROPERTY BASED ON ENERGY DISTRIBUTION OF CONNECTED NONLINEAR BUILDINGS

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ABSTRACT :

Connecting an adjacent new building with passive energy dissipation devices is one of the feasible ways to reduce seismic response of existing buildings. In this paper, two single-degree-of-freedom systems (one is nonlinear and another is linear) are connected each other with the connecting spring and damper to improve earthquake performance of existing nonlinear buildings. This paper shows an optimum connection property which minimizes plastic strain energy contributing directly to damage of the buildings under white noise excitation and mass ratio and frequency ratio which can bring out better coupling effects. The result can show efficiency of the proposed method.

KEYWORDS: Connected structure, Vibration control, Coupling effects, Optimum connection parameter, Nonlinear response

1. INTRODUCTION

There exist several retrofitting options that can save existing weak buildings against future earthquakes. Strengthening them, reduction of structural response with some special devices, are possible practical options. Response reduction by connecting with a new or an existing building is considered to be effective since not much engineering works are required when the two buildings get connected each other. In order to reduce response, the vibration property of newly added structural system is design parameter as well as the characteristic of joints comprising a spring and a damper. In this research suppose to build a newly structure and connect each other to improve the earthquake resistance of the existing building. It is inevitable to behave in nonlinear manner in a large earthquake, so it is necessary to find out optimum joint property to bring out high coupling effects even in nonlinear response range. It is understood that maximum coupling effects vary according to mass ratio and proper period ratio of two buildings. To maximize the coupling effects it is necessary to find not only the optimum characteristic of joints connecting of a spring and a damper but also the vibration property of newly added structural system.
Therefore, the purpose of this research is to find optimum characteristics of a new building and connection which maximize coupling effects even in nonlinear response by the parameter study within the range where the mass ratio and the proper period ratio of two buildings can be assumed to be realistic.

2. ANALYTICAL APPROACH

2.1. Vibration Model

Figure 1 shows the vibration model used in this research. Suppose two single-degree-of-freedom systems (SDOF) to aim at basic study. A main structure (M system) that is regarded as an existing weak building is connected with an additional new Structure (A system) by the Voigt model. Let m_M, k_M, $T_M = 2\pi\sqrt{m_M/k_M}$, h_M=5%, $C_M = 2h_M\sqrt{m_M k_M}$, and m_A, k_A, $T_A = 2\pi\sqrt{m_A/k_A}$, h_A=5%, $C_A = 2h_A\sqrt{m_A k_A}$ be the mass, stiffness, proper period, damping constant and damping coefficient of M system and A system respectively. Restoring force characteristic of M system is assumed normal bilinear. Stiffness after yield is 1/20 of initial stiffness. The yield displacement of M system is provided by the ratio β of the yield displacement to the elastic maximum response displacement. It is assumed that A system maintains the state of elasticity because M system is relatively weak compared with A system. Let γ_C and h_C be the frequency ratio of connecting spring and damping constant of connecting damper, expressed as

$$\gamma_C = \sqrt{k_C / k_M} \qquad (2.1)$$
$$h_C = C_C / 2 m_M \omega_M$$

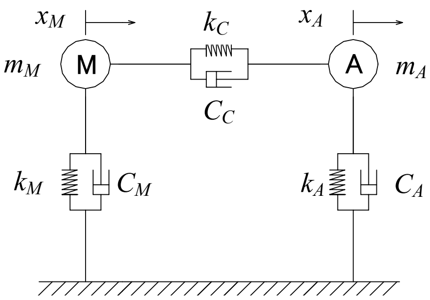

Figure 1 Vibration model

2.2. Index for Coupling Effects

It is the maximum response displacement ratio that is used often as an index in the coupling effect compared with disconnected building. It is thought to be an effective index in limited to a linear response of the building that leads to improvement of habitability or human comfort. However, it is insufficient only to decrease the maximum response displacement in aiming at the improvement of safety to the input of the large amplitude level, the building responds nonlinearly. There is much research that evaluates the damage of the structure, and the idea of the energy input is enhanced to connected structure. Concretely, the plastic strain energy described by 2.3 is calculated from response analysis, and evaluates it compare with disconnected state.

