Product Introduction

Variable Damping Type Oil Damper

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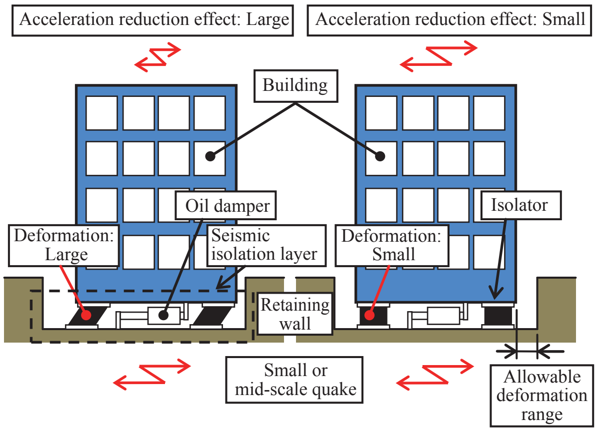
1 Introduction

Many buildings are made earthquake-proof with various seismic measures to protect lives and property. One of them is a "seismic isolation structure" that uses oil dampers. KYB Technical Review No.52 introduced the Seismic Isolation Damper for Narrow Land in City (with External Damping Force Switching Mechanism) and KYB Technical Review No.54 described the Oil Damper System for Seismically Isolated Structures with Lock Mechanism (Wind Sway Reduction System Using Electric Control). This report introduces an oil damper with a built-in damping force adjusting mechanism.

2 Challenges Left Against Big Earthquakes Including Long-Period Ground Motions

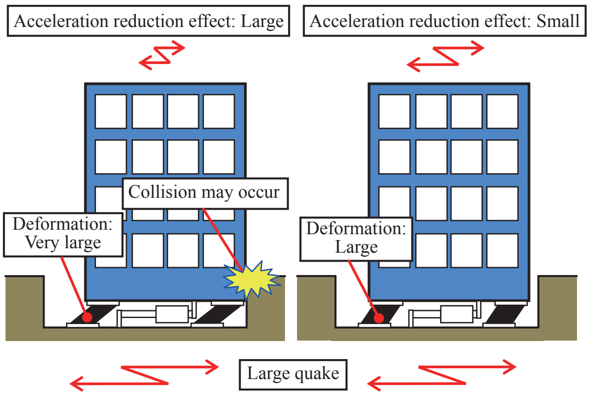
It is feared that a big earthquake would occur in the Nankai or Sagami Trough in the near future. If this is the case, a long-period ground motion that slowly sways the ground repeatedly for a long time is highly likely to occur. Seismic buildings are designed to slowly sway in the event of a long-period ground motion, but may sway much more heavily than the design seismic level. For example, seismic buildings designed in the early stage were constructed without taking into account the possibility of long-period ground motions. The seismic isolation layer in such buildings (a layer between the ground and the building into which a base isolator is inserted) only has a low allowable deformation range. It is pointed out that the building may collide against the retaining wall (the wall of the seismic isolation layer). In addition, even a newly constructed seismic isolation building is assumed to have big tremors that would exceed the deformation limit of isolators (such as laminated rubber or slide bearings).

With the background, attempts are being made to reduce the deformation of the seismic isolation layer. To suppress the deformation, it is effective to increase the damping force of the damper installed along with the isolator. However, if the damping force of the damper is determined from the postulated maximum quake, the whole seismic isolation layer would be too hard. Such a hard seismic isolation layer would suppress the deformation too much in the event of a small or mid-scale earthquake, which is relatively more likely to occur and would cause the layer only to slightly deform in the first place. The inherent performance of the layer that will not transfer the shake of a quake to the building (acceleration reduction effect) may be lost (Fig. 1).



(a) Small or mid-scale quake
Damper's damping force:
Small

(b) Small or mid-scale quake
Damper's damping force:
Large



(c) Large quake
Damper's damping force:
Small

(d) Large quake
Damper's damping force:
Large

Fig. 1 Effect of damper's damping force on seismic buildings

3 Background of Development

The variable damping type oil damper introduced in this report has been jointly developed by Shimizu Corporation and KYB. As stated above, if the damping force of the damper is set for big earthquakes, the acceleration reduction effect of the isolator would be degraded.

