Demin Feng
Chief Researcher, FUJITA Corporation, Tokyo, Japan

Wenguang Liu
Professor, Shanghai University, Shanghai, China

Takafumi Miyama
Professor, Tezukayama University, Nara, Japan

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Certification System of Seismic Isolation Devices in Japan

Abstract: *In In Japan, the building law has revised to include the seismic isolation technology into the building code in 2000. Notification (Kokuji) 2009 and 1446 stand for seismic design code and certification system of seismic isolation devices, respectively. All seismic isolation devices must be certified by Ministry of Land, Infrastructure, Transport and Tourism (MLIT) before using. In 2015, the factory production control (FPC) certification system to include inspection at factory was strengthened due to one company's falsifying FPC test data. Since there is no independent testing laboratory in Japan, all the type and FPC tests are usually conducted by the manufacturer themselves. In 2017, changes of characteristics of seismic isolation devices due to the long-period and long-duration ground motions have to be considered in the design in the determined long period areas. It is stipulated in the other code. The certification authorities known as notified inspection bodies are even opened to private companies now. The devices have been roughly classified into three kinds: isolators, dampers and restoring bearings. The Japan Society of Seismic Isolation (JSSI) has published a 750 pages catalog in 2009 to include all manufacturers for reference. The information about the certification authorities and certified devices can be checked easily vie web pages. This paper will focus on the performance properties of seismic isolation devices required for certification. Both type testing and FPC tests will be introduced. The details of lead rubber bearings and viscous fluid dampers are compared with EN15129 for better understanding. The contents of LRB include following categories: Materials, Dimensions, Horizontal capacities, Vertical properties, Horizontal properties, Dependency properties and Creep. The contents of viscous dampers include Materials, Dimensions, Horizontal properties and Dependency properties.*

Keywords: *building code, certification system, seismic isolation devices, lead rubber bearing, viscous damper.*

Демин Фенг, главный исследователь, FUJITA Corporation, Токио, Япония
Вэньгуан Лю, профессор Шанхайского университета, Шанхай, Китай
Такафуми Мияма, профессор университета Тезукаяма, Нара, Япония

Система сертификации сейсмоизолирующих устройств в Японии

Аннотация: *В 2000 году в Японии произошел пересмотр строительных норм с целью включения в них требований по применению технологии сейсмоизоляции. Положения (Kokuji) 2009 и 1446 содержат требования по проектированию и правила сертификации сейсмоизолирующих устройств, соответственно. Все применяемые сейсмоизолирующие устройства перед использованием должны быть сертифицированы Министерством земельных ресурсов, инфраструктуры, транспорта и туризма (MLIT). В результате фальсификации одной из компаний результатов испытаний, проводимых при сертификации на основе заводского производственного контроля (ЗПК), включающего инспектирование на заводе, в 2015 году требования сертификации при ЗПК были ужесточены. В связи с тем, что в Японии нет независимых испытательных лабораторий, все типы испытаний и ЗПК обычно проводятся самим производителем. В 2017 году, было принято решение, что при проектировании в длиннопериодной области необходимо учитывать изменения характеристик сейсмоизолирующих устройств, обусловленные наличием больших периодов и длительностью колебаний основания при землетрясении. Это предусмотрено в другом нормативном документе.*

Органы сертификации, известные как аккредитованные инспекционные органы, теперь открыты даже для частных компаний. Устройства были приблизительно классифицированы по 3 видам: изоляторы, демпферы и подшипники качения. Японское общество по сейсмоизоляции (JSSI) опубликовало в 2009 году каталог объемом в 750 страниц, включающий всех рекомендуемых производителей. Информацию о сертификационных центрах и сертифицированных устройствах можно легко проверить с помощью веб-страниц. В данной статье основное внимание будет уделено эксплуатационным свойствам сейсмоизолирующих устройств, необходимых для сертификации. Будут приведены как типовые испытания, так и испытания при ЗПК. Для лучшего понимания характеристики, предъявляемые к резинометаллическим опорам и вязкостным демпферам, сравниваются с содержащимися в EN15129. В характеристики резинометаллических опор со свинцовым сердечником входят следующие категории: материалы, размеры, несущая способность в горизонтальном направлении, свойства в вертикальном и горизонтальном направлениях, взаимозависимость свойств и скольжение. В характеристики вязкостных демпферов включены материалы, размеры, свойства в горизонтальном направлении и взаимозависимость свойств.

