DYNAMIC ANALYSIS OF ULTIMATE STATE FOR BRIDGES WITH MULTIPLE RESTRAINERS

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ABSTRACT

This paper presents the dynamic analysis of ultimate state for simply-supported bridges with multiple restrainers. Two types of restrainers were installed in bridge, including of restrainer Type 1 and Type 2 which were assembled between adjacent decks and between decks to column, respectively. The effectiveness of multiple unseating prevention devices in simply supported bridges were examined in numerically by using the Vector Form Intrinsic Finite Element (VFIFE). Ground motion recorded during 1999 Taiwan Chi-Chi Earthquake was selected in order to investigate the seismic behavior of the target bridges. According to the numerical results, it was found that installation of restrainer type 1 independently has a better result in protecting the deck of bridges from unseating and column failure.

Key words: dynamic analysis, restrainer, simply-supported bridge, ultimate state, VFIFE.

1. INTRODUCTION

Crossing over water, traffic, or other obstruction, a bridge is an important link in transportation network to permit the smooth and safe passage of vehicles. Especially in urban areas characterized by higher population density and civilization, a bridge plays a more important role in human living and economic activities.

A number of bridges suffered damage and even collapsed due to large earthquake such as the 1923 Japan Kanto earthquake, the 1995 Japan Kobe earthquake and the 1999 Taiwan Chi-Chi earthquake. Observed from the damaged bridges, column failure and deck unseating caused a more serious loss. Through the past experiences, it is demanded to develop a better seismic design method for reducing the damage of bridges under earthquakes.

A three-span simply supported bridge supported by elastomeric bearings has been analyzed by Matsumoto et al.[1)]. PC strand restrainers are accommodated between decks with the tension capacity being about a half of the code demand. Due to rotations of the decks, the pounding forces, forces induced in the restrainers and elastomeric bearings become large.

VFIFE has been recognized as a superior computational method in managing the engineering problems with material nonlinearity, discontinuity, large deformation, large displacement and arbitrary rigid body motions of deformable bodies. It has been adopted to successfully simulate the ultimate state of isolated and non-isolated bridges with unseating prevention devices by Lee et al. (2009). Nowadays, more than one type of unseating prevention devices are installed in bridges.

As the previous recommendation[2)], the effectiveness of multiple unseating prevention devices could be investigated for different type of the bridge with different ground motion. Furthermore, the ground motion under Sun-Moon Lake record during 1999 Taiwan Chi-Chi earthquake record will be analyzed.

Therefore, this study is aimed to study the effectiveness of multiple restrainers in simply-supported bridge through VFIFE.

2. LITERATURE REVIEWS

The Vector Form Intrinsic Finite Element (VFIFE) was developed[3)]. This computational method is superior in managing the engineering problems with material nonlinearity, discontinuity, large deformation, large displacement and arbitrary rigid body motions of deformable bodies.

A structural system consists of a finite number of sub-structures. To calculate the motion of each sub-structure, it is described by a finite number of particles. All displacements and forces for the nodal refer to the fixed global coordinates. From the Principle of Newton's Second Law, the equation of motion for the sub-structure at time $t + \Delta t$ as follows.

$$m_\alpha^* \ddot{d}_\alpha = F_\alpha^{ext} - F_\alpha^{\text{int}} \qquad (2.1)$$

$$M_\alpha \, \ddot{d}_\alpha = p_\alpha(t) - f_\alpha(t)$$

$$\alpha = 1, 2, 3, \ldots\ldots, n$$

where n is taken as the total number of mass particles in the system including all the sub-structures, $\boldsymbol{d_\alpha(t)}$ is nodal displacement vector, and $\mathbf{M}_\alpha$ is constant diagonal matrix of nodal mass. Masses and the equations of motion do not change during the motion. $p_\alpha(t)$ and $f_\alpha(t)$ refer to external and internal force vector.