This seemingly contradictory problem can be solved by enabling switching of the damping performance between for large quakes and for small/medium strength quakes to achieve both improved habitability and prevention of excessive deformation during a big quake. To achieve this, it is necessary to detect the magnitude of earthquakes. However, an electrically controlled switching system using sensors and solenoid valves may fail to work in the case of power failure.

Here, another system has been developed in which the seismic isolation layer detects the magnitude of an earthquake through its own deformation (i.e., the deformation quantity of its oil damper) and mechanically selects a damping function suitable for the magnitude of the quake without using electricity. This is called a "displacement-dependent damping performance switchable base isolator". Many of these types of products are designed to select a function for large quakes when a predetermined displacement is exceeded and retain the high damping force once the function is switched over. This design will greatly deliver the deformation suppression effect of the seismic isolation layer. However, because of this feature, the system needs to be manually returned to the function for small/medium strength quakes after shaking has subsided.

On the other hand, the variable damping type oil damper described in this report is constructed so that the damping performance can be mechanically switched over according to the damper deformation. The system automatically selects a low damping force for small/medium strength quakes at around the center where only small damper deformation occurs, while it selects a high damping force for large quakes when a predetermined displacement is exceeded. The relationship between the damping force and displacement of a standard oil damper can be plotted as an elliptical shape as shown in Fig. 2, and that for the variable damping type oil damper can be plotted as an H-shaped profile with its top and bottom centers concaved as shown in Fig 3. This implies that the deformation suppression effect during a big quake will slightly decrease. Still the system does not require manual operation after each quake since it switches the function over whenever necessary.

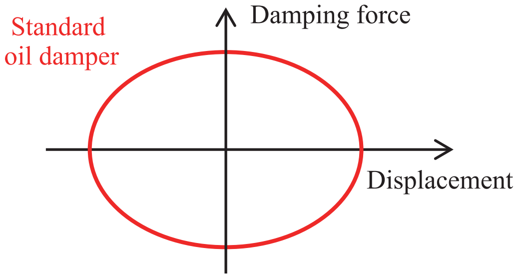


Fig. 2 Hysteresis loop of standard oil damper

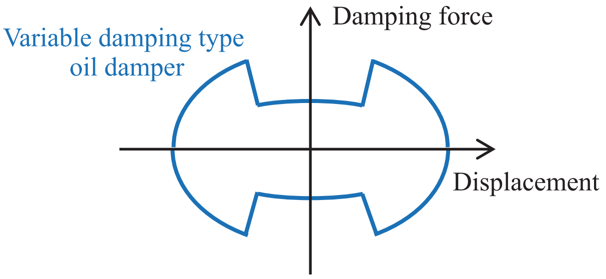


Fig. 3 Hysteresis loop of variable damping type oil damper

4 Configuration and Principle of Operation of Developed Dampers

Fig. 4 shows the configuration of the variable damping type oil damper. The damper mainly consists of a cylinder tube, inner tube, piston rod, piston and hydraulic fluid. In the cylinder tube there are pressure regulating valves that provide a damping force according to the speed, relief valves and check valves. This configuration is based on the standard Building Damper hi-Speed type (BDS) base-isolation oil damper for Kayaba's system machinery. For more information about the BDS oil damper, see KYB Technical Review No.26.

The variable damping type oil damper is added with a switching rod as a mechanism to adjust the damping force according to the deformation. The switching rod has a longitudinal groove along its center line over a certain length. The switching rod is installed so as to penetrate through the piston. The groove of the switching rod and piston constitutes a passage for the hydraulic oil, which is opened or closed by the relative movement of these two components. The damping performance can be switched over by the relative position of the switching rod. This relative travel of the switching rod is called switching displacement.