2.3.Definition of Energy Response of Connected Buildings

The energy response with connected buildings of SDOF systems is defined as in the following. The motion equation of the connected buildings that is subjected to ground motion input $\ddot{y}_0$ is

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + \{Q(x)\} = -\ddot{y}_0 [M]\{1\} \qquad (2.2)$$

$\{x\}$: relative displacement vector $\quad \{x\} = \{x_M \quad x_A\}^T$

$[M]$: mass matrix $\quad [M] = \begin{bmatrix} m_M & 0 \\ 0 & m_A \end{bmatrix}$

$[C]$: damping matrix $\quad [C] = \begin{bmatrix} C_M + C_C & -C_C \\ -C_C & C_A + C_C \end{bmatrix}$

$\{Q(x)\}$: restoring force vector $\quad \{Q(x)\} = \begin{bmatrix} k_M + k_C & -k_C \\ -k_C & k_A + k_C \end{bmatrix} \begin{Bmatrix} x_M \\ x_A \end{Bmatrix}$ (in elastic)

$\{\dot{x}\}^T$ is multiplied to both sides of Eqn.2.2 from the left and integrates them from time 0 to ∞, referring to Akiyama. The result becomes,

$$\underbrace{\left[\frac{1}{2} m_M \dot{x}_M^{\ 2} + \frac{1}{2} m_A \dot{x}_A^{\ 2}\right]_0^\infty}_{\text{kinetic energy } E_e} + \underbrace{C_M \int_0^\infty \dot{x}_M^{\ 2} dt + C_A \int_0^\infty \dot{x}_A^{\ 2} dt}_{\text{damping energy } E_h} + \underbrace{\int_0^\infty Q_M(x_M)\dot{x}_M dt + \int_0^\infty Q_A(x_A)\dot{x}_A dt}_{\text{plastic strain energy } E_p}$$
$$+ \underbrace{C_C \int_0^\infty (\dot{x}_M - \dot{x}_A)^2 dt}_{\text{absorbed energy by damper } E_{hC}} + \underbrace{\left[\frac{1}{2} k_C (x_M - x_A)^2\right]_0^\infty}_{\text{elastic vibration energy } E_{eC}} = \underbrace{-m_M \int_0^\infty \dot{x}_M \ddot{y}_0 dt - m_A \int_0^\infty \dot{x}_A \ddot{y}_0 dt}_{\text{total energy input } E_I} \qquad (2.3)$$

As the initial condition and after the response ends, it is assumed $x_M = x_A = \dot{x}_M = \dot{x}_A = 0$. Then, $E_e = E_{eC} = 0$. Therefore, Eqn.2.3 becomes Eqn.2.4

$$E_h + E_p + E_{hC} = E_I \tag{2.4}$$

E_p is defined as the plastic strain energy of M system, since A system is assumed to remain elastic.

2.4. Search of Optimum Connection Parameter

Connected part is assumed to be a Voigt type (connected with elastic spring and viscous damper) or rigid. Optimum connection parameters were sought using numerical calculation to maximize coupling effects against white noise input of the random phase because of aiming at a general solution. The mean value of the response of 30 white noise waves was used to disregard the influence by the phase.

2.5. Structural Range of Buildings

To clarify the influence of mass ratio $\left(\mu \equiv m_A / m_M\right)$, proper period ratio and yield displacement on the response of connected structure, a wide-ranging building combination is assumed. The mass ratio assumes three kinds 0.5, 1.0, and 2.0, and the combination of proper periods of 49 kinds of the grid point, 0.15-1.0sec. Parameter β is three kinds of 0.7, 0.5 and 0.3.

3. ANALYTICAL RESULT

3.1. Evaluation Criteria (Maximum Response Displacement Ratio)

Optimum connection parameter is decided to minimize displacement response of M system (optimization scheme 1). Figure 2 shows the maximum response displacement ratio which is able to be decreased compared with the original building (M system).

The bearing capacity of the building becomes comparatively weak to the input as β is small. When optimization scheme 1 is applied, the maximum response displacement ratio of any building combination is smaller than one, and it is understood that connection is effective. Under the condition of the same β the maximum response displacement ratio hardly changes regardless of μ. It is not possible to decrease so much when the proper period of the two is close and β is large. Coupling effect is high in the range of the lower right of the figure regardless of β or μ.

