Bull. ERS, No. 31 (1998)

PSEUDO-DYNAMIC TESTS ON FRAMES WITH LOW-YIELD-POINT STEEL DAMPERS

by

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ABSTRACT

In recent years, hystersis damper made of low yield point is expected to play an important role in controlling structural vibration induced by earthquake and wind. But their dynamic characteristics and energy dissipation effects on the whole structure model are not yet clarified well. This paper describes quasi-static and dynamic loading tests and a computer-controlled loading test, which are performed quasi-statically on the damper specimen simultaneously with a hybrid response analysis of the whole frame system.

1. INTRODUCTION

After the Great Hanshin-Awaji Earthquake, a pressing need is put on Japanese society to study the vulnerability of existing structures to the future earthquake, especially in public use, and to make a plan for retrofitting and/or upgrading if they have insufficient seismic performance. In most of the cases, an ordinary strengthening will do, but to strengthen a certain part of structure sometimes leads to make some other portions vulnerable, and those portions happened to be difficult to strengthen. In such a case another method is needed based on energy absorption or vibration control during earthquakes.

One of the devices used to reduce structural damage due to earthquakes is a passive damper attached to the ordinary structural system. Such a device is not only installed in a newly designed building but also used to retrofit an old building with insufficient seismic strength. A hysteretic damper made of low-yield-point (abbreviated as LYP) steel is sometimes employed to absorb the energy exerted into the structures, and it is supposed to work from moderate to severe earthquakes. The material has extraordinary ductility, and also the property of low-yield-point enables engineers to select appropriate dimensions and sizes of device details, in contrast to the use of high strength material when reducing plate thickness.

Many theoretical studies have been made on such kind of damper devices, but not so

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many experimentally about its earthquake response behaviors, especially when it is installed in a real structure [1], [2]. At first this paper presents the results of the quasi-static and dynamic loading tests. Next, a series of sub-structuring pseudo-dynamic tests on LYP damper inserted studs are performed to examine the ability to reduce seismic responses. These response behaviors simulated by the pseudo-dynamic tests are used to check the validity of constitutive modeling proposed for LYP panel dampers.

1. QUASI-STATIC AND DYNAMIC LOADING TESTS

To investigate the influence of the loading speed on the basic inelastic behaviors of the damper inserted studs, they are loaded quasi-statically as well as dynamically with almost monotonic loading paths including one cyclic reversal. The shear panel portions of the damper is made of LYP steel, and the mechanical properties of the LYP material are summarized in Table 1. Flange and end plates are made of ordinary mild steel, JIS SS400 grade. Dimensions of the damper specimen are shown in Fig. 1, and test setup is shown in Fig.2. The results of tests are shown in Figs.3 and 4.

The panel shear in the quasi-static test is increased over calculated tensile strength of panel cross-section, about 4-ton. This is supposed that a tension field is formed in the part of panel, and then flanges surrounding it behave like tension bar. Finally, welding part of flange is broken.

In the dynamic test, the speed of the shear panel deformation angle is within range of 6 to 13 (rad/sec) corresponding to the loading speed at 46 to 91 (cm/sec). The shear yield resistance is increased more than two times of quasi-static one.

2. SUBSTRUCTURING PSEUDO-DYNAMIC TESTS

(1) Outline of Pseudo-dynamic Tests

A series of pseudo-dynamic tests are conducted to simulate seismic responses of fictitious frames in which actual damper specimens are installed. A computer-controlled loading test is performed quasi-statically on the damper specimen simultaneously with a hybrid response analysis of the whole frame system.

The frame system analyzed herein in the pseudo-dynamic tests is a single-story planar frame retrofitted by a damper inserted stud as shown in Fig. 5.

