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JSSI MANUAL FOR BUILDING PASSIVE CONTROL TECHNOLOGY PART-2 CRITERIA FOR IMPLEMENTATION OF ENERGY DISSIPATION DEVICES

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SUMMARY

This paper introduces the efforts being made by the Japan Society of Seismic Isolation Response Control Committee toward development of a manual for the design and construction of passively-controlled buildings. The contents of the manual corresponding to the principle and mechanism, design, fabrication, testing, and quality control of various types of passive control devices are described in this paper. The contents were developed by the researchers and the engineers of software, construction, and design companies.

The present paper (Part 2) introduces the manual contents regarding analytical modeling for load-deformation relationship of damping devices. It also explains another part of the manual referring to the mechanical, chemical, and environmental characteristics as well as acceptable range and quality of each device type. Manual policies on declaration of device property, assurance of device quality, and maintenance for long-term use will be explained.

INTRODUCTION

In Japan, seismic energy dissipation systems are applied to almost all of the high-rise buildings constructed in the last several years. Furthermore, these systems are used also as an effective means to rehabilitate seismic resistance of existing buildings. There is very wide usage of the energy dissipation devices, when the damping mechanism is combined with the classification of the structure form. For the sake of further growth in this technology, the JSSI Response Control Committee is formulating the Manual for Design and Construction of Passively-Controlled Buildings.

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The contents of the manual corresponding to the principle and mechanism, design, fabrication, testing, and quality control of various types of passive control devices are described in this paper.

The manual suggests the standard dynamic characteristics range of the general buildings for engineers to create a uniform basis to assess the seismic response control effects, regardless of the kind of damper and structure form.

The companion paper (Part 1, see Ref.1) explained background and scopes as well as design concept of the JSSI Manual for Design and Construction of Passively Controlled Buildings. It briefly explained the contents of the manual regarding classifications of the seismic energy dissipation devices and framing types, as well as comprehensive methods to evaluate effectiveness of the devices and the framing schemes.

The present paper (Part 2) introduces the manual contents regarding analytical modeling for load-deformation relationship of each device type. Part 2 also explains another portion of the manual referring to the mechanical characteristics as well as acceptable range and quality of each device type. Finally, manual policies on declaration of device property, assurance of device quality, and maintenance for long-term use will be explained.

The following four papers introduce the fundamental principle, performance dependence nature by a various condition, testing and quality control method for each classified damper in detail.

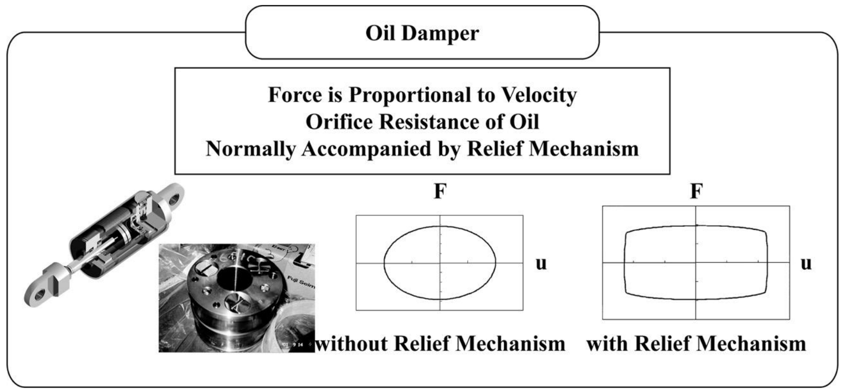
MECHANICAL CHARCTERISTICS OF DAMPING DEVICES

The following briefly describes the mechanical characteristics and analytical modeling of four kinds of damping device based on damping mechanism.