Next, figure 3 shows the plastic strain energy ratio in the optimization scheme 1. The shaded part is where the damage of the building increases by connection. In the combination to which the proper period of two buildings is almost equal, the plastic strain energy increases though the maximum response displacement decreased. This tendency becomes strong as β becomes small. In this way when designing taking it into consideration to a nonlinear response, there is danger that damage increases in the combination to which the proper period is close by using optimization scheme 1

3.2. Evaluation Criteria (Plastic Strain Energy Ratio)

Next, optimum connection parameter is decided to minimize the plastic strain energy of M system (optimization scheme 2). Figure 4, 5 shows the plastic strain energy ratio and the maximum response displacement ratio respectively which is able to decrease compared with disconnected building (M system). It is understood that the plastic strain energy decreases by all the building combinations compared with disconnected state regardless of mass ratio μ. Even when the proper period of two building is almost equal the plastic strain energy ratio decrease. This is a big difference from optimization scheme 1. The maximum response displacement and the plastic strain energy can be decreased at the same time.

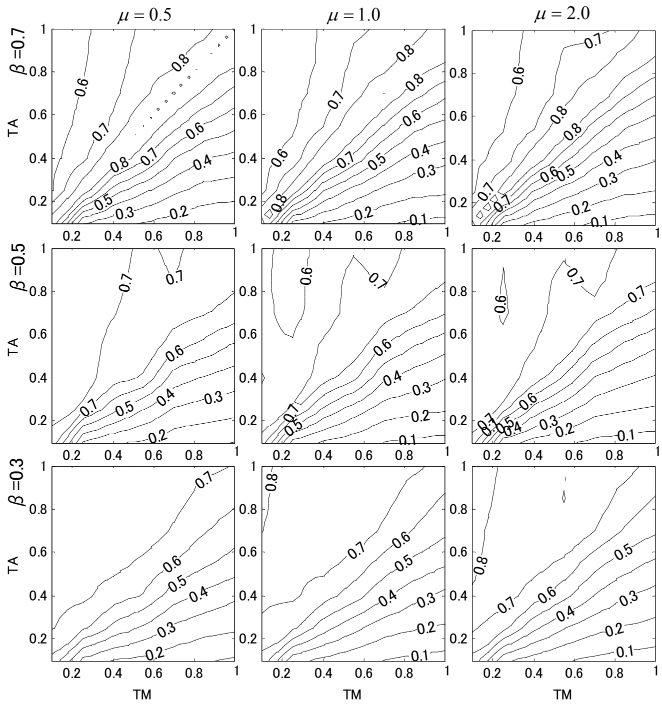

Figure 2 the maximum response displacement ratio
(Optimization scheme 1)

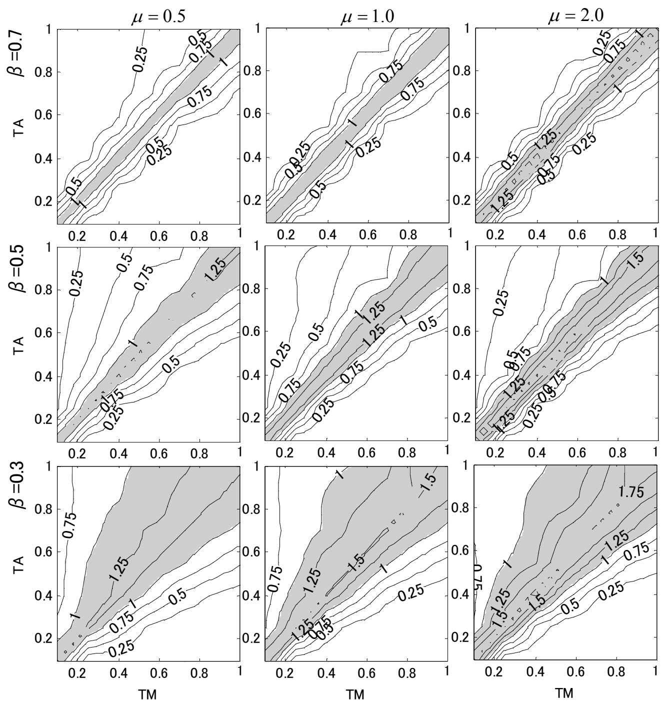

Figure 3 the plastic strain energy ratio
(Optimization scheme 1)

