**LEAD RUBBER BEARINGS: A PROMINENT APPLICATION OF EN15129:2009 ANTI-SEISMIC DEVICES STANDARD BEYOND EUROPE**

**DOI 10.37153/2686-7974-2019-16-73-81**

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**ABSTRACT**

The dynamic response of seismically-isolated buildings and infrastructures is mainly controlled by the anti-seismic devices provided in structures. For this reason, these special devices must be accurately engineered and manufactured to be compliant to the design characteristics provided by the designer. In this context, the European Standard EN 15129:2009 is one of the most advanced worldwide code which specifies functional requirements, general design rules of the devices for seismic design situations, material characteristics, manufacturing and testing requirements, as well as assessment and verification of constancy of performance, installation and maintenance requirements. Moreover, the EN15129:2009 is integrated with other harmonized standards for CE marking to ensure anti-seismic devices conformity and access to the entire European market. For this reason, this standard is increasingly adopted even in non-European countries, with the aim of imposing and ensuring high levels of quality and performance of the devices.

This paper illustrates the application of European Standard to an extraordinary project outside Europe: the Jakarta-Cikampek elevated toll.

*Keywords: Base Isolation; Anti-seismic Devices; Lead Rubber Bearing (LRB); EN 15129:2009; CE marking*

**1. INTRODUCTION**

Base isolation is one of the most advanced techniques for seismic protection of buildings and infrastructures. During a seismic event, the structure’s response is controlled by the behavior of the anti-seismic devices located in the structural system; therefore, these devices must meet stringent performance requirements. In this context, the European Standard EN15129:2009 is an advanced worldwide code which completely analyzes all the aspects related to anti-seismic devices: functional requirements, design rules, material characteristics, manufacturing and testing requirements, as well as assessment and verification of static and dynamic response. Furthermore, the Norm is integrated with other harmonized standards for CE marking to ensure conformity of the devices and access to the entire European market. This Standard is increasingly adopted even in non-European countries to impose high levels of control, quality and safety of the isolators. Scope of this paper is to illustrate the application of this Standard to one of the latest extraordinary Freyssinet’s projects: the Jakarta-Cikampek elevated toll in Indonesia.

**2. THE EUROPEAN STANDARD**

***2.1 General purpose of the standard***

This Standard covers the design of devices that are provided in the structural system, with the aim of modifying their response to the seismic action. It specifies functional requirements and general design rules for the seismic situation, material characteristics, manufacturing and testing requirements, as well as evaluation of conformity, installation and maintenance requirements. It is therefore one of the most worldwide complete norms in the field of anti-seismic devices. Within the context of base isolation, it specifies the performance requirements of elastomeric devices and sliders (both curved and flat surface).

***2.2 Performance requirements for elastomeric isolators***

The European Standard EN15129:2009 defines quantifiable characteristics that shall be determined for elastomeric devices. Among the types of devices, the Standard also includes in this category elastomeric isolators with holes plugged with lead (termed Lead Rubber Bearing, LRB), like those used in this project. The performance characteristics of the devices are determined through a massive test program, which comprises Type Test and Factory Production Control, the first with the aim of determining the behavior characteristics, the seconds to evaluate the constancy of the performances.

The horizontal behavior is tested under different conditions of rubber shear deformation, frequency, temperature and number of repeated cycling to quantify the influence of these factors on the response of the device. The horizontal characteristics shall be expressed in terms of effective horizontal stiffness, *Kb* and effective damping ratio, *ξb*; LRB may be characterized in terms of second branch (or post-yield) stiffness, *K2*, and characteristic strength, *Qd* (defined as the force at which the force-displacement loop intersects the force axis).The vertical characteristic shall be expressed in terms of secant compression stiffness, *Kv*, determined between 1/3*NSd*and *Nsd*, where *Nsd* is the axial load in permanent design combination.

The isolator testing and acceptance criteria for both Type Test and Factory Production Control are shown in Table 1.

Table 1. Isolator testing and acceptance criteria (reworked from Table 11 of EN15129:2009).

|  |  |  |
| --- | --- | --- |
| **Test** | **Type Test**  **requirements** | **Factory Production Control requirements** |
| Capacity in compression under zero horizontal displacement | Support *NSd*. No defects visible. | N/A |
| Compression stiffness | Report value. | Within ± 30% of Type Test value. No defect visible. |
| Horizontal characteristics *Kb* and *ξb* and (or *K2* and *Qd*) under cyclic deformation | Report strain dependence. At design displacement, *dbd*, values within ± 20% of design value. | Values within ± 20% of required values. |
| Variation of horizontal characteristics *Kb*and *ξb* (or *K2* and *Qd*) with frequency | Report variation. Maximum variation ± 20%. | N/A |
| Variation of horizontal characteristics *Kb*and *ξb* (or *K2* and *Qd*) with temperature | Report variation. Lowest temperature value within + 80% or -20% of 23°C value. Highest temperature value within ± 20% of 23°C value. | N/A |
| Dependence of horizontal characteristics *Kb*and *ξb* (or *K2* and *Qd*) on repeated cycling | Min/max ratio between second and tenth cycles not less than 0.7. Min/max ratio between first and tenth cycles not less than 0.6 (*Kb* or *K2* only). | N/A |
| Lateral capacity under maximum and minimum vertical loads | Force-displacement curve increasing up to *γbdEd*. No defects. | N/A |
| N/A = not applicable | | |

The Norm specifies the sampling frequency of the tests: each Type Test shall be carried out at least twice, using different isolators in each test. For each type of isolator, the Factory Production Control foresee a compression test and a combined compression-shear test (see Table 1); they shall be carried out on the first production isolator. Subsequently, at least 20% of the production isolators of each type, chosen randomly, shall be subjected to tests for Factory Production Control.

