ICSS(1):Concept And Fundamental Of Seismic Respons

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SUMMARY

The Isolation Seismic Controlled Slide System (so to call ICSS) is a newly proposed control seismic for multi-span continuous girder bridges using slide bearings, isolation bearings and seismic dampers. Applying this system, the bridge will be isolated so that the indeterminate force on bearings due to temperature change is greatly reduced. In addition, the seismic behavior will be controlled by the isolation bearings and seismic dampers installed to a limited number of piers. In this paper, dynamic analysis is performed to of identify the role for each device during earthquakes using model of an 18-span continuous steel bridge with 1,200m length. As a result, it was shown that the proposed system had sufficient damping ability and a stable behavior for the input ground motion considered and input directions.

Keywords: Seismic isolation control, Elastomeric bearing, Seismic damper, Slide bearing, ICSS

1. INTRODUCTION

I Excessive elongation of the fundamental natural period of the structural system is discouraged for the seismic isolation design of bridges in accordance with the Road and Bridge Specifications of Japan Road Association (2004). This is because an isolated bridge can be subjected to an increased seismic action depending on the relationship between the bridge's natural period and the ground characteristics; the seismic isolation design (*Menshin* design) philosophy in Japan puts on emphasis on the enhancement of structural damping to reduce the seismic load. This concept can be further extended to limit the restoring force components as much as possible, while a high level of structural damping is introduced with the use of high capacity seismic dampers to utilize seismic force reduction effect of the isolation system. Based on this idea, the Isolation Seismic Controlled Slide System (ICSS) has been proposed as a new seismic structural type with an optimum combination of elastomeric bearings, seismic dampers, slide bearings and other devices for multi-span continuous girder bridges (Matsuda et al., 2012) (Sakate et al., 2012) (Tsushima et al., 2012).

In this paper, the verification of seismic performance of the ICSS is shown and discussed based on the results of dynamic seismic response analyses of an 18-span continuous steel girder bridge with 1,200m length. The layout of the bearing and damper devices is such that the slide bearings are used in principle to support the girder allowing longitudinal and transverse movements, while the transverse displacement at the abutments is restrained by special restraining components, and elastomeric isolation bearings and seismic dampers are installed at two designated strong piers supporting the center span of the bridge. Providing the energy dissipation capability to the transverse response of the curved girder bridge, the orientation of the seismic dampers is diagonal with the angle of 45 degrees from the longitudinal direction of the girder. The seismic dampers are modeled with a nonlinear hysteretic load-displacement relationship and geometric nonlinearity, to account for large displacement and axial rotation during the seismic response. Not only the seismic response of the bridge to unidirectional seismic input accelerograms designated by the Japanese design standard specifications for highway bridges, also the dynamic response to bi-directional seismic inputs are analyzed in order to verify the performance of the bridge in realistic seismic events. The expected essential features of the seismic response of the bridge with the ICSS system are obtained by the analysis, showing the design seismic performance requirements are satisfied (Igarashi et al., 2012).

2. CONCEPT OF ICSS

Long multi-span continuous girder bridges supported by elastomeric bearings or rubber bearings are generally susceptible to greater statically indeterminate forces caused by temperature changes, desiccation shrinkage and creeps; accordingly, it causes unfavorable effects to response displacement of bearings and post-yield response of bridge piers(Uno et al., 2010). On the other hand, in the case of long multi-span continuous girder bridges with application of ICSS, statically indeterminate forces can be significantly reduced. Figure 2.1 shows the typical layout of ICSS with an optimum combination of elastomeric bearings, seismic dampers and slide bearings all over bridges. It is expected that the system will have beneficial effects on surmounting technical issues as stated below:

1) Statically indeterminate forces caused by temperature changes and others can be effectively reduced so that their influence on the seismic performance of bridges can be lessened.
2) Since the statically indeterminate force becomes lower, works for adjusting the location of bearings with “post-slide” and other procedures can be eliminated.
3) Substructures supporting the slide bearings can be streamlined while the limited member of substructures supporting the elastomeric bearings and seismic dampers can increase in size. As a result, the cost of the entire substructure system can be reduced.
4) A high level of structural damping is achieved by means of non-linear energy dissipation mechanisms of applied devices.

