DYNAMIC LOADING TEST OF SHEAR PANEL DAMPER

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INTRODUCTION

When a shear panel damper is equipped between superstructure and top of pier of elevated highway bridges, shear deformation is required more than 10%. To satisfy this demand, high performance shear panel damper using low yield steel (LYSPD) is developed by improving the panel shapes [1], [2]. The mean shear strain 70% was attained in this static increasing shear cyclic loading test.
For the damper with large deformation capacity, however, high temperature may be caused in the panel by internal friction of the material due to repeated high speed shear strain. Preliminary dynamic cyclic loading test [3] showed that the accumulated heat in shear panel reduced the rigidity of the material and resistance force of the damper rapidly. In this research, static and dynamic cyclic loading tests are conducted using the newly developed high performance dampers. Excitation frequencies f = 0, 0.5 Hz and 1.0 Hz are given under the four sine waves with the constant shear strain amplitudes each. From the test, the behaviour of the damper under the high speed loading is clarified.

1 STATIC AND DYNAMIC CYCLIC LOADING TEST

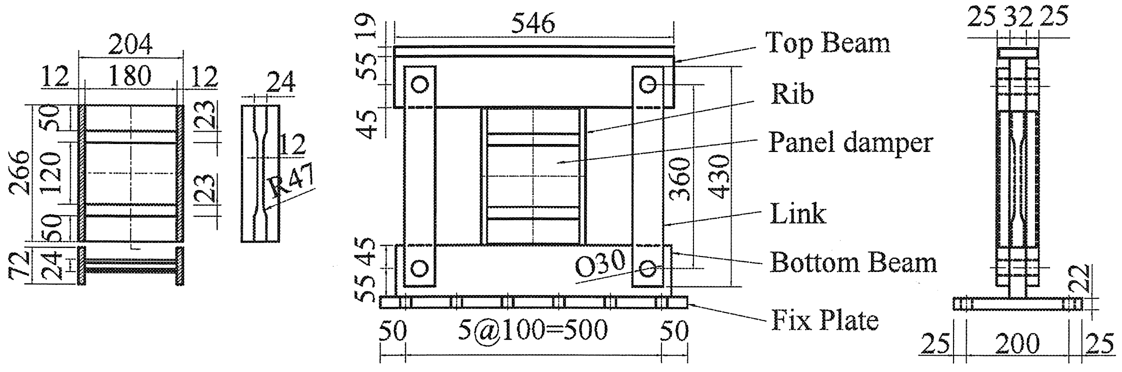
1.1 Test program and test shear panel damper

The shape and size of shear panel test specimen using both static and dynamic loading tests is shown in *Fig. 1(a)*. The panel thickness is changed vertically such that the thick horizontal stiffener with t=24mm, width 50mm is located at upper and lower side of the panel, following transition part of width 23mm changing the thickness from 24mm to 12mm, and reaches to the flat shear panel part with the thickness t_w=12mm and the height D=120mm. The total height is 266mm. The thickness of the panel is constant in the horizontal direction along with width W=180mm. The vertical ribs (t=12mm x b=72mm, material LYP100) are welded at the panel left and right sides in accordance with the total height of the panel as shown in *Fig. 1(a)*. Since the size of the flat part of the panel except of the welding leg size becomes D=120mm x W'=160mm, which width-thickness ratio D/t_w=10 is very small compared with conventional shear panel dampers with the width-thickness ratio 30 to 50, the shear buckling is hard to occur for this test panel. This test panel has the mean shear strain 70% in static cyclic loading testing under increasing shear strain amplitude, which is very large compared with conventional shear panel dampers with 10 to 12%.
The test panel is welded to the thick upper loading plate and lower fixed plate connecting with two links so that upper side of the panel moves parallel to the lower as shown in *Fig. 1(b)*. The distance between the pin centre of the links is 360mm, which is three times the panel height D=120mm.
From tensile coupon test of low yield steel (LYP100), the yield strength defined by the 0.2% offset value is obtained as 100.1 N/mm^2. The elongation reaches 60%, which is about three times the value of SS400 mild steel. The stress-strain curves are shown in *Fig. 2* with the SS400 mild steel as comparison.

