ICSS(4): A DESIGN APPLIED FOR A SUPER LONG MULTI-SPAN BRIDGE

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SUMMARY
The Isolation Seismic Controlled Slide System (ICSS) is a newly proposed structural system for multi-span continuous girder bridges. The ICSS consists of slide bearings, elastomeric bearings and energy dissipation devices. In order to apply the ICSS to a multi-span continuous bridge, it is important to understand the characteristics of slide bearings, elastomeric bearings and energy dissipation devices and to establish reliable numerical models. Application of the ICSS to an 18-span continuous steel girder bridge is investigated in this study. The superstructure is steel plate girder (2-I section girders + 1-box section girder) and the substructures (P1 to P17) are concrete piers. Slide bearings were installed at both abutments and intermediate piers except for two middle ones (P9 and P10). Furthermore, elastomeric bearings and energy dissipation devices were installed at two designated strong piers supporting the centre span of the bridge.

Keywords: Seismic isolation control, elastomeric bearing, seismic damper, slide bearing, ICSS

1. INTRODUCTION

The Imagiregawa Bridge is under construction as a part of Shikoku-Odan Expressway, located between Naruto and Tokushima, Japan. It forms a network with the Kobe-Awaji-Naruto Expressway and the Takamatsu Expressway that has already opened. It is expected that this bridge and the Shikoku-Odan Expressway will play important roles of industry, economy, and transportation, etc. in the eastern part of Shikoku Island. The bridge is an 18-span continuous steel girder type. The superstructure is a steel plate girder (2-I section girders + 1-box section girder) and the substructures (P1 to P17) are concrete piers. The Isolation Seismic Controlled Slide System (ICSS) are adopted and slide bearings are installed at both abutments and intermediate piers except for two middle ones (P9 and P10). Furthermore, isolation bearings and seismic dampers are installed at the two middle piers supporting the centre span of the bridge. Figure 1.1 shows side and plan views of the Imagiregawa Bridge, and Figure 1.2 shows front and plan views of the middle piers, respectively. The geometric alignment is represented by: R=3,000.000m - A=750 - R=1,500.000m - A=700 - R=1,000.000m.

2. CONCEPT OF ICSS

The ICSS (Ouchi et al. 2012) (Matsuda et al. 2012) (Sakate et al. 2012) provides a mitigation measure for the indeterminate forces acting on the girder due to thermal expansion and contraction, while the seismic action is controlled with isolation mechanism by low-friction slide bearings to support the spans, and elastomeric bearings and seismic dampers installed at concentrated locations. 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 centre span of the bridge. The following effects can be expected by applying this system to the multi-span continuous girder bridge.

