0119

DAMPING AND ENERGY CHARACTERISTICS OF PC RIGID-FRAME VIADUCT BRIDGES

Yoshitaka MATSUI[1], Toshiro HAYASHIKAWA[2], Koichi SATO[3] And Takakichi KANEKO[4]

SUMMARY

This study shows about damping characteristics of PC rigid-frame viaduct bridges. An analytical model is used an elastic-plastic plane frame. A purpose of study is to confirm an inflexion of damping coefficients and absorption of energy, because plastic hinge occurs in PC rigid-frame bridges. A nonlinear finite element analysis is used in this study. An inflexion of natural frequencies and damping coefficients and consumption energy is investigated in numerical example. Then, viscous damping at plastic domain is well adjustment with equivalent damping coefficients. A hysteric damping is extremely valid for absorption of energy.

INTRODUCTION

Bridge construction in Japan requires stricter and more complicated dynamic analysis. At the great earthquake in the southern part of Hyogo prefecture in Japan on 1995, bridge structures received many damages. In order to consider this seismic influence in Japan, a seismic design of rigid bridges shifted from an elastic design method to an elastic-plastic design method. An elastic design method is used that deformations and stresses of structural members must be within allowance limit. However, an elastic-plastic design method is used by considers a behavior after a yield point. Immediately, an elastic-plastic design is to consider a nonlinear characteristic for a bridge structural member. Therefore, a purpose of seismic design method on highway bridge in Japan has an appropriate ductility, even though structural member enters a nonlinear region. The plastic region of members is benefited to raise an absorption ability of energy further and defend from a collapse of structure whole systems.

At a guideline of seismic design of bridge structure, fundamental natural period and damping coefficients is extremely an important parameter. Specially, the damping coefficients make as dynamic responses of structures decrease. Those are a primary factor to be related to energy absorption of a structure system. As a part of energy absorption of these, a damping is classified nearly into two parts. One's way is a viscous damping of structure, a hysterics damping, friction at modal supports and a friction damping depending on a slip for division members, and a energy absorption is consumed from the inside structures. As a damping of one more, there is lost for periphery foundations, air and water. Namely, this is classified energy absorption by the energy dissipations. Therefore, damping characteristics of bridge structures are reported for an experiment in vibration a lot of data.

For example, Kawashima, et. al. presented estimating technique that absorption of energy is estimated each part structural systems of girders, towers and cables on cable stayed bridges. As how to estimate of vibration damping energy on cable stayed bridges, Yamaguchi is studied a validity of estimation by damping energy and these are examinated by using of vibration measurement on existance bridges. Yoneda has studied an affect on structural damping characteristics by using continuous box girder bridges and Lohse bridges. As a result, coulomb friction force at movable supports is considered among various damping factors in order to get some information for damping characteristics of these bridges. Tunomoto and Kazikawa have studied an affection on damping characteristics by energy estimation method by using suspension slab bridges. Nakazima et al. have studied as follow, in order to investigate the structural damping characteristics of the plate girder bridge, the

[1] *Graduate Student, Graduate school of Engineering, Hokkaido University, , Sapporo,Japan.,Email:matsui@mb.snowman.ne.jp*
[2] *Associate Professor, Graduate School of Engineering, Hokkaido University, Japan*
[3] *Professor, Graduate School of Engineering, Hokkaido University, Japan*
[4] *Professor,Department of civil engineering, Hokkaido College Senshu University, Japan*

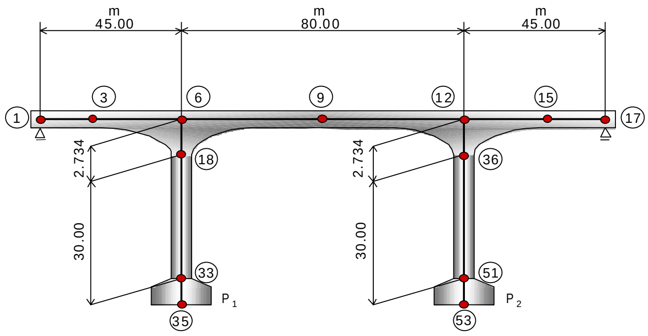


Figure 1.Analytical model

Table 1. Analytical properties

		sp.s	3.10×10^6
		sb.s	2.50×10^6
A	m^2	sp.s	8.62～15.69
		sb.s	19.98
I	m^2	sp.s	7.63～49.14
		sb.s	39.55

sp.s:super structure

Table 2. Nonlinear characteristic of pier

	cruck point	yeild point	limit point
cuvature(1/m)	7.835 $\times 10^{-5}$	58.562 $\times 10^{-5}$	2353.791 $\times 10^{-5}$
Bending Moment(tf・m	7747.46	18396.54	21143.84

