A Horizontal Loading Test of Viaduct Structure Model Retrofitted by Arc Shaped Damper

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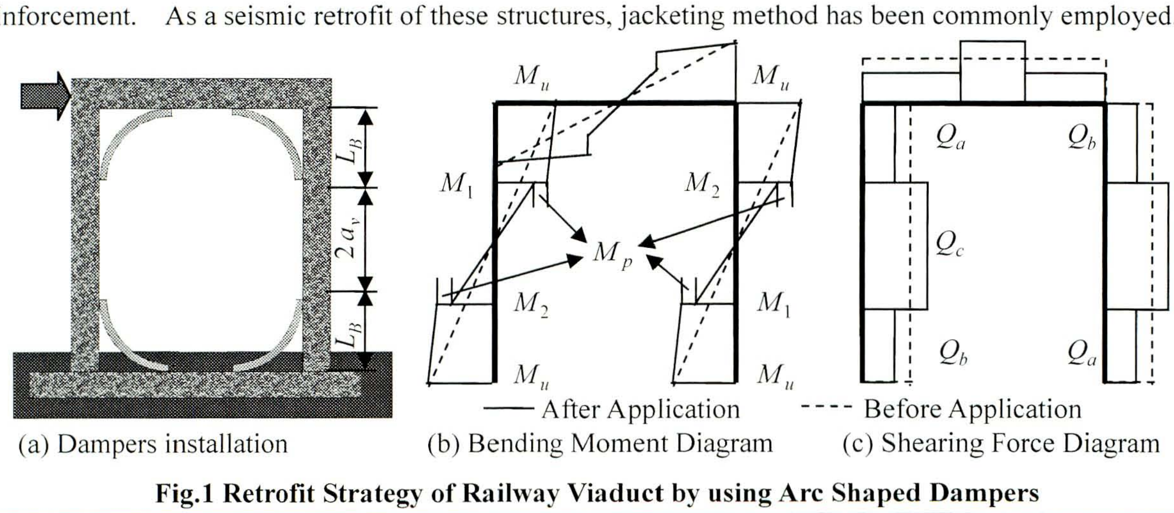
Synopsis

When considering social function of railway viaduct as infrastructure, less damage is expected even against significant earthquake such as the future Tokai and the Tonankai Earthquake. Response control technique with damping device can be one of alternative solutions. In responding, authors have developed the arc shaped damper retrofit technique. In order to investigate applicability of the proposed damper to rail way viaduct structures, horizontal loading test for verification were conducted focusing on strengthening and response control effect. Following results were obtained: the existing structure model provided post yielding shear failure, while retrofitted structure model assured flexural yielding ductile behavior with high energy absorption.

KEYWORDS: Arc Shaped Damper, Rail Way Viaduct Structure, Response Control

1. Introduction

In the current seismic design standard for rail way viaduct structures, less damage should be required against the design earthquake action of level 1 from less recovery aspect, while collapse prevention should be required against that of level 2 from life safety aspect.[1] On the other hand, many existing structures designed by previous specifications are to tend to fail in shear owing to less ductility with less amount of shear reinforcement. As a seismic retrofit of these structures, jacketing method has been commonly employed.



(a) Dampers installation (b) Bending Moment Diagram (c) Shearing Force Diagram

Fig.1 Retrofit Strategy of Railway Viaduct by using Arc Shaped Dampers

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However, considering their social function of infrastructure, an early recovery and less damage should be also desired against the level 2 action.

In these backgrounds, as an effective seismic retrofit method, we have developed an arc shaped steel damper installed at each corners of a portal frame structures as shown in Fig.1, which is to prevent a brittle failure and to assure damage control Noticeable features of the damper are as follows: First, buckling prevention of itself with its arc configuration. Second, larger distribution of plastic region for energy absorption Therefore, the following enhancements are assured, if the dampers are installed as shown in Fig. 1(a); First, strengthening of entire structure. Second, action of shear force decrease from broken lines to solid lines nearby the base of the columns as shown in Fig.1(c). Third, shear capacity increase expected due to deep beam action ~~in~~ around the middle portion of the column also as shown in Fig.1(c) Last, seismic response reduction with a high damping effect. In addition, the corner arrangement of the damper could draw an open space for usage within the viaduct as shown in Fig.1(a).

An analysis and corresponding experiment for the sole damper has been already conducted. In this paper, the effectiveness of the damper under cyclic loading is reported from a series of small scaled reinforced concrete viaduct model test results.

2. Experimental

2.1 Test Specimens

The parameters of all the four model specimens are listed in **Table.1**. Bearing force ratio herein is defined as a ratio of shear capacity to horizontal force when bending moments at all column ends reach its flexural capacity, those values are calculated for the column without retrofit. The first character of the tag as N or R indicates the specimen without or with the retrofit relevant to the third column of the table. Another parameter was volumetric shear reinforcement ratio of the columns varying from 0.05 to 0.25%, which reflects directly on the shear capacities of the columns.