3. METHOD OF ANALYSIS

A lumped-mass model is used to idealize the target structure in the Vector Form Intrinsic Finite Element (VFIFE), which are connected by deformable elements without mass. In order to strudy the behavior of the target bridges, the bridge will be analyzed with different combinations of gap for stopper and hook for restrainer.

First case consists of restrainers with fixed hook of 40 cm and stoppers with gaps varying from 10 cm to 40 cm at an increment of 10 cm. Second case consists of stoppers with fixed gap of 40 cm and restrainers with hook varying from 10 cm to 40 cm at an increment of 10 cm.

Two types of restrainers were installed in bridge. Restrainer type 1 *R1* was set between adjacent decks while restrainer type 2 *R2* was set between the deck and column. The hook and gap spring elements with fracture strength were used to simulate the behavior of restrainers and stoppers *S*, respectively. In addition, pounding between adjacent decks was simulated by gap spring element. Plastic hinges of column was simulated by bilinear element.

The simply-supported bridge was designed based on Japan Highway Bridge Design Codes, as shown in **Figure 1** and **Figure 2**, with the total length of 240 m and width of 12 m. The deck of the bridge was constructed by five steel I girders and a reinforced-concrete slab with the modulus of elasticity E = 2.04 x 10^7 t/m. The section area A and moment of inertia I_y of the transformed deck were 0.585 m^2 and 0.295 m^4, respectively. Total weight W of the deck per a span was 600 tf. The idealization for the bridges were shown in **Figure 3(a)** and **Figure 3(b)**.

The ground motion recorded at Sun-Moon Lake station during 1999 Chi-Chi earthquake was selected with the peak ground acceleration of 9.83 m/s^2, as shown in **Figure 4**. The magnitude of ground motions was amplified from 100% to 300% at an increment of 10% to predict the ultimate state of bridges.

Figure 5(a) through **Figure 5(d)** show the view of superstructure, column, pile configuration and dimension[2)]. Restrainers were modeled by 6 unit PC. cables, while stoppers by concrete box. The ultimate design strength of restrainers and stoppers were 569.85 tf and 500 tf, respectively.

4. SIMULATION RESULTS

The results of unseated decks for the first and the second case are shown in **Table 1** and **Table 2**, respectively.

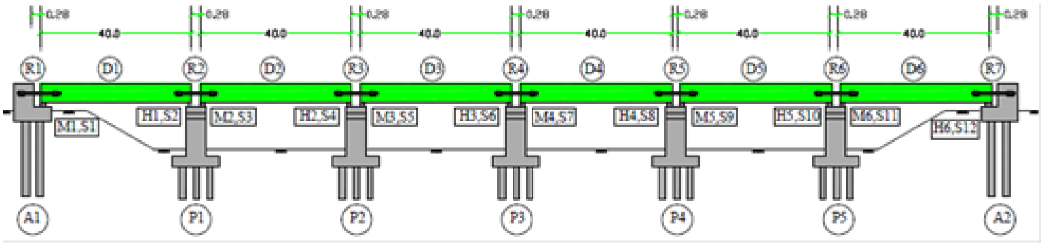

Figure 1. A six-span simply-supported bridge with restrainers Type 1, stoppers and rigid bearings

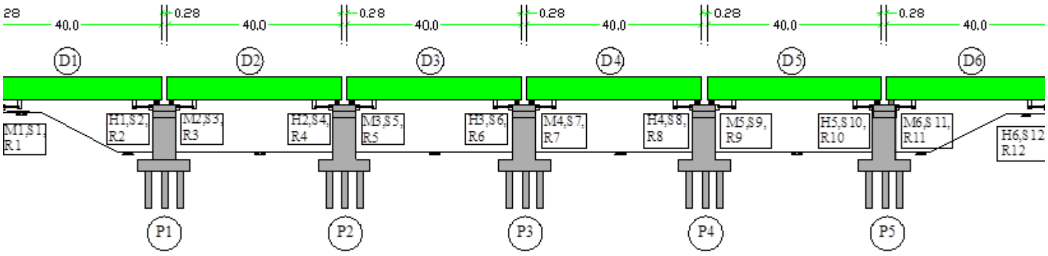

Figure 2. A six-span simply-supported bridge with restrainers Type 2, stoppers and rigid bearings

