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HIGH VELOCITY AND SEISMIC TESTING OF VISCOUS FLUID DAMPERS

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Abstract

Recent catastrophic Turkey-Syria Earthquake forced us realize again how important the properly prepared structures against seismic event. For this purpose, the seismic isolation system and the energy dissipation system are most commonly used and known to be very effective. MAURER SE producers both seismic isolators and dampers and offers numerous solutions of seismic protection all over the world. Among them, the recent development of viscous fluid dampers along with the world market trend is described in this paper.

The viscous fluid dampers can be employed as a part of structural bracing element to dissipate the seismic energy. For such a purpose, the relative displacement of the damper itself is not high, and the maximal speed is also rather limited due to the low amplitude.

On the other hand, when the viscous fluid dampers are used with the seismic isolation, the required stroke and velocity are much higher than the bracing dampers. Judging from the recent tendency of the market requests, it seems that the demand in the viscous fluid damper for seismic isolation is increasing. The development, design and production of viscous fluid damper with high velocity, high stroke and high force are challenging themselves but to make the situation worse, the testing such device is even more difficult. Yet, as it is not always possible to ignore this increase in such demands, some challenging projects with viscous fluid dampers are successfully finished in recent years.

Keywords: Viscous fluid damper, High velocity, Real seismic input, Seismic isolation

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1 INTRODUCTION

Recent catastrophic Turkey-Syria Earthquake forced us realize again how important the properly prepared structures against seismic event. For this purpose, the seismic isolation system and the energy dissipation system are most commonly used and known to be very effective. MAURER SE producers both seismic isolators and dampers, and they or the combined solution of both device types as a seismic isolation package are offered worldwide. For instance, the friction pendulum type bearings and the viscous fluid dampers are most commonly suggested and the effectiveness of such system is also acknowledged [1]. Among them, the recent development of viscous fluid dampers along with the world market trend is described in this paper.

2 MAURER VISOUS FLUID DAMPER

The viscous fluid damper is used to dissipate the external energy input to the structural system. The external energy input is caused by the ordinary live load such as wind or traffic but can be induced also by extreme loading cases such as seismic motion.

As can be seen in the following constitutive law (eq.1), viscous fluid damper is a velocity dependent device. Velocity dependence has an advantage such that the maximal damping force introduced by such devices does not occur at the moment of the maximal deformation, meaning that the maximal reaction force as the whole structure is not increased by such devices. Another advantage of the viscous fluid damper is that such devices do not add stiffness into the global structural system, ensuring the structural dynamic behaviour as close as planned in the design phase.

$$F = C \cdot V^{\alpha} \tag{1}$$

Where F, C, V and α are the damping force, damping constant, velocity and damping coefficient, respectively.

By changing the values of C and α, various damping behaviour can be set. While the damping constant determines the magnitude of damping, the damping exponent is describing the shape of the force-velocity relationship. MAURER viscous fluid damper enables a wide range of variety by employing the multiple valve system. Especially damping coefficient α can be varied theoretically from 0.04 to 2, which surely fulfills any specific demand of the structural design.

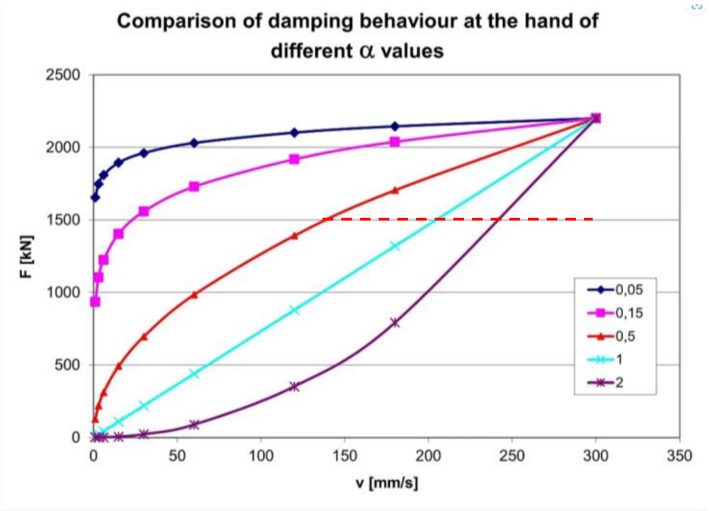


Figure 1: Exemplary diagram of damping force along with velocity for various α factors [2]