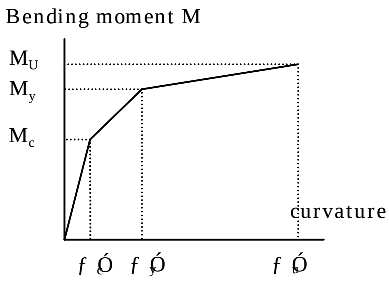


Figure 2.curvature curves

complex eigenvalue analysis is conducted using rigid-body spring model taking into account the damping properties which are resulted from material of concrete and steel themselves, friction of movable support, and friction and nonlinear behavior of the interface between the steel girder and the concrete slab.

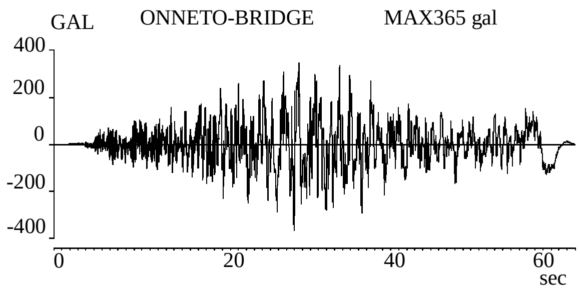


Figure 3.Input accelesion wave

A purpose of study is to confirm an inflexion of damping coefficients and absorption of energy, because plastic hinges occurs in continuous rigid-frame bridges. A numerical example is 3 span continuous PC rigid- frame bridge constructed in Japan and nonlinear characteristics of reinforcement pier is tri-linear model. A nonlinear finite element analysis is used in this study and an analytical model is used an elastic-plastic plane frame. And as plastic hinge increasing, hinge increasing, an inflexion of natural frequencies and damping coefficients and consumption energies is investigated in numerical example. These are investigated from three steps, as to follow. Firstly, the vibration characteristics are investigated by mean of complex eigenvalue when a plastic hinge occurs for structural members. Secondly, damping coefficients are estimated by damped free vibration waves with every time steps. Lastly, this study is investigated the time history of consumption energy quantity.

2. ANALYTICAL MODEL AND PROCESS

2.1 Analytical model

In this study, 3 span continuous rigid-frame bridges are analyzed as model cases shown in Fig.1. As size of structures, side span length is 45m, center span length is 85m and pier height is 30m. Table 1 has the physical properties needed for the calculation. Calculation of piers is used the M-φ curve of tri-linear (Takeda-model) as nonlinear metal element are shown in Fig.2 and Table 2. Ground acceleration wave is used a correcting wave of the Onneto-bridge in Japan as shown Fig.3. These are inputted to under the footing as 365 gal whole 60 seconds. And supper structure and footing except the pier are linear elements. The support comprises movable supports at abutment and fix supports at piers. Damping for analysis is as follow, a supper structure is assumed as an elastic domain is using 3%, foundation of piers is assumed 3% when it is an elastic domain, however, plastic domain using 2%. The plane frame model is used in analysis, number of total nodal points is 53 and number of total elements is 52.

2.2 Analytical process

In this study, the procedure of analysis is considered from 3 stage as follow. Firstly as first step, the vibration characteristics are investigated by mean of complex eigenvalue analysis when a plastic hinge occurs for structural members. The change of variations in viscous dampings and fundamental frequencies are accompanied the plastic hinges of piers by using the modal analysis are investigated. The second step is to investigate the change of damping coefficients that is estimated by damped free vibration waves on plastic hinge with every time by using logarithmic decrements. These are three remarkable points in time history response of dynamic behavior in this study. Firstly, it is time occurred the first plastic hinge. Secondly, it is time made maximum seismic motions. Finally, it is time finished a principal wave. The third steps is investigated the time history of consumption energy in internal of a structural system. But, the friction on supports does not consider. These are investigated a relationship between an input energy and a change of a kinetic energy, a viscous dumping energy and a hysteric damping energy on an absorption of energy.