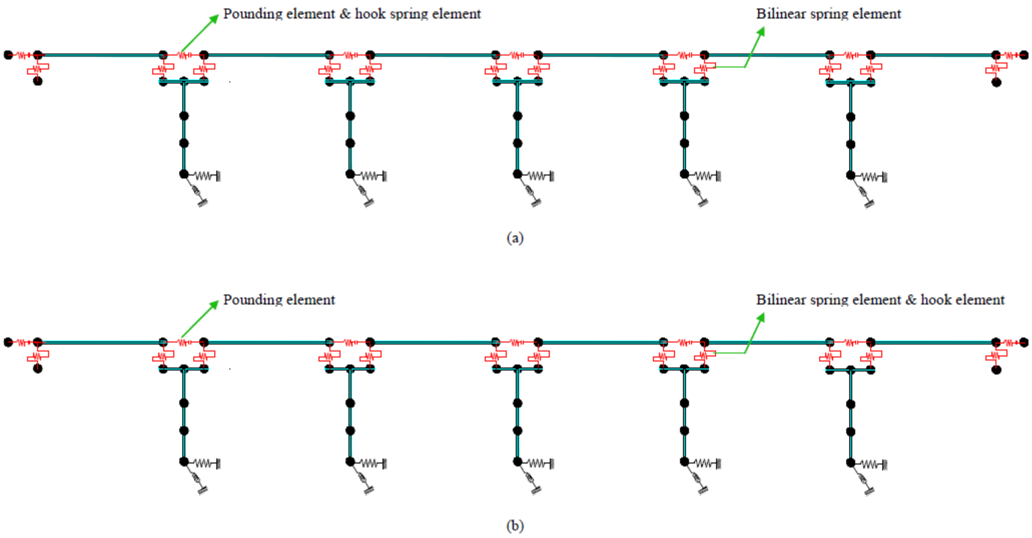

Figure 3. Idealization for a six-span simply-supported bridge with rigid bearings, (a) with restrainers Type 1, (b) with restrainers Type 2