1.2 Test setup and loading sequence of the static and dynamic loading test

Test setup is shown in *Fig. 3*. Cyclic lateral load is applied at the tip of the upper shear panel through a W-type levelling apparatus by a MTS 1000kN dynamic actuator. The horizontal displacement is measured by two laser displacement meters set at the upper and lower position of the shear panel and its difference is counted as the panel displacement. The mean shear strain is defined as the horizontal displacement divided by the panel effective height D=120mm. For the static loading, the mean shear strain velocity v_γ is set as 0.4% /sec (0.5mm/sec). The four different

shear strain amplitudes on either sides, 20%, 30%, 40% and 50% are provided to both static and dynamic cyclic loading test. The name of test specimen in static and dynamic loading is given with ST and D, respectively, followed by these numeral of strain amplitude 20 to 50.
For the dynamic test, different period T= 2.0 sec (frequency f= 0.5 Hz) and T= 1.0 sec (f= 1.0 Hz) are given under sine wave. The frequency code 05 and 10 are affixed after the name of test specimen, such as D05-20 or D10-20. Four test panels for static and eight for dynamic are prepared. Test program is summarized in *Table 1.*



(a) Dimension of test panel (b) Panel with link mechanism (c) Side view

Fig. 1. Detail of test shear panel

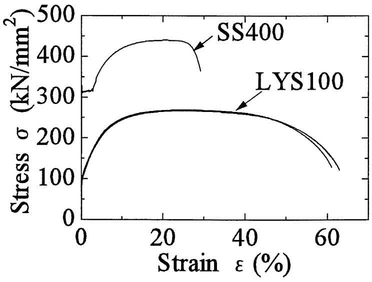


Fig. 2. Stress-strain curves

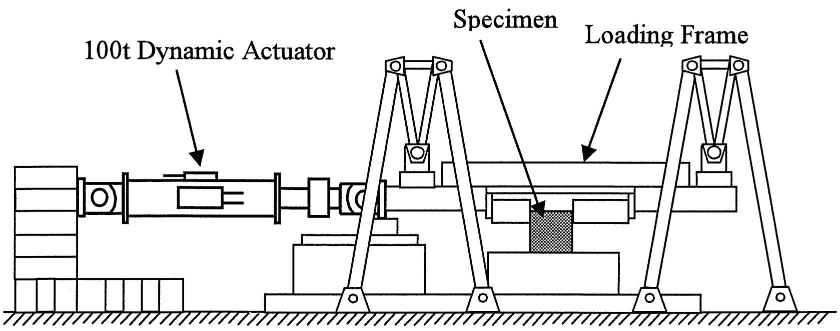


Fig. 3. Test setup

Table 1. Test program

	Test Panel Name	Frequency f (Hz)	Period T (sec)	Mean shear strain amplitude γ_a (%)	Mean shear strain velocity v_γ (%/sec)
Static (ST)	S20	-	-	20	0.4
	S30			30	
	S40			40	
	S50			50	
Dynamic (D05)	D05-20	0.5	2	20	40
	D05-30			30	60
	D05-40			40	80
	D05-50			50	100
Dynamic (D10)	D10-20	1.0	1	20	80
	D10-30			30	120
	D10-40			40	160
	D10-50			50	200

2 TEST RESULTS AND CONSIDERATIONS

2.1 Shear force and shear strain hysteretic curves

Shear force and shear strain hysteretic curves obtained from static and dynamic cyclic loading are illustrated in *Fig. 4,* where results for shear strain amplitude γ_a = 20% and 50% are shown as representative. Figures of left hand side column indicate the results from static cyclic loading, from which it is observed that the shear force increases gradually along with the shear strain during first half cycle. Curves on centre and right columns in *Fig. 4* are the results due to the dynamic cyclic loading with frequency f = 0.5 Hz and 1.0 Hz, respectively. Whereas hysteretic curves due to static loading shows tilt at unloading and reloading path, no such behaviour is observed on the curves due to the dynamic loadings. They form rectangular shapes.

