A STUDY ON SEISMIC BEHAVIOR AND DISPLACEMENT CONTROL OF A CONTINUOUS GIRDER BRIDGE WITH LOW FRICTION SLIDING BEARING SUPPORT

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ABSTRACT :

Authors have shown the superiority using the low friction sliding bearing support (LFSBS) for continuous girder bridges by the seismic response analysis and shake table test using small steel girder bridge model. This paper inspects the validity of this system by the seismic response analysis for an existing three span continuous steel girder bridge with seven different bearing supports conditions. Accelerations, displacements, bending moments and curvatures are calculated and compared each other. It became clear that in the bridge with LFSBS piers vibrate independently from girder, and curvature at the bottom of the pier becomes very small compared to those of the ordinal support type bridge. The effect of damper installed between end of the girder and abutment to reduce the large displacement of the girder is also clarified.

KEYWORDS: LOW FRICTION SLIDING BEARING SUPPORT, SEISMIC RETROFIT, CONTROL OF DISPLACEMENT

1. INTRODUCTION

According to the 1995 Hyogoken- Nanbu Earthquake many highway viaducts suffered severe damages. Design specification for highway bridges was revised to insure the seismic safety of bridges for near source earthquake of magnitude 7 class earthquake. In this revision bearing supports are considered as one of the important members of bridges.
After this earthquake many base isolated bridges has been designed and constructed. However in plate boundary type large earthquake long term ground motions are expected, long term structures such as long span flexible bridges and base isolated bridges may be suffered severe damages. Furthermore rubber bearing supports for base isolation are comparatively expensive and difficult to set up on the narrow top of piers.
Focusing the seismic retrofit of bridges, most of piers (single type columns) on the ground have been retrofitted, but seldom piers in the river have retrofitted because of the difficulty of construction work.
Low friction sliding bearing supports(LFSBS) with only 2% friction coefficient even in high velocity region of 2m/s, has been newly developed using the fiber reinforced and heat hardening resin. Furthermore down sizing of the support and cost reducing is expected, because this material has twice the allowable surface pressure of the ordinary materials.
Authors conducted the research to develop a new bridge system using this LFSBS. This system is expected to reduce the inertia forces from the superstructures to the substructures drastically, and the cost of the substructures and bearing supports are also reduced. Fig. 1 shows the comparison of piers designed by ordinal earthquake resistant design method, seismic isolation method and the idea of LFSBS system. Understanding from this figure, piers designed by LFSBS system has very small inertia force from superstructure.
Authors' research has been conduced using two different works, i.e. one is the shake table test of scale model bridge, and the other is the numerical analysis of existing bridge.
About the former research, from the test results of single span and three span continuous girder bridges, the following are made clear. The response acceleration of girder and bending strain of pier bottom are reduced in LFSBS system, displacement of girder is controlled by dampers attached at girder ends, and horizontal displacements of girder which occur for example in ordinal traffic loads because of the small values of

friction of bearing supports are successfully controlled by device with trigger.
About the latter research for 5- span continuous PC girder bridge, from nonlinear dynamic analysis it was clarified that bending moments of piers are reduced in spite of characteristics of ground motions.
But the countermeasure for girder displacements increased by adopting LFSBS has not been investigated in existing bridge level. Possibility of reduction of increased girder displacement is easily expected using damper system. But the reduction is also possible by the combination of bearing supports with different friction coefficients.
This paper shows some discussion from this point of view. First of all earthquake response analysis for 3-span continuous steel girder bridges with ordinal bearing supports and various combination of friction type bearing supports were conducted. From these analysis it was pointed out that bridges with LFSBS is superior and safe for earthquake. Secondly the effectiveness of girder end dampers and the combination of relatively large friction bearing supports to reduce the displacements of girders are discussed.