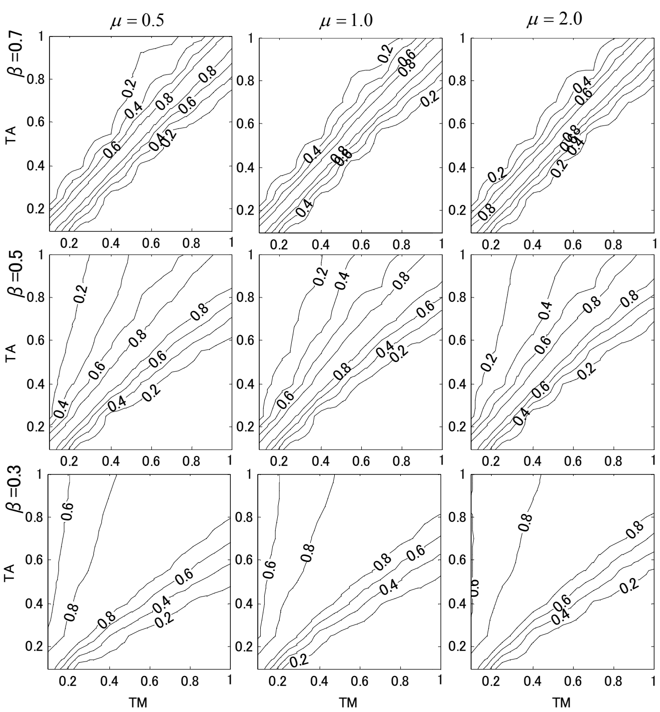

Figure 4 the plastic strain energy ratio
(Optimization scheme 2)

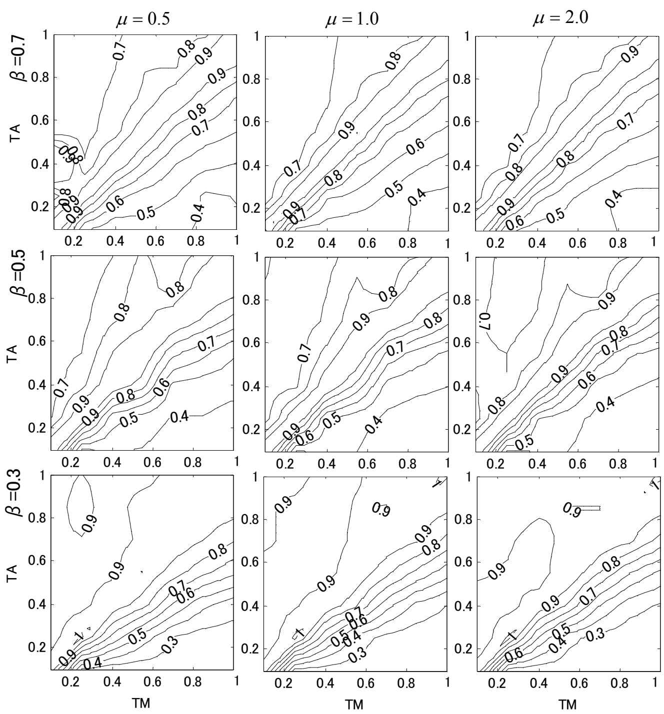

Figure 5 the maximum response displacement ratio
(Optimization scheme 2)

3.3. Influence of Difference of Index for Coupling effects on Plastic Strain Energy

As described above 3.1, 3.2, plastic strain energy changes considerably depending on optimization scheme. Consider it from three value of energy response, V_E (equivalent velocity solved by Eqn.3.1), E_{hC}/E_I (proportion of absorbed energy by connecting damper to total energy input) and E_p/E_I (proportion of plastic strain energy to total energy input).

$$V_E = \sqrt{\frac{2E_I}{m_M + m_A}} \tag{3.1}$$

Consider distinctive 3 cases (at μ=2.0, β=0.3). Table 3.1 shows the proper period of two buildings and optimum connection parameter of each optimization scheme. Figure 6 shows equivalent velocity and ratio of energy for each optimization scheme. V_E is approximately constant regardless of combination of building and optimization scheme. In case 1 E_{hC}/E_I is very low for both optimization schemes, and coupling effect cannot be expected. In case 2 E_{hC}/E_I is high for both optimization schemes, and so E_p/E_I is low. In case 3 E_p/E_I is 0, because of constraining displacement by connecting rigidly in optimization scheme 1, and of high absorbing energy by connecting damper in optimization scheme 2. Consider more generally the relationship between the plastic strain energy of M system and absorbed energy by connecting damper. Figure 7 shows E_{hC}/E_I and E_p/E_I in optimization scheme 2 at μ=1.0. E_p/E_I becomes higher as β becomes lower. For each β E_{hC}/E_I and E_p/E_I are negatively-correlated. In other words, deciding connecting parameter to decrease the plastic strain energy leads to absorb energy by connecting damper.