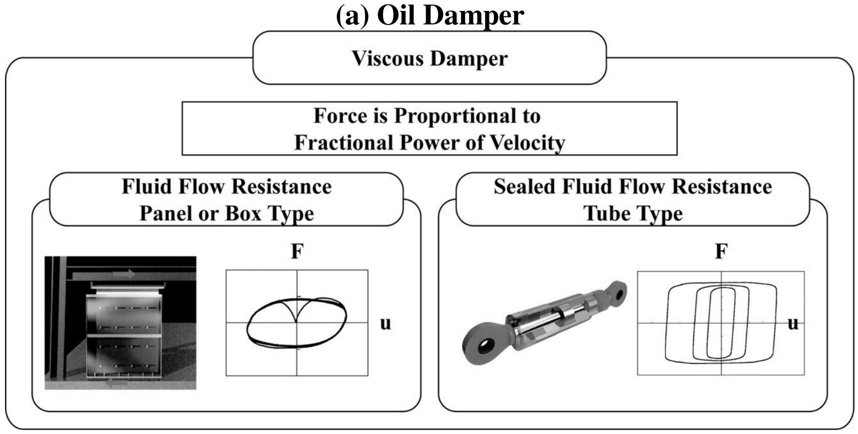
Oil damper produces the hysteresis loop of ellipse (Fig. 1 a). The material used therein is oil, and its orifice resistance against the flow produces the damper force [2]. The damper possesses a configuration of cylinder. It can be modeled by a linear dashpot against a small deformation rate. However, since the Japanese oil damper typically has the relief mechanism, the viscous coefficient of the linear dashpot needs to be reset small when subjected to a large deformation rate [2, 6].

Viscous damper produces the hysteresis loop of combined ellipse and rectangle (Fig. 1 b). The material used is typically silicon fluid, and its resistance against flow produces the damper force [3]. The damper possesses a configuration of vertical panel, box, or cylinder. Unlike the oil damper discussed above, its model uses a nonlinear dashpot whose force is a fractional power of deformation rate. For some types possessing elastic stiffness, the model considers an in-series combination of the spring and the nonlinear dashpot [3, 7]. The elastic stiffness may be a nonlinear function of the deformation [7]. Sensitivity against temperature must be modeled for some type [3].

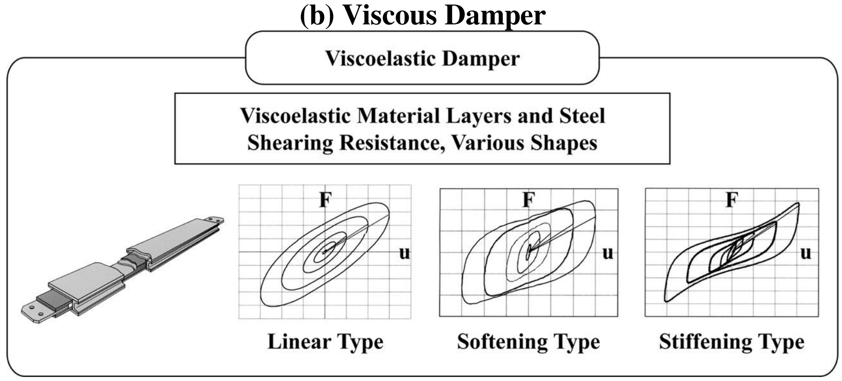
Viscoelastic damper could be either linear type, softening type, or stiffening type (Fig. 1 c). Hysteresis loops of the three types show commonly an inclined ellipse at relatively small deformation, but they differ considerably at larger deformation. The material used is polymer composite of acryl, butadiene, silicon, or others, and resistance is produced from the molecular motion caused by loading [4, 8]. The damper has a configuration of vertical panel or tube, but it could be designed for many other configurations as well. It produces two forces, one proportional to deformation and another proportional to deformation rate, and mostly it is sensitive to frequency and temperature [4]. In order to simulate these, some models consist of in-series as well as parallel combinations of dashpots and springs [8], and another model directly expresses the constitutive equation of the damper using fractional time-derivatives of the force and deformation [8].



