A NEW TYPE OF SHEAR PANEL DAMPERS FOR HIGHWAY BRIDGE BEARINGS

T. Aoki[a], Y. Liu [b], T. Takaku[c], and Y. Fukumoto[d]

[a] Aichi Institute of Technology, Dept. of Urban and Environment , Toyota, Japan

[b] Graduate Student, Aichi Institute of Technology, Toyota, Japan

[c] Toko Consultants Co Ltd, Director of Structural Division, Tokyo, Japan

[d] Professor Emeritus, Osaka University, Osaka, Japan

INTRODUCTION

Function-unified bearing system [1] uses elastomeric bearings which serve as both vertical bearing devices for service loads and lateral resistant devices for seismic loads. The bearings must be designed for all loads including seismic loads. Function-separated bearing system, on the other hand, consists of two separate bearings which are designed according to each separate functional requirement. One bearing supports the vertical force including dead and live loads, and another one serves as a lateral resistant bearing for seismic loads.

This paper presents the development of a new low-yield (LY) steel shear-type bearing for a function-separated system which serves as lateral shear resisting bearing against seismic loads. One-directional quasi-static cyclic shear tests were conducted for four different web shapes. The dynamic effects of the developed shear-type dampers are examined for a five-span continuous girder bridge resting on high rise piers. The time-history analysis is carried out for the several ground acceleration records which are specified in the Japanese Specifications for Highway Bridges [2].

1 CYCLIC SHEAR TEST OF SEISMIC DAMPERS

1.1 Test specimens, Test setup and Loading sequence

Tensile coupon tests for low-yield 100(LY100) steel were conducted and the obtained stress-strain curves are shown in Fig. 1. The yield strength defined by the 0.2% offset value of LY100 is 80.1 N/mm^2 and the elongation reaches 60%, which is about three times the values of SS400 mild steel [4]. Shapes of the shear panel specimens are shown in Fig.2. Each test specimen has a uniform plate thickness of t_w=12mm. The test specimens are listed in Table 1. In order that the upper side can move horizontally, the upper plate is connected to the lower plate through links. Cyclic lateral load was applied at the tip of the upper beam through a W-type levelling apparatus. The increments of the shear displacement in each loading cycle are $\pm 1\ \delta_y$, where δ_y=5mm which is the shear yield displacement corresponding to the 0.2% offset yield stress. The displacement history is imposed on the specimens through 5 to 14 cycles until failure.

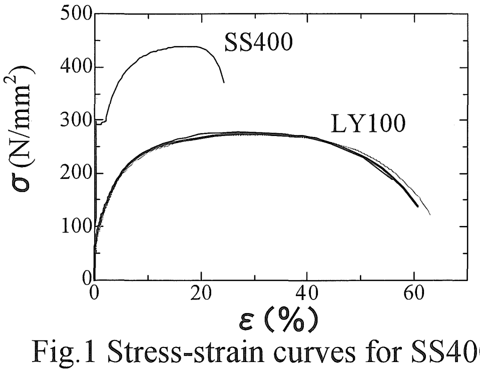
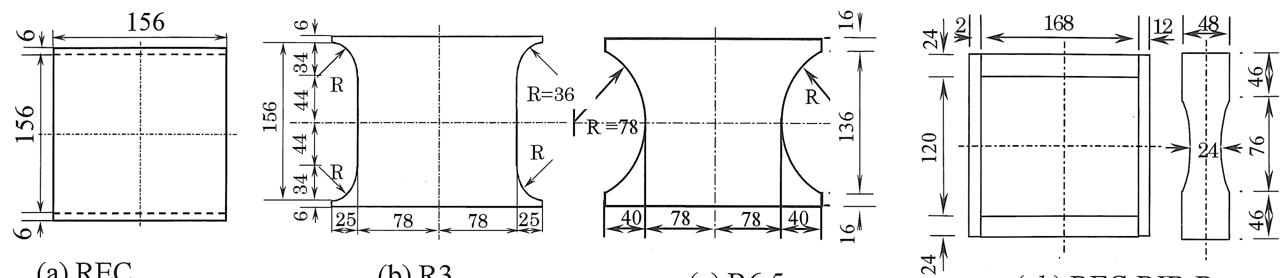


