THE EFFECT OF ABUTMENTS AS DISPLACEMENT LIMITING MEASURE ON SEISMIC PERFORMANCE OF BRIDGES

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ABSTRACT

The objective of this research is to make the structure of the girder end of bridges more rational and to adopt the high seismic performance bridges. With numerical simulation of inelastic seismic response considering the collision between bridge girder and abutment, the effect of abutments as displacement limiting measure on seismic performance of bridges are presented.

INTRODUCTION

In the recent seismic design of highway bridges, the girder end often incorporate sufficient laying gap to prevent the girder and abutment or neighboring girders from colliding with each other during a major earthquake. Many aspects of the mechanism that the dynamic behavior of collision between the girder end and the abutment have not been completely understood yet. In reality, as a bridge using rubber bearings generally has relatively large displacement at the bearing during intensive earthquake, the large enough laying gap at the girder is necessary to avoid a collision. In these cases, although the expansion joints with large displacement stroke are required, the expansion joint with large displacement stroke is not effective because of the economical reasons.

Where a major earthquake occurs, the relative displacement at the girder end becomes large and the collision between the girder end and the abutment or neighboring girder may be occurred. In the past earthquakes, there were cases that the collision between the neighboring girders increased the displacement of one girder and caused the deformation and damage of the girder end and the parapet wall of abutment. Conversely, it was surmised from the damage experiences that absorbing the energy and limiting the girder displacement by the collision between the girder and the abutment or neighboring girders reduced the damage of other structural members such as bridge columns.

From the results of author's analysis, when the collision between girder and abutment having appropriate stiffness occurred, it was found that earthquake response of bridges could be reduced [Unjoh 2002]. It is important to understand the effect of the collision between girder and abutment during the major earthquake on seismic performance of bridges, and to make the structure of the girder end of bridges more

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rational and to adopt the high seismic performance bridges.

This paper presents earthquake response characteristics considering the collision between girder and abutment during the major earthquake. The earthquake response characteristics for highway bridge with abutments at each end of the bridge are analyzed. The effect of abutments as a displacement limiting measure on seismic performance of bridges is examined to study the possibility to increase the seismic performance.

EARTHQUAKE RESPONSE ANALYSIS

Analytical Model of Bridge

In this study, this frame model shown in Figure 1 is employed as analytical model of inelastic response analysis considering the collision phenomenon. The superstructure is modeled as two-dimensional beam and the piers and abutments are modeled as frame member supported by ground spring. Plastic hinge spring is assumed at the base of piers. The bearings are rubber bearings modeled as a linear spring. The model of abutment is

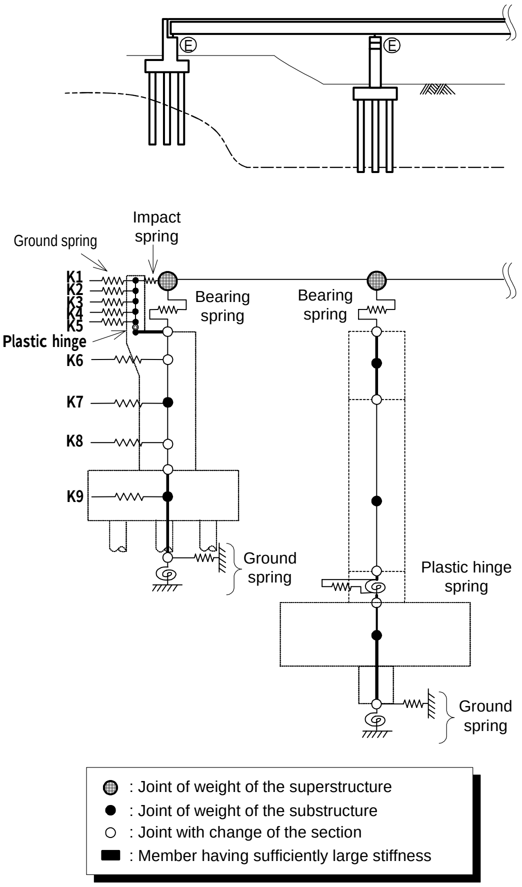


Figure 1. Analytical Model considering the Collision between Girder and Abutment

beam member considering inelastic response characteristics, and foundation is modeled as a linear spring. The backfill soil is modeled as discrete inelastic springs.