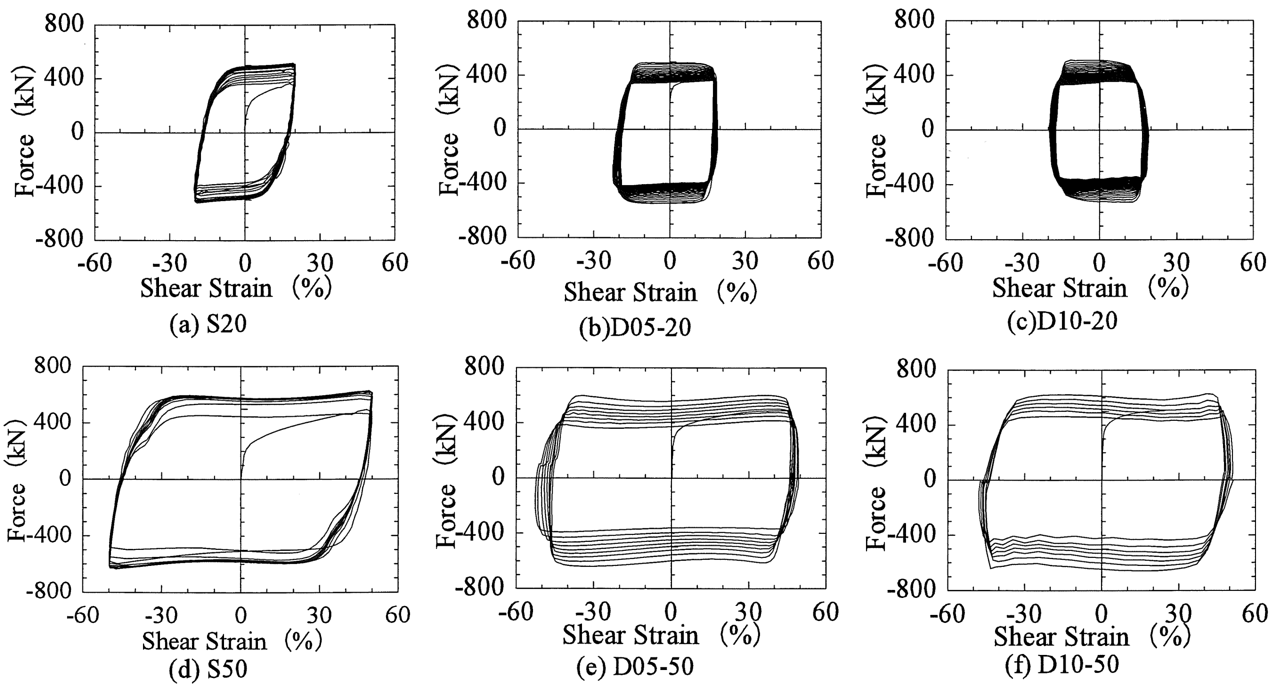


Fig. 4. Shear force and shear strain hysteretic curves due to static and dynamic cyclic loading

2.2 Maximum load

The maximum load at each hysteretic loop is called "peak load" in this study. The relationship between peak load and loading cycle number is illustrated as *Fig. 5 (a)* for static loading and *Fig. 5 (b)* for dynamic loading of frequency 1.0 Hz. For the static loading, it is recognized from the figure that the peak loads are kept to be constant to the loading cycle numbers after one or two cycles, whereas for the dynamic test, linear decreasing of shear force along with the cyclic numbers are observed after the maximum load occurred at two or three cycles. This attributes to occurrence of heat caused due to friction among crystal particles in the steel material during high speed cyclic loading, and leads to softening of steel material by the accumulated heat.

Relationship between the rate of temperature ascend T_v (C/sec) and the shear strain speed γ_v (%/sec) is illustrated in *Fig. 6,* where linear relation is obtained. Relationship between the rate of force descendent (kN/sec) and the shear strain speed (%/sec) is shown in *Fig. 7,* where a linear line is also drawn for these data.

2.3 Low cycle fatigue characteristics

With the increase of the cyclic number, fatigue failure may happen as the panel causes cracks and develops tears along welding seams of vertical ribs. The cyclic numbers where the resistance force deteriorates down to 70% of the maximum force is defined as fatigue failure cycle N_{70} in this study.