The restoring force of the damper inserted stud is measured from computer-controlled loading test in the setup as well, and it is combined with the fictitious restoring force of the surrounding original frame as shown in Fig.6, and reflected in the numerical integration of the equation of motion of the whole system. The fictitious original frame is assumed to be elastic herein. The ratio of the initial stiffness damper inserted stud to that of original frame is set to 1.0, 5.0, and 9.0, respectively in three cases. Fictitious mass is adjusted so that each system in three cases has an identical natural period of 0.4 seconds. The NS component recorded at El Centro in 1940 is used as input excitation with a reduced peak acceleration, 70cm/s/s. These parameters of pseudo-dynamic tests are summarized in Table 2.

(2) Test Results

The three time histories of displacement responses simulated by pseudo-dynamic tests are not so different as shown in Fig. 7 while the magnitudes of the whole resistance must differ considerably due to the different stiffness of the surrounding frame. One of the reasons is that each case has an identical natural period in elastic range and is subjected to the same intensity of input excitation. That of the entirely elastic system with the identical natural period sometimes approximates the peak displacement response of inelastic system. From this point of view, it is not surprising that three cases might result in almost the same peak displacement response with that of elastic system. Elastic response is also plotted as the solid curve in Fig. 5, and its peak response is not so different from the inelastic ones. However, the overall inelastic responses during the whole duration are much reduced compared with the elastic one. The elastic one corresponds to the response in the case of retrofit by a stud only. Generally, even a mere stud may work to reduce the peak displacement by stiffening the original frame, but a damper inserted stud will achieve a more preferable response suppressed over the whole duration by adding hysteretic damping.

To examine the effect of response suppression, the test histories are compared with the response history of the original frame without studs as shown in Fig. 8. Sufficient response suppression is observed in each case.

(3) Comparison with Completely Numerical Analysis

The test results are also compared with the results simulated numerically, which is based on a constitutive modeling of damper termed ‘skeleton shift model’ [4]. The hysteresis rule in this model is illustrated in Fig. 9. In this model, initial skeleton curves in positive side and negative side are assumed independently, but usually as identical ones. Target points are prepared on both side skeleton curves. Loading along one side skeleton curve is experienced, the target point on the curve moves together with loading, and at the same time, the opposite side skeleton curve is shifted with its target point along the deformation axis as much as Ψ times of the experienced plastic deformation. Unloading from one side skeleton curve is arranged as a softened curve such as expressed by the Ramberg-Osgood function until it reaches to the target point on the opposite side skeleton curve. By adjusting the Ψ value, various types of hysteresis loops can be expressed like a mixed rule of kinematic and isotropic hardening. In the case of cyclic reversals of mild steel material, the values around 0.5 through 0.9 were used in the past studies.

In the arrangement of model parameters here, the skeleton curve derived from the test hysteresis loops of panel damper is approximated by a tri-linear curve, and the Ψ value is taken about 0.9. Based on such a model, numerical response analysis is carried out for each test case, and the results are compared in Figs. 10, 11, and 12, where solid curves are tested responses and broken curves are computed ones. It is confirmed that the tested and computed responses agree with each other with sufficient accuracy.

4. CONCLUDING REMARKS

By the difference of the loading speed, the shear yield resistance of the panel is influenced considerably. In these tests, the shear yield resistance in dynamic test is increased more than two times of quasi-static one. This effect is not considered in the earthquake simulation presented herein, and it should be studied in the future research.

A series of sub-structuring pseudo-dynamic tests are conducted on low-yield-point steel dampers and the hybrid responses of a single-story structure retrofitted by it are simulated. These test results demonstrates that the panel damper inserted studs are very effective to reduce response of the original frame. This is due to hysteretic damping added by the panel damper as well as stiffness added by the studs.

A hysteresis model termed shifted skeleton model is proposed to simulate hysteretic behaviors of low-yield-point steel dampers. Numerically simulated responses based on the model agree fairly well with the test results.

5. REFERENCES

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ACKNOWLEDGMENTS

This study was financially supported by JSSC research committee on new steel structural design method, and low-yield-point damper specimen was offered by Fujita Corporation.