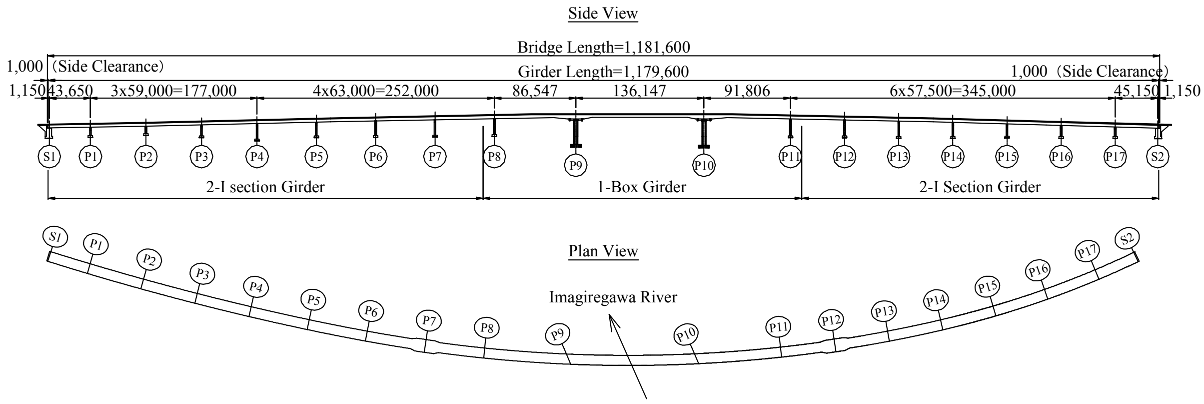

Figure 1.1 Side and plan views of Imagiregawa Bridge

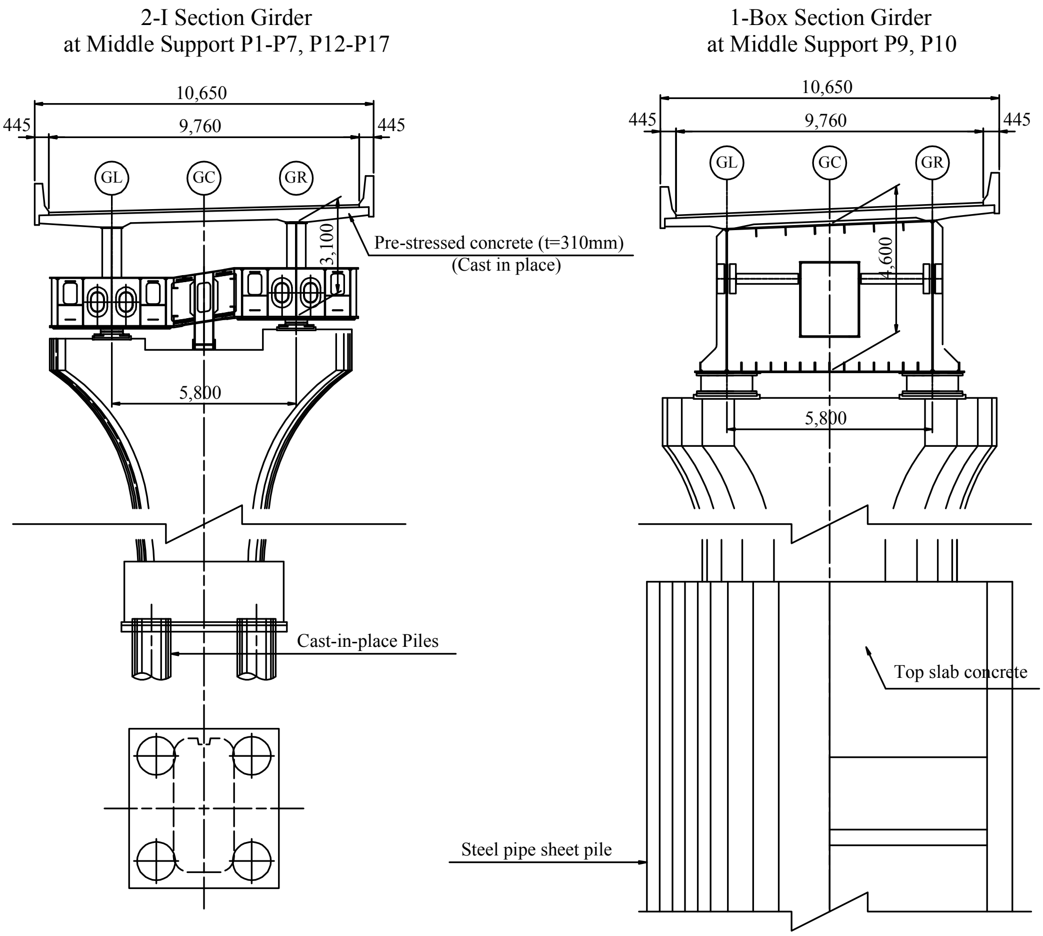

Figure 1.2 Front and plan views of middle piers

1) The influence of the temperature change and creep can be reduced.
2) The “Post Slide” adjustment procedure, which is usually required if elastomeric bearings are used for all the piers, is not necessary owing to the use of slide bearings. The use of slide bearings also contributes the reduction of the seismic force in the piers and construction costs.
3) The number of isolation bearings installed can be reduced, resulting in economical advantage.

4) The seismic response reduction can be enhanced by allowing rotational deformation of the seismic damper with the particular orientation of 45-degrees direction from the local axis of main girder (See Figure 2.1).

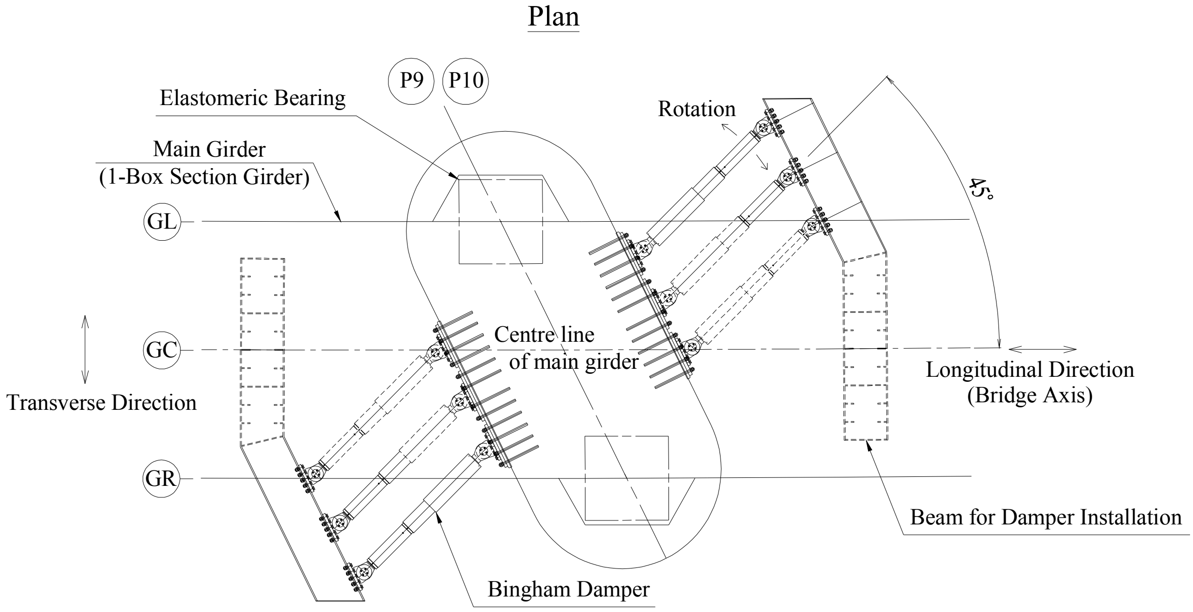

Figure 2.1 Installation angle of seismic damper

In West Nippon Expressway Company Limited, the ICSS is adopted for Imagiregawa Bridge expecting the decrease of the total cost of the bridge construction. A detailed design of superstructure of the Imagiregawa Bridge based on the ICSS is reported in this paper.