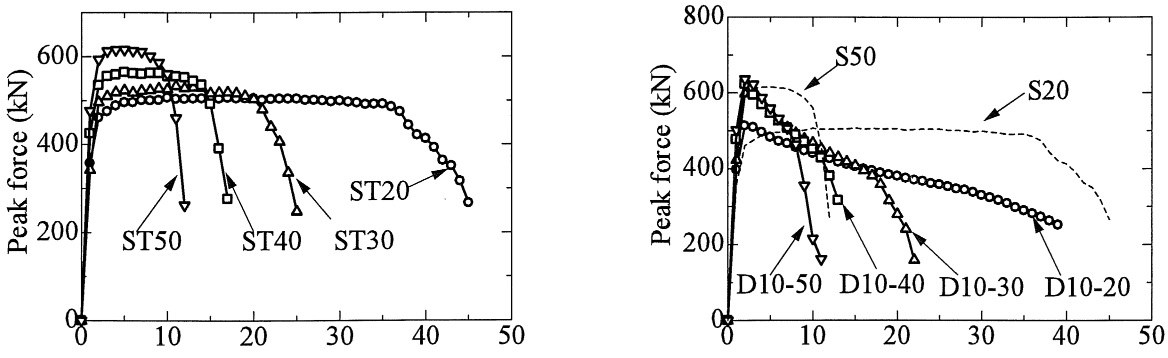
The relationship between the shear strain amplitudes and the number of fatigue cycles N_{70} are illustrated in *Fig. 8.* The regression equations *Eq. (1)* to *(3)* based on Manson-Coffin's law are obtained in good agreement with each test data.

$$\gamma_a = 239 N_{70}^{-0.66} \tag{1}$$

$$\gamma_a = 294 N_{70}^{-0.78} \tag{2}$$

$$\gamma_a = 275 N_{70}^{-0.81} \tag{3}$$

where, γ_a: shear strain amplitude, N_{70}: number of fatigue cycle.



(a) Static (b) Dynamic (D10)

Fig. 5. Peak force and number of loading cycles

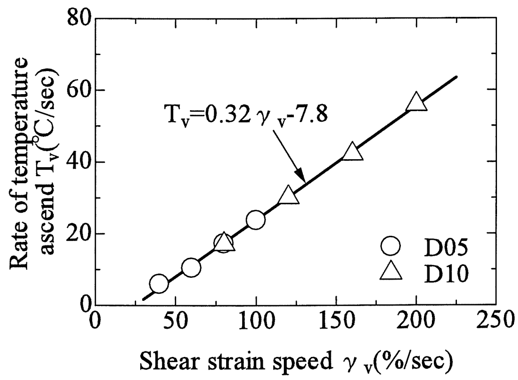


Fig. 6. Temperature ascend T_v (°C/sec) and shear strain speed γ_v (%/sec)

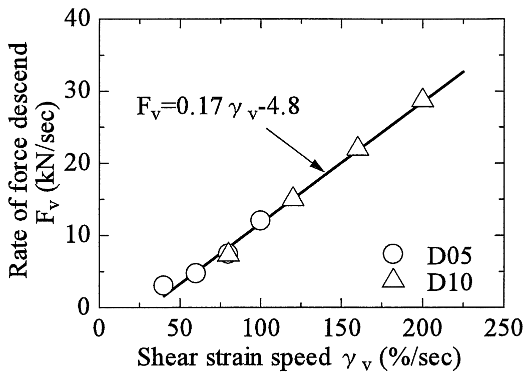


Fig. 7. The rate of force descendent (kN/sec) and shear strain speed (%/sec)

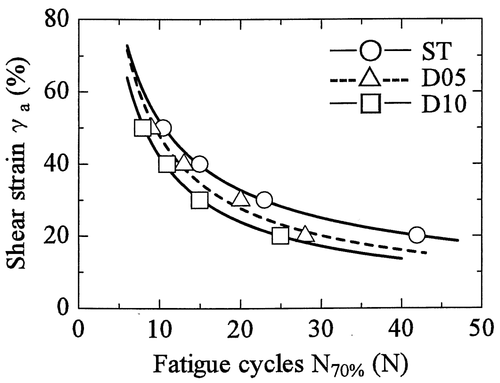


Fig. 8. Shear strain amplitudes and number of fatigue cycles

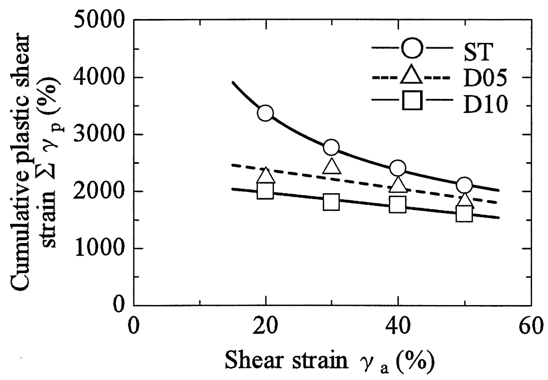


Fig. 9. Cumulative plastic shear strain (CPS) and excitation shear strain amplitude γ_a