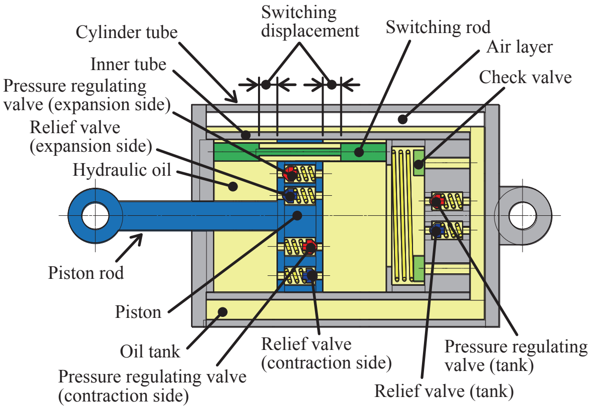


Fig. 4 Configuration of variable damping type oil damper

Since the mechanism to implement the variable damping performance (switching rod) is completely included in the oil damper, the shape and dimensions are the same as those of the standard (BDS) oil damper (Photo 1).

Fig. 5 shows the design damping characteristics of the variable damping type oil damper. Low damping performance with small damping deformation is called low damping and high damping performance with large damping deformation is called high damping. In the primary damping region for low damping, the damping performance of the expansion side differs from that of

Photo 1 Appearance of test specimen

the contraction side. This is because the piston rod of the variable damping type oil damper only extends to one side and the contraction and expansion sides have different pressure receiving areas, but the groove area of the switching rod is evenly distributed between the contraction and expansion sides.

The damping performance is designed to be represented by a bilinear diagram in which the damping force is switched over at a certain speed for either the high or low damping. The damper can deliver high damping forces at low speeds up to a certain speed level (primary damping region). Once the speed level is exceeded, it maintains the damping force at almost the same level without a spike up to the maximum speed (secondary damping region). This switching feature is also used in the standard (BDS) oil damper.

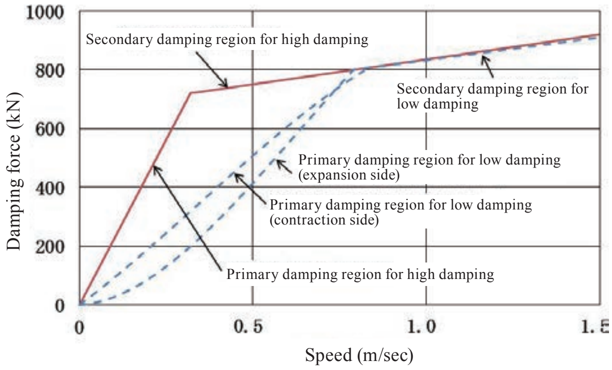


Fig. 5 Design damping characteristics

The following explains the principle of operation of the variable damping type oil damper.

(1) Principle of operation (expansion, low damping)

Fig. 6 shows the principle of operation during the expansion stroke for low damping. The variable damping type oil damper expands or contracts in response to vibration of the objects installed on the both sides of the damper. When the piston rod expands, the connected piston moves to raise the pressure in chamber A. The hydraulic oil passes through the pressure regulating valve (expansion side), relief valve (expansion side) and groove of the switching rod, and then flows into chamber B. The hydraulic resistance then acts as a damping force according to the piston speed. During this stroke the hydraulic oil mainly flows through the groove of the switching rod, rather than through the pressure regulating valve (expansion side) and relief valve (expansion side), resulting in a lower flow in the latter two valves. Compared to the case in which the oil only passes through the pressure regulating valve (expansion side) and relief valve (expansion side), the damping force is lower for the same speed (i.e., low damping). The damping force is controlled by the pressure regulating valves for the primary damping region and is controlled by the relief valves for the secondary damping region. Note that the amount of hydraulic oil in chamber A is lower than that in chamber B by the volume of the piston rod. To compensate for the difference, the hydraulic oil is supplied from the oil tank to chamber B via the check valve, making the piston ready for next contraction process.