3. FUNCTIONS OF ISOLATION / SLIDE BEARINGS AND SEISMIC DAMPERS

The ICSS consists of elastomeric bearings, slide bearings and seismic dampers and these devices are arranged as shown in Figure 3.1. Figure 3.2 shows the middle support of the 2-I section girder where the slide bearings are installed and Figure 3.3 shows the middle support of the 1-box section girder where the elastomeric bearings and seismic dampers are installed, respectively.

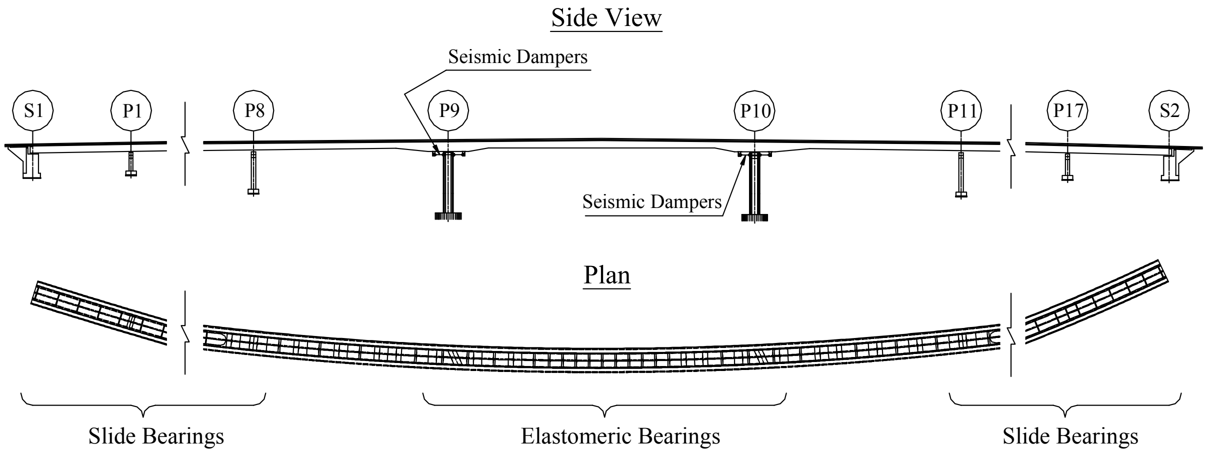

Figure 3.1 Device arrangement

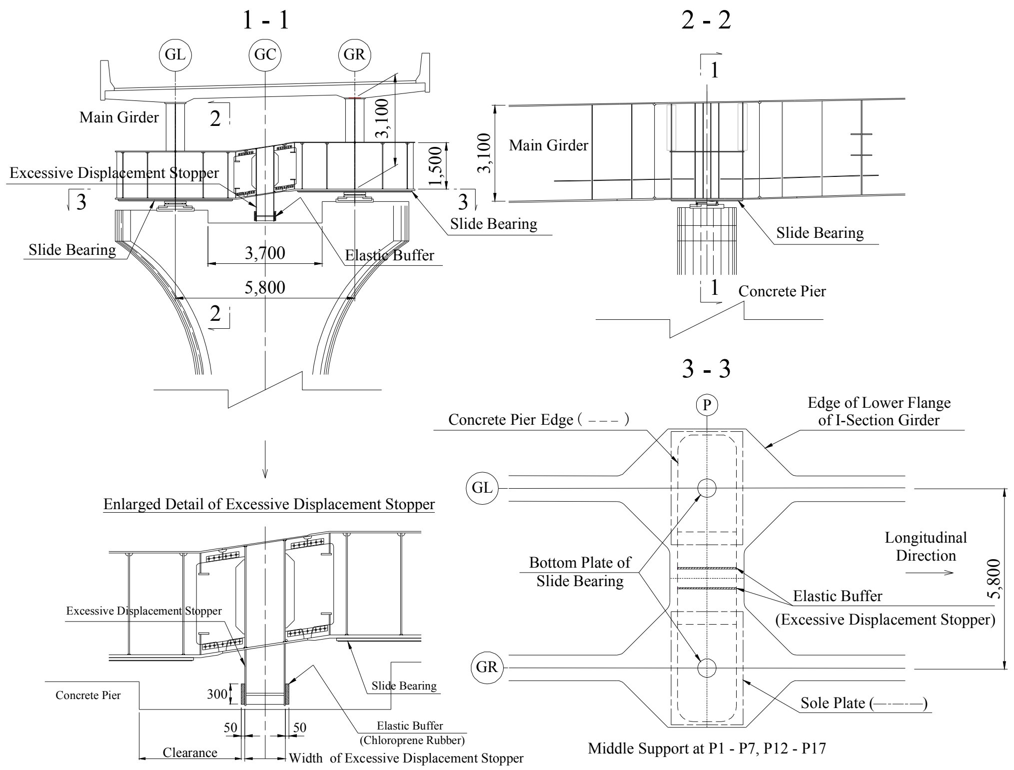

Figure 3.2 Middle support of 2-I section girder and slide bearings

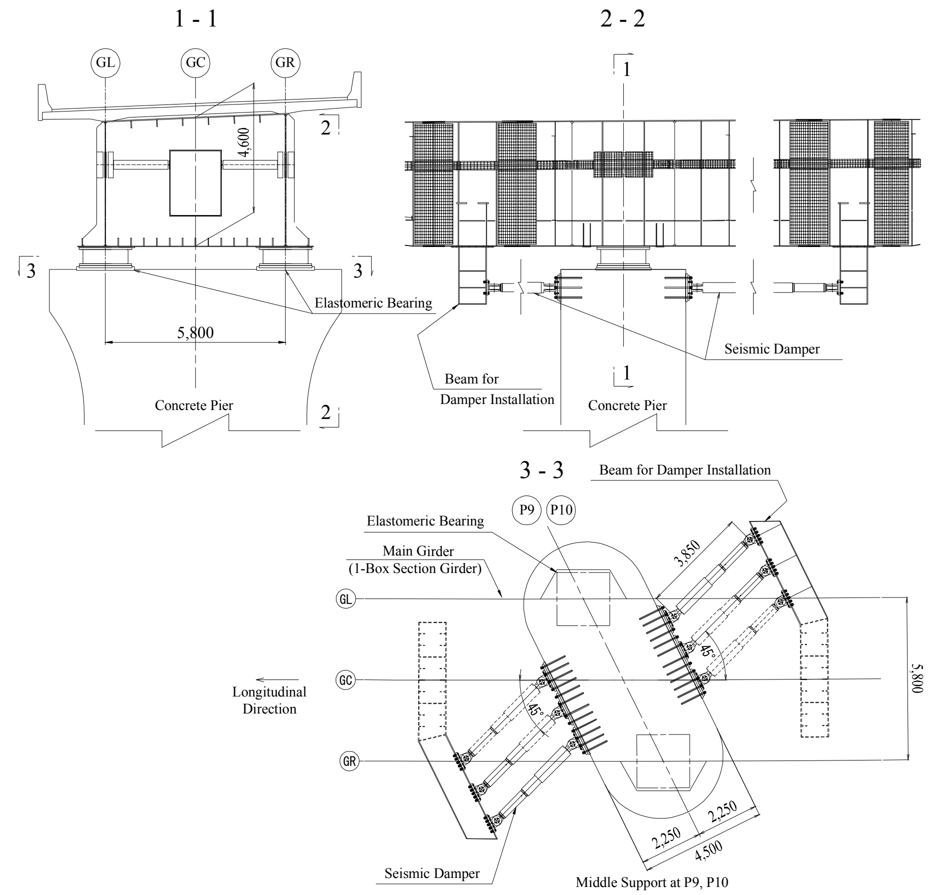

Figure 3.3 Middle support of 1-box section girder installed the lead rubber bearings and seismic dampers

1) Elastomeric Bearings (P9, P10)
The lead rubber bearing (LRB) was adopted as the elastomeric bearing. The LRB is an assembly of laminated natural rubber block and lead plugs. The laminated natural rubber block is a resilient force element, while the lead plug doesn't show elastic stiffness after yielding.

2) Seismic Dampers (P9, P10)
The bingham damper of the friction type was adopted as the seismic damper. The resistance force of this damper is proportional to 0.1th power of velocity.

3) Slide Bearings (A1, P1 – P8, P11 – P17, A2)
The superstructure is isolated from the substructures by employing slide material with small friction coefficients. The behaviour of slide bearings is characterized by the friction coefficient of 0.05 with a elasto-perfectly plastic model of yield displacement of 2.5mm.

4. UNSEATING PREVENTION SYSTEM

In general, a slide bearing is classified into "Type A Bearing", but slide bearings in this bridge keeps the displacement at the Level 2 Earthquake Ground Motion for both longitudinal and transverse directions. Therefore, these are defined as "Type B Bearing" although the slide bearings in this bridge don't bear the seismic forces. The unseating prevention system was installed according to Specifications for Highway Bridges (Japan Road Association, 2002) as shown in Table 4.1 and Figure 4.1.