The scale of the specimens was almost one-fifth of that of an ordinary reinforced concrete railway portal framed viaduct. A typical specimen we used as shown in **Fig.2** were designed based upon STANDARD SPECIFICATIONS FOR CONCRETE STRUCTURES[2]. Furthermore, the dimensions of the damper of SS400 grade steel are also shown in **Fig.3**. The dampers were installed to the model with PC steel rod passed through in a frame.

The reinforcement's arrangement for the specimen of N15, also identical to R15, having a shear reinforcement ratio of 0.15% is shown in **Fig.4**. Shear reinforcement rebars used in N15, R15 and R25 specimens were D4 as a manufactured deformed steel bar with a nominal diameter of 4mm, while those of R05 were D2. Therefore, according to the prescribed shear reinforcement ratios in **Table 1**, the intervals of the bars, so-called hoop-ties were determined 54mm in R25, and 67mm in R05. Furthermore, the material properties of the damper, concrete and rebar are shown in **Table 2**.

Table 1 Parameters of Specimens

Specimens	Shear reinforcement ratio(%)	Retrofit	Bearing force ratio
N15	0.15	without	1.09
R15	0.15	with	1.09
R05	0.05	with	0.81
R25	0.25	with	1.35

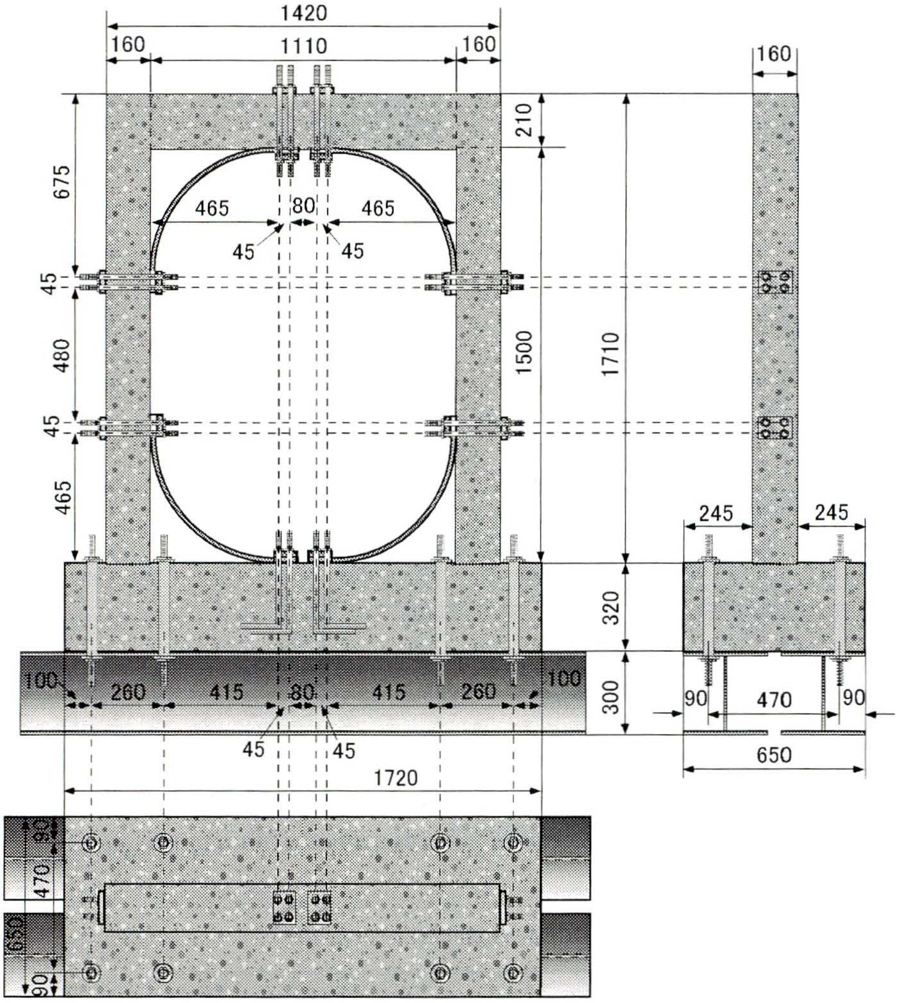


Fig.2 Overview of Specimen (unit:mm)