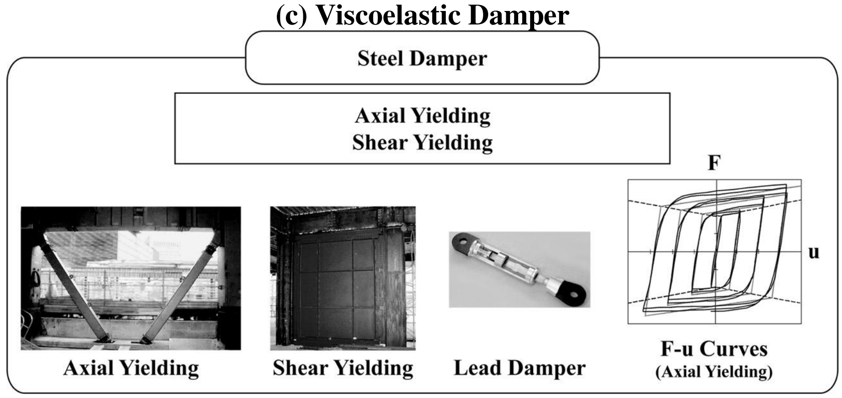
(a) Oil Damper



(b) Viscous Damper



(c) Viscoelastic Damper



(d) Steel Damper

Fig. 1 Device Types of Considered in Manual

Steel damper produces hysteresis of approximately bi-linear characteristics (Fig. 1 d). It is a vertical panel utilizing shear yielding or a brace utilizing axial yielding of the steel, and can be designed for other configurations [5]. Analytical model can utilize the constitutive equations of steel material readily known from the past research, but the typical Japanese model assumes purely bi-linear behavior [5]. The damper using lead or friction pad may be analytically treated in a similar manner. Note that the input parameters such as steel yield strength, ultimate strength, and strain-hardening modulus are the nominal values, not necessarily the actual ones. The analysis results must be cross-referenced to cumulative damage of the damper, since the damper is typically designed to yield under the small and frequent seismic loads. Special model is developed for some dampers designed to a post-buckled range.

VARIOUS TESTS AND DISSEMINATION OF PROPERTY DATA

Each of the above device types is designed and produced differently by the manufacturers in Japan. And, the Japanese structural engineers are currently making their own search and judgment when using the products, relying on the database from each manufacturer. The manual is intended to provide broad information for assisting such an effort, as well as a uniform basis for assessment of the various products in order to enable fair judgment and better quality control. In the manual, the property of each damper is described for common ranges of the loading and environmental conditions indicated in Table 1. For the data at the conditions not included in Table 1, the special performance check should be made.

Table 1 Common Ranges of Loading and Environmental Conditions and Benchmark

Condition	Loading	Design Parameter Range	Benchmark
Frequency	**Normal**	**0.2～3.0 Hz***	**0.3 Hz, 1.0 Hz**
Temperature	**Normal**	**10～30℃****	**20℃**
Story Drift Angle	**Major Earthquake**	**1/100 rad.**	**1/100 rad.**
	Rare Wind Storm	**1/200 rad.**	
	Frequent Wind	**1/10,000 rad.**	
Number of Cyclic Excursions	**Major Earthquake**	**10 cycles**	
	Rare Wind Storm	**1,000 cycles**	
	Frequent Wind	**1,000,000 cycles**	

*** Special design condition will be given for frequencies under 0.2 Hz, or over 3～10 Hz.**

**** Special design condition will be given for low temperature -10～0℃, or high temperature 30～40℃.**

Furthermore, the manual specifies the benchmark for the loading and environmental conditions. The benchmark conditions are: (1) vibration frequencies of 0.3 Hz and 1 Hz, typical values for a high-rise building and a medium-rise building, respectively; (2) temperature of 20°C, a typical value in a room where dampers are, and; (3) story drift angle of 0.01 rad., a traditionally used deformation limit against the so-called level-2 earthquake considered in Japan. The benchmark data will be also used as a comparative basis, to which variations of property and performance will be described for the ranges specified in Table 1.

Fig.2 shows existing combinations of the above-mentioned device types and framing types that are seen from current Japanese practice. The framing types are named as brace, wall, shear link, stud, bracket, connector, column, outrigger, and amplified types, respectively. More systems are expected to appear in the near future, as better control performance is sought.