Table 4.1 Unseating prevention system for Imagiregawa Bridge

Abutment [A1, A2]	Longitudinal direction	Seat length between girder and abutment
		Unseating prevention structure
	Transverse direction	Unnecessary *1 (Special restraining component with concrete block)

Middle Piers [P1 – P17]	Longitudinal direction	Unnecessary
	Transverse direction	Excessive displacement stopper *2

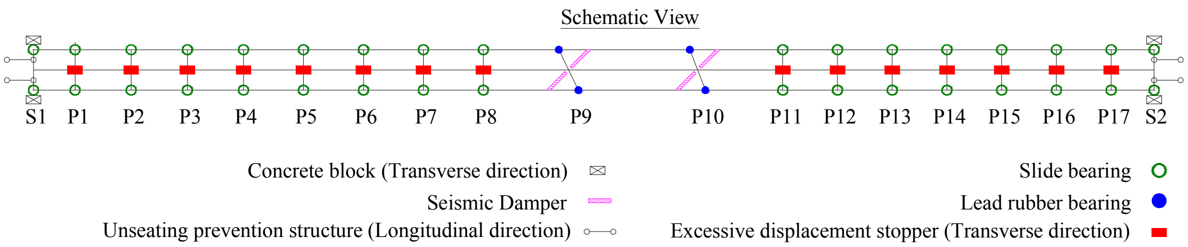

Figure 4.1 Arrangement of unseating prevention system for Imagiregawa Bridge

Here;
*1: About transverse direction in both abutments, special restraining components with the concrete block are installed so that the bridge fall should not occur. So the transverse direction in both abutments is assumed to be fixed in Level 1 and 2 Earthquake Ground Motions.

*2: Taking a dynamic characteristic of this bridge into consideration, the displacement of the superstructure at the middle piers which installed only slide bearings is large. So it is concerned about the width of the transverse direction at middle piers being relatively small. The clearance between superstructures and concrete piers are sown in Table 4.2.

Table 4.2 Clearance between superstructures and concrete piers (Transverse direction)

Middle piers	Girder type	Clearance	Width of excessive displacement stopper
P1-P7, P12-P17	2-I section girder	1,500mm	600mm
P8, P11	1-box section girder	1,375mm	850mm

5. NONLINEAR DYNAMIC RESPONSE ANALYSIS

The nonlinear dynamic response analysis to the Imagiregawa Bridge was conducted to grasp the dynamic characteristics of this bridge which the ICSS is applied to.

5.1. Analytical Model

5.1.1. Superstructures

Superstructures are modelled by linear structural members disregarding the longitudinal slope. The sectional area and the member rigidity of concrete deck slab were converted into the value of steel (Young's modulus ratio n =7).

5.1.2. Reinforced concrete pier

The reinforced concrete pier was modelled by the $M-\phi$ element considering the difficulty in specifying the plastic hinge location. The hysteretic model of $M-\phi$ was used for a degrading tri-linear model (Takeda type).

5.1.3. Footing

The footing was modelled as rigid members because this stiffness was much larger than the column.

5.1.4. Foundation and Ground

The foundation and ground were modelled as a node spring.

5.1.5. Elastomeric bearing

Based on the Specification for Highway Bridges (Japan Road Association, 2002), the elastomeric bearings were set to be a bi-linear model as shown in Figure 5.1.

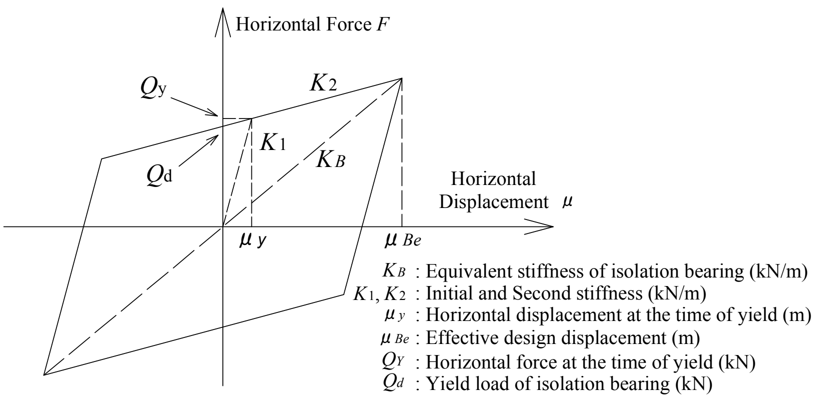

Figure 5.1 Modeling for elastomeric bearing

5.1.6. Slide bearing

In the analytical model, the slide bearings installed under the right web (GR) and left web (GL) shown in the Figure 3.2 were consolidated in one place on the centre of main girder. Their mechanical properties were modeled as a bi-linear model. The yield displacement was set to be 2.5mm, the initial stiffness k_1 was defined as shown in the Figure 5.2 and second stiffness was $k_2 = k_1 \times 10^{-6}$.