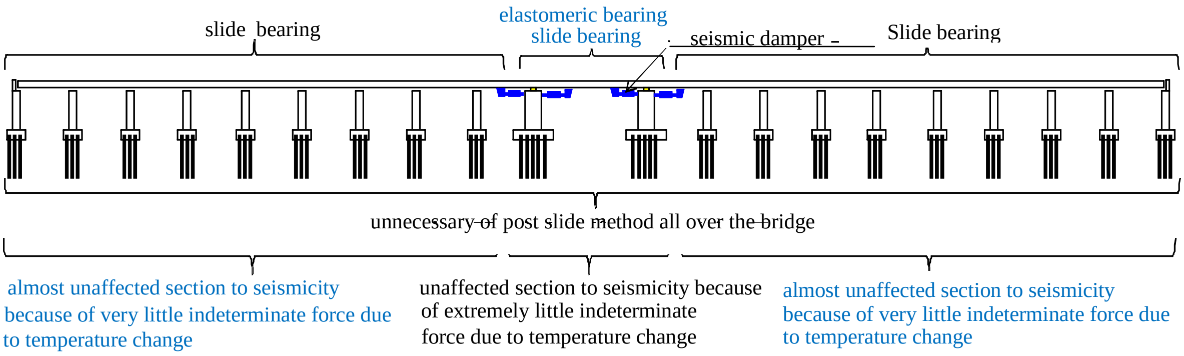


Figure 2.1. Example of application example of ICSS

3. THE CHARATCTERISTICS OF EACH DEVICE IN ICSS

The characteristics of each device used for bearing is as follows.

1) Isolation Bearing

A lead rubber bearing(LRB) is applied as the isolation bearing. LRB consists of a rubber bearing and lead plugs. Rubber bearing is a restoring force element without an energy absorption function and a lead plugs has only an energy absorption function.

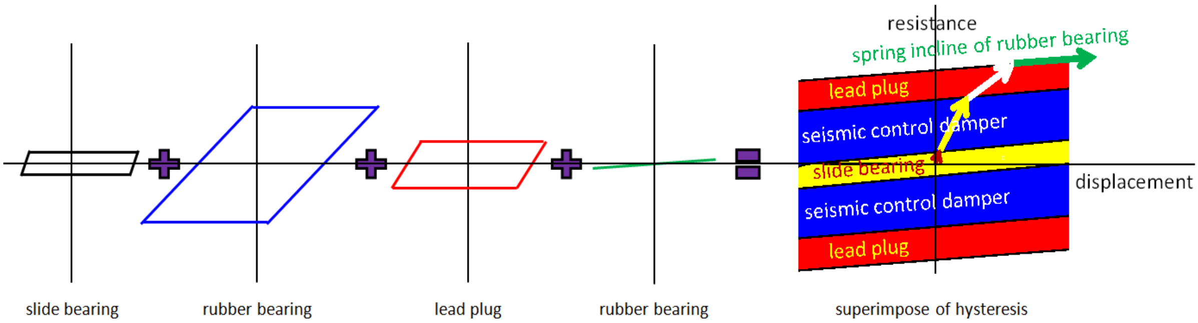


Figure 3.1. Superposition of the device response and concept of resistance on ICSS

2) Seismic Control Damper

The friction hysteresis type damper utilizing Bingham fluids is adopted as the seismic control damper. The resistance of the seismic control damper employed for the analysis is proportional to the 0.1th power of velocity.

3) Slide Bearing

Slide bearings isolate the superstructure from substructure by employing slide material with small coefficient of friction. The friction coefficient of slide bearing assumed in this system is in the range of 0.01-0.05 depending on the slide velocity.

The inertia force resisted by the each device is divided as shown in Figure 3.1. The function of each device is activated in order of slide bearings, seismic control dampers, and lead plugs in accordance with the initial rigidity. After the yielding of all the devices, rubber bearing generates resilient forces in addition to the almost constant resistance force (Matsuda et al., 2012).