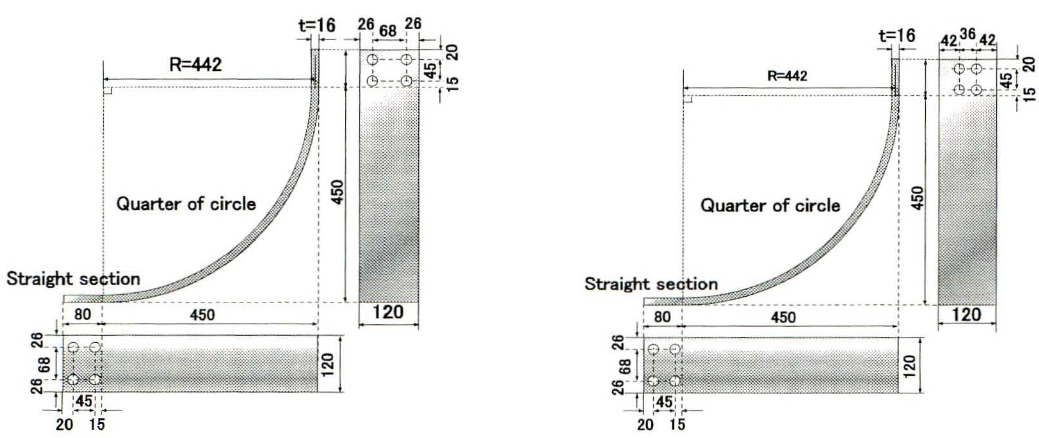


Fig.3 Dimensions of Damper (unit:mm)

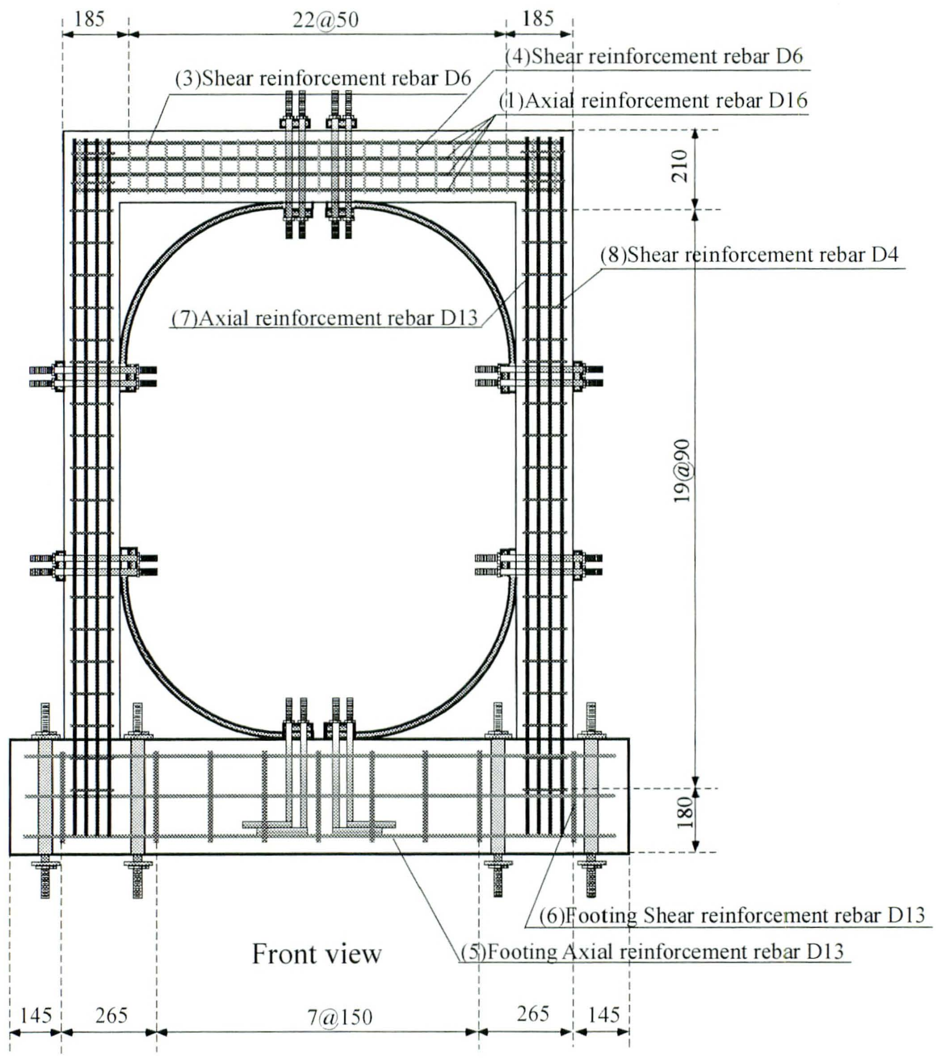


Fig.4 Reinforcement's Arrangements (unit:mm)