3. NUMERICAL RESULTS

3.1 Natural frequency and damping coefficients

When a strong earthquake ground motion acts on PC rigid-frame viaduct bridges, the plastic hinges will be occurred in top and bottom ends of each pier. The natural frequencies and damping coefficients of bridges may be estimate to be changed. In this case, the change of frequencies and damping coefficients on plastic hinges of structural members is investigated by using a complex eigenvalue analysis. It is estimated that the plastic hinges occure, when the reinforcing bars of concrete piers yield. Fig.4 shows the time, the order, and nodal points of occurring plastic hinges. Therefore, the nodal analysis is performed in consideration after plastic stiffness in the plastic hinge points. From the above calculations, plastic hinges of pier confirmed to occur from bottom to top pier and they are occurred both P_1 and P_2 at same time. As shown in Fig.5, a relationship

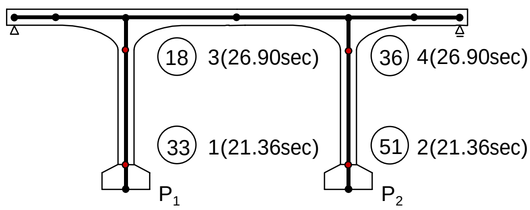
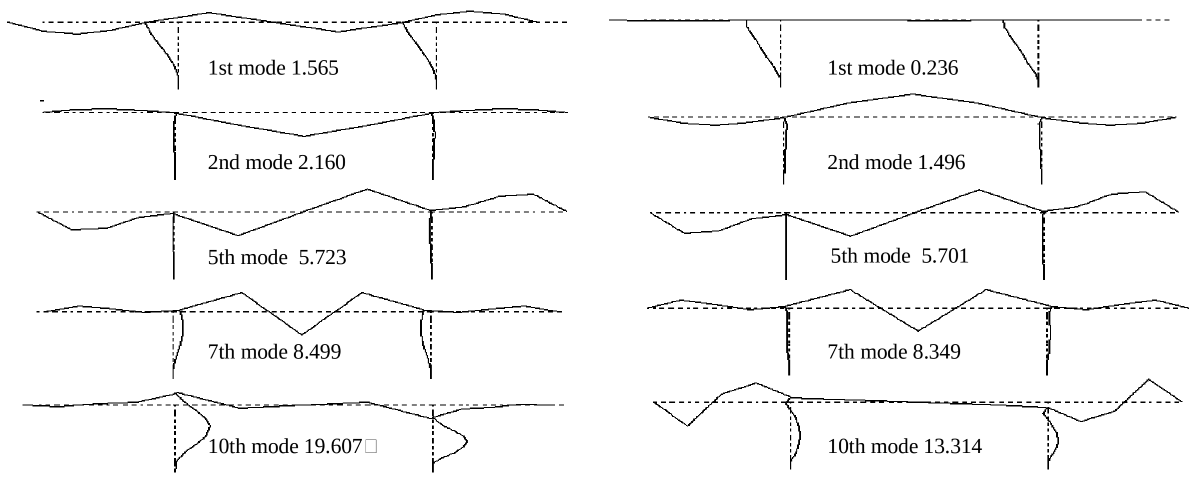


Figure 4.Incidence procedure of



(a) Elastic domain without plastic hinges

(b) Plastic domain with plastic hinges

Figure 5.Natural mode shapes and frequencies (Hz)

between natural made shapes and frequencies is confirmed to orthogonal and coupling with both superstructure and piers in the elastic domain. But, the natural mode shapes on elastic domain that are exceeding in horizontal direction are confirmed Fig.5 (b). It is depend on the plastic hinges. As their relationsVip, the fundamental natural frequency of plastic domain is smaller than that of elastic domain. In other words, the natural period of the bridge with plastic hinges is longer than that without plastic hinges. Fig.6 in shows that the natural frequencies decrease as the number of plastic hinges increases. It is considered that the whole structural system is longer periods. Because, stiffness of member due to plastic hinges is small.Fig.7 in shows that damping coefficients decrease as the number of plastic hinges increases. It is seen calculations that there are four hinges in a structural system and damping coefficient of first mode is exceeded.