Fig.1 Stress-strain curves for SS400 and LY100 tension coupons

Table 1. Characteristics of specimens

Name	Specimen details
REC	Basic specimen of 156×156mm square plate, t_w=12mm
R3	REC with curved transition R=3t_w at the four corners
R6.5	REC with round R=6.5t_w along both side edges
REC-RIB-R	REC with curved vertical flanges along the both sides and with plates at the upper and bottom edges of shear plate

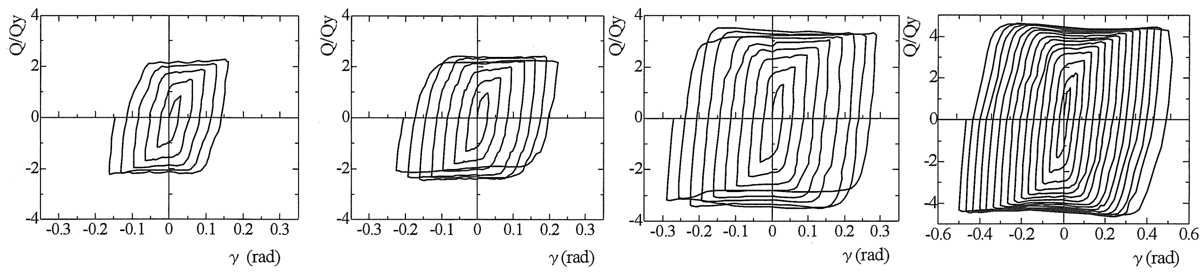


(a) REC (b) R3 (c) R6.5 (d) REC-RIB-R

Fig.2 Test specimens

1.2 Test results

The hysteretic relationship of the normalized shear force (Q/Q_{yREC}) to the shear strain ($\gamma = \delta/H$ in rad) for cyclic test specimens is shown in Fig.3, where the shear yield force is Q_{yREC}=86.5kN and H=156mm. One cycle is equivalent to the shear strain of 3.2%. A typical shear force-shear strain hysteretic loops is approximately rectangular, improving significantly in order of (a) to (d) according to the specimen details. The energy dissipated in each cycle is calculated as the area surrounded by the hysteretic loop and the area becomes larger from (a) to (d). A summary of test results for Q_{max}, γ_{max} and δ_{max} is given in Table 2. The crack process of fatigue to fracture can be delayed by the reduction of stress concentration at the four corners of shear panel.



(a) REC (b) R3 (c) R6.5 (d) REC-RIB-R

Fig.3 Shear force versus shear strain relationships

Table 2. Maximum shear force and shear strain for test specimens

Specimen	Q_{max}/Q_{yREC}	γ_{max}(%)	$\gamma_{max}/\gamma_{max\,REC}$	$\delta_{max}/\delta_{yREC}$
REC	2.2	16	1.0	5(cycles)
R3	2.3	23	1.4	7
R6.5	3.2	29	1.8	9
REC-RIB-R	4.6	50	3.1	15

2 DYNAMIC ANALYSIS OF A BRIDGE EXAMPLE

2.1 Analytical approach and modeling

The bridge shown in Fig.4 is a five-span continuous girder bridge with a reinforced concrete (RC) slab on RC piers with total span length of 200m. The pier rise is 12.2m each. A single mass is assumed for the weight of the superstructure and nine beam elements are used for the pier. The bottom of the pier including the site soil condition is modeled as linear springs for the horizontal and rotational directions as shown in Fig.5. Three types of bearings are considered in the analysis, that is, a fixed bearing, an elastomeric bearing and a shear panel damper for a function-separated system. An elastic-plastic model indicated in Fig.6 is employed in the shear panel damper based on the test results of REC-RIB-R shown in Fig.3 (d). Input ground accelerograms are selected from the recording of the 1995 Kobe earthquake.

The time-history dynamic analyses [3] are carried out by using the Newmark β method [5] (β =0.25). Based on the nonlinearity of the pier, the integration interval of time is set 0.002 (1/500) seconds.