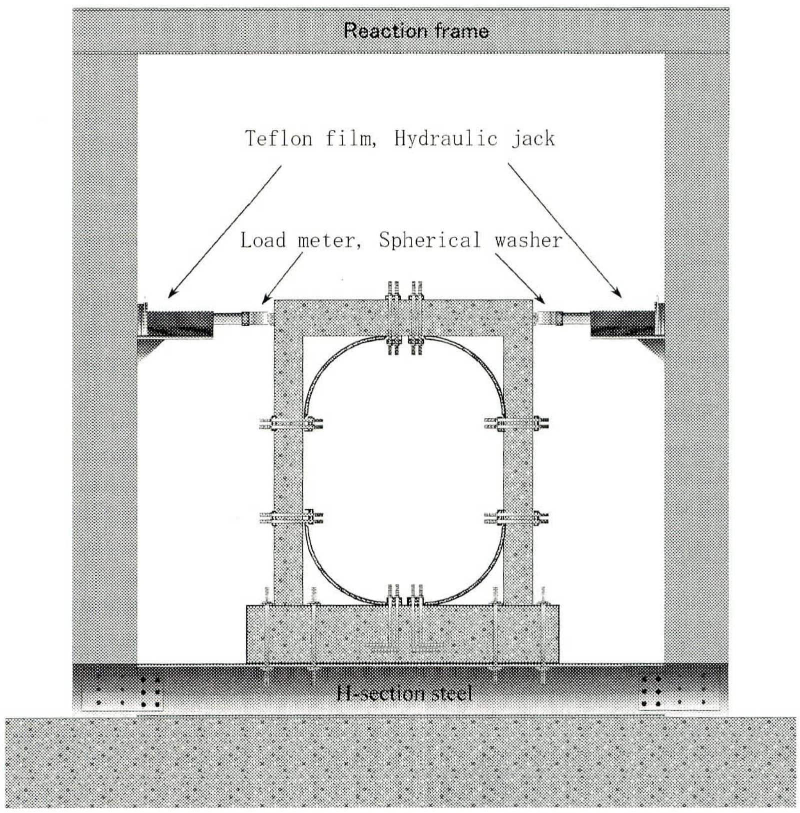
Table 2 Material properties

Materials		Properties	Values
damper	ss400	Elastic Modulus(GPa)	200
		Yield Stress(Mpa)	289
		Poisson's Ratio	0.3
concrete	N15	Compressive Stress(Mpa)	23.4
		Elastic Modulus(GPa)	25.4
		Poisson's Ratio	0.18
	R15	Compressive Stress(Mpa)	25.6
		Elastic Modulus(GPa)	27.6
		Poisson's Ratio	0.22
	R05,R25	Compressive Stress(Mpa)	25.4
		Elastic Modulus(GPa)	24.6
		Poisson's Ratio	0.18
rebar	D16	Elastic Modulus(GPa)	177
		Yield Stress(Mpa)	368
	D13	Elastic Modulus(GPa)	178
		Yield Stress(Mpa)	361
	D4	Elastic Modulus(GPa)	254
		Yield Stress(Mpa)	441
	D2	Elastic Modulus(GPa)	163
		Yield Stress(Mpa)	350

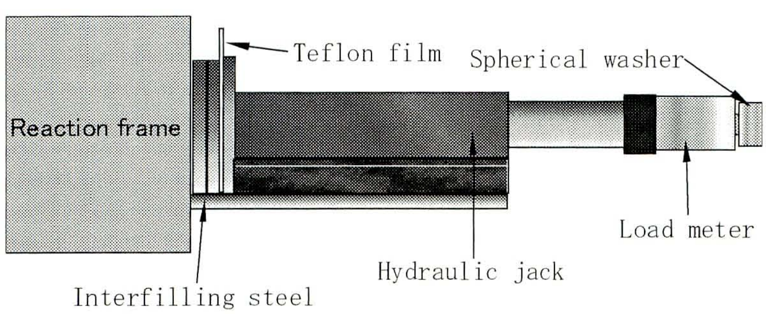
2.2 Test Procedure

The specimen and a testing setup are shown in **Fig.5**. Loading device consists of a portal reaction frame, two hydraulic jacks horizontally arranged for loading, H-section steel at bottom for fixing the specimen, load meter for measurement and spherical washer and Teflon film for adjusting lean.

The program of loading due to an incremental and reversal displacement as a drift angle is shown in **Fig.6**.



(a) Overall view



(b) Detail view

Fig.5 Specimen and Testing Setup

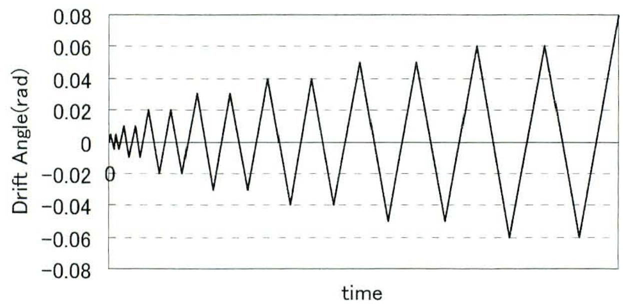


Fig.6 The program of loading

3. Test Results

3.1 Crack Pattern

The crack pattern of N15 specimen is shown in **Fig.7**. There was a diagonal shear crack in the bottom portion of the right column. Crack concentration could be also observed at both the columns' ends, while no crack could be found in middle portion of both the columns. Flowingly, local compressive failure occurred at both the columns' ends. However, the specimen failed in shear at last.