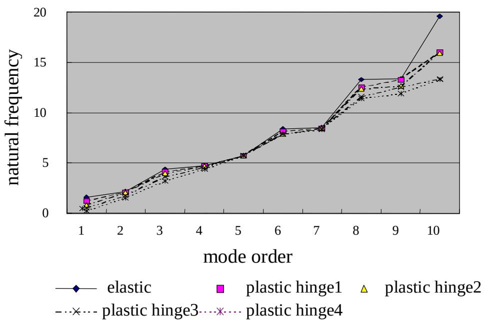


Figure 6.variation of natural frequency
by plastic hinge

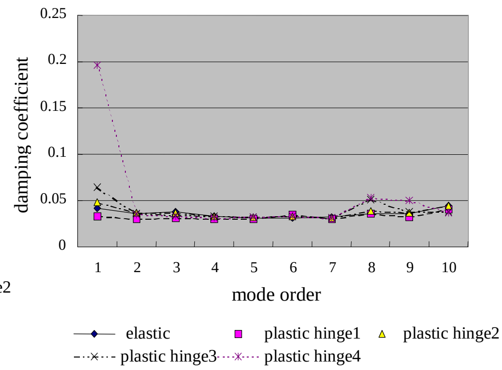


Figure 7.variation of damping coefficient

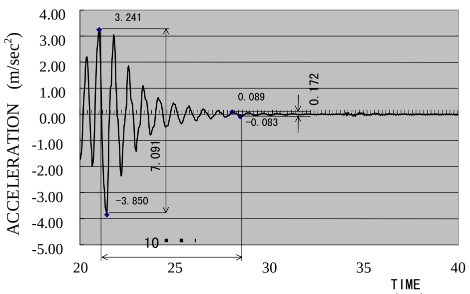


Figure 8.Damped free vibration wave of nodal point (T=21.36 sec)

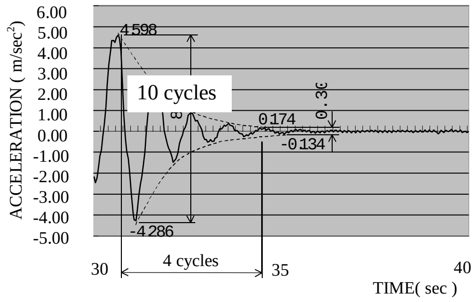


Figure 9.Damped free vibration wave of nodal point ? (T=31.71 sec)

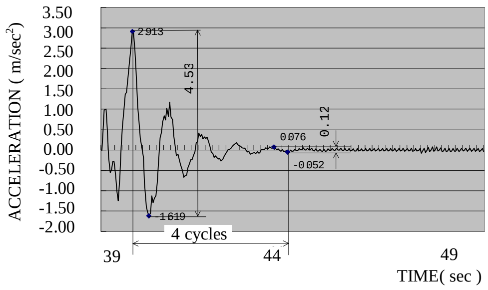


Figure 10.Damped free vibration wave of nodal point ? (T=40.00 sec)

3.2 Logarithmic decrement of damping

In this case, damping coefficient is calculated by using damped free vibration wave. The damped free vibration wave is made by stopping at the remarkable time. The damping coefficient is estimated to request a logarithmic decrement by using the damped free vibration wave. In this case, the time of remarkable time set t=21.36 sec, 30.71 sec and t=40.00 sec. The first time step is selected a damped free vibration wave when a plastic hinges in bottom of pier. The second time step is selected on time (t=30.71 sec) when the input wave the maximum, the maximum is about 365 gal. As final step, the time is t=40.00 sec, this time is after an input principal wave. The dynamic response of acceleration at times 21.36 sec, 31.71 sec, and 40.00 sec are indicated in Fig.8, 9, and 10 respectively. The logarithmic decrements δ and the damping coefficients h are calculated by equation (1).

$$\delta = log_e\left(\frac{x_{i-1}}{x_i}\right)\ h\ \ \frac{\delta}{2\pi} \qquad (1)$$

in which, x_i is the amplitude of acceleration.

By equation (1), the calculated logarithmic decrementsδ and damping coefficients h are as follows ; δ=0.378 and h= 0.059 on time t=21.36

sec,δ=0.84 and h=0.134 on time t=31.71 sec, δ=0.812 and h=0.142 on time t=40.00 sec. Step1 show elastic domain and step2 is plastic domain. They are considered as follow. The former is conformed within 10%, and the latter is within 12-20%. Because, they are conformed for the seismic design of Japan road specification.

3.3 Estimate of absorption energy

Change of the consumption energy stored in the structural system is investigated. But, the influence of friction dampings movable support is not considered. Fig.11 in shows the time history's changing of the input energy and inside energy shows as the kinetic energy, the viscous damping energy and hysteretic damping energy. As shown in Fig.4, the first and second plastic hinges are occurred at the bottom of piers P_1 and P_2, respectively, on time t=21.36 sec. Moreover, the third and fourth plastic hinges are occurred the top of piers on time t=26.90 sec. The kinetic, viscous and hysteretic damping energies have a tendency to increase as the plastic hinges increase.