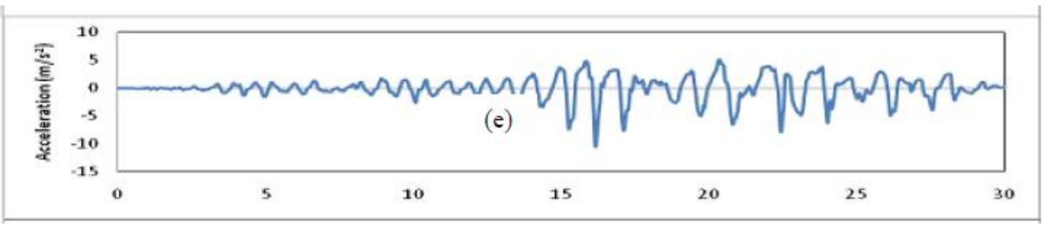

Figure 4. Input accelerations from Sun-Moon Lake station

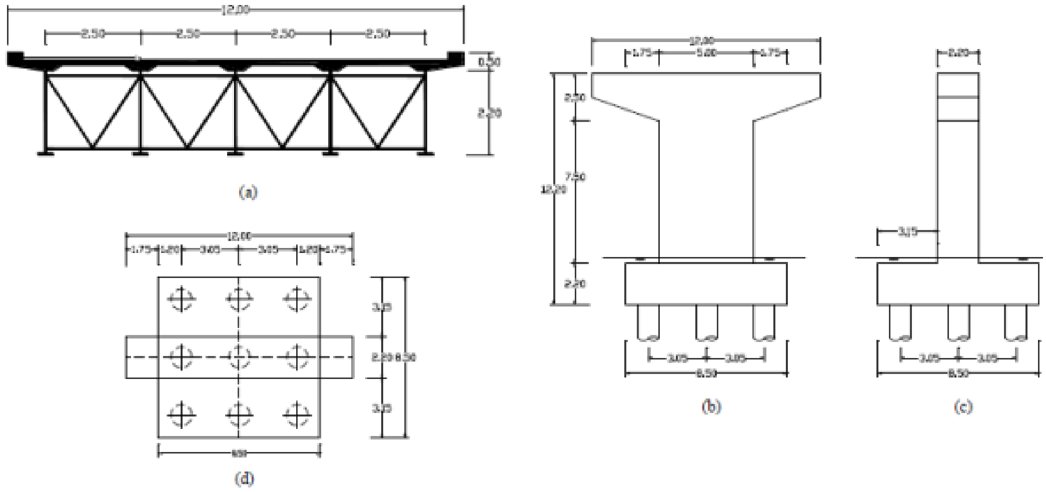

Figure 5. (a) Lateral view of superstructure, (b) lateral view of column, (c) side view of column, and (d) pile configuration

Table 1. Number of unseated decks for bridges with restrainers type 1, type 2, stoppers (the first case)

GM Scale	Number of Unseated Decks (Restrainer type 1)					Number of Unseated Decks (Restrainer type 2)				
	R1	R1 & S (gap 10)	R1 & S (gap 20)	R1 & S (gap 30)	R1 & S (gap 40)	R2	R2 & S (gap 10)	R2 & S (gap 20)	R2 & S (gap 30)	R2 & S (gap 40)
100%	0	0	0	0	0	0	0	0	0	0
110%	0	0	0	0	0	0	0	0	0	0
120%	0	0	0	1	1	2	0	1	0	0
130%	0	1	2	2	2	0	0	3	2	0
140%	2	2	2	0	1	0	0	3	3	1
150%	1	1	0	1	3	2	3	3	0	3
160%	3	3	6	4	5	2	3	2	4	2
170%	2	4	6	2	4	2	3	3	5	3
180%	6	6	6	6	6	4	6	6	6	6
190%	6	6	6	6	6	1	6	6	6	6
200%	5	6	6	6	6	6	6	6	6	6
210%	6	6	6	6	6	6	6	6	6	6
220%	5	6	6	6	6	6	6	6	6	6
230%	5	6	6	6	6	6	6	6	6	6
240%	6	6	6	6	6	6	6	6	6	6
250%	6	6	6	6	6	6	6	6	5	6
260%	6	6	6	6	6	6	6	6	6	6
270%	6	6	6	6	6	6	6	6	6	6
280%	6	6	6	6	6	6	6	6	6	6
290%	6	6	6	6	6	6	6	6	6	6
300%	6	6	6	6	6	6	6	6	6	6

Table 2. Number of unseated decks for bridges with restrainers Type 1, Type 2, stoppers (the second case)

GM Scale	Number of Unseated Decks (Restrainer type 1)					Number of Unseated Decks (Restrainer type 2)				
	R1	R1 & S (hook 10)	R1 & S (hook 20)	R1 & S (hook 30)	R1 & S (hook 40)	R2	R2 & S (hook 10)	R2 & S (hook 20)	R2 & S (hook 30)	R2 & S (hook 40)
100%	0	0	0	0	0	0	0	0	0	0
110%	0	0	0	0	0	0	0	0	0	0
120%	0	2	1	1	2	2	2	0	1	0
130%	0	0	0	2	2	0	0	0	1	3
140%	2	0	1	2	1	0	2	0	2	3
150%	1	3	2	3	2	2	1	2	1	2
160%	3	5	5	3	5	2	0	2	2	4
170%	2	6	3	2	2	2	0	5	1	4
180%	6	6	6	6	6	4	6	6	5	6
190%	6	6	6	6	6	1	6	5	5	6
200%	5	6	6	6	6	6	6	6	6	6
210%	6	6	6	6	6	6	6	6	6	6
220%	5	6	6	6	6	6	6	6	6	6
230%	5	6	6	6	6	6	6	6	6	6
240%	6	6	6	6	6	6	6	6	6	6
250%	6	6	6	6	6	6	6	6	6	6
260%	6	6	6	6	6	6	6	6	6	6
270%	6	6	6	6	6	6	6	6	6	6
280%	6	6	6	6	6	6	6	6	6	6
290%	6	6	6	6	6	6	6	6	6	6
300%	6	6	6	6	6	6	6	6	6	6