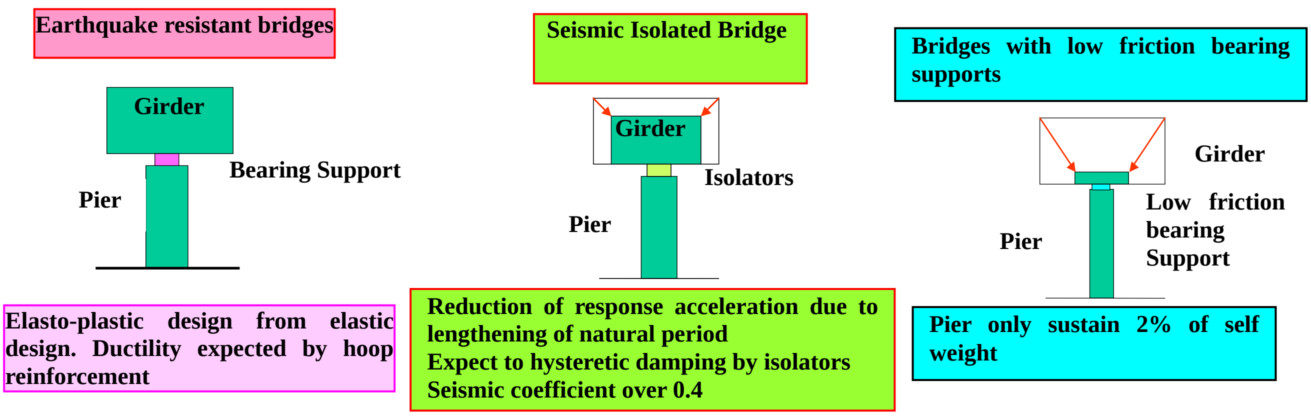


Fig.1 Comparison of Different Design for Earthquake

2. TARGET BRIDGE FOR ANALYSIS AND ANALYTICAL CONDITION

2.1. Outline of Target bridge

A target bridge of this paper is 3-span continuous non composite plate girder bridge(existing bridge) with bridge length of 135m, equal pier height and slightly different abutment heights. Bridge dimension is shown in Table 1. Piers are single column with overhang beam made by reinforced concrete, abutments are inverse T shape, and piles are cast in place reinforced concrete with 1.2m diameter. Superstructure is composed with 4 main girder and effective width is 8.5m.
Frame model for analysis is shown in Fig.2. Superstructure and abutment are assumed as liner beam elements, column portions of piers are nonlinear beam elements, and overhang beams and footings are rigid body. Pile foundation is treated as sway- rocking model with linear springs. Takeda model (moment –curvature relation) is used for nonlinear characteristics of pier column.

Table 1 Dimensions of the Target Bridge

Type of bridge	3-span continuous non composite steel girder bridge
Bridge length	L=135.0m
Span length	44.7m +44.7m + 44.7m
Height of pier	P1=P2=8.30m
Height of abutment	A1=7.97m A2= 6.59m

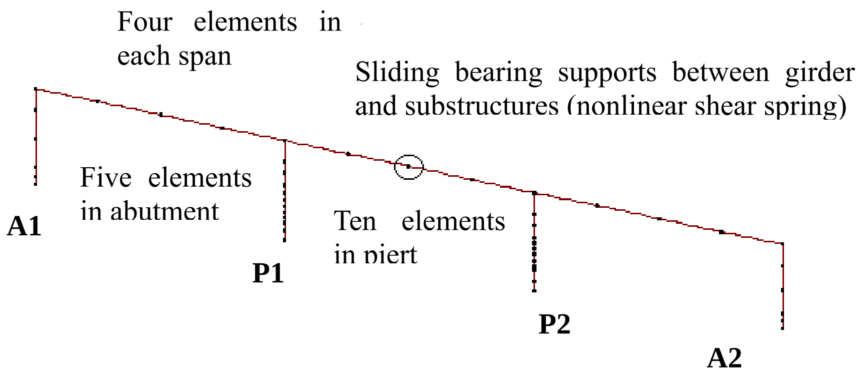


Fig 2 Outline of analytical model

2.2. Modeling of Bearing Supports

Seismic performances of bridges with different bearing supports are compared. Condition of supports are fix (F), high(Sh), moderate(Sm), and low (Sl) friction sliding bearing supports. Table 2 shows the combination of bearing supports and friction coefficients of each sliding bearing support. Models 1 and 2 are ordinal girder bridges with one fix support and three moderate friction SBS. Models 3,4, and 5 are bridges with low, moderate, and high friction SBS each other. Models 6 and 7 are bridges with high friction SBS on abutments and moderate or low friction SBS on piers.

Restoring forces of SBS are given by spring, and their hysteresis are almost rigid-plastic (bilinear) type skelton. The validity of bilinear type skelton is insured as safety side assumption comparing the results of analysis using exact hysteresis loops of SBS. The k1 and k2 are same values for three types of SBS. Yielding forces are calculated using the values of initial vertical forces multiplied by friction coefficient. The initial vertical forces are obtained by dead load analysis. The validation of vertical forces during earthquake are ignored.