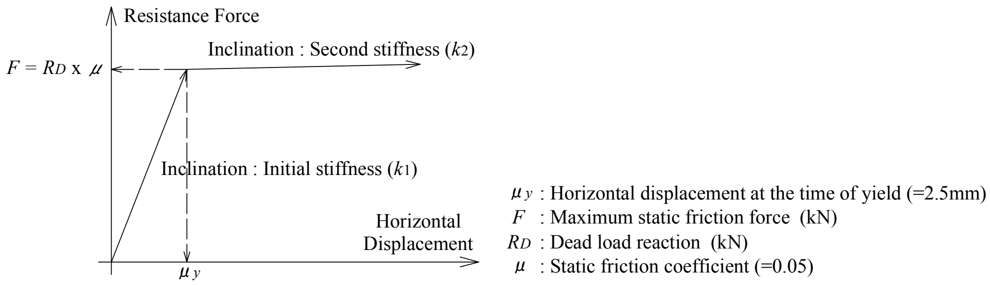

Figure 5.2 Modeling for slide bearing

5.1.7. Seismic damper

The seismic dampers were installed at both sides of P9 and P10, and the installation angle to the centerline of main girder (GC) was set to be 45 degrees. The restoring force characteristic was adopted for The Velocity Dependency Model as shown in Figure 5.3.

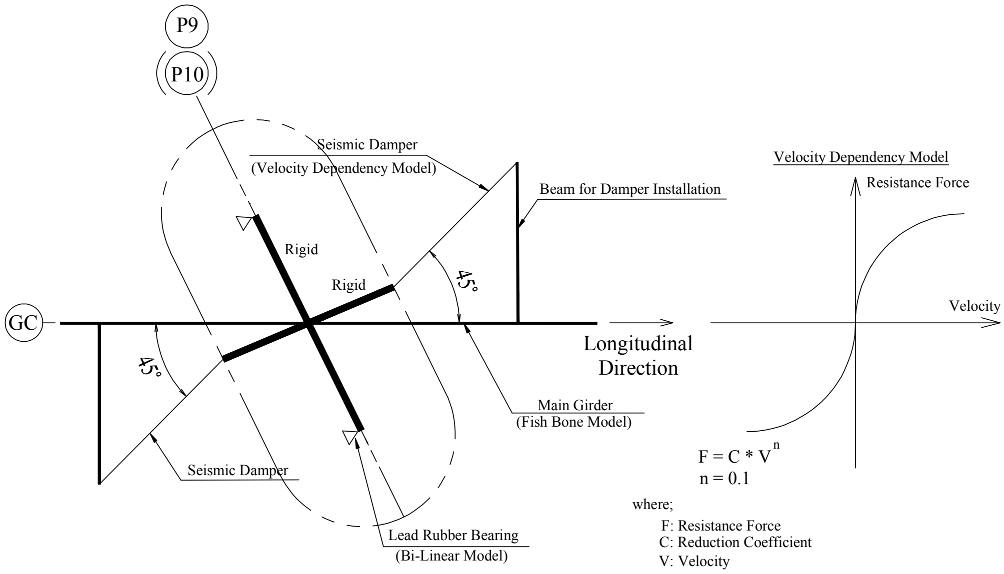

Figure 5.3 Modeling for seismic damper

5.1.8. Excessive displacement stopper

The nonlinear elasticity model was employed only when the stopper collides with the concrete pier.

5.2. Input Ground Motion

The standard waves (Level 2 Earthquake Ground Motion) provided by Specification for Highway Bridges (Japan Road Association, 2002) were used for the input ground motion. The angle of input ground motions θ defined in Figure 5.4 were 8 (θ=0, 30, 45, 60, 90, 120, 135 and 150) degrees. These 8 degrees were every 30 degree and installation angles of seismic dampers (θ=45 and 135). These input ground motions are unidirectional.

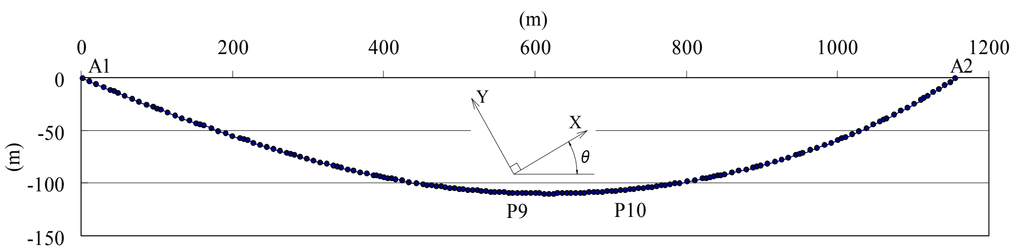

Figure 5.4 Definition of angle for input ground motion

5.3. Result of Nonlinear Dynamic Response Analysis

5.3.1. Displacement of slide bearings

From the nonlinear dynamic response analysis, it was found that the collision between superstructures and concrete piers in the transverse direction occurred in case of Level 2/Type 1 Earthquake Ground Motion only. The displacement of slide bearings in the Level 2/Type 1 Earthquake Ground Motion are shown in Figure 5.5 and Table 5.1.

