**Certification system of seismic isolation devices in Japan**

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**ABSTRACT**

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*

**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) | ○\*1 | ○ | ○ | ○ |
| FPC inspection  (notified body) | ○ | ○ | - | - |
| 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.

**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

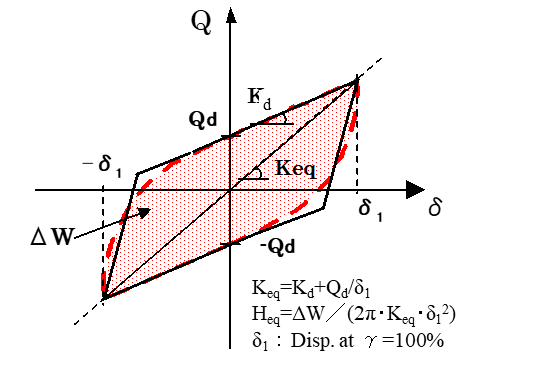
Dependency properties: shear strain, temperature, vertical load, ageing

* + - Creep property

Standard vertical pressure is defined upon the 2nd shape coefficient (S2) of the device, which ranges from 6-15 MPa corresponding with S2=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 oC, 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 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.



a) Fundamental property b) Critical vertical strength dependent on shear strain

Figure 1. Definition of horizontal properties of lead rubber bearing

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



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 1.3*N*SD,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 Kb and **b (or *K*2 and *Q*d) under cyclic deformation | Report strain dependence. At design displacement, dbd, 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 **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 Kb and **b (or *K*2 and *Q*d) with frequency | Report variation. Maximum variation ±20 %. | N/A | N/A | N/A |
| Variation of horizontal characteristics Kb and **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 Kb and **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 b*d*Ed. No defects. | N/A | Constitutive law test for  -  relationship. | N/A |
| Change of horizontal characteristics *K*2 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 104 min. | N/A | Creep rate < 8 % | N/A |

**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 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  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 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.

a) Oil damper b) Viscous damper

Figure 2. Constitutive law of velocity-dependent dampers

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=CVα | | | | |
| 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 |

**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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