Table 2 Support condition

(a) Analytical model

	A1	P1	P2	A2
Model 1	Sm	Sm	F	Sm
Model 2	Sm	Sm	Sm	F
Model 3	Sl	Sl	Sl	Sl
Model 4	Sm	Sm	Sm	Sm
Model 5	Sh	Sh	Sh	Sh
Model 6	Sh	Sm	Sm	Sh
Model 7	Sh	Sl	Sl	Sh

(b) friction coefficient of each support

	Type of Sliding Bearing Supports	Coefficient of Friction
Sh	High Friction	0.4
Sm	Medium Friction	0.1
Sl	Low Friction	0.02
F	Fix	—

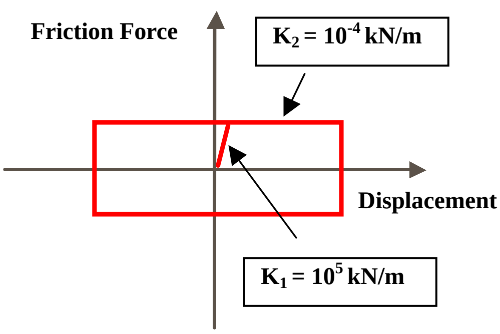


Fig.3 Hysteresis loop of sliding support

2.3. Analytical Condition

Newmark β method (β=1/4) and interval period 0.001sec is used for nonlinear time history analysis. The commercial software RESP-T is adopted. Stiffness portion type viscous damping matrix is used not to consider extreme damping. Damping coefficient of each element are 3% for girder, 5% for pier and abutment, 20% for foundations, and 0% for SBS.

3. DISCUSSION FOR IGENVALUE OF THE TARGET BRIDGE

Natural period with maximum effective mass ratio for longitudinal or vertical direction displacement mode for each model is obtained as shown in Table 3. Natural periods except model 1 and 2 are same because of the coincidence of initial stiffness of SBS, therefore model 3 is the representative of other models.

Model 3 has shorter natural period compared to model 1, and this tendency is clear in longitudinal direction. The difference of model 1 and 2 comes from the different location of fix bearing support, and natural period of the bridge with end fix bearing support become long in longitudinal direction mode, but become short in vertical direction mode. But the maximum difference is only 7%, therefore it may be concluded that the characteristics of natural vibration is almost same among all models.

Table 3 Comparison of natural period of main mode
(unit : sec, figures in parenthesis is ratio to model 1)

Mode	Model 1	Model 2	Model 3
Longitudinal direction	0.541 (1)	0.577 (1.067)	0.510 (0.942)
Transverse direction	0.530 (1)	0.497 (0.938)	0.514 (0.970)

4. SEISMIC PERFORMANCE OF THE TARGET BRIDGE FOR LEVEL 2 GROUND MOTIONS

Earthquake response analysis for the continuous girder bridge with LFSBS is conducted to clarify the dynamic behavior for the large earthquake. Input motion is one of the standard wave of level 2 (type2-2-1, maximum acceleration is 6.87m/s) specified by design specification of highway bridges. Time history is shown in Fig.4.

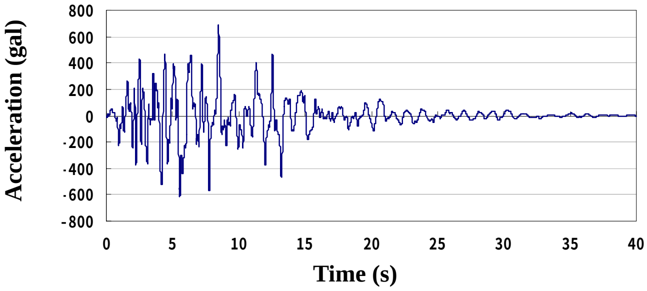


Fig.4 Time history of input motion

4.1.Comparison of response displacement

Fig.5 shows comparison of time histories of girder (mid point of mid span) and top of pier 2 for models 1, 3,4 and 5. Displacements of girder and pier top are almost same in the model 1. Because the bearing support on pier 2 is fix. In the cases of bridges with SBS girder displacements become large after cutting of friction. The maximum and residual response displacements become larger according to decrease of friction coefficients.