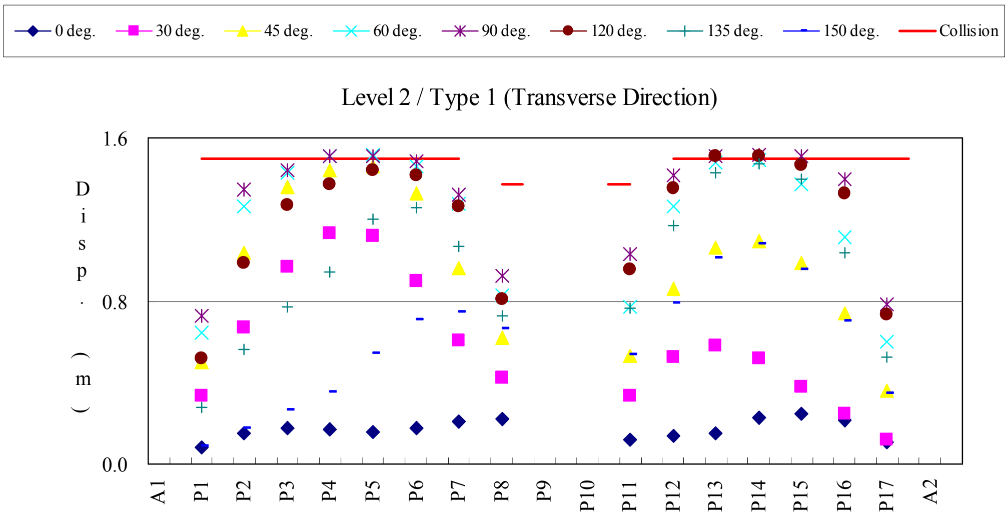

Figure 5.5 Displacement of slide bearings

Table 5.1 Collision between superstructures and concrete piers

Angle of Input Earthquake Ground Motion	Collision between superstructures and concrete piers
θ=60 degree	Pier 4 and 5
θ=90 degree	Pier 4, 5, 13, 14 and 15
θ=120 degree	Pier 13 and 14

In the analysis, it was found that collision between superstructures and concrete piers took place in the cases shown in Table 5.1. However, these stoppers were installed for the all middle piers (P1 to P8 and P11 to P17) in order to prevent from the bridge falling down in case of the earthquake bigger than the design assumption.

5.3.2. Deformation of seismic dampers

The deformations of seismic dampers installed at P9 and P10 in case of Level 2 Earthquake Ground Motion are shown in Figure 5.6. The maximum deformation of seismic damper was about 330mm and was less than the allowable displacement (± 500mm).

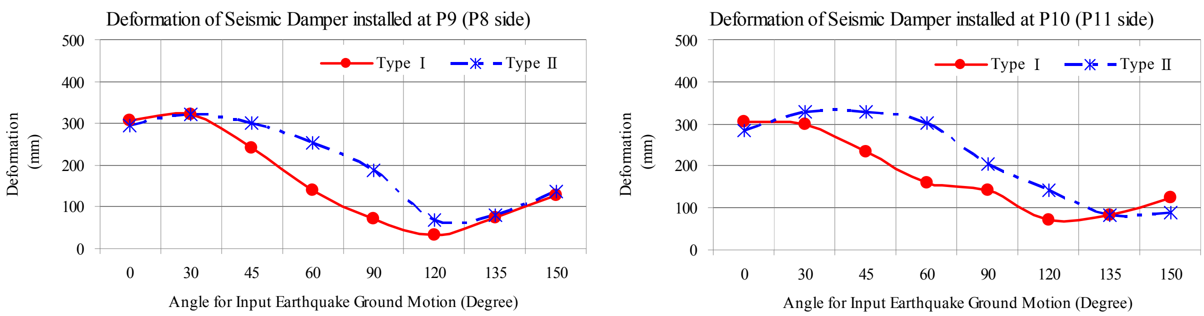

Figure 5.6 Deformation of seismic damper at Pier 9 and Pier 10

5.3.3. Shear strain of lead rubber bearings

The shear strain of lead rubber bearing for longitudinal and transverse directions installed at P9 in case of Level 2 Earthquake Ground Motion is shown in Figure 5.7. The vertical axis shows the shear strain made dimensionless by the thickness of rubber. The allowable shear strain is 250%.

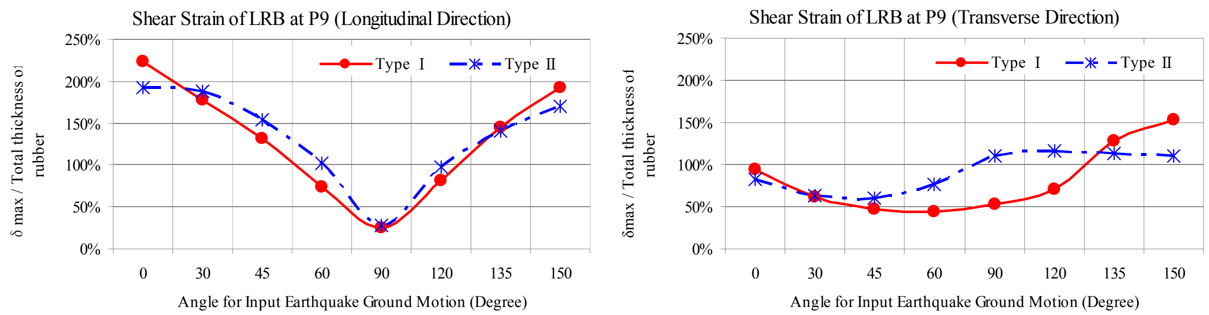

Figure 5.7 Shear strain of lead rubber bearing at Pier 9

6. DESIGN OF UNSEATING PREVENTION SYSTEM

6.1. Seat Length at End Supports (A1 and A2 Abutments)

The seat length at abutment was S_E =4m based on Specification for Highway Bridges (Japan Road Association, 2002) as shown in Figure 6.1.