This reason is considered to be due to large deformation of piers and absorption energy of plastic hinges. Each energy as shown in Fig.11 do not increase at instantinuous time of occurring of plastic hinges. For this reason, it is considered that the inside energy is released. The time history response of velocity at nodal point 18 as shown in Fig.1 is indicated in Fig.12. Fig.13 shows the time history response of moment at same nodal point. It is seen from Fig.12 and 13 that the time history curves are almost similar. The rations of each energies to input energy are shown in Fig.14. According to the calculated result, the ratio of consumption by the kinetic energy is considerable small. The ratio of consumption by viscous damping energy is dominated in elastic domain, but it's ratio becomes smaller after time t=21.36 sec. The ratio of consumption by the hysteristic damping energy is smaller in elastic domain, however, hysteristic damping energy becomes larger in the plastic domain after time t=21.36 sec. It is concluded from Fig.14 that the hysteric energy accounts for 65% of the input energy, the viscous damping energy is about 35% and kinetic energy is negligible small. Therefore, the hysteric damping energy is extremely important in the elastic-plastic design of bridge structures.

4. CONCULUSIONS

In this study, an inflexion of natural frequencies, damping coefficients and consumption energies is investigated by using a prestressed concrete continuous bridge. They are investigated from three steps as follows. Firstly, the vibration characteristics are investigated by mean of complex eigenvalue analysis when a plastic hinge occurs for structural members. As plastic hinge increasing, it is seen that natural frequencies get small and damping coefficients are large. Secondly, damping coefficients are estimated by damped free vibration waves with every time. The damping coefficients of above-described plastic region are almost approximated equivalent damping coefficients of above-described plastic region are almost approximated equivalent damping coefficients. Lastly, this study is investigated the time history of consumption energy quantity. Consumption energy has tended to increase suddenly by occurrence of a plastic hinge. A hysteric damping energy compared with an input energy is about 65%, viscous damping energy is about 35% and kinetic energy has scarcely. It is concluded that the hysteric damping is extremely important in elastic-plastic design of bridge structures.

ACKNOWLEDGEMENTS

The authors would you like to acknowledge to Dr. Ohshima T.(Kitami institute of technology, Japan) and Mr. Aochi, T., (Kaihatsu Koei Co.Ltd.,Japan) for helpful and valuable discussion.