Table 3. Number of columns failure for bridges with restrainers type 1, type 2, stoppers (the first case)

GM Scale	Number of Columns Failure (Restrainer type 1)					Number of Columns Failure (Restrainer type 2)				
	R1	R1 & S (gap 10)	R1 & S (gap 20)	R1 & S (gap30)	R1 & S (gap 40)	R2	R2 & S (gap 10)	R2 & S (gap 20)	R2 & S (gap30)	R2 & S (gap 40)
100%	0	0	0	0	0	0	0	0	0	0
110%	0	0	0	0	0	0	0	0	0	0
120%	0	0	0	0	0	0	0	0	0	0
130%	0	0	0	0	0	0	0	0	0	0
140%	0	0	0	0	0	0	0	0	0	0
150%	0	0	0	0	0	0	0	0	0	0
160%	0	1	1	1	1	0	1	0	1	0
170%	0	1	1	1	1	0	2	1	3	3
180%	0	4	5	3	5	0	5	5	5	5
190%	1	5	5	5	5	1	5	5	5	5
200%	5	5	5	5	5	3	5	5	5	5
210%	5	5	5	5	5	5	5	5	5	5
220%	5	5	5	5	5	5	5	5	5	5
230%	5	5	5	5	5	5	5	5	5	5
240%	5	5	5	5	5	5	5	5	5	5
250%	5	5	5	5	5	5	5	5	5	5
260%	5	5	5	5	5	5	5	5	5	5
270%	5	5	5	5	5	5	5	5	5	5
280%	5	5	5	5	5	5	5	5	5	5
290%	5	5	5	5	5	5	5	5	5	5
300%	5	5	5	5	5	5	5	5	5	5

Figure 6 and **Figure 7** depict the result of ductility for each column. Although in a vary condition, all columns for the bridge with restrainers and stoppers (*R1+S* and *R2+S*) in fixed hook of 40 cm reach the ultimate ductility with an input seismic motion less than the bridge with *R1* and *R2*. The similar result is found for bridge with *R2+S* in fixed gap of 40 cm. Interesting result occur for bridge in fixed gap of 40 cm, when the ultimate ductility of column with *R1* occur in a smaller input of seismic motion comparing to bridge with *R1+S*.

Table 4. Number of columns failure for bridges with restrainers type 1, type 2, stoppers (the second case)

GM Scale	Number of Columns Failure (Restrainer type 1)					Number of Columns Failure (Restrainer type 2)				
	R1	R1 & S (hook 10)	R1 & S (hook 20)	R1 & S (hook 30)	R1 & S (hook 40)	R2	R2 & S (hook 10)	R2 & S (hook 20)	R2 & S (hook 30)	R2 & S (hook 40)
100%	0	0	0	0	0	0	0	0	0	0
110%	0	0	0	0	0	0	0	0	0	0
120%	0	0	0	0	0	0	0	0	0	0
130%	0	0	0	0	0	0	0	0	0	0
140%	0	0	0	0	0	0	0	0	0	0
150%	0	0	0	0	0	0	0	0	0	0
160%	0	1	1	0	1	0	0	0	0	0
170%	0	1	1	1	1	0	0	1	0	2
180%	0	5	5	5	5	0	4	3	1	5
190%	1	5	5	5	5	1	5	2	4	5
200%	5	5	5	5	5	3	5	5	5	5
210%	5	5	5	5	5	5	5	5	5	5
220%	5	5	5	5	5	5	5	5	5	5
230%	5	5	5	5	5	5	5	5	5	5
240%	5	5	5	5	5	5	5	5	5	5
250%	5	5	5	5	5	5	5	5	5	5
260%	5	5	5	5	5	5	5	5	5	5
270%	5	5	5	5	5	5	5	5	5	5
280%	5	5	5	5	5	5	5	5	5	5
290%	5	5	5	5	5	5	5	5	5	5
300%	5	5	5	5	5	5	5	5	5	5