Ключевые слова: *строительные нормы, системы сертификации, сейсмоизолирующие устройства, резинометаллическая опора со свинцовым сердечником, вязкостный демпфер.*

1. Introduction

After the 1994 Northridge earthquake in the USA, the 1995 Hyogoken-Nanbu earthquake in Japan and the 1999 Chi-Chi earthquake in Taiwan, the number of seismically isolated buildings has increased rapidly in Japan. The most recent building code provisions took effect in 2000 to include design method of seismically isolated buildings (Notification No. 2009) and certification system of seismic isolation devices (Notification No. 1446, MLIT 2019a, BCJ 2016). This certification system of seismic isolation devices is limited to be used in buildings. Unfortunately, the energy dissipation devices were not covered by this provision. Before 2000, these devices were usually reviewed at the review process of the building design, since all these kinds of buildings had to be reviewed at a special route using time history analysis method. All seismic isolation devices must be certified by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) before using. In 2015, the factory production control (FPC) certification system to include inspection at factory was strengthened due to one company's falsifying FPC test data.

In the other hand, European Standard EN 15129 "anti-seismic devices" covered all devices used in the building seismic isolation, energy dissipation and civil engineering. It was revised in 2018 and became legally binding in the countries of the European Union. In China (Ministry of Construction, 2010) and USA (ASCE 2016), there are some technical standards for seismic isolation devices. However, there are no certification system for manufacturers.

In table 1, the certification systems are compared together. FPC inspection and verification of conformity usually are conducted by the same certification authority or notified body. There are about ten certification authorities, capable to review seismic isolation devices, approved by MLIT in Japan. One can find the information about the authorities in the web pages (MLIT 2019b, Building Performance Standardization Association (BPSA) 2019a). The major authorities are Building Center of Japan (BCJ), Japan Society of Seismic Isolation (JSS) and General Building Research Corporation of Japan (GBRC). However, there is no independent laboratory having enough facilities to conduct tests in Japan. All the type and FPC tests are conducted by manufacturers themselves.

Table 1 *— Certification system comparison of Japan, EU, China and USA*

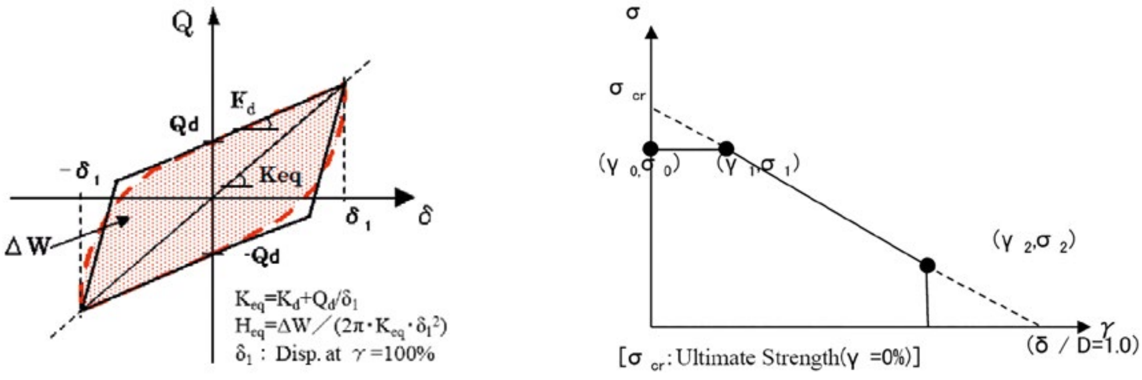
	Japan	**EN15129**	**China**	**USA**
Type testing (notified laboratory)	o*1	o	o	o
FPC inspection (notified body)	o	o	-	-
Verification of conformity and issuance of the certification (notified body)	MLIT Certification	CE Marking	-	-

*1: There is no independent laboratory having enough facilities conducting tests in Japan. All the type and FPC tests are conducted by manufacturers themselves.