The crack patterns of three of R series specimens are shown in **Figs. 8, 9** and **10**. There was a diagonal shear crack in the middle portion of the column in both of R15 and R25 specimens. Consequently, a shear failure did not occurred, because their shear capacities increased owing to a deep beam action in their column middle portions. R05 specimen, however, failed in shear because of a lack of shear reinforcement amount.

From the above observation, it could be said that the damper installation might make the column failure mode from in shear to in flexural.

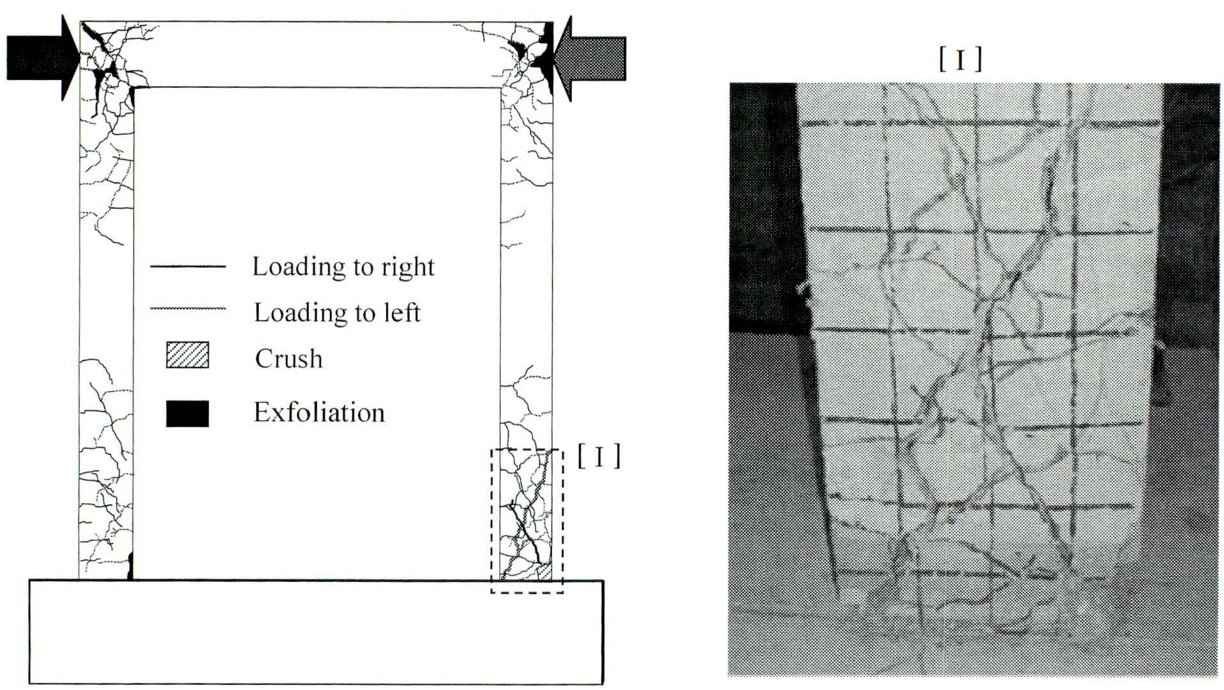


Fig.7 Cracking Pattern of N15 Specimen