2.4 Cumulative plastic shear strain

Fig. 9 shows the relationship between the cumulative plastic shear strain (CPS) and the excitation shear strain amplitude γ_a, where CPS is calculated from hysteretic curve of each cyclic loading test. CPS due to static loading test shows decrease along with γ_a as an exponential function, whereas those of dynamic loadings indicate linear decrease along with γ_a.

Since the test results due to dynamic cyclic loadings are obtained from continuous sine wave loading in the constant strain amplitude condition, the generated heat in the panel may accumulate without rest. On the other hand, the displacement response at a panel damper due to actual seismic excitation has random shear strain amplitudes and irregular loading velocity as well. Therefore, the generated heat can reduce its value by radiation and conduction during small shear amplitude after the large one. This means that the regular cyclic loading test as done in this study may give the extreme heat condition. Consequently, it brings large reduction of shear force to the fatigue cycle and the cumulative plastic shear strain (CPS) as shown in *Fig. 9*.

In this research, mean value 1775% of CPS at excitation frequency f=1.0 Hz (T=1.0 sec) is considered as the limit CPS for the tested panel damper. It is also recognized from *Fig. 9* that this limit value is constant along with the shear strain amplitude and the strain velocity as well.

2.5 Cumulative energy absorption

Cumulative energy absorption capacities (CEA) are found by calculating the area of hysteretic curves obtained from cyclic loading test. *Fig. 10* shows relationship between CEA and the mean shear strain amplitude for static and two dynamic loading tests. The regression equations for the test data are found as following linear equations.

$$\sum E_{70} = -9\gamma_a + 1704 \tag{4}$$

$$\sum E_{70} = -3\gamma_a + 1107 \tag{5}$$

$$\sum E_{70} = 2\gamma_a + 803 \tag{6}$$

It is observed from *Fig. 10* that as the loading speed becomes fast, the values of CEA are reduced. Following the same philosophy as the cumulative plastic shear strain in previous section, the mean cumulative energy absorption value 880 kN· m at the test conducted in f= 1.0 Hz is considered as representative limit CEA value for this shear panel.

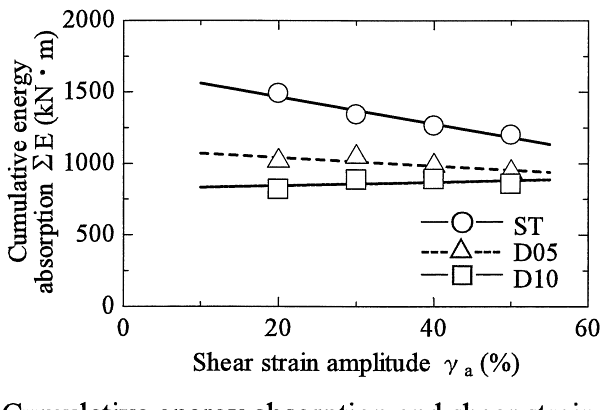


Fig. 10. Cumulative energy absorption and shear strain amplitude γ_a

2.6 Failure mode

Fig. 11 (a) and (b) are test panel of S20 and S50 of static cyclic loading near failure. In spite of small width-thickness ratio, shear buckling deformations are observed. The failure mode of S30 and S40 showed almost the same. The shear panels in static loading caused cracks at panel corners and led to collapse. The panels of D20 to D50 near failure in dynamic loadings are shown in *Fig. 11 (c)* to *(f)*. With the increase of the number of loading cycles, heat generated from whole panel and turned red gradually, after that tear happened along the welding line of the vertical stiffeners.

Finally strong red colour band appeared horizontally in the panel and tore along this band as shown in Figures. Failure modes of static and dynamic loading are also appeared differently.