***Table 2** — Sample of JSSI catalog (JSSI 2009) for lead rubber bearings*

H = 200 mm Series Lead Rubber Bearings (20°C)				ERIL-H-G4-900-160	ERIL-H-G4-900-180	ERIL-H-G4-900-200
	G		N/mm^2			
Dimensions	Diameter		mm	900	900	900
	Diameter of lead plug		mm	160	180	200
	Thickness of inner rubber		mm	6.0	6.0	6.0
	Total number of inner rubber		sheet	34	34	34
	Total thickness of rubber		mm	204.0	204.0	204.0
	S1			37.5	37.5	37.5
	S2			4.41	4.41	4.41
	Thickness of inner plate		mm			
	Diameter of flange		mm	1300	1300	1300
	Thickness of flange (middle)		mm	43.0	43.0	43.0
	Total height		mm	438.5	438.5	438.5
Critical property	Critical strain (Vertical load = 0)		%	400	400	400
	Critical strain (Vertical load = σ)		%	388	388	388
	Hysteresis					
Vertical property	Critical strength (γ_0, σ_0)		(%, N/mm^2)	(0.43.7)	(0.43.7)	(0.43.7)
	Critical strength (γ_1, σ_1)		(%, N/mm^2)	(99,43.7)	(99,43.7)	(99,43.7)
	Critical strength (γ_2, σ_2)		(%, N/mm^2)	(400,10.7)	(400,10.7)	(400,10.7)
	Vertical stiffness (Kv)		×10^{3}kN/m	3895	3895	3895
	Standart vertical pressure (σ)		N/mm^2	12	12	12
	Standart vertical load (V)		kN	7634	7634	7634
	Critical tensile strength		N/mm^2			
Horizontal property	Unloading stiffness (K1 = 13×Kd)		kN/m	15,926	15,992	16,065
	After yielding stiffnes (Kd)		kN/m	1,225	1,230	1,236
	Yield load (Qd)		kN	160	203	250
	Equivalent stiffness (Keq)		kN/m	2,011	2,225	2,463
	Equivalent damping ratio (Heq)		%	23.5	26.5	29.1
	Standart shear strain		%			
Variation	Range of Kv		%			
	Range of Kd		%			
	Range of Qv		%			
Dependency property	Degradation	Kd (%)	(60 years)/(Initial)			
		Qd (%)	(60 years)/(Initial)			
	Temperature	Kd (%)	(-10 °C)/(20°C)			
			(0 °C)/(20°C)			
			(30 °C)/(20°C)			
			(40 °C)/(20°C)			
		Qd (%)	(-10 °C)/(20°C)			
			(0 °C)/(20°C)			
			(30 °C)/(20°C)			
			(40 °C)/(20°C)			
	Shear strain	Kd (%)	(50%)/ (100%)			
			(200%)/ (100%)			
		Qd (%)	(50%)/ (100%)			
			(200%)/ (100%)			
Creep		(%)	20°C×60 years			

ERIL-H-G4-950-170	ERIL-H-G4-950-190	ERIL-H-G4-950-210	ERIL-H-G4-1000-180	ERIL-H-G4-1000-200	ERIL-H-G4-1000-220	ERIL-H-G4-1100-200	ERIL-H-G4-1100-220	ERIL-H-G4-1100-240
0.392								
950	950	950	1000	1000	1000	1100	1100	1100
170	190	210	180	200	220	200	220	240
6.4	6.4	6.4	7.0	7.0	7.0	7.0	7.0	7.0
31	31	31	29	29	29	29	29	29
198.4	198.4	198.4	203.0	203.0	203.0	203.0	203.0	203.0
37.1	37.1	37.1	35.7	35.7	35.7	39.3	39.3	39.3
4.79	4.79	4.79	4.93	4.93	4.93	5.42	5.42	5.42
4.5								
1350	1350	1350	1400	1400	1400	1500	1500	1500
43.0	43.0	43.0	48.0	48.0	48.0	48.0	48.0	48.0
419.4	419.4	419.4	425.0	425.0	425.0	425.0	425.0	425.0
400	400	400	400	400	400	400	400	400
400	400	400	400	400	400	400	400	400
Q=Kd×δ+Qd								
(0.47.1)	(0.47.1)	(0.47.1)	(0.47.2)	(0.47.2)	(0.47.2)	(0.55.4)	(0.55.4)	(0.55.4)
(113,47.1)	(113,47.1)	(113,47.1)	(118,47.2)	(118,47.2)	(118,47.2)	(131,4755.4)	(131,4755.4)	(131,4755.4)
(400,17.2)	(400,17.2)	(400,17.2)	(400,19.1)	(400,19.1)	(400,19.1)	(400,27)	(400,27)	(400,27)
4429	4429	4429	4660	4660	4660	6042	6042	6042
14	14	14	15	15	15	15	15	15
9924	9924	9924	11781	11781	11781	14255	14255	14255
1.0								
18,249	18,321	18,400	19,766	19,840	19,922	23,925	24,006	24,096
1,404	1,409	1,415	1,520	1,526	1,532	1,840	1,847	1,854
181	226	276	203	250	303	250	303	361
2,316	2,549	2,807	2,520	2,760	3,025	3,074	3,339	3,630
23.7	26.5	29.0	23.9	26,5	28.9	24.1	26.5	28.7
100								
between ± 20%								
between ± 15%								
between ± 15%								
under + 10%								
under + 5%								
+ 8.5% (based on shear strain dependency formulation)								
+ 5.6% (based on shear strain dependency formulation)								
– 2.7% (based on shear strain dependency formulation)								
– 5.3% (based on shear strain dependency formulation)								
+ 30.2% (based on shear strain dependency formulation)								
+ 19.2% (based on shear strain dependency formulation)								
– 8.4% (based on shear strain dependency formulation)								
– 16.1% (based on shear strain dependency formulation)								
+ 18.9% (based on shear strain dependency formulation)								
– 8.0% (based on shear strain dependency formulation)								
± 0.0% (based on shear strain dependency formulation)								
± 0.0% (based on shear strain dependency formulation)								
under 8%								