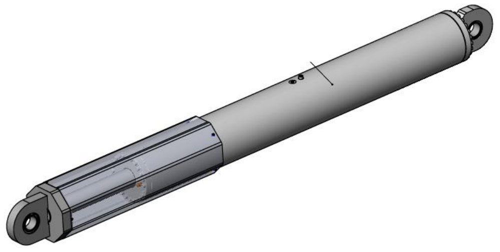
Also, it is possible to set a specific threshold velocity to activate the damping below which only a very small reaction force is generated. Such a function is necessary for bridge construction to allow to move with thermal effect without constraint of the damper. Another possibility of MAURER multi-valve system is that MAURER viscous fluid damper can have a varying damping factor α depends on the velocity range. One practical example of it is so-called force limiter like shown in the figure 1 with a dotted red line coming out of the line with α=0.5. The constitutive law can follow up to the certain velocity/force and then once reached this set value, the damping force does not increase further, so that the connection part of the structure side would not be damaged, even if an unpredicted higher seismic motion occurs. In [3] it is mentioned that the damper could have positive effects as well as negative ones depending on the configuration. Yet with the fine tuning of damping factor, the whole isolation system could be optimized.

3 TEST LABS

MAURER SE coordinates all test activities with independent testing labs all over the world depending on their capacity and availability. Majority of the initial type testing for the seismic isolator bearings such as MAURER Sliding Isolation Pendulum Bearing (SIP) is performed in EUCENTRE in Pavia Italy as their bi-axial testing machine has very high loading capacity and excellent displacement control for both vertical and horizontal directions. Whereas the viscous fluid dampers are often tested in SISMALAB in Crispiano Italy, as their damper test machine has now a very high velocity capacity. The viscous damper projects presented in the following chapters were all tested there.

4 EXPERIEMNT ON VISOUD FLUID DAMPER WITH REAL SEISMIC IMPUT

One of the interesting test projects on MAURER viscous fluid damper was the test with actual seismic input. For this project, damper type MHD1500kN with the following characteristic values was designed and tested.



Max. damping force in kN	1500
Max. amplitude in mm	±500
Max. velocity in mm/s	1000
Damping coefficient α	1

Figure 2: test damper and its characteristics

Several measured seismic inputs from the construction region as acceleration data were provided to MAURER, which were already scaled to the design maximal velocity. This acceleration data was first filtered and integrated twice with respect to time to obtain the displacement history, and then for the implementation for testing the signal is smoothed. In total six seismic time history acceleration data with running times of 60 seconds were tested with one prototype damper. Despite the velocity capacity was designed for 1 m/s, the device experienced peak velocities up to 1.2 m/s. After the seismic tests the same device was used for initial type testing for CE-marking according to EN15129 [4] without any signs of deterioration or leakages. One of the example inputs is shown in figure 2 below.

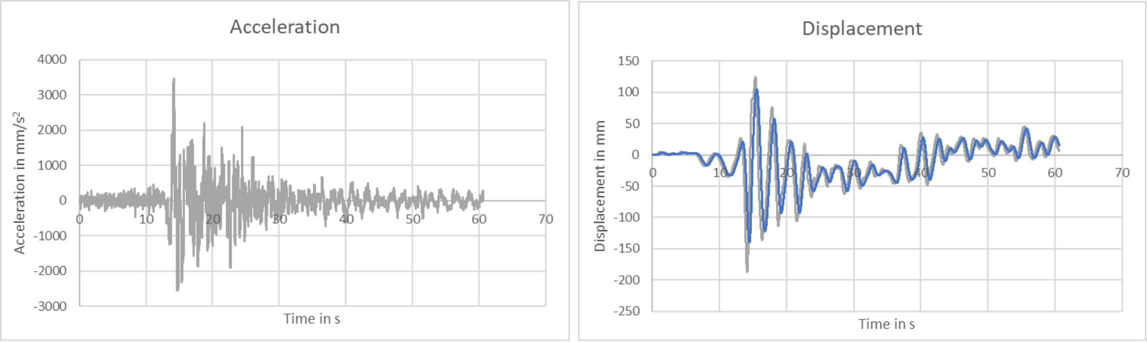


Figure 3: Original acceleration history (left) and generated displacement history (right)

The test was successfully carried out and the hysteretic loop measured in the test with the input parameter of figure 2 is shown below.