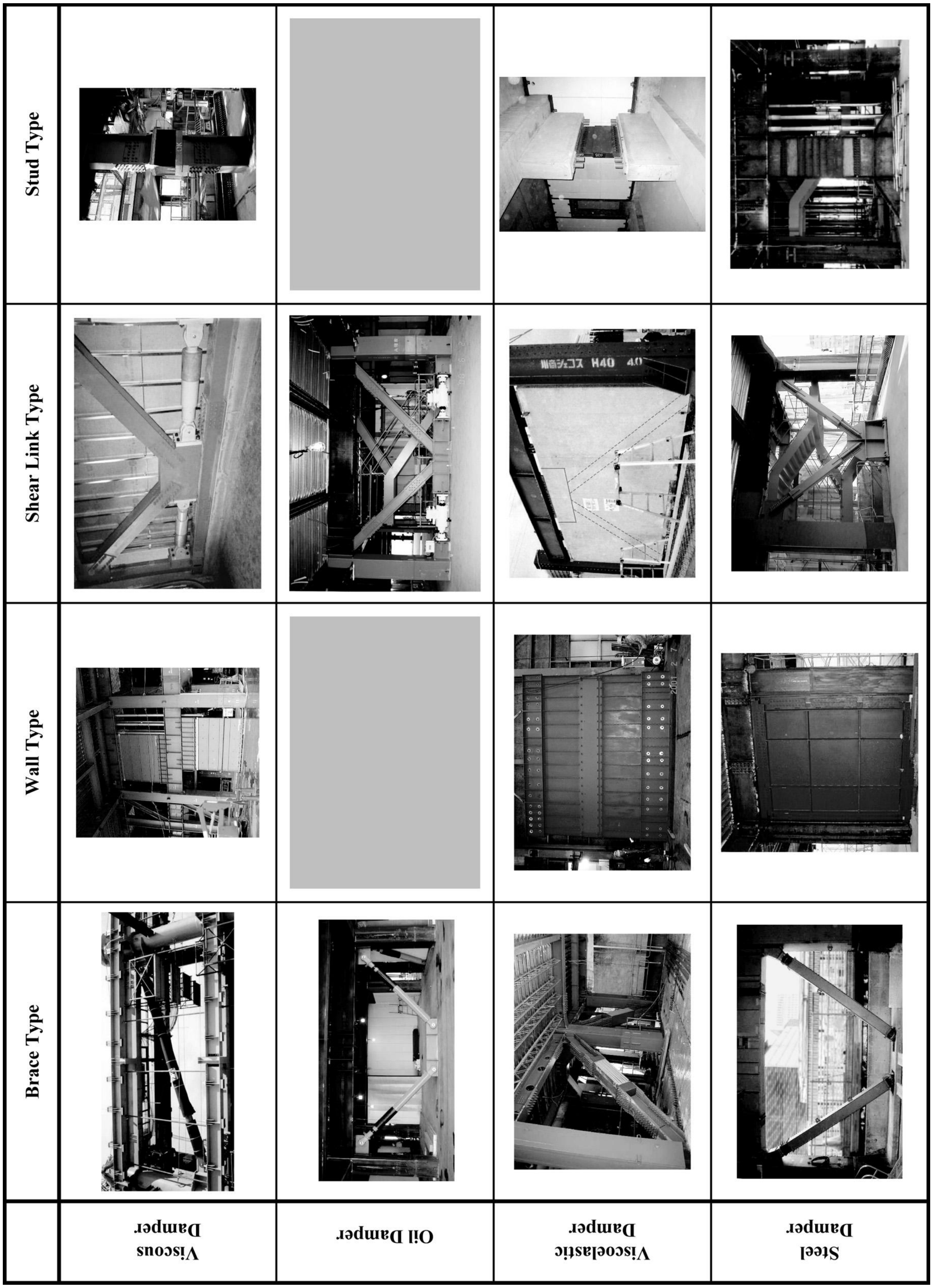


Fig.2 Existing Combinations of Various Device Types and Framing Types in Japan
(a) System Using Brace Type, Wall Type, Shear Link Type, or Stud Type