a) Fundamental property

b) Critical vertical strength dependent on shear strain

Figure 1 *— Definition of horizontal properties of lead rubber bearing*

2. Certification system in Japan

Seismic isolation devices are one of the materials implemented in Notification No. 1446 issued by MLIT. The main purpose of Notification No. 1446 can be summarized as follows. In accordance with the provisions of Article 37 of the Building Standard Law (Law No. 201 of 1950) technical criteria shall be established as specified below with respect to building materials used for the foundation and principal building parts of buildings and with respect to Japanese Industrial Standards or Japanese Agricultural Standards, and quality that should apply to these building materials. If one material is not stipulated in the Building Code, it should be certified by a certification authority before using. A certification authority will be approved by MLIT according the material category. The certification authority shall submit their certification procedure including review committee, documents formats etc. to MLIT to be proven.

A manufacturer should submit required documents to an authority for certification based on the guideline (BCJ 2019). The authority will hold a review committee to judge the application. The documents usually include two parts: quality control system of the factory and test results of the device. From 2015, the authority shall inspect the factory on site and witness the test in addition to the document review at the review committee. If a manufacturer has obtained ISO 9001 Quality Management System certification, audition of quality control system may be partially omitted. Since there is no independent laboratory having enough facilities conducting tests, performance tests conducted by manufacturers can be accepted by the authority.

There are three kinds of isolation devices popularly used in Japan: isolator, damper and restoring bearing. In the isolator devices, there are natural rubber bearing (RB), lead rubber bearing (LRB), high damping rubber bearing (HDR), flat slider and friction pendulum system (FPS). In the damper devices, there are oil damper, viscous damper, steel damper and lead damper. The restoring bearing, which will not support the gravity load of a structure and provide only restoring force, is usually used in the detached houses with flat slider or roller bearing. A list of certified devices in Japan can be found in a web page (MLIT 2019c). There is a search engine operated by Building Performance Standardization Association (BPSA 2019b). JSSI has published a 750 pages catalog in 2009 to include all certified devices for reference.

This paper will focus on the performance properties of seismic isolation devices required for certification. Both type testing and FPC test will be introduced. In the following sections, the test contents of lead rubber bearings and velocity-dependent viscous dampers will be introduced comparing with EN 15129.

3. Required test contents of lead rubber bearings

The percentage of lead rubber bearings used in Japan is about 30% in the isolator devices. The lead rubber bearing has all three functions needed for the seismic isolation system: supporting gravity of building, providing restoring force and damping to absorb energy. Following items should be stipulated in the application documents.

- Materials: Standard, mechanical properties and chemical composition etc.
- Dimensions: thickness, diameter etc.
- Materials: standard, mechanical properties and chemical composition etc.
- Properties of the products
  - Horizontal capacities: max. deformation capacity, hysteresis loop
  - Vertical properties: standard vertical pressure, vertical stiffness (Kv), critical vertical strength (γ, σ) shown in Figure 1b, tension-shear property
  - Horizontal properties: after yielding stiffness (Kd), yield load of lead plug (Qd) shown in Figure 1a
  - Dependency properties: shear strain, temperature, vertical load, ageing
  - Creep property

Standard vertical pressure is defined upon the 2nd shape coefficient (S_2) of the device, which ranges from 6-15 MPa corresponding with S_2=3-5. The fundamental properties such Kv, Kd and Qd, max. deformation capacity, hysteresis loop etc. will be tested upon this value. The tension-shear property is usually conducted at 100% shear strain to obtain the tension elastic limit.