4. DISPLACEMENT RESTRAINING MECHANISM OF PIERS

In the ICSS, since fixed support condition is established in the perpendicular direction at both of the abutments, the superstructure is allowed to move only in the longitudinal direction. For this reason, full-down of the superstructure can be prevented if sufficient beam starting length is prepared, and the safety margin for this type of failure is enhanced by adopting a displacement restraining mechanism for excessive transverse displacement to piers with slide bearings, as shown in Figure4.1.

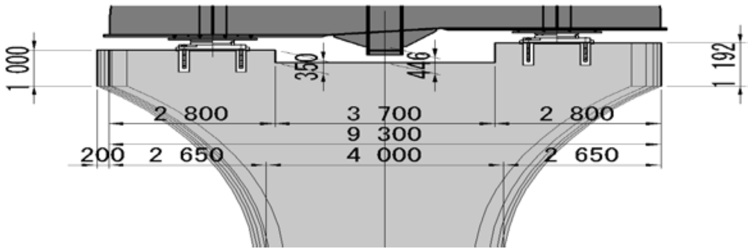


Figure 4.1. Limiting displacement structures figure of piers in slide bearing

5. SPECIFICATIONS OF THE BRIDGE

5.1Type and size of the bridge

The bridge to be designed is a steel box- and plate- mixed girder [a 18-span continuous curved-bridge]. The maximum curvature radius is 750m, the total length about 1200m, as shown in Figure 5.1. Bearing devices are arranged as shown in Figure 5.2. The steel box- and plate- composite type girder of the 18-span continuous bridge consists of steel box girders in the section between P8 and P11 crossing a river and twin steel plate girders in the rest of the spans.

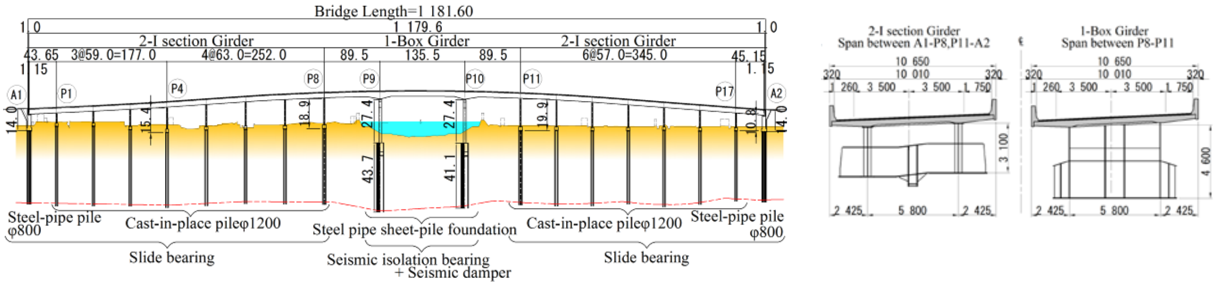
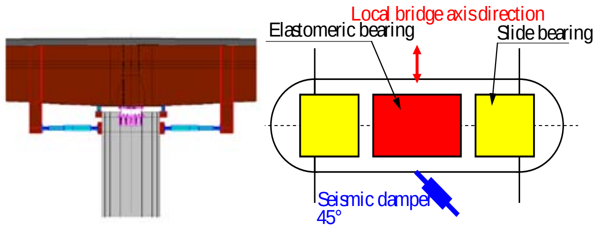


Figure 5.1. Side view and cross section of the bridge to be designed



(a) Side view (b) Layout concept of each device

Figure 5.2. Allocation of bearing devices (P9 pier)

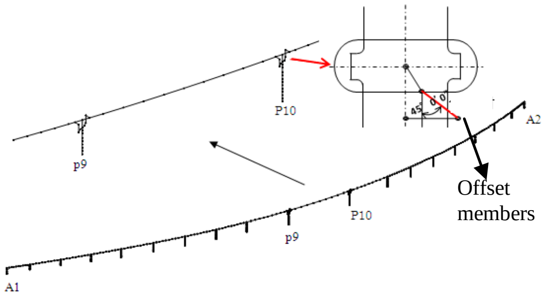


Figure 5.3. A whole model figure and a vibration control damper

5.2 Analysis model

The bridge axis is defined as the direction of the line connecting the two abutments, and transverse direction of the pier P6 was made into bridge axis transverse direction. The longitudinally entail gradient is not taken into consideration for the model of the beam. The cross-section area of the beam and rigidity are calculated as a synthetic beam, and the rigidity of the box- girder account only for the deck plate in consideration of the steel box- girder and the floor slab. The offset members are prepared in the position of the superstructure where inertial force forces acts from under the beam. Division of the beam into 10 sections between the bridge piers is carried out. The analysis model is shown in Figure 5.2. The positive/negative sign of the response value coincides with the definition of the coordinate axis .