4.2 .Comparison of bending moments and curvature of pier bottoms

Fig.6 shows comparison of bending moment-curvature relations of pier 2 for models 1, 3, 4 and 5. In the bottom of pier 2(fix supports) of model 1 large bending moments occurred, but bending moments of model

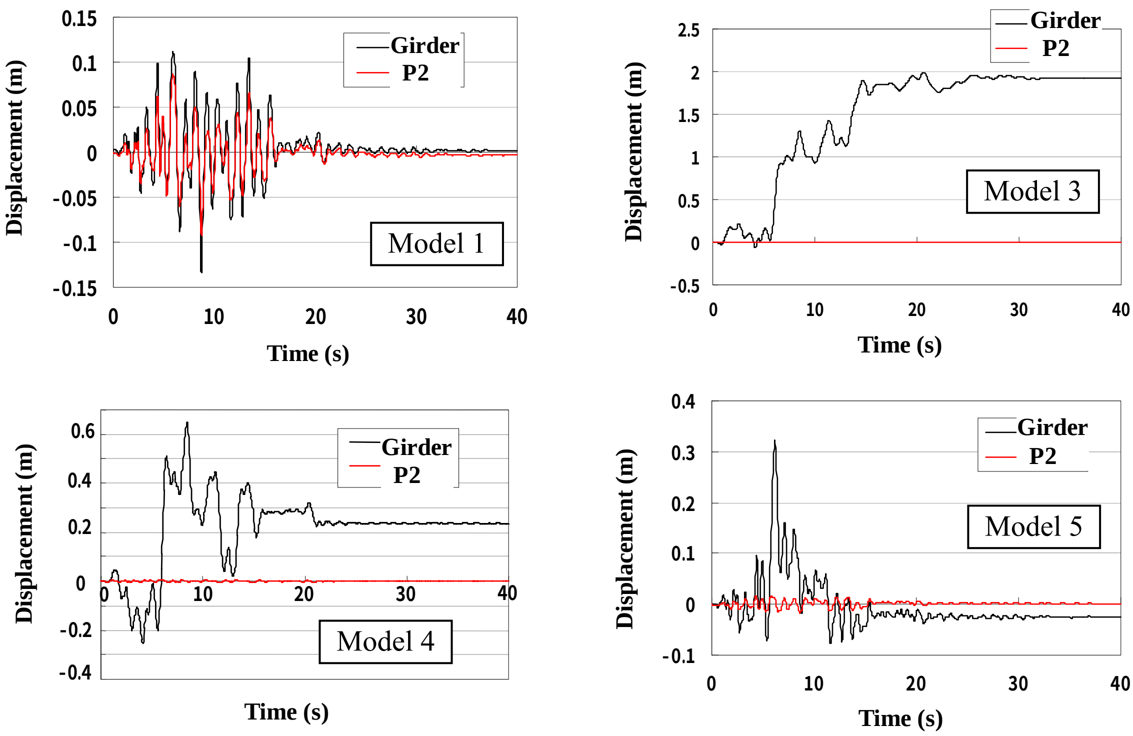
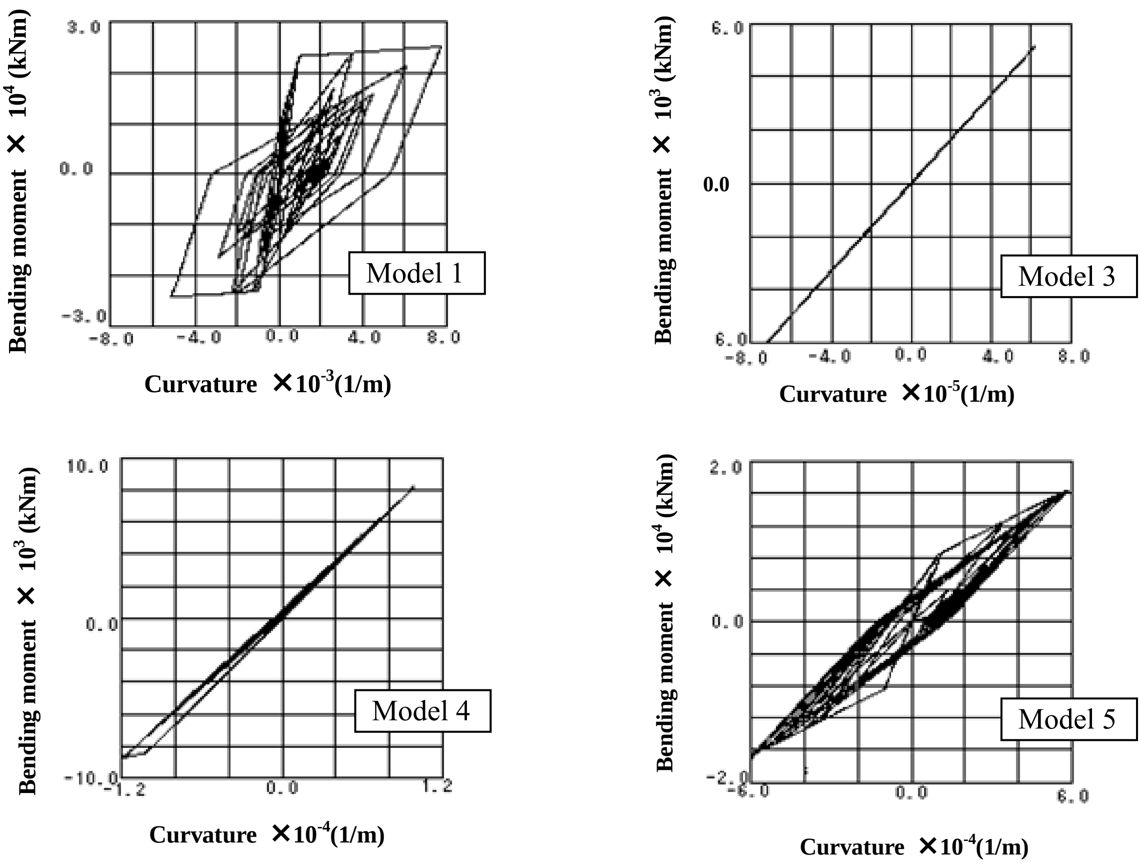