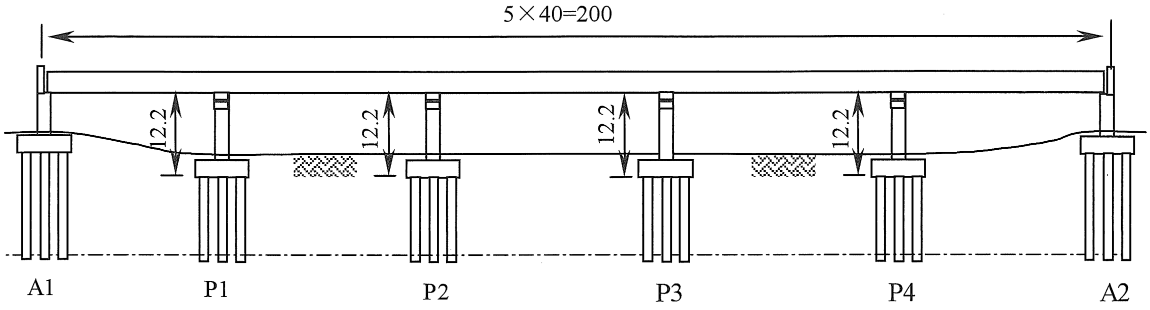


Fig.4 Bridge example for dynamic analysis (m)

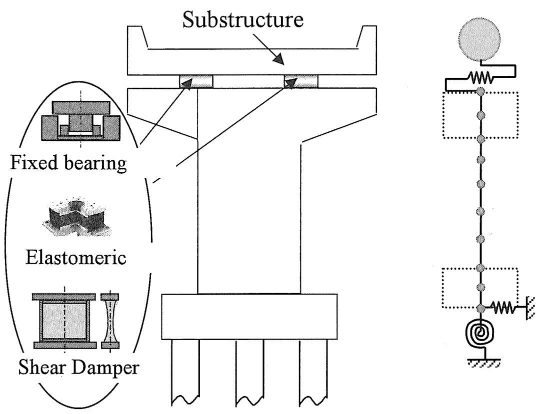


Fig.5 Analysis model for pier

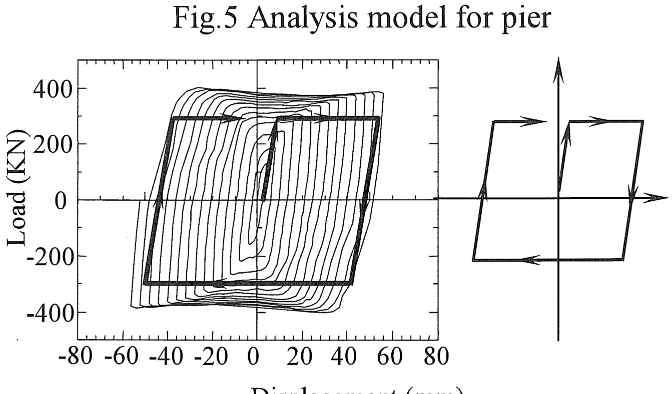


Fig.6 Idealized model for shear panel damper

2.2 Analytical results

(1) Pier response

Fig.7 shows the comparison of the bending moment-curvature history at the pier base for a fixed bearing, for an elastomeric bearing and for a shear panel damper. Vertical dashed lines for the positive and negative curvature sides represent the permissible curvature value ϕ_a[3] for the pier. Seismic upgrading of the pier is required for a fixed bearing when the response curvature exceeds the permissible one. On the other hand, the maximum response curvature for an elastomeric bearing and a shear panel damper decreases significantly and remains below the permissible curvature, and the seismic upgrading of the pier is not required.

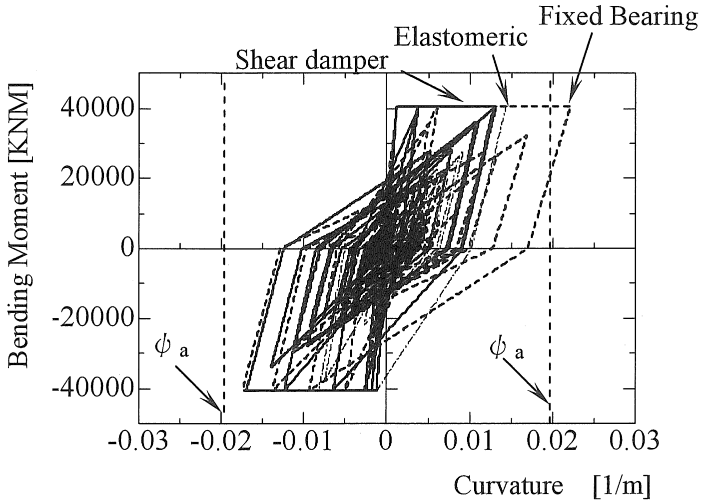


Fig.7 Bending moment-curvature history at the pier base of P2 pier

Table.3 Seismic response of P2 pier for three bearings

	Bearing Type	Response Value	Permissible Value	Judgment
Maximum Ratio	Fixed Bearing	6.40	6.83	OK
	Shear Panel Damper	4.75		OK
	Elastomeric Bearing	4.76		OK
Residual Displacement	Fixed Bearing	0.111 (m)	0.100 (m)	OUT
	Shear Panel Damper	0.077(m)		OK
	Elastomeric Bearing	0.077(m)		OK