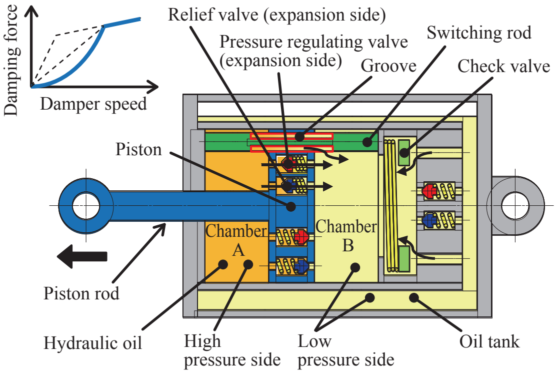


Fig. 6 Principle of operation (expansion, low damping)

(2) Principle of operation (expansion, high damping)

Fig. 7 shows the principle of operation during the expansion stroke for high damping. The piston rod further expands. When the damper deformation exceeds the relevant switching displacement, the piston goes beyond the groove provided on the switching rod. The hydraulic oil no longer flows in the switching rod section and only flows in the pressure regulating valve (expansion side) and relief valve (expansion side). Now the oil flows into chamber B via the pressure regulating valve (expansion side) and relief valve (expansion side), and the hydraulic resistance based on these two valves acts as a damping force according to the piston speed (high damping).

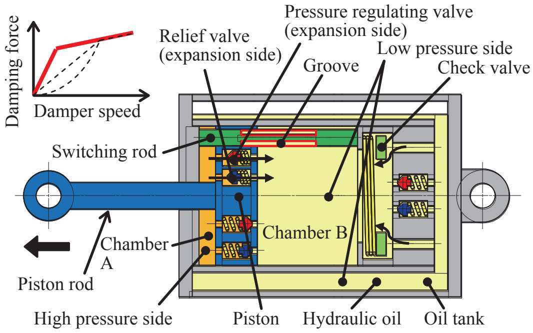


Fig. 7 Principle of operation (expansion, high damping)

(3) Principle of operation (contraction, low damping)

Fig. 8 shows the principle of operation during the contraction stroke for low damping. As the piston rod contracts, the check valve is closed and the pressure in chamber B increases. The hydraulic oil passes through the pressure regulating valve (contraction side), relief valve (contraction side) and groove of the switching rod, and then flows into chamber A. Like the expansion stroke, this contraction stroke also controls the damping force with the pressure regulating valves for the primary damping region and controls the force with the relief valves for the secondary damping region. The hydraulic resistance then acts as a damping force according to the piston speed. During this stroke the hydraulic oil mainly flows through the groove of the switching rod rather than through the pressure regulating valve (contraction side) and relief valve (contraction side), resulting in a lower flow in the latter two valves. Compared to the case in which the oil only passes through the pressure regulating valve (contraction side) and relief valve (contraction side), the damping force is lower for the same speed (i.e., low damping). The amount of hydraulic oil equivalent to the volume of the piston rod flows into the oil tank via the pressure regulating valve (tank) and relief valve (tank). The oil flows through the groove of the switching rod on a priority basis again, resulting in a lower damping force for the same speed.

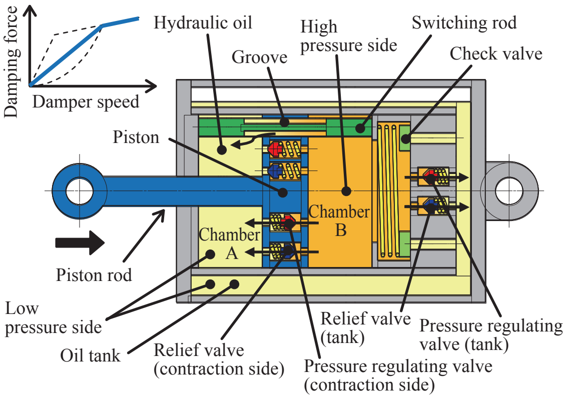


Fig. 8 Principle of operation (contraction, low damping)

(4) Principle of operation (contraction, high damping)

Fig. 9 shows the principle of operation during the contraction stroke for high damping. The piston rod further contracts. When the damper deformation exceeds the relevant switching displacement, the piston goes beyond the groove provided on the switching rod. The hydraulic oil no longer flows in the switching rod section and only flows in the pressure regulating valve (contraction side) and relief valve (contraction side). Now the oil flows into chamber A via the pressure regulating valve (contraction side) and relief valve (contraction side), and the hydraulic resistance based on these two valves acts as a damping force according to the piston speed (high damping). In addition, the amount of hydraulic oil equivalent to the volume of the piston rod flows into the oil tank via the pressure regulating valve (tank) and relief valve (tank). The hydraulic resistance then acts as a damping force according to the piston speed.