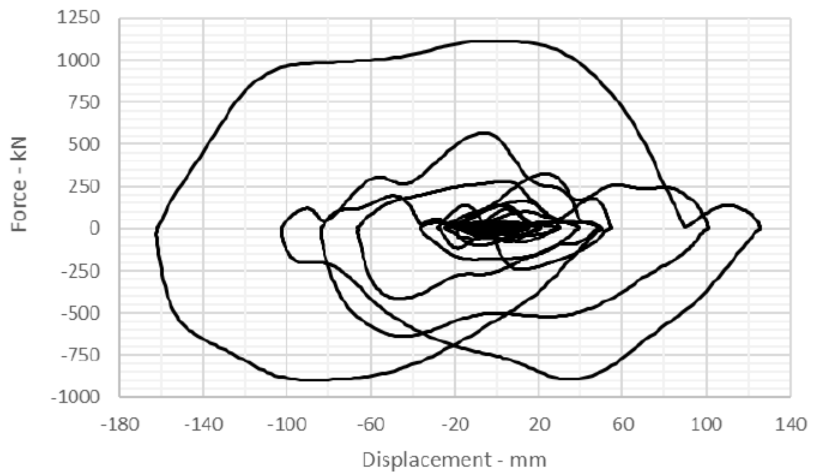


Figure 4: Measured hysteretic loop for the seismic input of figure 2

This tested viscous fluid damper was designed for the application of seismic isolation parallel to seismic isolators. Then to be precise, the seismic input to the damper has to consider the relative displacement between both ends of the device, because one side is connected to the ground and the other side is connected to the structure which is drifting with the seismic isolation period. This would be the next step to check the more realistic performance of the viscous fluid damper in the seismically isolated structure, if another possibility arises in the future.

5 VISCOUS FLUID DAMPER WITH LONG STROKE AND HIGH VELOCITY

Another remarkable and challenging project was the viscous fluid damper with a very high capacity in terms of force, stroke and velocity. MAURER delivered two types of viscous fluid dampers for the maximal target force of 3842 kN and 4400 kN, maximal amplitude of +/-1m and maximal design velocity of 1.3 m/s and 1.4 m/s, respectively. They are installed again as an additional energy dissipator of seismic isolation building in Turkey along with the seismic isolator bearings. In the following figure and table, the tested damper and its characteristic value are presented.

Figure 5: Picture of the damper type MHD4400kN

Damper type	MHD3842kN	MHD4400kN
Max. damping force in kN	3842	4400
Max. amplitude in mm	±1000	±1000
Max. velocity in mm/s	1400	1300
Damping coefficient α	0.3	0.3

Table 1: Characteristics of the tested dameprs

This high-capacity damper was a newly developed type of MAURER MHD damper and expected for some iteration process to adjust the multi-valve setting, For this iteration, it was very important to have a test possibility nearby in Europe. The successful test results are shown below in Figure 6 and Table 2 and 3.

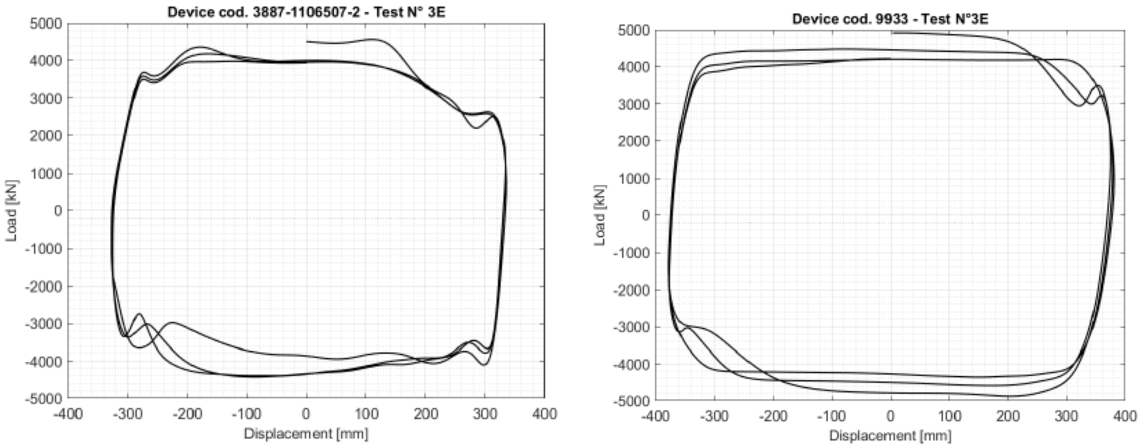


Figure 6: Measured hysteretic loop for the maximal velocity test– 3842 kN type (left), 4400kN type (right)