Fig.5 Time histories of response displacement of girder and Pier 2



Fif.6 Bending moment- curvature of pier 2 bottom

3,4 and 5 are very small compared to those of model 1. For example bending moments of model 3(LFSBS) is only 0.9% of model 1(FIX), and 12 % of model 5(HFSBS) and 59% of model 3(MFSBS).
Occurrence of bending moment at the bottom of the pier is classified into two reasons by cause. One is the force from bearing support (inertia force from superstructure) and the other is inertia force of pier itself. On the top of pier 2 friction forces are 115kN for model 3, 574kN for model 4, and 2297kN for model 5. Considering the height of pier 2 (6.5m), bending moments according to friction forces at the bottom of the pier are 748kNm, 3731kNm, and 14930kNm respectively. These values are small compared to total bending moments. For example in model 3 this value is only 12% of total bending moment, so pier size is expected to become small for the bridge with LFSBS.

4.3. Comparison of acceleration

Fig. 7 shows maximum acceleration of girder (mid point of center span). Models 3 to 7 which have SBS in all supports show small maximum acceleration of girder compare to Models 1 and 2 which have fix support. For example the maximum acceleration of model 3 is reduced to until only 20% of those of models 1 and 2. Increase of girder acceleration according to the increase of friction coefficient is clear. Considering this result and variation of girder displacement shown in Fig 5, smaller coefficient of friction produce larger displacement, and smaller acceleration of girder, therefore smaller collision force between girder and parapet wall of abutment is expected.

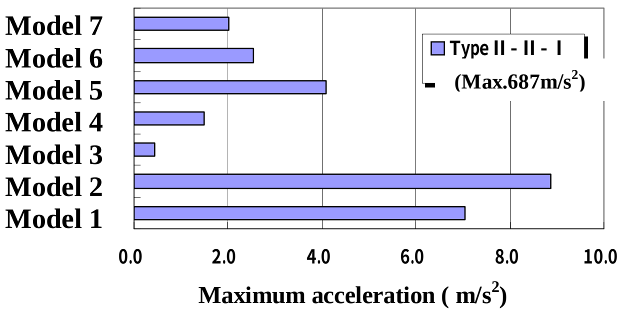


Fig.7 Maximum acceleration of girder

5. COUNTERMEASURE FOR CONTROL OF GIRDER DISPLACEMENTS AND ITS RESULT

Until the former chapter it is made clear that in continuous girder bridges with LFSBS bending moments of piers can be drastically reduced. But the possibility of collision between girder and abutment and falling down of the girder may increase because of the large displacement of girder. As countermeasure of control of girder displacement which are insured by experiments using scale model bridge are as follows.
(1) Install of buffer
Horizontal clearance at abutment is decided for dead load and Level 1 earthquake, and during the Level 2 earthquake collision of girder and abutment is permitted and girder displacement is controlled by the buffer. Various type of buffer has been developed using rubber, steel, fiber, and so on.
(2) Install of damper between girder and abutment
Abutment and girder are connected by dampers to reduce the girder displacements. Girder displacement should be reduced within limited stroke of damper.
Dynamic analysis using countermeasure No. 2 is conducted in the following section.