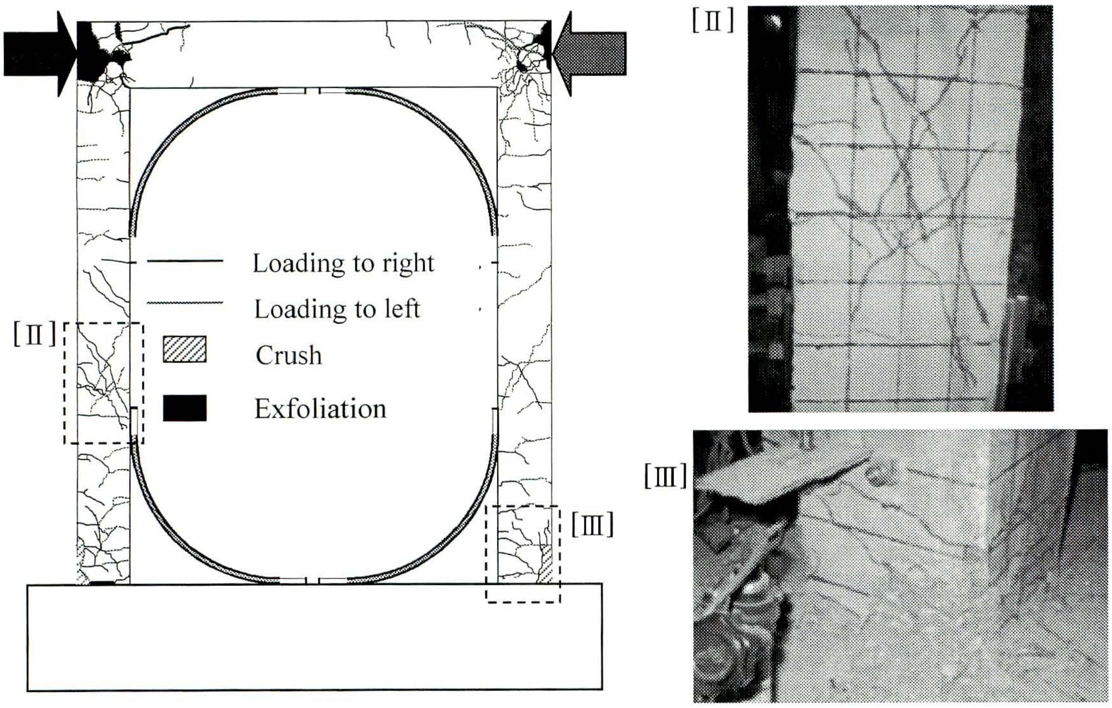


Fig.8 Cracking Pattern of R15 Specimen

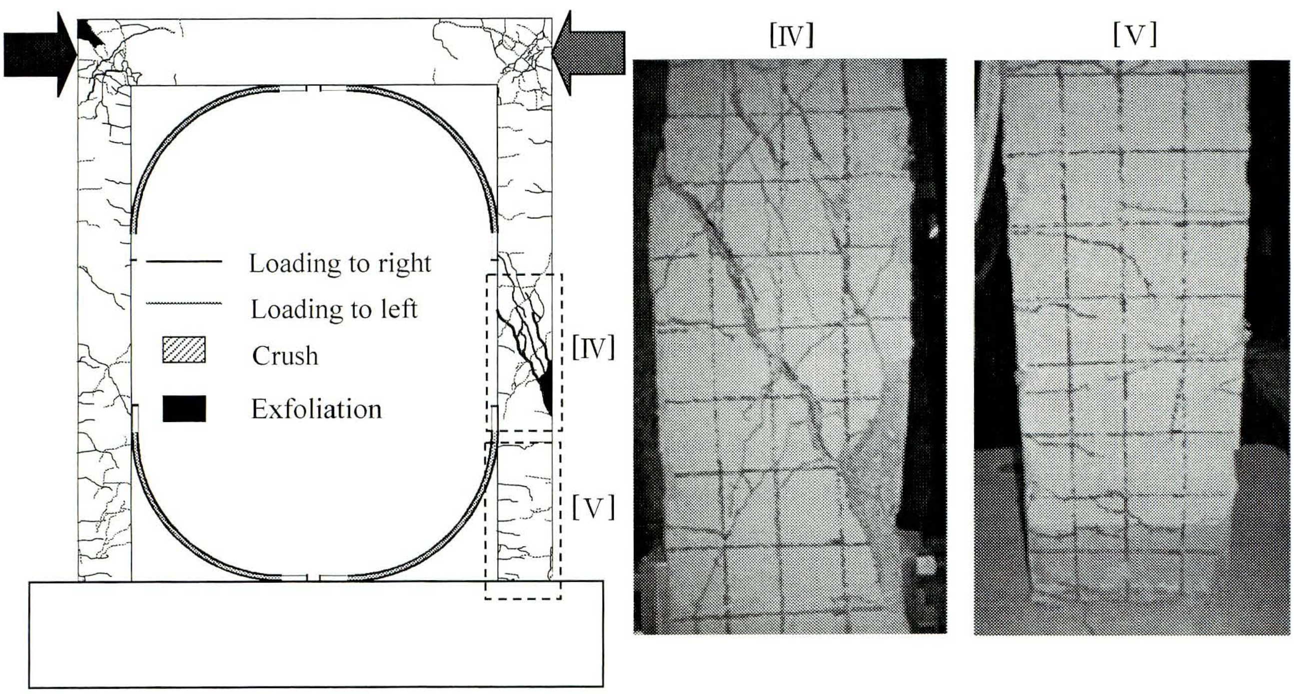


Fig.9 Cracking Pattern of R05 Specimen

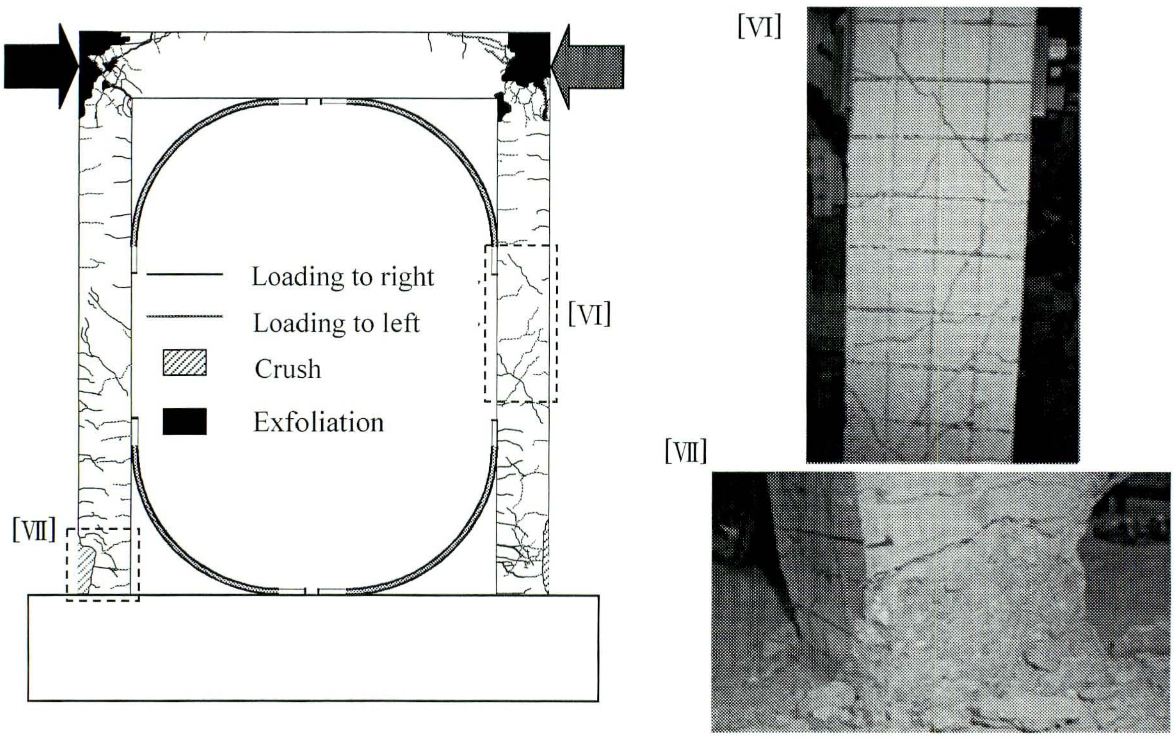


Fig.10 Cracking Pattern of R25 Specimen

3.2 Load-Drift Angle Relationships

Relations between horizontal load and drift angle of column of N15 and R15 specimens are shown in **Fig.11**. Both of the rigidity and load carrying capacity of R15 were superior to those of N15, in which the latter of R15 was about 1.4 times of that of N15. It was obvious evidence that the damper installation led an enhancement of load carrying capacity. In addition, the area of R15 loop was also larger than that of N15, which of area is an important index of energy absorption.

Furthermore, load-drift angle relationships of R05 and R25 specimens are shown in **Fig.12**. The rigidity and load carrying capacity of R05 are as same as those of R25 until drift angle attained at 4/100. R25 is flexural failure type, although its load carrying capacity was not impaired when its deformation was so large, because of strain hardening of damper. R05 is shear failure type, whose load carrying capacity fell down abruptly. Finally, these results of all the specimens are summarized in **Table 3**.