Analytical Model of Impact Spring

The collision phenomenon between the bridge girder end and the parapet wall of abutment is modeled as an impact spring with inelastic hysteretic characteristics. When the superstructure moves across the laying gap and approaches the parapet wall of abutment during an earthquake, it is assumed that the reaction force is developed at the impact spring with stiffness K.

As the collision phenomenon is the impact phenomenon in a very shot time, it is important that the impact spring constant, integral time step and damping factor are set to appropriately reproduce the behavior of bridges during a major earthquake in inelastic analysis. In this paper, the impact spring constant K is employed by equation (1) [Kawashima 1999].

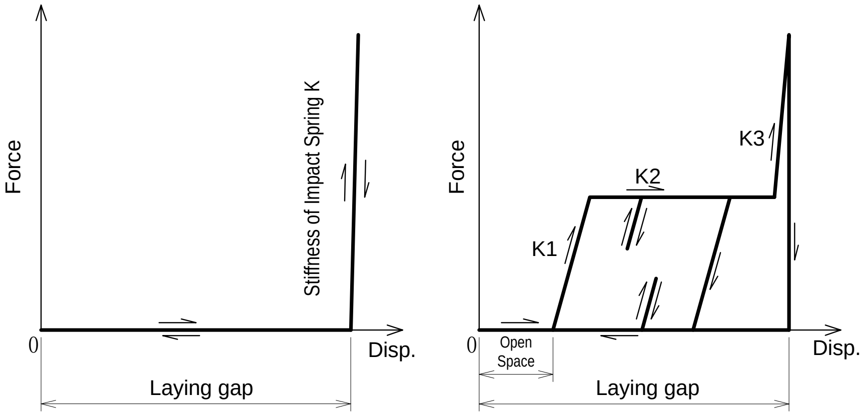
$$K = \gamma EA/L \tag{1}$$

Where;

EA : Stiffness of Axial Cross Section of Superstructure
L : Length of the Member of Superstructure
γ: Ratio of Impact Spring Stiffness to Stiffness of Superstructure

In this analysis, the γ value is assumed as 20 from the study to check the relationship between the spring constant of impact spring and the integral time distance [Unjoh 2003].

Figure 2 shows the analytical models of the impact spring. These models are assumed for the case of free end (Figure 2(a)) and the case with shock absorbing device (Figure 2(b)).



(a) Free End

(b) Yielding Type
(with shock absorbing device)

Figure 2. Model of Impact Spring

Numerical Analysis

Three earthquake waves for class II ground in the Level 2 (type II) standard acceleration waves are used as an input earthquake motion. Reyleigh type of damping matrix is assumed as damping factor considering the first mode (h=3.7%) as the horizontal behavior of the superstructure and the second mode (h=12.2%) as the behavior of the pier. The integral time step is 1/1000 second for stability of numerical analysis.

BRIDGE ANALYZED AND ANALYTICAL PARAMETER

Bridges Analyzed

The bridge analyzed is 5 span continuous bridge with rubber bearings to distribute the lateral force during an earthquake shown in Figure 3 [Road Association of Japan 1997]. It is assumed that the collision at the girder end occurs between the girder and right-and-left both abutments. The design parameters of the bridge analyzed are shown in Table 1.