$$S_E = \mu_R + \mu_G = 0.897 + 0.005 \times (1179.6/2) = 3.85m \geq S_{EM} \quad (6.1)$$

$$S_{EM} = 0.7 + 0.005 \times l = 0.7 + 0.005 \times 45.15m = 0.926m \quad (6.2)$$

$$\mu_G = \varepsilon_G \times L \quad (6.3)$$

Where;

S_E : Seat length (m)

μ_R : Maximum relative displacement between superstructure and substructure in case of Level 2 Earthquake Ground Motion (m)

μ_G : Relative ground displacement caused by the ground strain at the time of earthquake

S_{EM} : Minimum seat length (m)

ε_G : Ground strain at the time of earthquake (ε_G=0.005)

L : Distance between substructures which affects the seat length (Girder length L=1179.6m)

l : Span length (l=45.150m)

6.2. Excessive Displacement Stopper at Middle Supports (P1 to P8 and P11 to P17 Middle Supports)

The excessive displacement stoppers were designed considering the follow conditions;

a) The excessive displacement stopper is installed at the centre of main girder, and the horizontal force acts at the time of collision with concrete pier.

b) Maximum movement of the superstructures will be in the transverse direction at the time of earthquake is assumed.

c) Cross beams with excessive displacement stopper are combined with the jacking-up stiffeners in bearing replacement.

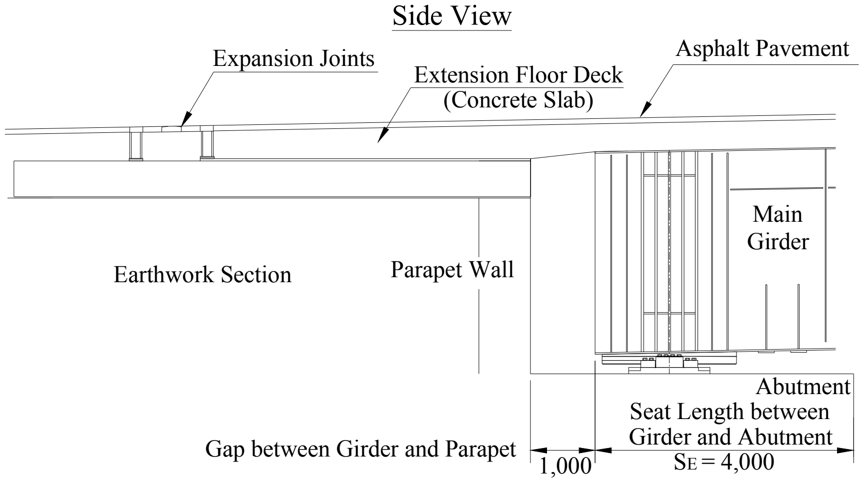

Figure 6.1 Seat length

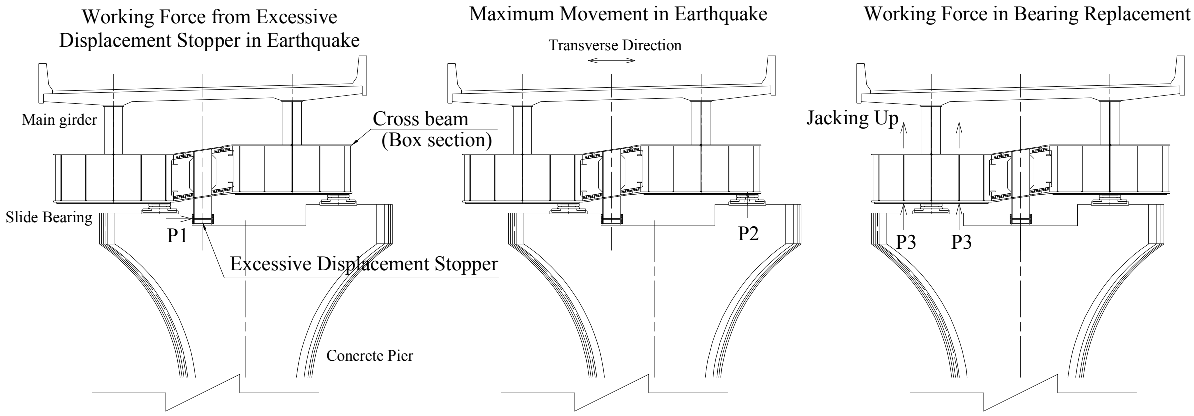

Figure 6.2 Design force for cross beams with excessive displacement stopper

7. CONCLUSION

The Imagiregawa Bridge is advanced in production of steel girders as of April 2012 and erection works will start soon. The member of design, production and erection in this project continuously make more effort in order to fulfil the required quality and complete this project safety.

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