The analytical results for three bearings at the base of pier P2 are summarized in Table 3. The ratio of the maximum response displacement at the pier top to the yield one is given in the table. The permissible ratio is defined in the Manual [3] The response values for the elastomeric and the shear panel damper are the same and they are within the permissible ones for the maximum response ratio and for the residual displacement and thus the safety of pier P2 is confirmed for the two bearing types.

(2) Relative displacements at bearings

Comparison of the analytical results for the displacement–time history at the bearing of pier P2 is shown in Fig.8. The maximum displacement of the shear panel damper remains 53mm, which is only 27% of a lead rubber bearing of 193mm, and therefore the shear panel damper can reduce the moving distance of expansion joints considerably.
Fig.9 shows the shear force-shear strain history for the shear panel damper. As shown in the figure, the maximum shear strain is 42%, which is below the maximum 50% shear strain.

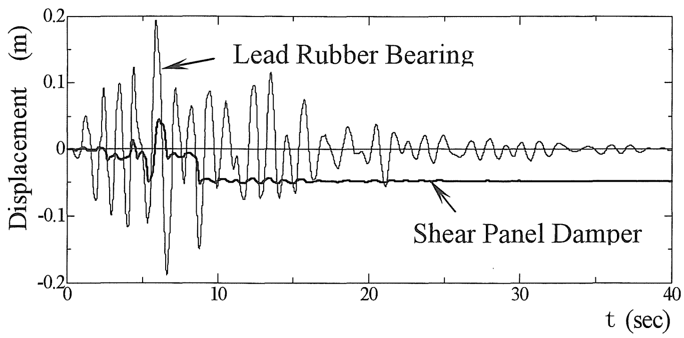


Fig.8 Displacement–time history at the bearing of the three cases

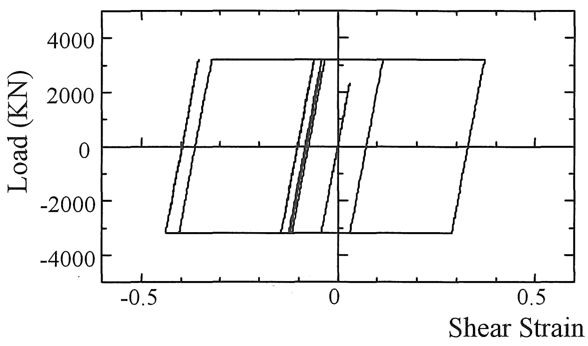


Fig.9 Load-displacement history of the shear damper

2.3 Response curves for shear panel damper

Fig.10 shows the maximum shear force for the damper and the maximum response displacement at the bearing of the bridge example subjected to several major earthquake waves provided in Ref. [2], where three waves are specified for three ground conditions of I, II and III. It can be observed from the figure that the amount of the maximum shear force decreases with increase of the maximum response displacement. A single representative curve shown in Fig.11 is excerpted from a group of response curves of Fig.10. The abscissa in the figure represents the maximum shear strain for the shear damper when the height of the damper is 300mm.
Since the shear force of the damper is equal to the applied force at the pier top, the permissible force for the pier can be demonstrated in the ordinate by a dashed line in Fig.11. The resistance force of the damper should be below this limit. The maximum displacement response corresponding to this resistance force can be read as 50mm (18% shear strain) from this curve.
Since the shear dampers developed in the present study have a maximum strain limit of 50%, the applied force to the pier can be reduced by 25% as shown in Fig.11.