	Cycle 1	Cycle 2	Cycle 3
Measured max. velocity in mm/s	1384	1319	1301
Measured max. force in kN	4334	4301	4184

Table 2: Measured peak velocity and force during the maximal velocity test – 3842kN Type

	Cycle 1	Cycle 2	Cycle 3
Measured max. velocity in mm/s	1422	1359	1241
Measured max. force in kN	4900	4522	4288

Table 3: Measured peak velocity and force during the maximal velocity test – 4400kN Type

With this high force and high velocity, obviously the velocity could not be kept constat for all three cycles, but it is still the second cycle was performed with the peak velocity of only 6 % less than target value. This is a great achievement. The tested damper devices performed also very well keeping the damping force within the project specified force tolerance of 15% despite the difficulty in the machine control. It is also worth noting, that the device was tested in maximal extended position with short amplitudes due to the machine capacity to check the buckling stability of the large stroke device within the prototype testing. A reference test with the same device with full stroke testing at the UCSD facility verify the test method of testing the device buckling stability with short amplitude testing in extended position.

It is a clear tendency that the number of seismically isolated structures is increasing all over the world and when the viscous fluid dampers are applied for such purposes, it should be expected for a high moving capacity and also high peak velocity. In the past, the possibility for such tests was very limited and hence, it was a constraint among others that determined the design limit in the past. With more test possibilities, the structural designer and the manufacturer of the seismic devices may be able to explore more effective and more economical design.

6 VISOUS FLUID DAMPER WITH EXTREMELY HIGH VELOCITY

MAURER SE has now obtained the ministry approval of two viscous fluid damper types for seismic isolation according to the clause 37 of Japanese building code. For the approval process, both damper types underwent the prototype test to prove the damper properties as designed. Japan is known to have a number of earthquakes with high magnitude and for that reason, the protection of the infrastructures against seismic motion had to be developed. Indeed, the country has the highest number of seismically isolated structures exhibiting its effectiveness, see for instance [5]. Due to the soft ground type in many regions in Japan, they expect long-period seismic wave and then the seismic isolation period has to be elongated even further. It is common to set the isolation period there from 4.5 to 6 seconds. For the seismically isolated building with such a long period the displacement becomes large and the peak velocity also becomes high accordingly. To accommodate all possibilities, both damper types MHD1000kN and MHD1500kN types are designed with the maximal velocity of 2m/s. As shown in the figure below, both damper types are built with external sleeve for stabilization purpose because the dampers are slim and long to accommodate the large displacement.

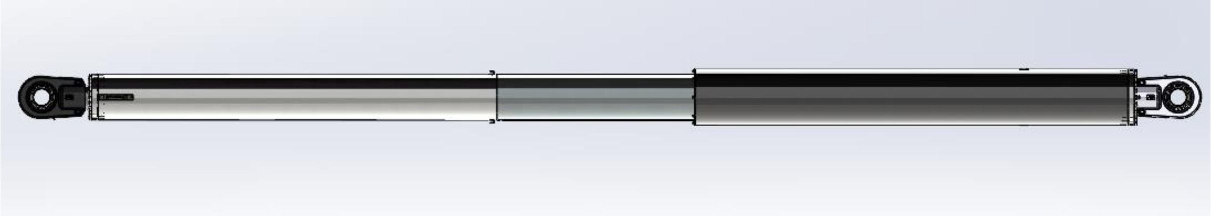


Figure 7: Side view of MHD1000kN type

Damper type	MHD1000kN	MHD1500kN
Max. damping force in kN	1000	1500
Max. amplitude in mm	±1000	±1000
Max. velocity in mm/s	2000	2000
Damping coefficient α	0.3	0.3

Table 4: Characteristics of the dampers for Japanese ministry approval

Reaching this maximal velocity of 2 m/s was obviously a challenge. After several trials, the laboratory implemented the idea of using two actuators from both ends and applied the half amount of displacement and velocity in opposite direction, so that the test damper undergoes the targeted velocity as a relative value between two actuators. In this way, the machine control was also more stable, and the test was successfully performed.