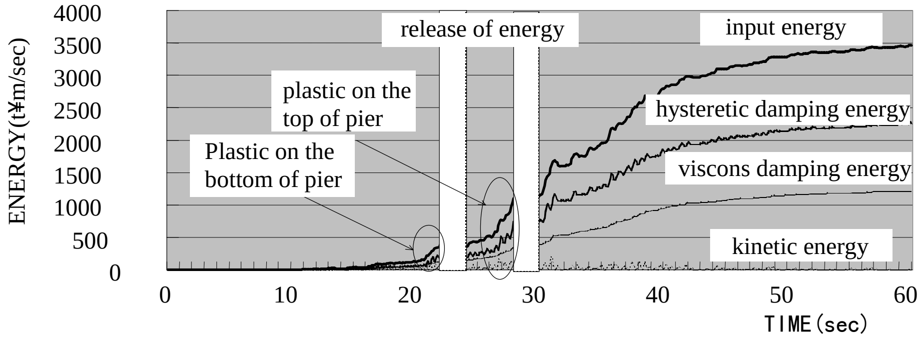


Figure 11.Time variation of each energies

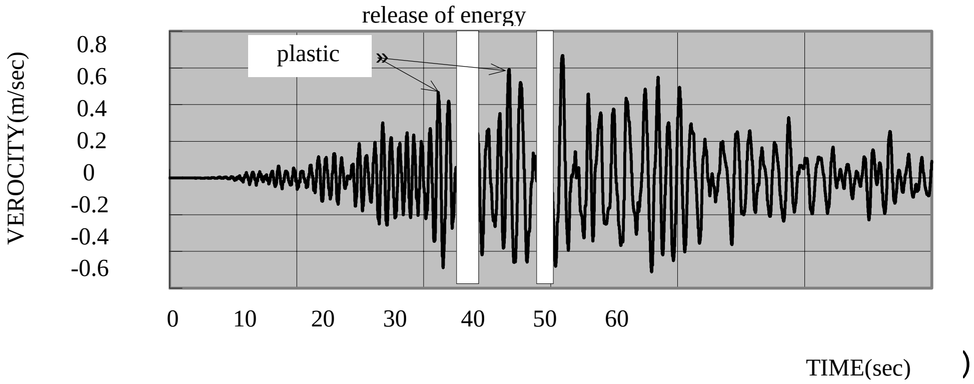


Figure 12.Moment on the top of pier

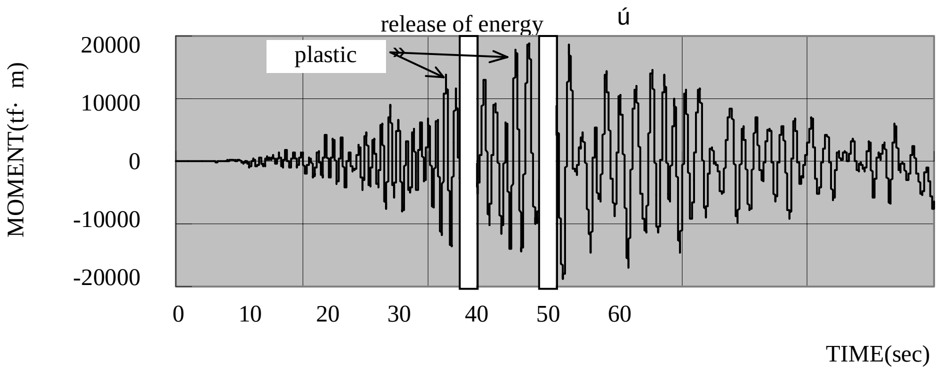


Figure 13.Moment on the top of pier

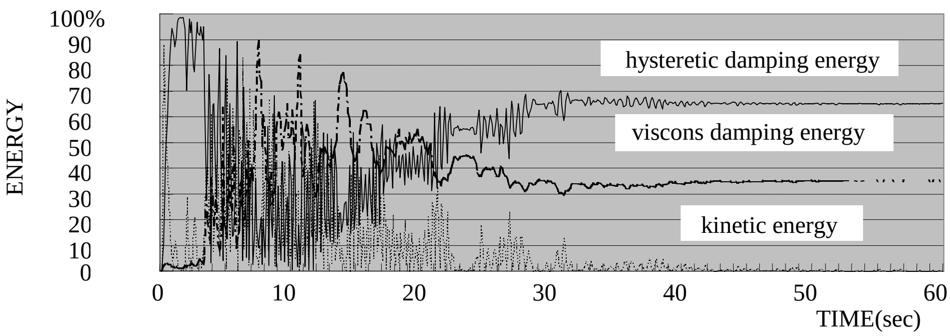


Figure 14.Ratio of each energies at input energy

REFERENCES

Japan road association ,"*Specifications for highway bridges (earthquake resistant design of highway bridges)*" ,1996.

Kato,M.and Shimada,S.,"Structural analysis on the measured bridge vibration data",*Proceedings of JSCE*., No.311,1981,pp.49-58.

Kawashima,K.,Unjoh,S.and Tsunomoto,M.,"The estimate method of damping coefficients of cable-stayed bridges by using seismic design", *Journal of bridge and foundation* ,1990, pp.35-40.

Konishi,I.and Yamada,Y.,"On the structural damping and it's applications to forced vibration characteristics in beam bridge", Proceedings of JSCE.,No.41-2,1956,pp.47-53.

Nakajima,A.and Doki,H., "Fundamental study on structural damping characteristics of plate girder bridge employing rigid-body spring model analysis", *Proceedings of Structural Engineering* ,*JSCE*.,vol.44A,1998, pp.793-800.

Tunomoto,M.,Kajikawa,Y.and Okabayashi,T.,"An influence of damping characteristics of a suspension slab bridges",*Proceedings of 52th Conference of JSCE*.,1997,pp.458-459.

Yamaguchi,H.,Ito,M.,Sakamoto,K.and Rajesh Adhikari,"Damping database of cable-stayed bridges and it's analysis",*Journal of constructional steel*,Vol.1,1993,pp.359-364.

Yamaguchi,H.,Takano,H.,Ogasawara,M.,Shimosato,T.,Kato,M.and Kato,H.,"Energy-based damping evaluation of cable -stayed bridges and it's application to Tsurumi tsubasa bridge",*Proceedings of JSCE*, No.543/I-36,1996,pp.217-227.

Yoneda,M.,"Some considerations on damping characteristics of bridge structures due to coulomb friction force at movable supports",*Proceedings of JSCE.*,No.492/VI-23,1994,pp.137-145.