Table 3.1 Combination of building and optimum connection parameter of each case

	T_M	T_A	Optimization scheme 1		Optimization scheme 2	
	(sec)	(sec)	γ_C	h_C	γ_C	h_C
case1	0.7	0.7	rigid		0.01	0.01
case2	0.25	0.85	0.16	0.08	0.12	0.10
case3	0.85	0.25	rigid		0.62	0.75

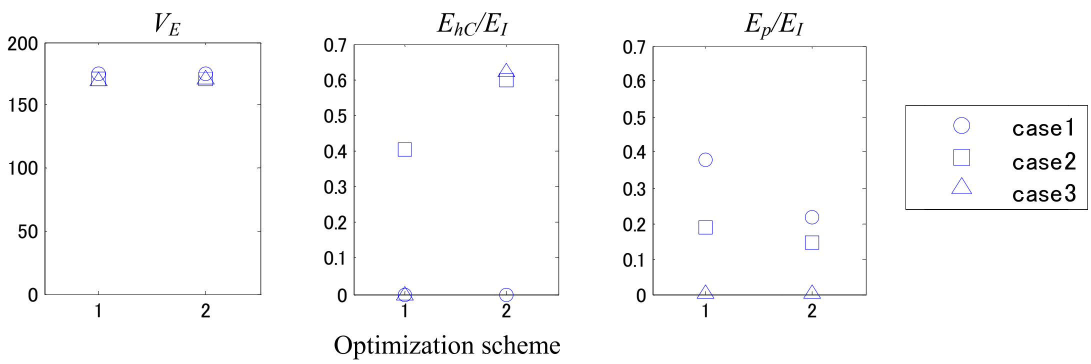

Figure 6 equivalent velocity and ratio of energy for each optimization scheme

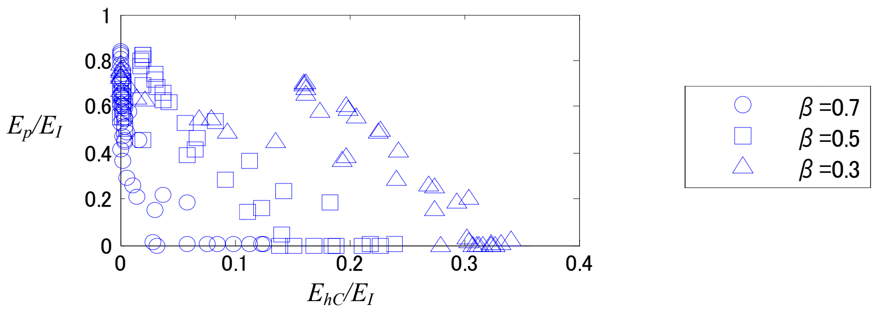

Figure 7 Relationship between E_{hC}/E_I and E_p/E_I

4. CONCLUSION

In this research, aiming at the earthquake resistance improvement of the existing weak non-linear building, assume to connect with adjacent newly-built linear structure by the connecting spring and damper. And identify the optimum connection property and the vibration property of newly added structural system which maximizes coupling effects (the maximum response displacement ratio or the plastic strain energy ratio) even when the building responds nonlinearly.
Results are summarized as follows.

(1) Optimum connection parameter is decided to minimize displacement of M system (optimization scheme 1). The maximum response displacement ratio of any building combination is smaller than one, but the plastic strain energy increases in the combination to which the proper period of two buildings is almost equal. When designing taking it into consideration to a nonlinear response, where is danger that damage increases by optimization scheme 1

(2) Optimum connection parameter is decided to minimize the plastic strain energy of M system (optimization scheme 2). It is able to decrease both the plastic strain energy ratio and the maximum response displacement ratio compared with disconnected state. This shows effectiveness of optimization scheme 2.

(3) The relationship between the plastic strain energy of M system and absorbed energy by connecting damper is negatively-correlated. So, deciding connecting parameter to decrease the plastic strain energy leads to absorb energy by connecting damper.

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