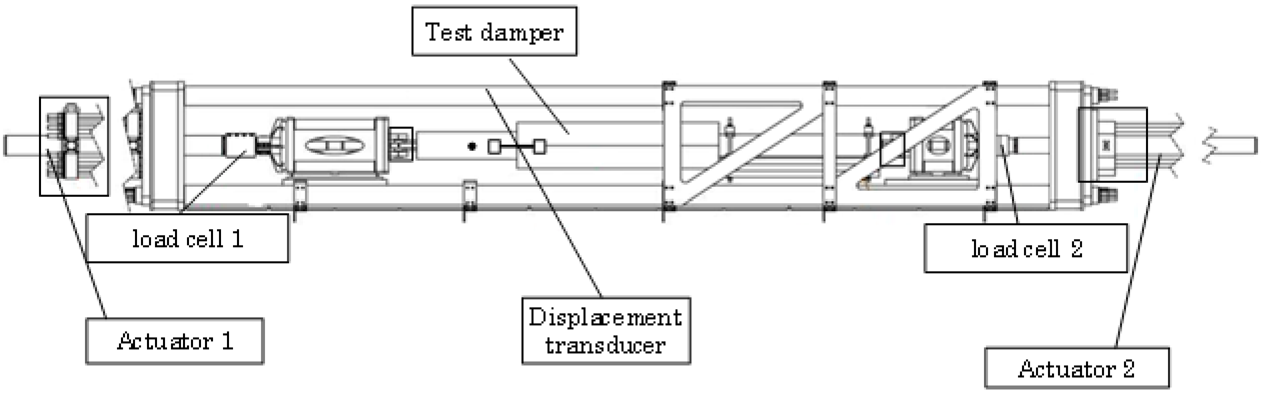


Figure 8: Test setup for extremely high velocity

As shown in the hysteretic loops below, both damper types performed well and the measured damping force lie withing the tolerance.

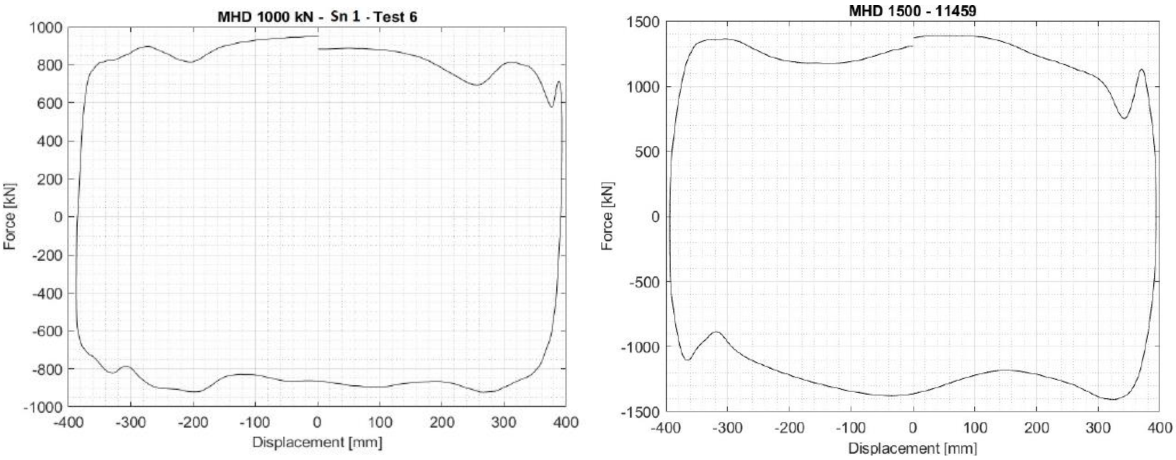
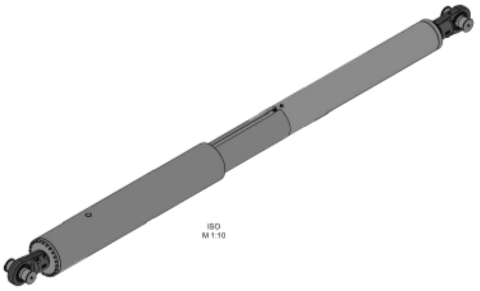