Table 1 Mechanical Properties of panel material

σ_y	σ_u	ε_u	τ_y
0.82 t/cm^2	2.51 t/cm^2	40.70%	0.48 t/cm^2

Notes

σ_y : Yield stress

ε_u : Strain at tensile stregth

σ_u : Tensile strength

τ_y : Shear yield stress

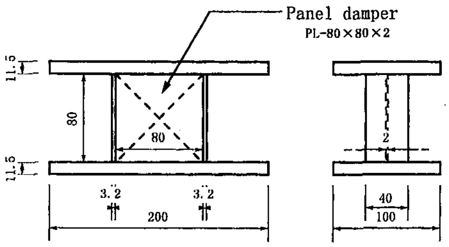


Fig.1 Panel damper specimen

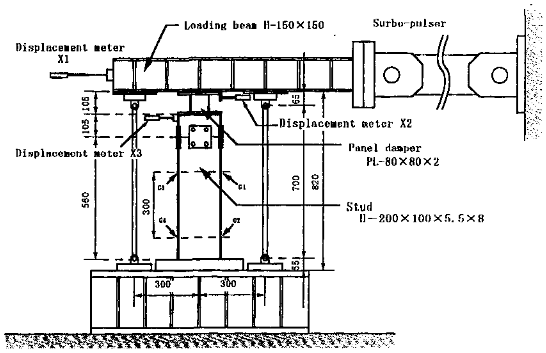


Fig.2 Test set up

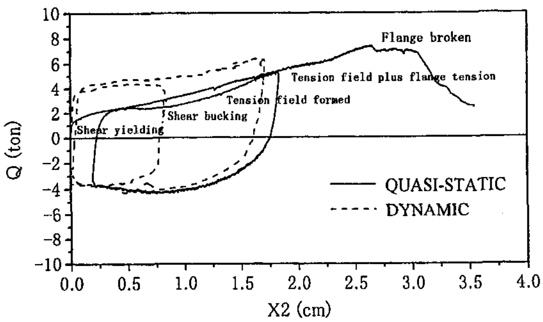


Fig.3 Comparison of the quasi-static and dynamic tests

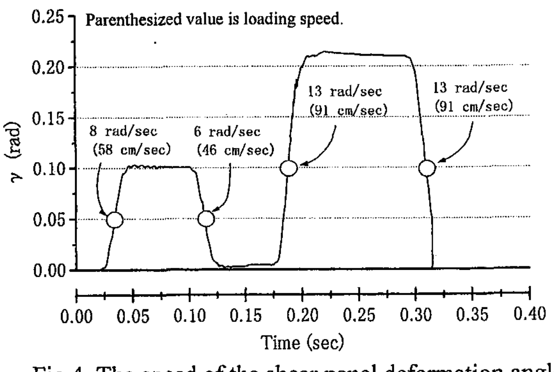


Fig.4 The speed of the shear panel deformation angle

Table 2 Summary of parameters pseudo-dynamic test

Ratio	Initial stiffness		Hybrid system analyzed					Input ground motion
K_E/K_F	K_E (t/cm)	K_F (t/cm)	K_V (t/cm)	M ($t\ s^2$/cm)	C (t s/cm)	T (s)	h	A_{max} (gal)
1	16.080	16.080	32.160	0.1305	0.00410	0.4	0.001	70.0
5	16.080	3.216	19.296	0.0783	0.00246			
9	16.080	1.787	17.867	0.0725	0.00228			

Notes

K_E : Stud with panel damper
K_F : Fictitious elastic frame
K_V : Initial stiffness
M : Fictitious mass
C : Fictitious damping coefficient
T : Natural period
h : Fictitious damping constant
A_{max} : Peak acceleration of scaled El Centro NS,1940