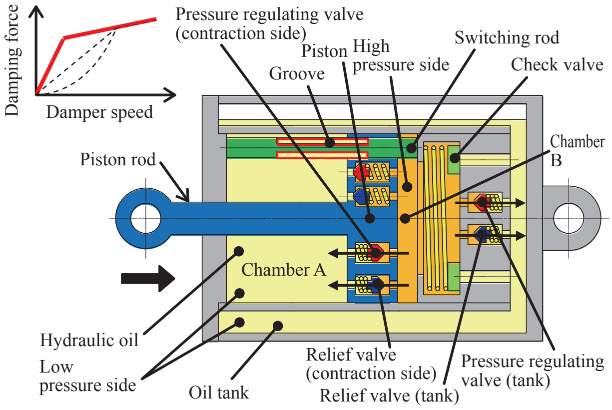


Fig. 9 Principle of operation (contraction, high damping)

5 Verifying the Variable Damping Performance

In relation to the performance of the variable damping type oil damper, the repeatability of the design damping characteristics was examined. To verify the performance for both low and high damping forces, sine wave vibration experiments were conducted with the vibration starting point shifted. The vibration center was established at the point when the piston was contracted until it went beyond the installed length for low damping measurement, or until it went beyond the switching displacement for high damping measurement.

Fig. 10 shows the result for low damping and Fig. 11 for high damping. In both figures, the experiment results at five different vibration speeds overlapped. The piston speed is higher at a larger displacement, thereby raising the damping force. The two most external curves in the low damping diagram and all five curves in the high damping diagram show the experiment results for the secondary

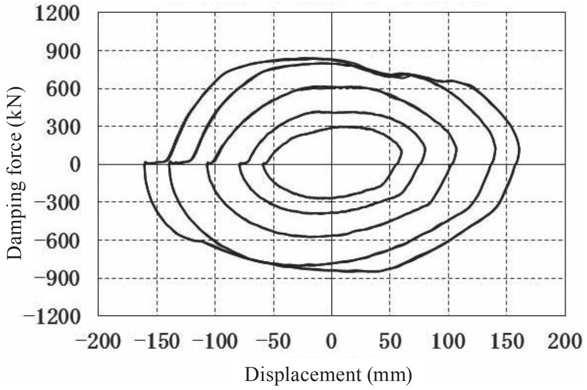


Fig. 10 Damping force - Displacement hysteresis curves (low damping)

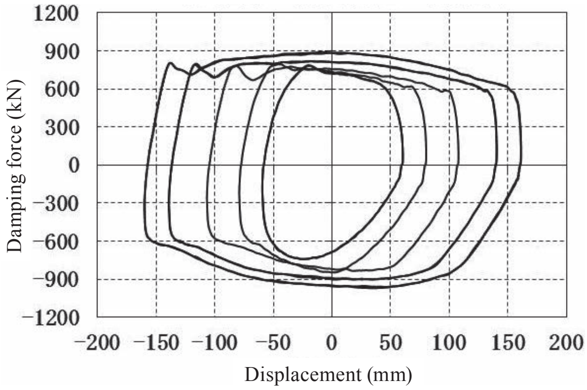


Fig. 11 Damping force - Displacement hysteresis curves (high damping)

damping region. They indicate that the damping force becomes unlikely to rise from a certain value due to the effect of the relief valve, making the profile of the curves almost rectangle.

Fig. 12 plots the maximum damping forces at various speeds for the high and low damping forces. For comparison purposes, the design damping characteristics in Fig. 5 are also indicated by solid and broken lines. It can be verified from the figure that the experiment results are in accordance with the design damping characteristics for both high and low damping forces.