5.3 Restoring force characteristic of devices

The assumed hysteretic response of slide bearings, elastomeric bearings and seismic control dampers installed at piers P9 and P10 are shown in Figure 5.4. Specification of each device is as follows.

1) Elastomeric Bearing

The LRB of dimensions 1,600×2,600 mm, and total rubber thickness =325 mm(13-layers×25 mm) are assumed to be used

One unit is installed on P9 and P10, respectively.

The restoring force characteristics are modeled by a bilinear model with parameters at 250 % shear deformation.

2)Seismic Damper

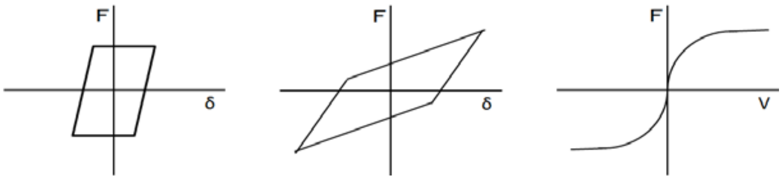
The force of the seismic dampers is modeled by Eqn. (4.1). The distance between the end set pins is 3.85 m. These are installed in the orientation of 45 degrees from the local bridge axis.

$$F = C \cdot V^{0.1} \tag{5.1}$$

Where, F: Resistance Force (kN)(6000 kN at velocity 50 kine)

C : Reduction Coefficient ($kN \cdot s^{0.1}/m^{0.1}$)

V: Velocity(m/s)



a) Slide bearing (b) isolation bearing (c) seismic damper

Figure 5.4. Restore characteristic of bearing devices

3)Slide Bearing

The behavior of slide bearings is characterized by the friction coefficient of 0.05 with a elastomeric-perfectly plastic model of yield displacement of 2.5mm.

5.4 Restoring force characteristics of Piers

The layout of rebars used in piers P9 and P10, to which the isolation bearings and seismic control dampers are installed is shown in **Figure 5.4.** The M-φ model of the piers is shown in **Figure 5.5.** and the nonlinearity in each direction are considered independently without interaction. The Takeda type tri-linear model, and the SR foundation spring model on TypeⅢground are used in the analysis.

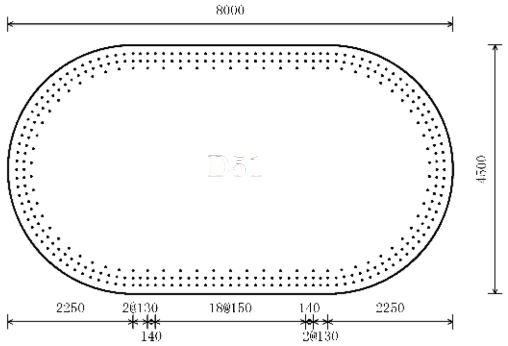


Figure 5.4 Arrangement of deformed steel bar in piers P9 and P10

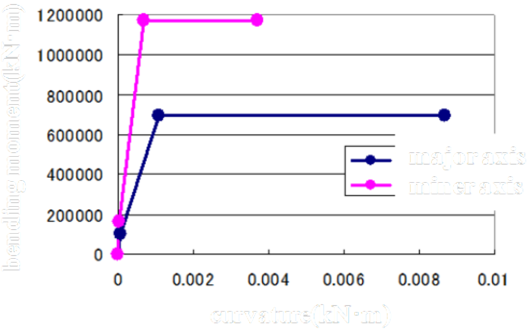


Figure 5.5 M- ϕ characteristics of pier

5.5 Input Seismic Ground Motion

The seismic ground motions used as the input are the standard accelerograms of Type I and Ⅱof Level 2 Earthquake Ground Motion of theⅢkind foundation specified in Japan Specifications for Highway Bridges. Table5.1 summarizes the input accelerograms used in the analysis. The longitudinal and transverse directions are the cases for excitation angles. The assessment is made based the mean of the three cases of accelerograms for each excitation direction in the category.