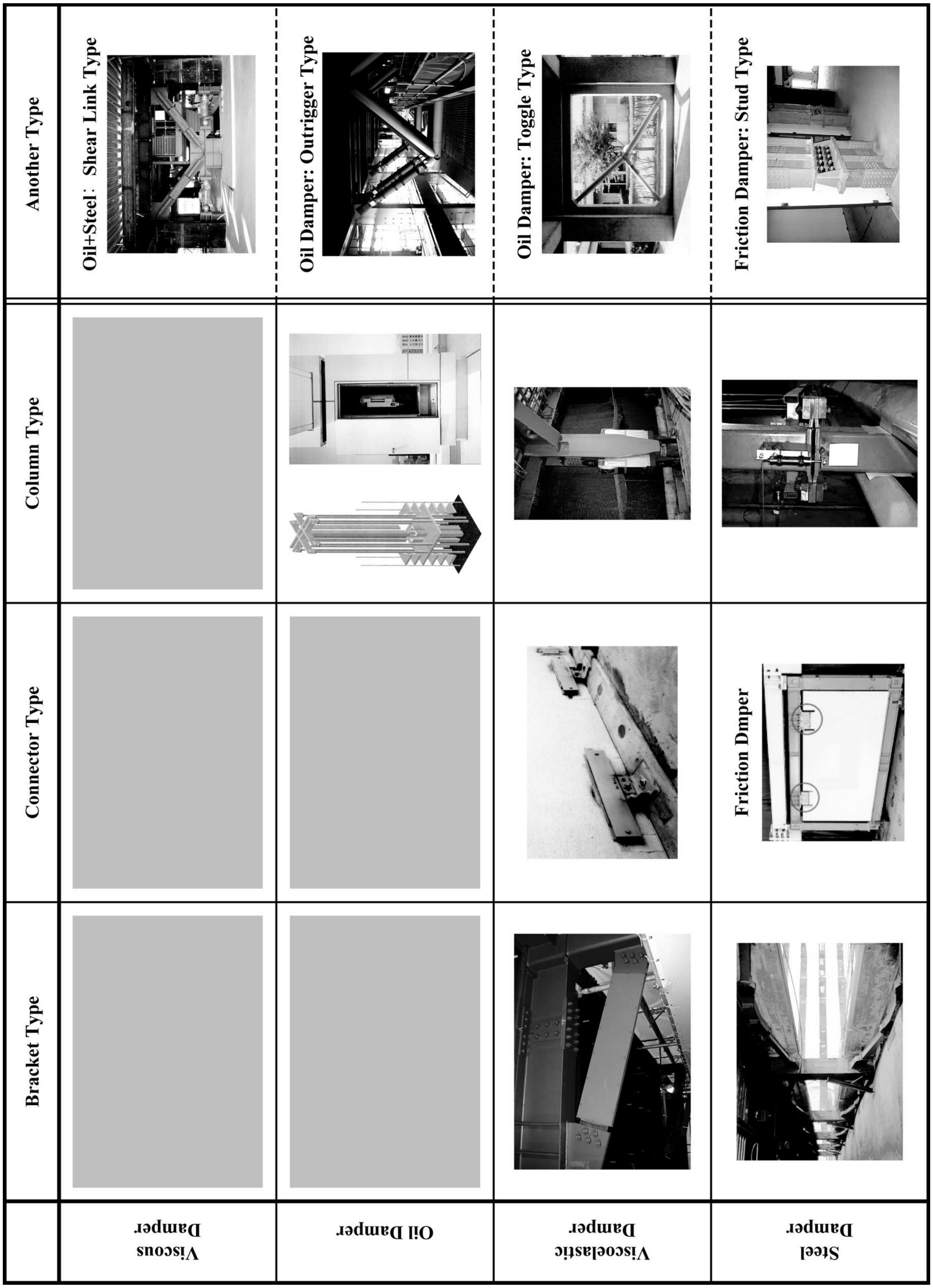


Fig.2 Existing Combinations of Various Device Types and Framing Types in Japan
(b) System Using Bracket Type, Connector Type, Column Type, or Other Types

Policies on Property Declaration, Quality Assurance, and Maintenance

The demand from the society to quality of building and its component has become more severe nowadays, as shown in Fig.3. As an example of the result, the Japanese law about promotion of quality of a residential building was enacted in July 2000, and the ten-year warranty for the function of main structural member is required now.

(1) Target Performance

For the design of passively controlled buildings to external disturbance as earthquake or windstorm, two levels of external load shall be set, and the target performance of damages for each load level shall be defined considering the frequency of external load together with the expected life of the building.

It is common to set the external load for Level 1 that a few time occur during life of building, and for level 2 to set the values to take into account extremely rare events. Practically, structural designer set the return period of 500 years for level 2 wind load, and maximum value for level 2 earthquake load with possibility based on historical seismic disaster records of the construction place.