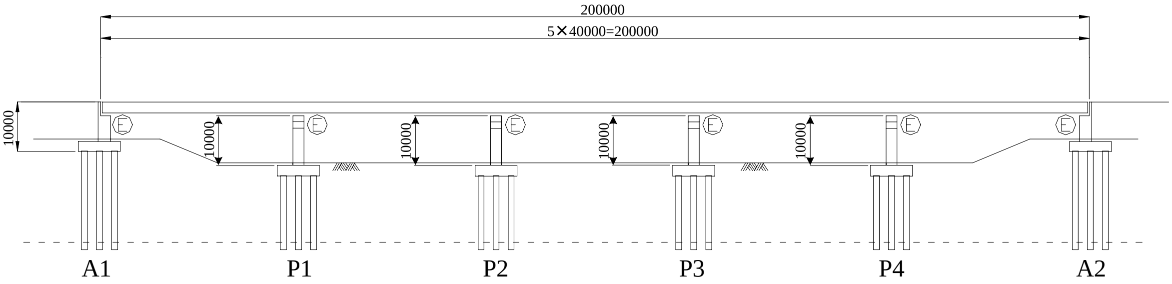


Figure 3. Analytical model of Bridges

Table 1 Design Parameters of Bridge Analyzed

Superstructure styles	5 span continuous steel plate girder bridge
Bridge length and span	200m (5@40m)
Abutment styles	Cantilever
Pier styles and Height	Single column pier, Height = 10m
Foundation styles	Piled foundation
Bearing styles	Rubber bearing
Ground types	Class II

Analytical Parameter (Ground Spring Model of Backfill)

The relation between bearing capacity and deformation of backfill soil shown in Figure 1 is modeled as a spring model yielding in compression side and no resistance in tension side (Figure 4). The accurate behavior of backfill in case of with the collision at the girder end since the experimental and analytical study is inadequate. In this study, the ground spring of backfill is assumed as 3 kind of model, as follows. Table 2 shows the stiffness and upper limit for bearing capacity of backfill soil.

a) No considering (Case 1)
b) Stiffness and upper limit for bearing capacity based on the study for the caisson foundations (Case 2) [Road Association of Japan 2002b]
c) Upper limit based on the passive earth pressure (Case 3) [Road Association of Japan 2002a]
d) Stiffness and upper limit based on the design code of Caltrans (Case 4) [Caltrans 1992]

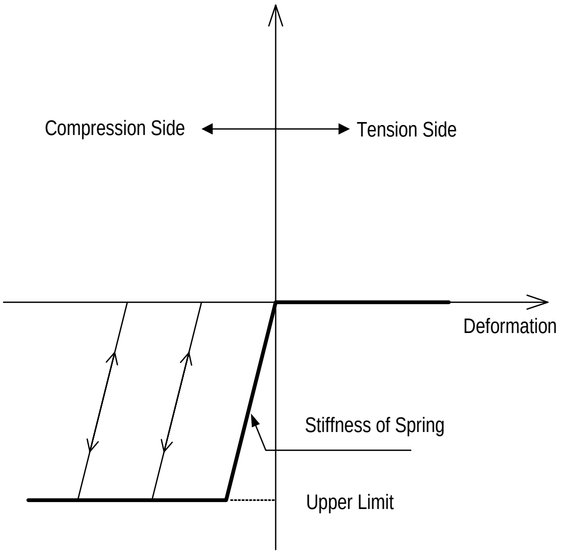


Figure 4 Spring Model of Backfill

Table 2 Spring Constant and Upper Limit for Bearing Capacity of Backfill Soil

Number	The name of model		K1	K2	K3	K4	K5	K6	K7	K8	K9
Case 2	Based on the caisson foundation	spring constant	110871	73914	73914	73914	110871	246873	246873	246873	295656
		upper limit	569	776	1190	1620	3101	11154	17057	23591	37695
Case 3	Based on the caisson foundation and the passive earth pressure	spring constant	110871	73914	73914	73914	110871	246873	246873	246873	295656
		upper limit	427	582	894	1212	2328	8369	12788	17676	28235
Case 4	Suggested by Caltrans	spring constant	0	0	1692000	0	0	0	2820000	0	1128000
		upper limit	—	—	3567	—	—	—	25526	—	18842

Analytical Parameter (Model of Abutment)

When the collision between the girder and the abutment occurs, the parapet wall of abutment may be damaged. The damage of the parapet wall causes the increase of the displacement of the superstructure and the extent of damage at the pier. Even if the collision between the girder and the abutment occurs, it might be desirable not to receive damage for the parapet wall of abutment. Therefore, the parapet wall of abutment is modeled as 2 types;

a) Thickness of the parapet wall of 0.5m
   The parapet wall of abutment is modeled as inelastic member and has the plastic hinge at the base.
b) The thickness of parapet wall of 2.0m
   The parapet wall is modeled as an elastic member.