The values of dimensions or test results should be converted to the values at 20 °C, if performed at a different environment. Feng et al. (2004) have reported typical test results listed above in detail. Sample of JSSI catalog (JSSI 2009) is shown Table 2, which listed all information needed for structural design.

In Table 3, comparison of testing requirement between EN15129 and N.1446 is shown. Most of the requirement on

Table 3 — *Comparison of testing requirement between EN15129 and N.1446 for lead rubber bearings*

Test contents	EN15129		N. 1446	
	Type Testing	FPC	Type Testing	FPC
Capacity in compression under zero horizontal displacement	Load 1.3NSD,ULS. No defects visible	N/A	N/A	N/A
Compression stiffness	Report value	Within ±30% of type test value. No defects	Within ±20% of design value	Within 20% of design value
Tension-shear test	N/A	N/A	Report tension elastic limit at 100% shear strain	N/A
Horizontal characteristics K_b and ξ_b (or K_2 and Q_d) under cyclic deformation	Report strain dependence. At design displacement, d_{bd}, values within ±20% of design value.	Values within ±20% of required values at design shear strain	Report strain dependence. At 100% shear strain, within ±10% or 15% of design value	At 100% shear strain, within ±10% or 15% of design value
Horizontal stiffness under a one-sided ramp loading	Report value at design displacement, d_{bd}	Within ± 20 % of adjusted type test value	N/A	N/A
Cyclic test to determine Kb and ξ_b (or K_2 and Q_d), performed at one of the low shear strain amplitudes	N/A	Within ± 20 % of Type Test values at shear strain chosen for test	N/A	N/A
Variation of horizontal characteristics K_b and ξ_b (or K_2 and Q_d) with frequency	Report variation. Maximum variation ±20 %	N/A	N/A	N/A
Variation of horizontal characteristics K_b and ξ_b (or K_2 and Q_d) with temperature	Report variation. Maximum variation within limits	N/A	Report variation	N/A
Dependence of horizontal characteristics K_b and ξ_b (or K_2 and Q_d) on repeated cycling	Dependence within limits	N/A	(other code)	N/A
Horizontal capacity under maximum and minimum vertical loads	Force-displacement curve increasing up to $\gamma_b d_{Ed}$. No defects	N/A	Constitutive law test for $\sigma - \gamma$ relationship	N/A
Change of horizontal characteristics K2 only for LRB due to ageing	Change < 20 %	N/A	Report value	N/A
Creep test under vertical load	Total Creep rate < 20% between 10 and 10^4 min	N/A	Creep rate < 8 %	N/A

the properties are same in both codes. In type testing, the frequency dependence test is not required in N.1446. The repeated cycling test should be conducted at a period of 3-5 second, while total accumulated displacement must be over 50m. It is implemented in the other code in Japan as reported by Kikuchi, M and K. Ishii (2018). The tension-shear property is not required in EN 15129. In the factory production control testing, all the production shall be tested by the manufacturer in Japan. However, the first production and 20% randomly chosen production are conducted in EN15129.

4. Required test contents of viscous dampers

Oil dampers and Viscous dampers have been widely used in Japan. In a severe earthquake, these kind velocity-dependent dampers can keep good performance and continuously function well to make sure the structures safe. Fluid type