Table 5.1. The analysis case of the direction input seismic waves

Category	Case	Accelerograms	Excitation
Level 2 Type- Ⅰ	1	+Ⅰ−Ⅲ−1	**Longitudinal**
	2	+Ⅰ−Ⅲ−2	
	3	+Ⅰ−Ⅲ−3	
		[illegible]	
	4	+Ⅰ−Ⅲ−1	**Transverse**
	5	+Ⅰ−Ⅲ−2	
	6	+Ⅰ−Ⅲ−3	
		[illegible]	
Level 2 Type-Ⅱ	1	+Ⅱ−Ⅲ−1	**Longitudinal**
	2	+Ⅱ−Ⅲ−2	
	3	+Ⅱ−Ⅲ−3	
		[illegible]	
	4	+Ⅱ−Ⅲ−1	**Transverse**
	5	+Ⅱ−Ⅲ−2	
	6	+Ⅱ−Ⅲ−3	
		[illegible]	

6. NATURAL MODES AND DYNAMIC ANALYSIS CONDITIONS

Only the elastomeric bearings are taken into consideration in the evaluation of the damping characteristic using Rayleigh damping. The equivalent damping ratios of the superstructure, the pier, the isolation bearing and the foundation are 2%, 2%, 10% and 5%, respectively. The fundamental natural period of the system in the longitudinal, transverse and vertical directions are 5.3 sec, 16.3 sec and 1.6 sec, respectively. Rayleigh damping constants are a= 0.016667 and ß= 0.00654 determined by the 1st and 38th modes. The dynamic response of the model is analyzed by means of the nonlinear step-by-step time history response analysis using the Newmark-ß method (ß = 1/4) with the step interval of Δt=0.001 sec, accounting for finite deformationn evaluation of the damping characteristic of bearing, only isolation bearing was taken into consideration at Rayleigh damping. The equivalent damping constant of each structure element set up the superstructure, the pier, the isolation bearing and the foundation to 2%, 2%,.10% and 5% respectively. The primary natural period of the longitudinal direction, the transverse direction and the vertical direction as this oscillating system are 5.3 sec, 16.3 sec and 1.6 sec respectively. Rayleigh damping constants were set up with a= 0.016667 and ß= 0.00654 by the 1st and 38th frequency.

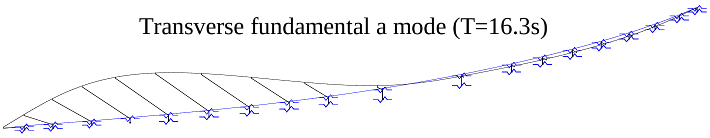


Figure 6.1. Fundamental natural mode shape

7. RESPONSE CHARACTERISTICS

7.1Displacement of damper

Figure 7.1 shows the representative displacements of the two connection points of the seismic damper attached to the pier P9 and the girder, indicating the orientation of the damper at the times of maximum tension/compression response for the case of Ⅱ-Ⅲ-1 input accelerogram. The symbol 'O' in the figure represents the initial positions of the seismic damper's end pins connected to the pier and the girder. It clearly shows that considerable rotational displacement of the damper takes place during the seismic response of the bridge. The influence of this horizontal rigid-body rotation of the damper appears to be even greater than the damper end displacement, implying that variation of the damper force directions associated with the rotation of the damper is regarded as one of the prominent features of the dynamic response of the bridge with the ICSS mechanism.