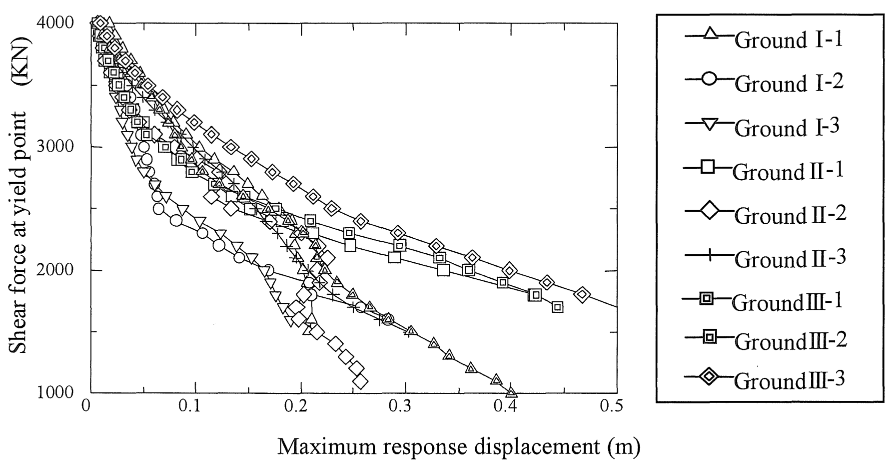


Fig.10 Shear force and maximum displacement response of the shear damper subjected to several ground motions

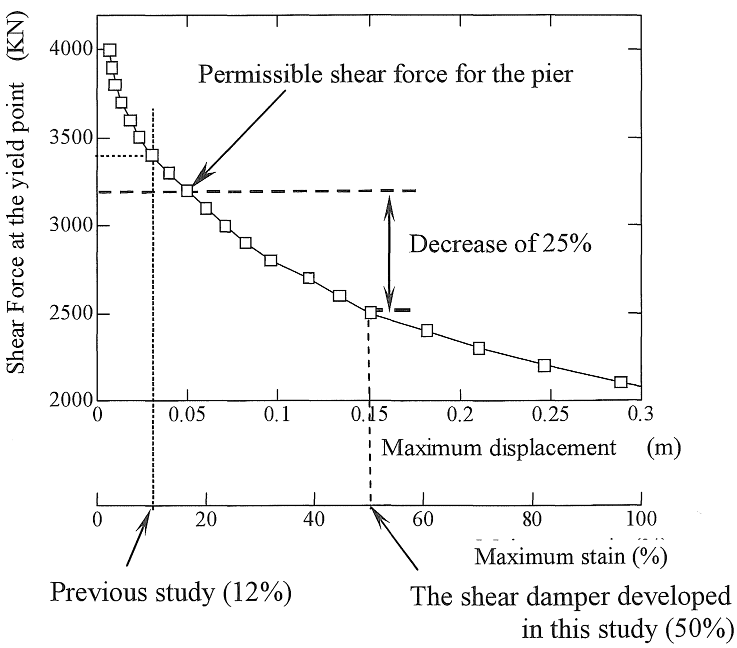


Fig.11 Response curve of the shear damper

3 CONCLUSIONS

In this paper the performance assessment of LY100 shear panel dampers is presented based on laboratory tests and dynamic analyses. The main conclusions of this study are:
1) High energy dissipation shear dampers are developed using low-yield steel, which function up to a maximum of 50% shear strain.
2) The earthquake time-history analysis of a five-span continuous bridge example is carried out using the developed shear damper and good results are obtained when compared to fixed and elastomeric bearings.
3) Based on the obtained response shear force vs shear displacement, a maximum displacement design method is developed and a reduction of the applied shear force to the pier top is obtained for bridge bearings and piers.

ACKNOWLEDGMENTS

The writers would like to thank Hiroshi Suzuki and graduate students for their efforts and expertise in conducting the experiments. The test program was carried out at the Seismic Research Center at Aichi Institute of Technology.

REFERENCES

[1] Japan Road Association: Manual of Bearings for Highway Bridges, 2004.
[2] Japan Road Association: Specifications for Highway Bridges・Part V: Seismic Design, 2000.
[3] Public Works Research Center: Manual of Dynamic Seismic Design for Highway Bridges, 2006.
[4] Aoki, T., Liu, Y., Takaku, T., Uenoya, M. and Fukumoto, Y.: Experimental Investigation of Tapered Shear-Type Seismic Devices for Bridge Bearings, 8th Pacific Structural Steel Conference (PSSC) 2007, New Zealand.
[5] Newmark, N.W.: A Method of Computation for Structural Dynamics. Journal of Engineering Mechanics Division, ASCE, 85 (EM3), 1959.