From some examples of target performance corresponding to external load levels, the structure designer usually set the target performance that the building structure does not receive the damage of plastic deformation and remains functional for level 1 load, and that the building does not reach collapse or an unstable state for level 2 load, as shown in Table 2 and 3. In the case of response control against normal wind, it is occasionally required to set the target performance within the occupants' comfort range.

Table 2 Example of Target Performance for Earthquake Disturbance

Frequency of External Disturbance		Rarely occurred event	Extremely rarely occurred event
Velocity amplitude of earthquake motion		0.25 m/s	0.50 m/s
Items	Main Frame	Not exceed damage limit	Not exceed safety limit
	Energy dissipation member	Not exceed allowable limit	Not exceed damage limit
	Response acceleration	5 m/s^2	10 m/s^2
	Story drift angle	5×10^{-3} rad.	10×10^{-3} rad.
	Story drift velocity	0.1 m/s	0.2 m/s
	Whole drift angle	45×10^{-3} rad.	7×10^{-3} rad.

Table 3 Example of Target Performance for Windstorm Disturbance

Frequency of External Disturbance		Frequently occurred event	Rarely occurred event	Extremely rarely occurred event
Wind Velocity		15 m/s	34 m/s	42.5 m/s
Items	Main Frame	Not exceed damage limit	Not exceed damage limit	Not exceed safety limit
	Energy dissipation member	Not exceed allowable limit	Not exceed allowable limit	Not exceed damage limit
	Response acceleration	0.04 m/s^2	5 m/s^2	10 m/s^2
	Story drift angle	0.05×10^{-3} rad.	5×10^{-3} rad.	10×10^{-3} rad.

(2) Property Declaration

It is necessary to specify the target performance for the damper as well as performance limit of the selected damper in a building plan document. The target performance should reflect the items listed in Tables 1 and 2, and could include information such as expected maximum responses at the design load level. It is also desirable to indicate in the document and damper itself whether or not the damper is to be replaced after a major earthquake. When the damper is intended for a long-term use, careful evaluations must be made for the effects of a series of earthquakes that could be experienced by the damper. Especially when using a damper that yields and deforms permanently, expected consequence must be stated in the document and explained to the building owners.

Post-earthquake investigations into a trace of proper functioning as well as possible damage of the damper must be performed as efficiently as possible, and it is desirable to provide the architectural detail that makes this task easy. However, in most cases the finish materials covering the damper need to be destroyed, and such possibility must be declared in the document. Furthermore, when two or more earthquakes are experienced, it becomes very important to establish a judgment basis for the investigation. The damage in the members transferring the damper force must be carefully evaluated, especially in a case of retrofitted building.

(3) Quality Assurance

The performance of the passively controlled building superior to general earthquake-resistant construction, the quality of this type building must be assured by taking all possible measures (Fig.3). Long-term warranty is highly desirable for the passive devices, but realizing it may be difficult due to the following: this new scheme has very little database for the actual performance, and the damage of the device may stem from inadequate structural design rather than defect of the device itself. These obviously make it difficult to establish any warranty agreement among the device manufacturer, structural engineer, and building owner.