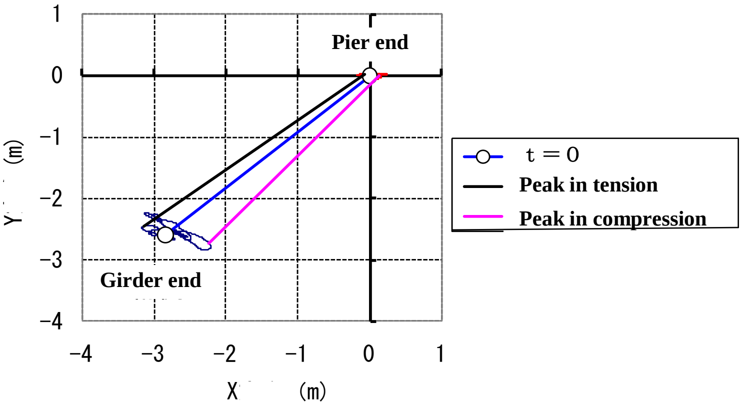
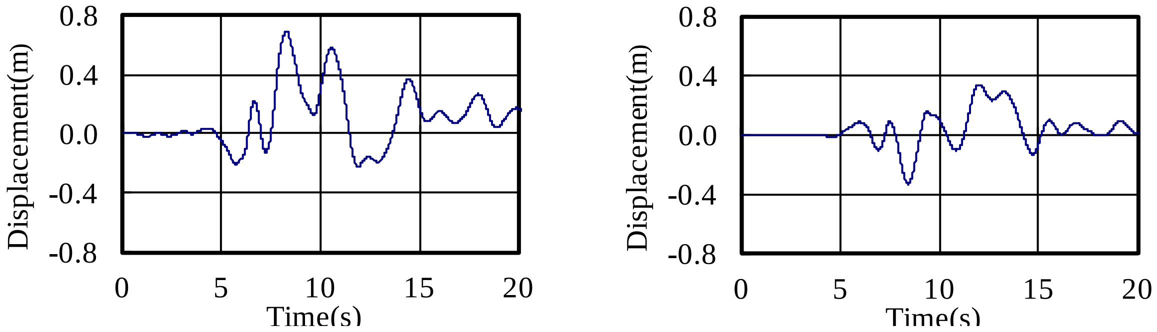


Figure7.1 Displacement of P9 vibration-control damper

The time history of displacement for II-III-1 input case is shown in **Figure 7.2.** Although the transverse displacement is not large, the in-plane motion is induced by the damper arranged in the direction of 45 degrees from the bridge axis. The resistance forces and displacement of the damper is shown in **Figure 7.3.**.



(a)Longitudinal component (b)Transverse component

Figure 7.2. End-pin response of seismic damper attached to pier P9 (II-III -1)

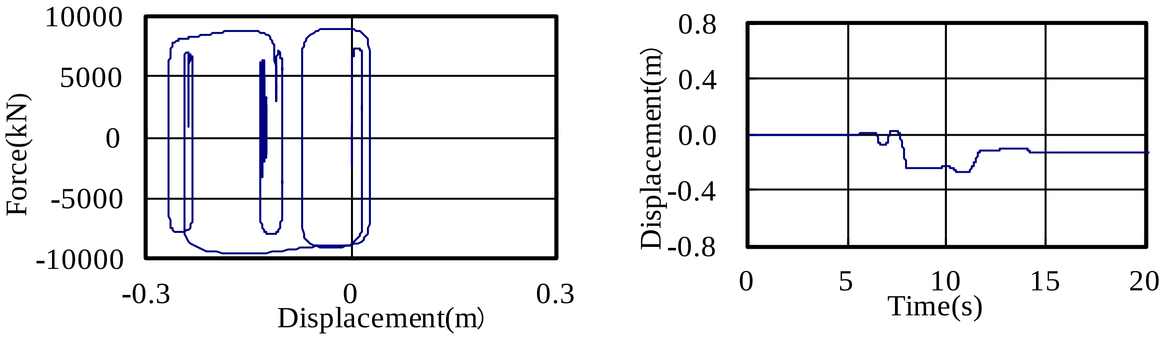
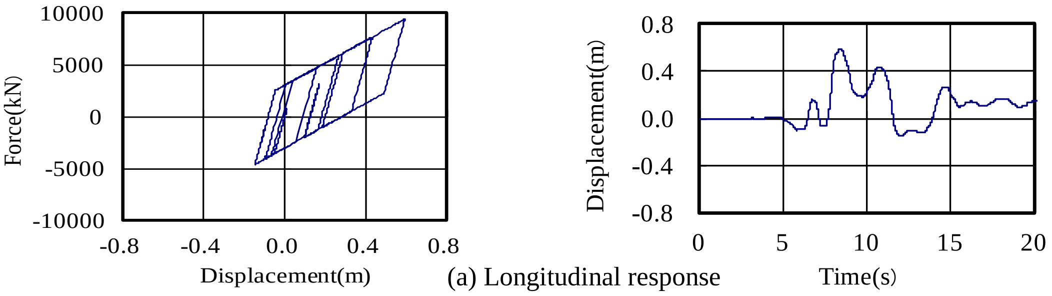