NUMERICAL RESULTS OF INELASTIC RESPONSE ANALYSIS

Effect of Model for the Parapet Wall of Abutment

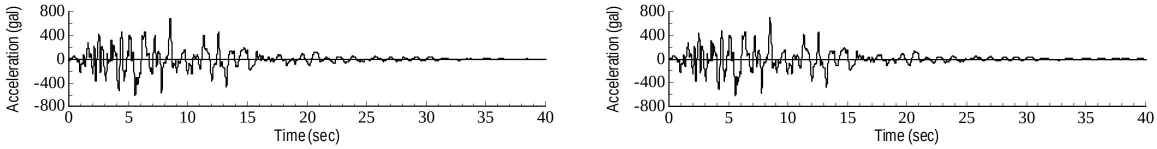
Figure 5 shows the effect of the model for the parapet wall of abutment on earthquake response considering the collision between the girder end and abutment. In these figures, the laying gap is assumed as 25cm, the ground spring model for backfill is the model based on the caisson foundation and the thickness of the parapet wall is 0.5m (in the left figures) and 2.0m (in the right figures).

In Figure 5(1), the parapet of the abutment behaves in a plastic range by the collision between the girder end and abutment at the time of around 6 second, and residual displacement of the parapet is developed. By the plastic deformation of the parapet, the displacement of girder end becomes peak at around 7 second. The behavior at the top of the pier is almost the same as the behavior at the girder end. In Figure 5(2), the parapet of the abutment behaves elastically. The impact force is less than 1/4 force for the case of plastic parapet compared to elastic parapet. However, the response displacement at the top of the pier with the elastic (strong) parapet is significantly reduced than that one with the plastic (weak) parapet.

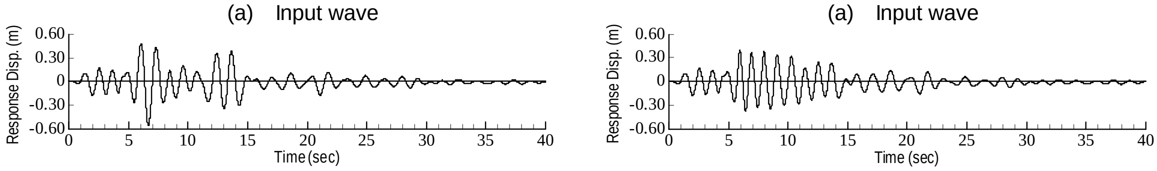
Effect of the Ground Spring Model for the Backfill

Figure 6 shows the effect of the ground spring model for the backfill on earthquake response considering the collision between the girder end and abutment. In these figures, the laying gap is assumed as 25cm, the parapet model with the thickness of 0.5m is assumed.

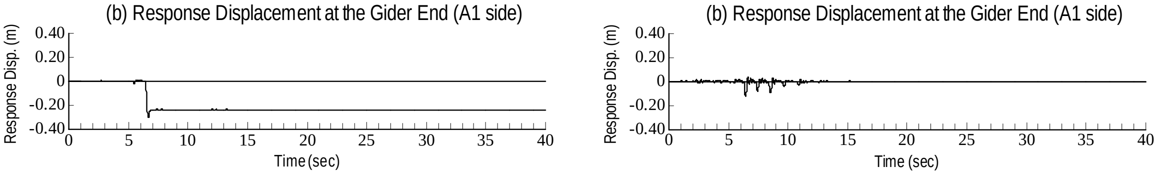
From Figure 6, plastic hinge rotation at the base of pier changes somewhat with the ground spring model for the backfill to be used. However, even if which model is assumed, the analysis results is hardly different.