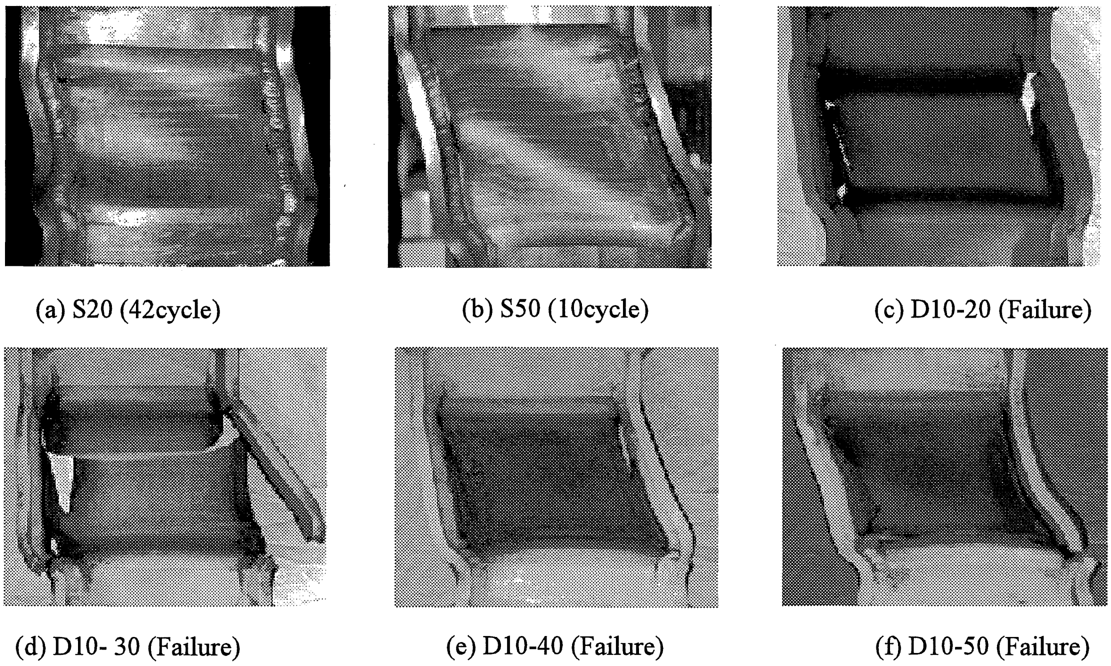


Fig.11. Failure mode of the shear panels

3 SUMMARY AND ACKNOWLEDGMENT

Static and dynamic cyclic loading tests for the high seismic performance low yield steel shear panel damper (LYSPD) are conducted under four different constant shear strain amplitudes. The test results show great difference between static and dynamic cyclic loading, especially in degrading of the resistance force along with the number of loading cycles in the dynamic loading. The relationships between shear strain amplitude and fatigue cycles, shear strain amplitude and cumulative plastic shear strain are also appeared large differences due to cyclic loading speed. From these test results, it may be said that the evaluation of the seismic performance of LYSPD should not be judged based only on the static cyclic loading test results, because it leads to unsafe side.
Since the dynamic cyclic loading test under the constant shear strain amplitude tends to accumulate heat in the panel, it easily causes softening of the material and degradation of the resistance force of the shear panel damper, which is different from the actual seismic excitation condition. Therefore, the test results due to the dynamic loading conducted here does not always express the actual condition including random shear strain amplitudes and strain velocities. Recognizing these facts, and from the restricted test data, the dynamic test results for frequency f=1.0 Hz are considered as a design basis of this shear panel damper. The cumulative plastic shear strain (CPS) can be used for the evaluation of damage. The limit value of CPS for the tested dumper is considered as 1775%.
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REFERENCES

[1] Chao feng Zhang, Tetsuhiko Aoki, "Development of high deformation low yield strength steel shear panel damper", Japanese Society of Steel Construction (under review).

[2] T. Aoki, Y. Liu, T. Takaku and Y. Fukumoto, "A new type of shear panel dampers for highway bridge bearings", EUROSTEEL 2008, Graz, Austria, pp1305-1310, 2008.

[3] T. Aoki, J. Dang, C. Zhang, T. Takaku and Y. Fukumoto, "Dynamic shear tests of low –yield steel panel dampers for bridge bearing", Sixth International Conference, Behaviour of Steel Structures in Seismic Areas, STESSA2009, Philadelphia, USA, pp647-652, 2009.