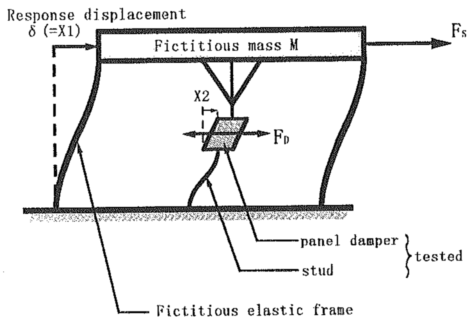


Fig.5 Hybrid system analyed

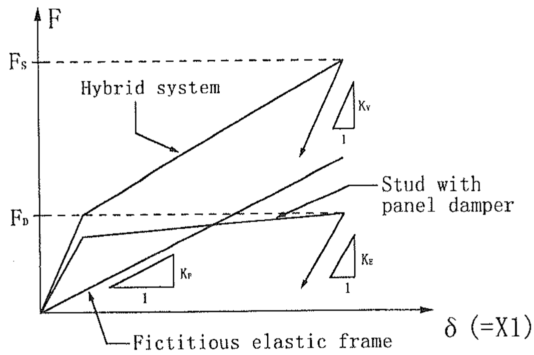


Fig.6 Notation of restoring forces

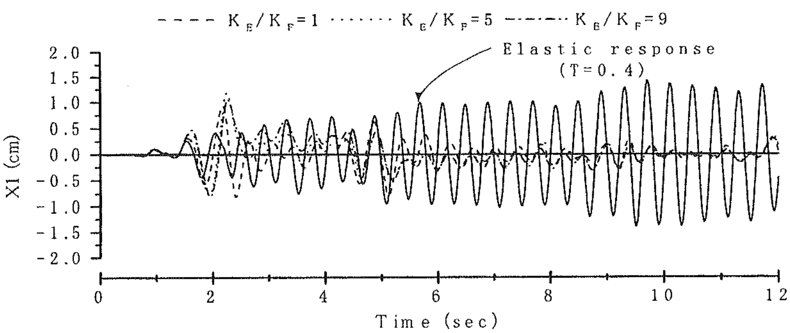
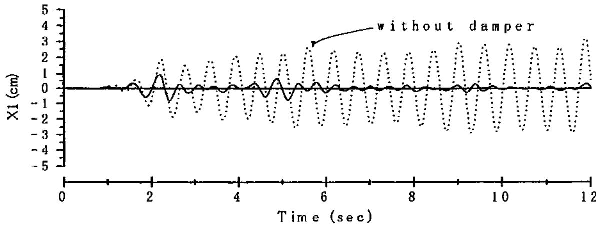
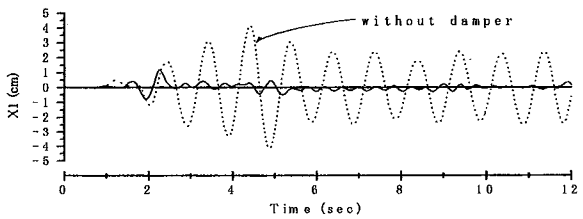


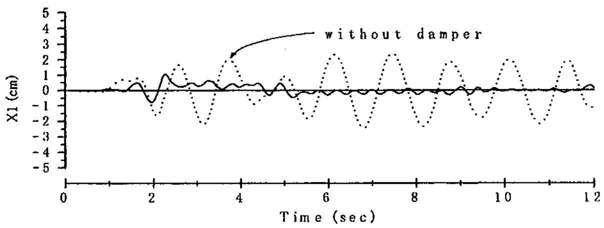
Fig.7 Hybrid inelastic responses and elastic response