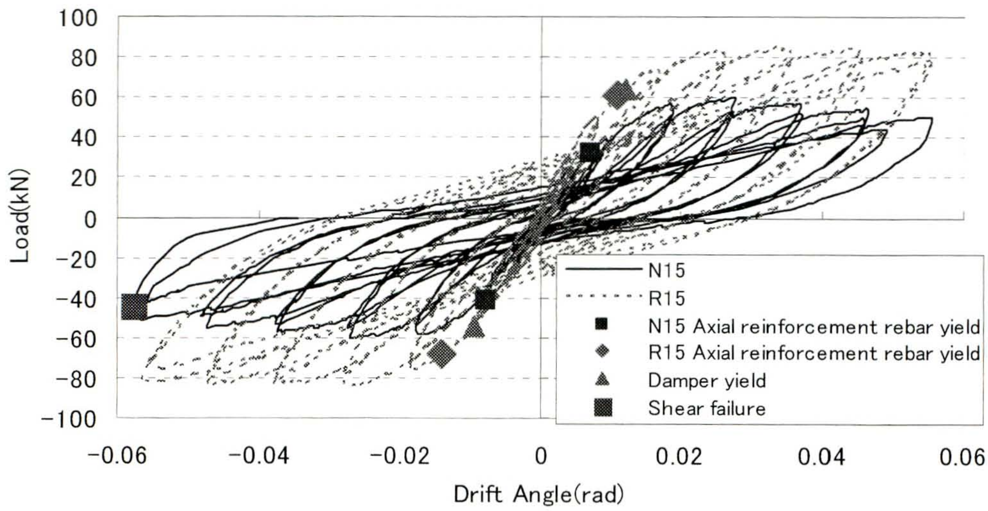


Fig.11 Load-Drift angle relationship of N15 and R15

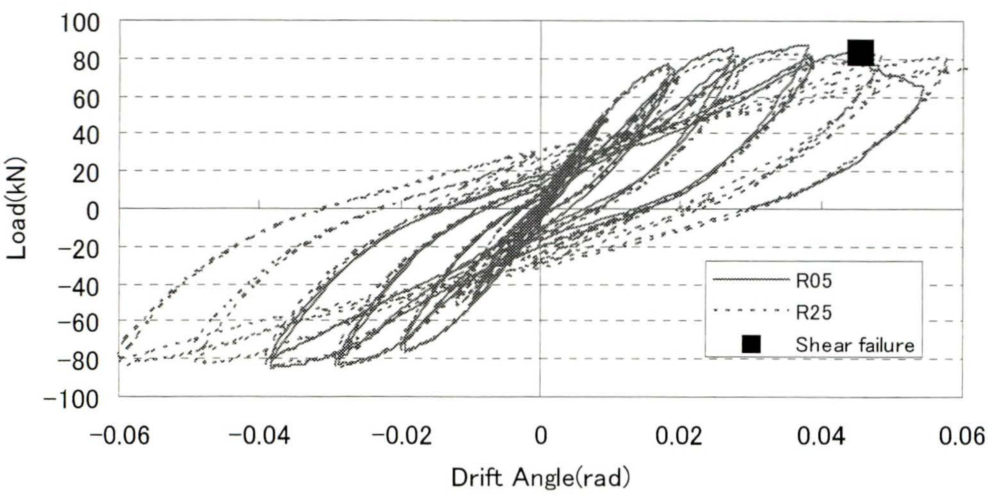


Fig.12 Load-Drift angle relationship of R05 and R25

Table 3 Test Results

Specimens	Yielding State		maximum load	Ultimate State		Failure Type
	Drift Angle R_y(rad)	Load P_y(kN)	P_{max}(kN)	Drift Angle R_u(rad)	Ductility Factor μ_u	
N15	R_y=-0.008	P_y=-40.8	P_{max}=59.8	R_u=-0.058	μ_u=7.9	Shear Failure
R15	R_y=0.013	P_y=66.6	P_{max}=87.7	R_u>0.092	μ_u>8.0	Flexural Failure
R05	R_y=0.012	P_y=62.1	P_{max}=87.1	R_u=0.045	μ_u=4.2	Shear Failure
R25	R_y=0.013	P_y=63.5	P_{max}=87.7	R_u>0.091	μ_u>8.1	Flexural Failure

3.3 Hysteretic Damping

Equivalent viscous damping factors of all the specimens are shown in **Fig.13**, those are calculated when their drift angle attained to 1/100, 2/100, 3/100, 4/100, 5/100 and 6/100. The factors of R series specimens were higher than that of N series specimen as their drift angle became larger.

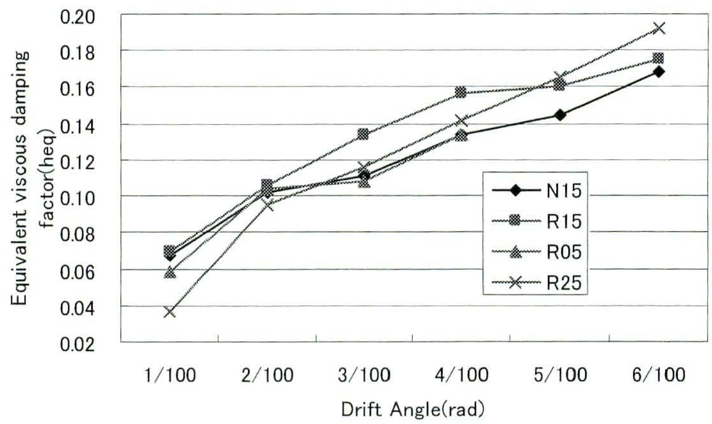


Fig.13 Equivalent viscous damping factor

4. Concluding Remarks

From the loading tests, followings are concluded.

1) Existing structure can be shifted from shear failure to flexural failure type by the present damper retrofit technique.
2) Retrofitted series specimens provided 1.4 times loading capacity of existing model specimen.
3) Equivalent viscous damping factor of retrofitted specimen is higher than that of existing model in the large displacement range.

REFERENCES

1) Railway Technical Research Institute: The Model Code for Design of Concrete Railway Structures (2004) (in Japanese)

2) Japan Society of Civil Engineers: STANDARD SPECIFICATIONS FOR CONCRETE STRUCTURES -1996, Seismic Design (1996) (in Japanese)