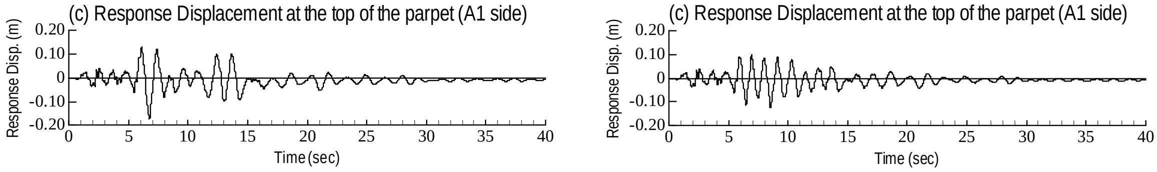
(a) Input wave (a) Input wave



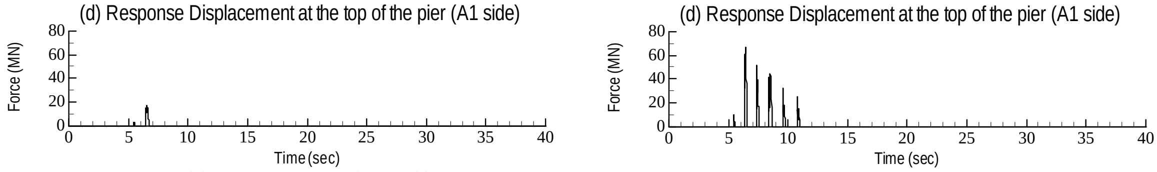
(b) Response Displacement at the Gider End (A1 side) (b) Response Displacement at the Gider End (A1 side)



(c) Response Displacement at the top of the parpet (A1 side) (c) Response Displacement at the top of the parpet (A1 side)



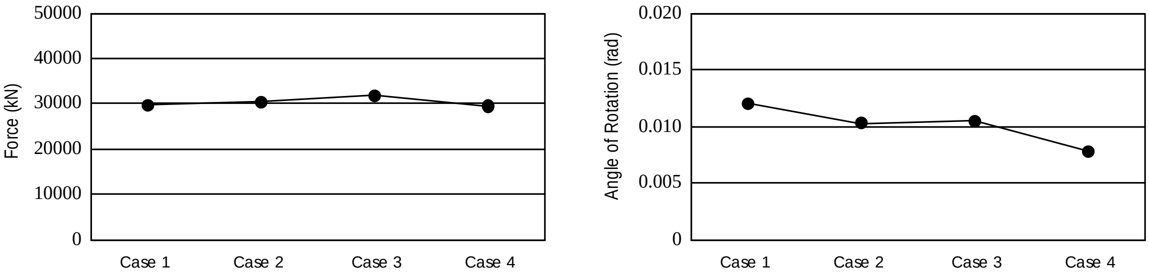
(d) Response Displacement at the top of the pier (A1 side) (d) Response Displacement at the top of the pier (A1 side)



(e) Impact Force at the A1 side (e) Impact Force at the A1 side

(1) Thickness of the parapet : 0.5m (2) Thickness of the parapet : 2.0m

Figure 5 Effect of Parapet Model on Earthquake Response



(1) Impact force (A1 side) (2) Plastic hinge rotation at the base of pier

(3) Response displacement at the center of girder and the top of pier (4) Response displacement at the top of parapet of abutment

Figure 6 Effect of Ground Spring Model for Backfill on Earthquake Response

CONCLUSIONS

The followings are the major findings on the effect of abutments as displacement limiting measure on seismic performance of bridges;

1. The response displacement at the top of the parapet of abutment and the pier is limited by the collision between the girder end and the parapet wall of abutment.
2. The effect of the ground spring model for backfill on the response of bridges is not significant for the analyzed bridge model.

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