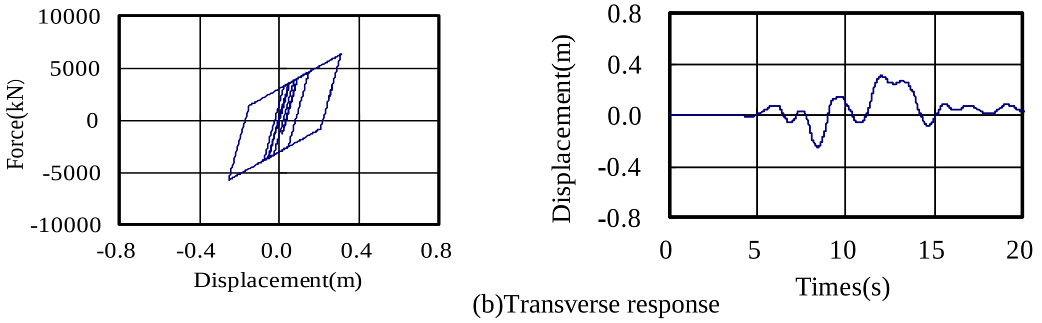
Figure 7.3. Force and stroke displacement response of seismic damper (II-III-1)

7.2. Response characteristic of elastomeric bearing (LRB)

The hysteretic force-displacement plot and displacement time history for the calculated response of the elastomeric isolation bearing with energy dissipation capability (LRB) installed on pier P9 are shown in **Figure 7.4.** Time history of the LRB displacement is equivalent to that of the seismic damper.



(a) Longitudinal response



(b)Transverse response

Figure 7.4. Response of elastomeric isolation bearing on pier P9 (II-III -1)