5.1. Modeling of damper

Damper should not be connected to pier to avoid the increase of transmitted force from girder to pier. Therefore damper is connected between girder ends and abutments. The friction type of damper is recommended. In the analysis restoring forces of the dampers are given by bilinear type spring elements. Yield force of a damper is increased at a interval of 500kN.

5.2.Discussion of effect for reduction of girder displacement

Fig. 8 shows the relation of maximum response displacement and yielding forces of dampers (for each abutment). The maximum response displacement decrease according to increase of yield forces of dampers. If we decide that the allowable displacement is 0.25m (it is shown as dotted line in the same figure), the following fact become clear. To satisfy the allowable displacement, yielding forces 500kN is necessary for model 5, 2000kN for model 6, 2500kN for model 4 &7, 3500kN for model 3. This means larger forces are necessary for smaller friction coefficients. Furthermore comparing models 3 and 7, thanks to installing of high friction SBS in model 7, we understand that yielding forces for an abutment decrease about 920kN.

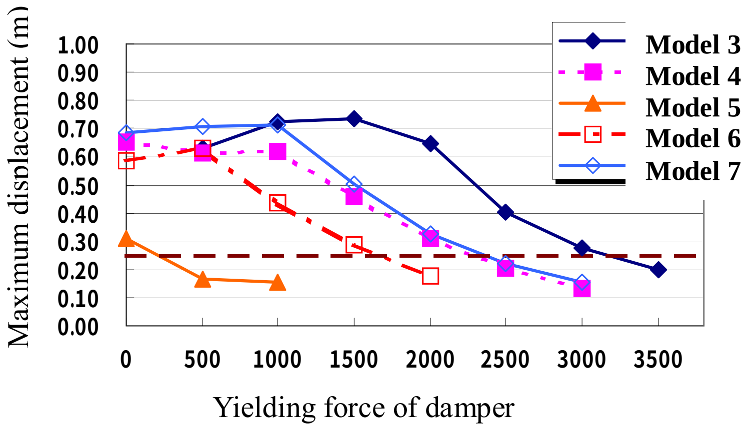


Fig.8 Variation of maximum displacement of girder due to yielding force of damper

5.3. Influence to girder acceleration and pier(abutment) curvature

The relation of maximum girder acceleration and yielding forces of dampers in models 3 and 7 is linear. Girder acceleration increase in proportion to yielding forces of dampers in both models. To control the displacements under 0.25m, yielding forces of 3500kN are necessary in model 3 and 2500kN in model 7. In these cases maximum girder acceleration are 6.3m/s^2 in model 3 and 5.1m/s^2 in model 7 respectively. These values are 90% and 73% of acceleration of model 1. Therefore dampers with high yielding forces do not always increase the acceleration.

Checking the variation of curvature of bottom of abutments and piers, the curvature increase in proportion to yielding forces in abutment, but not in piers. Because the dampers are attached to abutments. Therefore it is necessary to select the suitable location for dampers.

6. CONCLUSION

The following features are pointed out for bridges with LFSBS.

(a) Bending moments and shearing forces of substructures are reduced, because most of seismic forces are not transmitted between girders and substructures due to the low friction forces. Therefore section forces by inertia forces of substructure itself become superior forces for piers.

(b) After sliding occurs at bearing supports, girder vibrates independently, so response displacements and residual displacements become large. Therefore installation of devices to control the displacement would be necessary.

Our research assures the above mentioned phenomenon due to the calculation of existing bridge, and clarifies the effectiveness of proposed countermeasures. The following are conclusion of this paper.

1) Using dampers at the end of girders for the bridges with low FSBS enable the control of inordinate displacement of girder

2) Using high friction SBS is effective as substitution of dampers.

3) Dampers should be attached between girder and abutment, so piers have no influence about installing the dampers.

Designing a new bridge with LFSBS, pier and abutment can be designed for small friction forces, so cost reduction of substructures is expected. Seismic retrofitting of substructures of existing bridges is also achieved by exchange of bearing supports instead of strengthening of substructures.

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