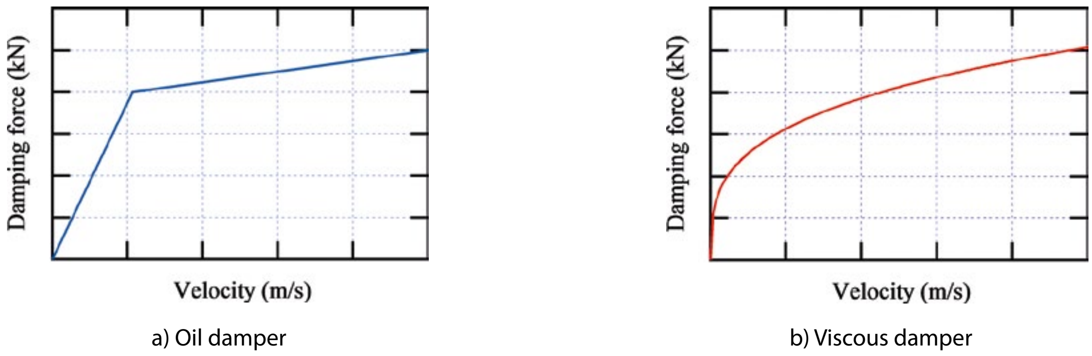


Figure 2 *— Constitutive law of velocity-dependent dampers*

dampers are mainly referred to as viscous dampers that use viscous force, and oil dampers that mainly use inertial force. Thus, the fluid viscosity is much different in these two kinds fluid dampers. Oil dampers, using low viscosity fluid, have a bi-linear model corresponding with the velocity shown in Figure 2a, which have been used more widely in Japan. However, the viscous damper, using high viscosity fluid, is more common in the world, where the damping force is designed being proportional to α velocity exponent shown in Figure 2b.

Following items should be stipulated in the application documents for the viscous dampers:

- Materials: Standard, mechanical properties and chemical composition etc.
- Dimensions: length, diameter etc.
- Properties of the products
  - Horizontal properties: constitutive law test, stroke verification test, buckle test
  - Dependency properties: temperature, repeated cycling test

In the constitutive law test, the applied velocity shall include several velocity values and the maximum rated velocity. In the stroke verification test, static loading is permitted to accommodate the rated stroke. In the buckle test, the damper

Table 4 *— Sample of JSSI catalog (JSSI 2009) for viscous dampers*

Contents		Production model				
		VD- 500-500	VD-1000-500	VD-500-600	VD-1000-600	VD-1600-600
Dimensions	Diameter of cover (mm)	240	321	240	321	398
	Width clevis plate (mm)	80	120	80	120	140
	Diam. of pin(mm)	80	110	80	110	160
	Length(mm)	3300	3400	3800	3900	4300
	Max Length(mm)	3800	3900	4400	4500	4900
	Min Length(mm)	2800	2900	3200	3300	3700
	Stroke (mm)	1000	1000	1200	1200	1200
Capacity	Max disp.(mm)	±500	±500	±600	±600	±600
	Constitutive law	$F=CV^{\alpha}$				
	Max vel.(m/s)	1.0	1.0	1.0	1.0	1.0
	Max force(kN)	450	900	450	900	1440
Constitutive law	Type	velocity-dependent				
	Exponent α	0.3	0.3	0.3	0.3	0.3
	C(kNs/m)	450	900	450	900	1440
Dispersion	C value	±15%				
Dependence	Temperature	during -20℃~+80℃, the variation of C is within±10%				
	Repeated Cycling	Variation of damping force within ±10%				

***Table 5** — Comparison of testing requirement between EN15129 and N.1446 for viscous dampers*

Test contents	EN15129		N. 1446	
	Type Testing	FPC	Type Testing	FPC
Pressure test	X	X	N/A	N/A
Low velocity test	X	X	N/A	N/A
Constitutive law test	X	X	X	X
Damping efficiency test	X	X	N/A	N/A
Wind load test	X	N/A	N/A	N/A
Seal wear test	X	N/A	N/A	N/A
Stroke verification test	X	N/A	N/A	N/A

will be confirmed safety at the maximum length with the maximum damping force, while the damper suffered vertical acceleration response. Since it is difficult to conduct this kind of test dynamically, static test is allowed in practice. The repeated cycling test should be conducted at a period of 3-5 second, while total accumulated displacement must be over 50m. It is implemented in the other code in Japan. Oil damper was reported to have few changes in the mechanical property after suffering such large input energy (BRI 2016). In the determined long period area, if the change of the property is large, it should be considered in the structural design.

Feng et al. (2017) have reported typical test results listed above in detail. Sample of JSSI catalog (JSSI 2009) is shown Table 4. In Table 5, comparison of testing requirement between EN15129 and N.1446 is shown. N.1446 required only constitutive law tests. In the factory production control test, 100% of the production shall be conducted by the manufacturer in Japan. However, in EN15129, one unit per production lot shall be subjected to the following tests: Low Velocity Test, Constitutive Law Test, Damping Efficiency Test. The Pressure test shall be performed to 100% of the production units.

5. Conclusions

The certification system of seismic isolation devices based on Notification No. 1446 in Japan was introduced. All seismic isolation devices must be certified by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) before using. Since there is no independent laboratory having enough facilities conducting tests in Japan, all type testing and factory production control tests are conducted by manufacturers. In the factory production control test, 100% of the production shall be conducted for all kind seismic isolation devices.

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