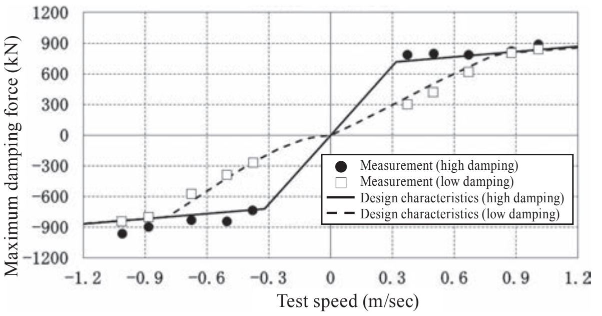


Fig. 12 Maximum damping force - speed characteristics

To verify the switching performance, an experiment using sine and random waves with a vibration amplitude exceeding the switching displacement was conducted. Fig. 13 plots the experimental result of vibration with a large amplitude. The variable damping type oil damper used in the experiment has a switching displacement of +/-200 mm. According to the diagram, the damping force is switched over at a displacement of 200mm at any of the speed conditions.

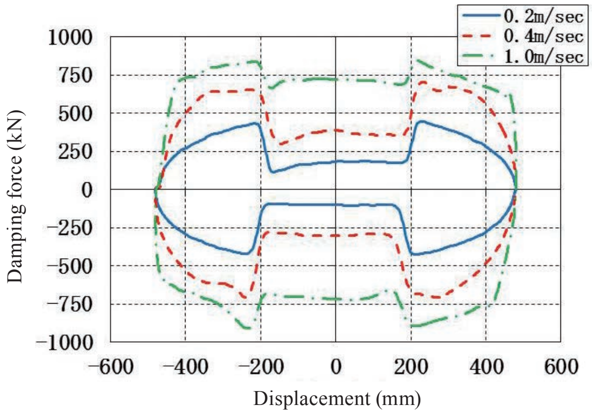


Fig. 13 Damping force - displacement hysteresis loop (vibration with a large amplitude)

After the vibration experiment with a random wave input, the measurements were compared to the analysis result. Fig. 14 shows a hysteresis loop of the overlapped measurement and analysis results. The comparison of the hysteresis loop between measurement and analysis has revealed that the damping performance is switched over repeatedly at the switching displacement of +/-200 mm for both measurement and analysis. In addition, the switch-over of damping performance measurements occurs with almost no delay from the analysis result. Therefore, it is unnecessary to take into account the time needed for switching-over when carrying out an earthquake response analysis to verify the seismic performance of base isolation buildings as well.

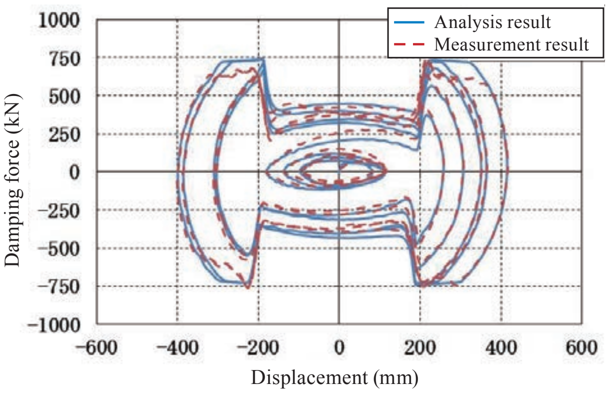


Fig. 14 Damping force - displacement hysteresis loop (vibration with a random wave)

6 In Closing

The variable damping type oil damper was certified by the Minister as a seismic isolation component (certificate No. MVBR-0576) in April 2017. The damper is expected to help improve the habitability of base isolation buildings in the event of a small or medium strength quake, or prevent base isolation buildings from colliding with the retaining wall in the event of a large quake.

Finally, I would like to extend deep gratitude to those who are in charge of the development and personnel in the related functions of Shimizu Corporation, various internal divisions, as well as those from related partner companies for their cooperation in product development.

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