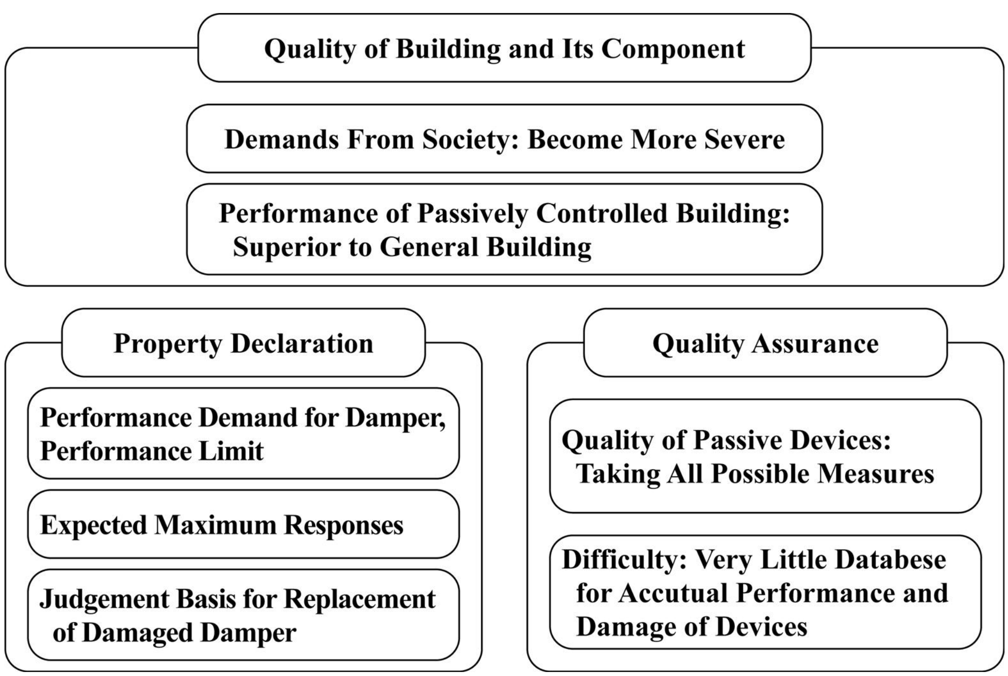


Fig.3 Policy on Property Declaration and Quality Assurance

(4) Maintenance

Maintenance may be required for some passive devices that are nearly machine products, especially when the device warranty is sought. Note that the traditional building members were not subjected to maintenance, and the periodical check and repair may be difficult to require. However, considering the normal use period of 60 to 100 years for a building, it is strongly felt reasonable to enforce maintenance management of the devices that plays a key role in building response. The post-earthquake investigation explained earlier could be also considered as a part of maintenance. In a case of the base-isolated building, the maintenance of the isolators and other components, including the post-earthquake investigation, are required now. And, the same consideration would be necessary for the passively controlled buildings (Fig.4).

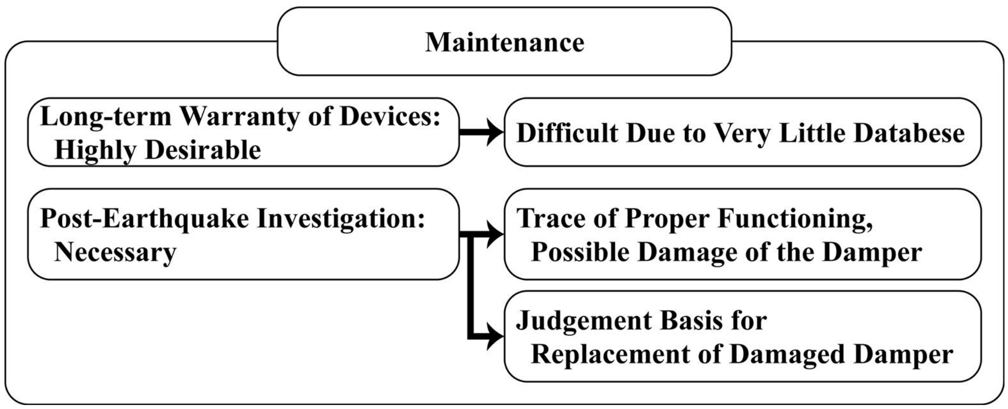


Fig.4 Policy on Maintenance

CONCLUSIONS

Passive control scheme has established its status as a viable means to enhance seismic performance of buildings. For the sake of further growth in this technology, it is necessary to promote understanding of the passive control schemes, as well as to create a uniform basis for assessment of the various stages to be followed during the design and construction process. Pursuant to this, the JSSI Response Control Committee is currently formulating the Manual for Design and Construction of Passively-Controlled Buildings. The companion paper (Part 1) and this paper (Part 2) described the effort of the committee.

In particular, Part 2 introduced the manual contents regarding analytical modeling, numerical algorithm, and example computer codes for load-deformation relationship of each device type. It also explained another part of the manual referring to the mechanical and environmental characteristics as well as acceptable range and quality of each device type. Manual policies on declaration of the device property, assurance of the device quality, and maintenance for the long-term use were also explained.

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