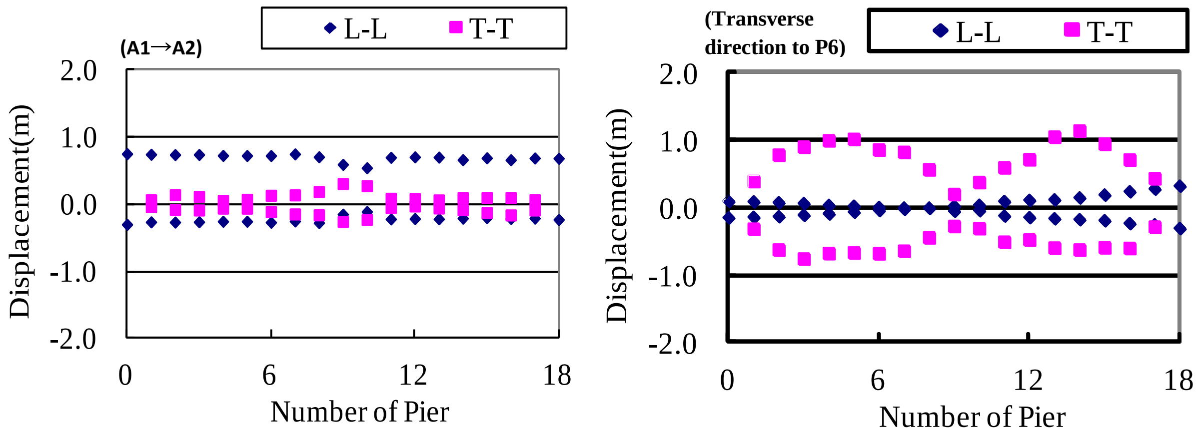


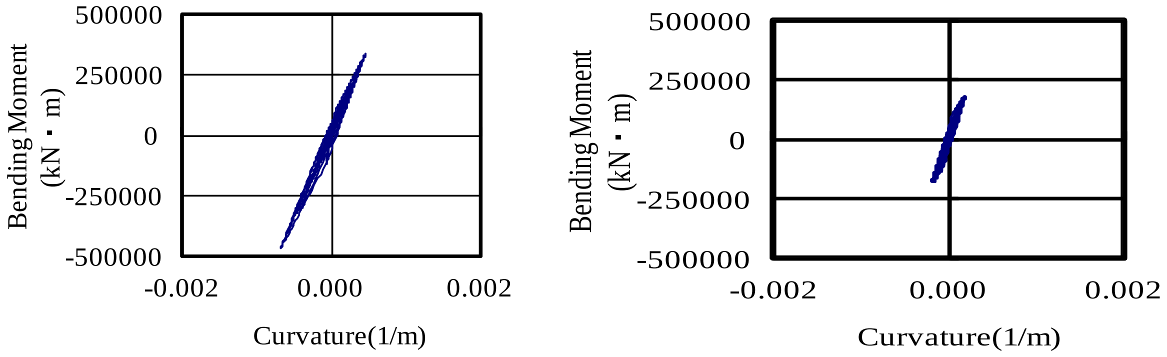
Figure 7.5. Response of slide bearing — maximum displacement (II-III -1)

7.3. Response characteristics of slide bearings

The maximum response displacements of the slide bearings are shown in Figure 7.5. It can be seen in the figure that the transverse displacement of the slide bearings tend to be larger than the longitudinal displacements. The greater displacement amplitude in the transverse direction can be explained by the difference in the characters of the transverse and longitudinal responses. Since the restoring force against the displacement in the transverse fundamental mode shape is mainly provided only by the flexural rigidity of the beam as the result of isolation of the superstructure with the use of low-friction slide bearings, the transverse response induces a long-period motion of the girder. On the other hand, owing to high axial rigidity of the superstructure, longitudinal response is mostly dominated by the girder’s rigid body motion resisted by the resilient forces of the elastomeric bearings.

7.4. Responses characteristics of piers

The moment-curvature response of the pier P9 at the base of the column is shown in Figure 7.6. The critical factor in the design of the pier, especially the cross section and rebar layout, is the seismic performance requirement against the Level-2 earthquake. Although the seismic response of the pier to Level-2 earthquakes exceeds the cracking limit state at the column base, the response dose not reach the yield level almost within the elastic range. It ensures that the restoring force generated by the elastomeric bearings and seismic dampers is fully provided to control the response of the superstructure, and the seismic performance requirement to the structural system is satisfied.



(a) Longitudinal response

(b)Transverse response

Figure 7.6. Seismic response of the bridge pier

9. CONCLUSION

In this paper, the verifications of seismic performance of a bridge with the Isolation Seismic Controlled Slide System(ICSS) is shown and discussed based on the results of dynamic seismic response analysis of an 18-span continuous steel girder bridges with 1,200m length. The seismic performance of the bridge model, including elastomeric bearings with energy dissipation capability (LRB), seismic dampers and slide bearings is examined.

The key findings obtained by the seismic response analysis can be summarized as follows.

1. Considerable rotation displacement of the damper takes place during the seismic response of the bridge. The influence of this horizontal rigid-body rotation of the damper appears to be even greater than the damper-end displacement, implying that variation of the damper force directions associated with the rotation of the damper is regarded as one of the prominent features of the dynamic response of the bridge with the ICSS mechanism.
2. The damper stroke displacement can be made smaller than the end-pin displacement by using a oblique orientation of the seismic dampers.
3. The traverse displacement of the slide bearings tend to be larger than the longitudinal displacement, due to the difference in the characters of the transverse and longitudinal responses of the system.

In ICSS, the elastomeric bearings and seismic dampers are installed to a limited number of piers, which are P9 and P10 in the bridge model used in this study. Design of piers P9 and P10 is proved to be feasible by adopting steel pipe sheet pile foundations using high intensity material (σ_{ck}=40N/mm^2, SD490) , with the intention of reduction of the number of piers with elastomeric bearings and of the size of the substructure/foundations. As a result, 22% reduction of the projected construction cost of the substructures including the bearings is achieved, compared with conventional seismic isolation design conforming to the current design standard in Japan.

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