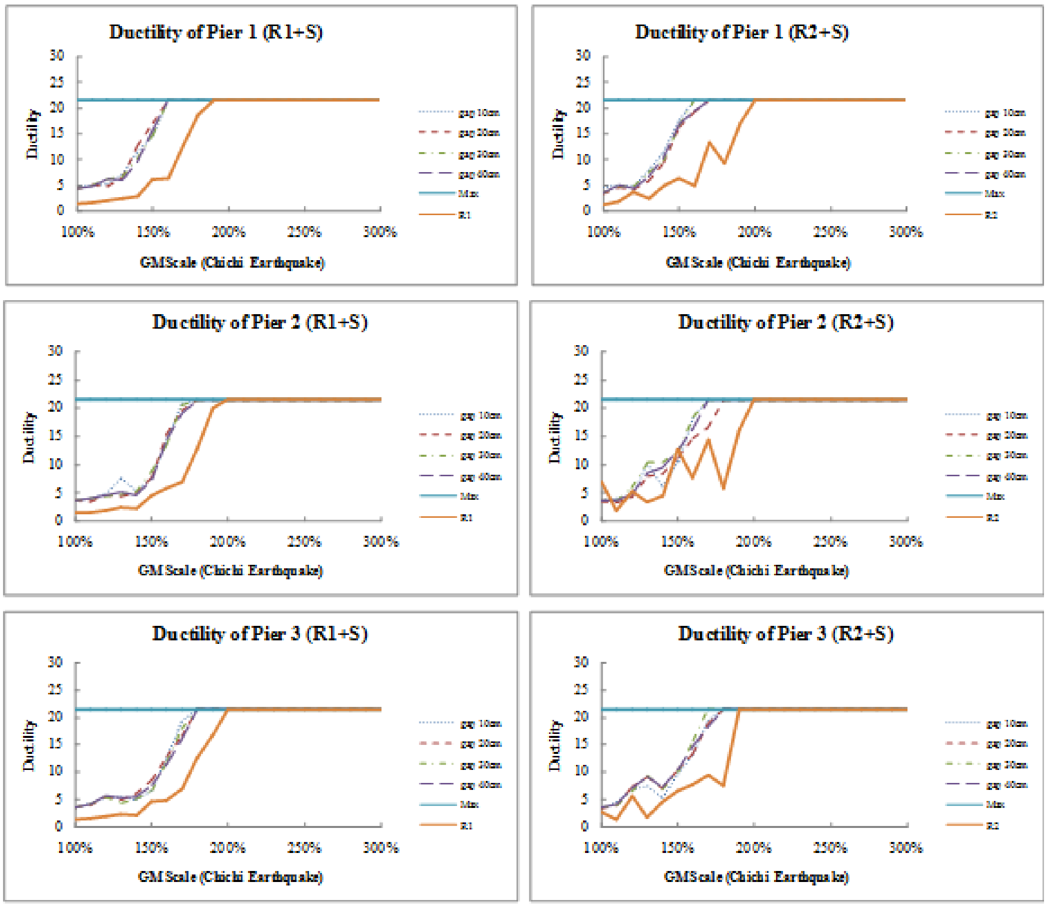

Figure 6. Ductility of column 1 to 3 for bridges with restrainers Type 1, Type 2, stoppers (the first case)