Figure 9: Hysteretic loop of the maximal velocity test - MHD1000kN (left) and MHD1500kN (right)

7 VISOUS FLUID DAMPER WITH FORCE LIMITER

Last example is the damper type MHD1400kN also for the seismic isolation of the building in New Zealand. The structure of the damper is very similar to MHD1500kN type that is presented in the previous chapter for Japanese ministry approval. The specialty of this damper is that the damping coefficient differs below the design seismic velocity of 1 m/s and above that velocity. The designer wanted to limit the maximal damping force if unexpectedly high seismic action takes place. The characteristic values of the viscous damper are as follows:



Max. damping force in kN	1400
Max. amplitude in mm	±780
Max. velocity in mm/s	2300
Damping coefficient α	0.7 (≤1 m/s) 0.05 (>1 m/s)

Figure 10: test damper and its characteristics

With this kind of configuration, the damping force should increase along with increasing velocity based on the constitutive law with a damping coefficient of 0.7 up to 1 m/s, and after reaching this velocity, the damping force should stay nearly constant up to given maximal velocity. This is equivalent to having a force limiter after reaching the velocity of 1 m/s.

The maximal test velocity is again 2 m/s and therefore, the same test configuration explained in the previous chapter was employed. Then the test based on EN15129 plus the over velocity test above 1 m/s was carried out. In the following figure, the damping force measured during the test are plotted along with the theoretical constitutive law with the tolerance envelop of ±15%.

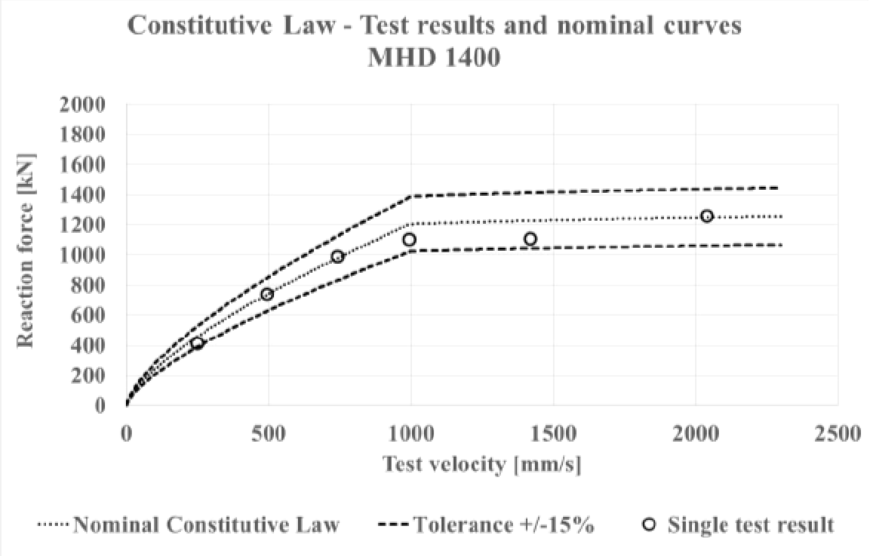


Figure 11: Measured damping force along with the theoretical constitutive law

The measured forces are all within tolerance and it can be observed that the development of damping force really follows two different constitutive laws below and above the design seismic velocity of 1m/s.

This force limiting concept is useful for the retrofitting by seismic isolation of historical buildings, in which some of the structural members have to be used and their resistance against input reaction force is limited without any possibilities of reinforcing.

8 CONCLUSIONS

All presented testing projects on MAURER viscous dampers here were considered as extreme and nearly non-feasible until recent years except some special facilities such as Caltrans Seismic Response Modification Device (SRMD) Test facility in San Diego, for instance. Both, the improvement of test machine capacity and the development of MAURER dampers to a next generation devices for seismic protection, requested intensive cooperation between the manufacturer and the independent testing laboratory. Now, following the market demand, the test possibility for such “extreme” condition is also here in Europe, and assumedly the other labs will follow this tendency. Then the development of the viscous fluid dampers, or even other anti-seismic devices will be accelerated further to meet a wider range of demand in the future and make more structures worldwide secure.

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