(1) $K_E/K_F=1$

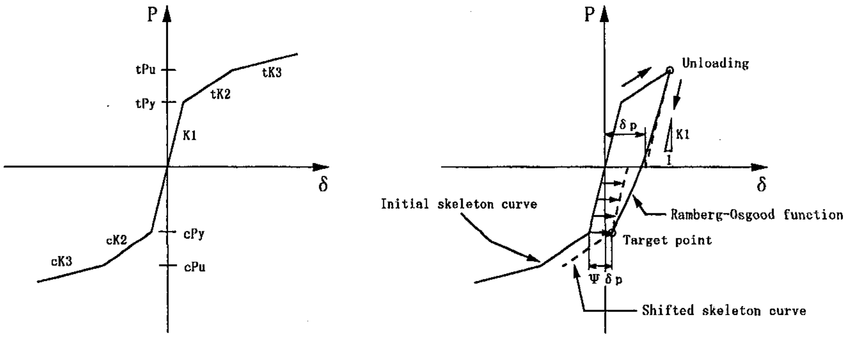


(2) $K_E/K_F=5$



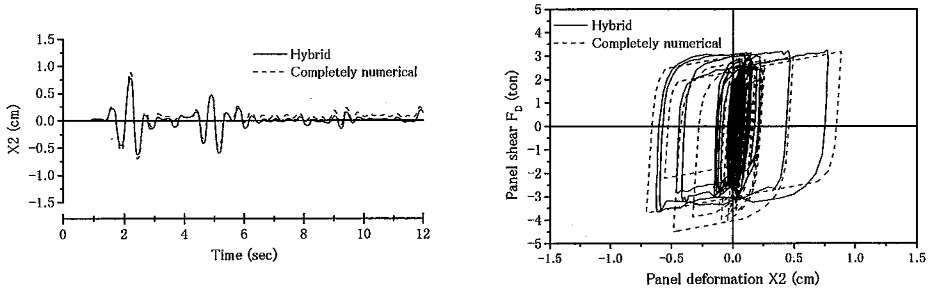
(3) $K_E/K_F=9$

Fig.8 Comparison of displacement with or without damper



Tri-liner skeleton curve Shifting of skeleton curve

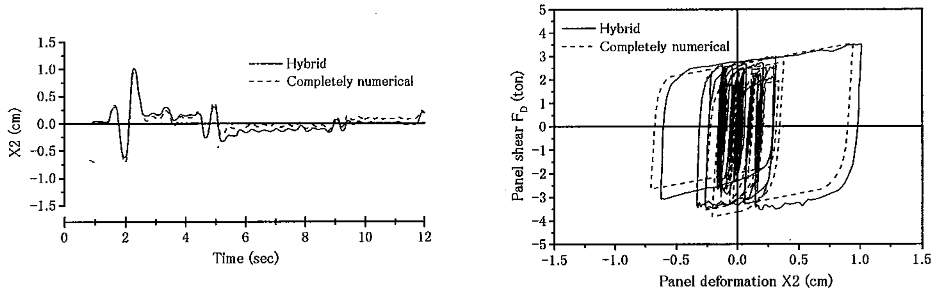
Fig.9 shifted skeleton hysteresis for completelly numerical analysis



(1) Time histories of response displacement

(2) Hysterisis loops

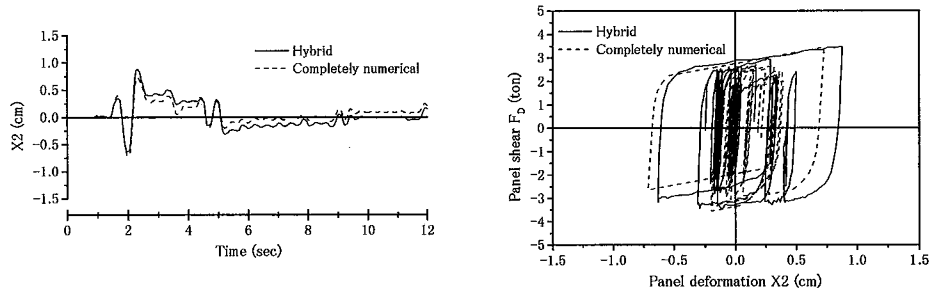
Fig.10 Hybrid responses and completely numerical responses (K_E/K_F=1.0)



(1) Time histories of response displacement

(2) Hysterisis loops

Fig.11 Hybrid responses and completely numerical responses (K_E/K_F=5.0)



(1) Time histories of response displacement

(2) Hysterisis loops

Fig.12 Hybrid responses and completely numerical responses (K_E/K_F=9.0)