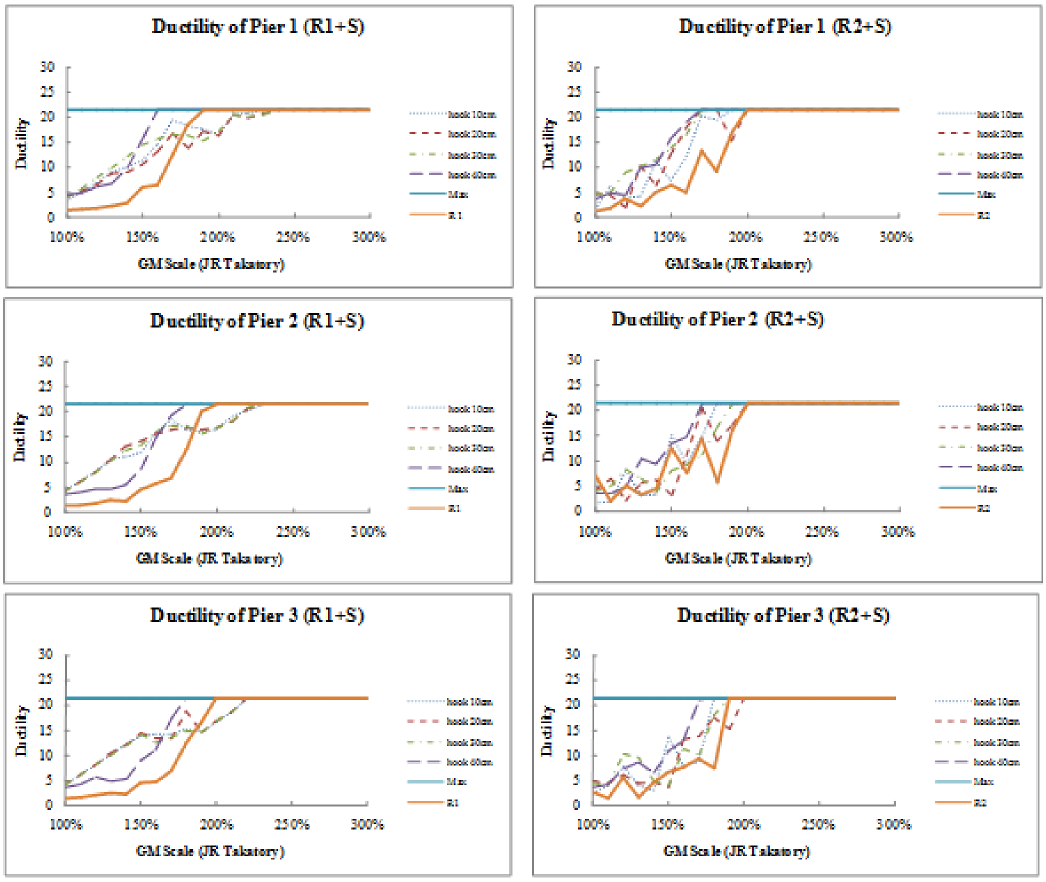

Figure 7. Ductility of column 1 to 3 for bridges with restrainers Type 1, Type 2, stoppers (the second case)

4. CONCLUSIONS AND SUGGESTIONS

The effectiveness of multiple restrainers in simply sipported bridges during 1999 Taiwan Chi-Chi earthquake were studied. Observed from the result of numerical simulations, several conclusions are listed in the following:

1. In most cases, installation of restrainer type 1 (*R1*) independently has a better result in protecting the deck of bridges from unseating.
2. The bridge with multiple restrainers (*R1+S* and *R2+S*) suffers column failure as the amplification of ground motion is less than bridge with single restrainer. It is detected when the ductility demand exceeds the ultimate ductility of column.
3. Failure of the simply-supported bridge is caused by unseating of deck, then failure of column.
4. Thus, it is important to check the effectiveness of restrainer type 1 in protecting the deck of the continuous bridge from unseating. In addition, supplementary dampers can be determined in order to dissipate the seismic energy.

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