**3. THE JAPEK-CIKAMPEK ELEVATED TOLL, INDONESIA**

***3.1 Project details***

The new Jakarta-Cikampek (JaPek) elevated toll road represents an important and ambitious infrastructure, as well as a recent example of seismic isolation of long viaducts. This elevated toll road is about 38 km long and will pass over some sections of the existing one, connecting the Indonesia capital, Jakarta, to the industrial district of Cikampek to reduce traffic congestion. Moreover, due to the high seismic risk of the territory, it was decided to protect the infrastructure from earthquake attacks through Lead Rubber Bearings, placed between the cap of the piers and the decks. Figure 1 shows a rendering of the infrastructure, with the type of pier, deck and the location of the isolators while Figure 2 illustrates phases of construction of the piers.

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Figure 1. Rendering of the new Jakarta-Cikampek elevated toll road

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Figure 2. Phases of construction of the piers

For this important project, the Freyssinet Group designed, supplied and tested 1450 ISOSISM® LRB devices.

These anti-seismic devices provide in a single unit the combined features of vertical load support, horizontal flexibility and energy dissipation capacity required for the isolation of the infrastructure. Figure 3 illustrates characteristics of this device.

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Figure 3. LRB geometry (left), horizontal flexibility (center) and typical hysteretic shear behavior (right)

Specific analysis of the ground crossed by the infrastructure led to the identification of two types of soil: loose-to-medium cohesionless deposits and soil with surface alluvium layer underlined by stiffer material (“D” and “E” ground types respectively, according to standard classifications). This diversification causes variable levels of seismic acceleration/deformation demand along the development of the infrastructure (see response spectra in Figure 4), which led to the optimized design of two types of LRB, with different stiffness, damping and displacement capacity, according to the local soil condition of the viaduct: the 700 mm diameter LRB SE (for the parts of the infrastructure crossing type E soils) and the 600 mm diameter LRB SD (for those crossing type D).

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Figure 4. Design acceleration response spectrum for type D and E soil

The devices designed by Freyssinet have been supplied by FPC Italia, the specialized pole of Freyssinet for seismic devices, and fully produced by FPC Rubber, the manufacturing company of Freyssinet’s rubber devices. Table 2 summarizes the main technical characteristics of LRB type SE and SD required in this project.

Table 2. LRB characteristics.

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|  | | **Typology** | |
| **SE** | **SD** |
| Diameter | *Ø* | 700 mm | 600 mm |
| Rubber height | *h* | 160 mm | 126 mm |
| Number of devices | *n* | 524 | 926 |
| Maximum seismic vertical load | *NEd,max* | 4200 kN | 3800 kN |
| Minimum seismic vertical load | *NEd,min* | 1600 kN | 1000 kN |
| Design displacement | *dbd* | ± 230 mm | ± 170 mm |
| Expected characteristic strength | *Qd* | 373 kN | 196 kN |
| Expected second branch stiffness | *Kr* | 1.25 kN/mm | 1.34 kN/mm |
| Yielding displacement | *dy* | 33 mm | 16 mm |
| Max. seismic displacement | *dmax* | ± 360 mm | ± 270 mm |
| Effective horizontal stiffness at *dbd* | *Kb*(*dbd*) | 2.87 kN/mm | 2.49 kN/mm |
| Effective damping ratio at *dbd* | *ξb*(*dbd*) | 30.8% | 26.7% |

Two prototypes of both types of LRB have been tested by the Notified Body as per procedure to obtain CE certification for construction products and to qualify the isolators for the project design specifications. The tests have been performed with the presence of representative of the client and Indonesian Public Works Department, for type SD in an external laboratory, while for type SE at ISOLAB, the internal dynamic testing facility of Freyssinet.

***3.2 Application of EN15129:2009 to the LRB anti-seismic devices***

In this section, the details of the tests performed on the devices, according to EN15129:2009 requirements are summarized. The LRBs type SE were tested at ISOLAB, the innovative testing facility of Freyssinet Group, based in Montebello della Battaglia, Pavia, Italy. ISOLAB Testing Lab was developed thanks to 20 years of experience in earthquake engineering, manufacturing and testing of anti-seismic devices and structural bearings. The laboratory is equipped with various testing machines, which allow to manage the tests of many devices, as in the case of this project, which required the testing of about 300 devices. It allows testing in dynamic and static conditions and to perform Type Test and Factory Production Control in accordance to main relevant European and worldwide Standards.

Figure 5 shows the 70 MN testing machine of ISOLAB, the most powerful of the laboratory, which allows to perform static tests with vertical loads up to 70 MN, and dynamic tests with horizontal force up to 3000 kN, peak velocity up to 850 mm/s and 1000 mm stroke.

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Figure 5. The 70 MN press of ISOLAB

Figure 6 illustrates a sample of LRB before shipping to Jakarta.

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Figure 6. LRB devices before shipping

Table 3 shows the complete test matrix of LRB SE only, for brevity of exposure, according to the European Standard. For each LRB, two prototypes were tested.

Table 3. Type Tests matrix of LRB SE according to EN15129:2009.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **test** | **label** | **direction** | **amplitude**  **[mm]** | **frequency**  **[Hz]** | **peak velocity [mm/s]** | **input load shape** | **vert. load**  **[kN]** | **cycles** | **T [°C]** |
| 1 | CS | vertical | - | - | 400 kN/min | ramp | 4000 | - | 23 |
| 2 | HCC | horizontal | ± 8 | 0.50 | 25 | sine | 2500 | 3 | 23 |
| 3 | HCC | horizontal | ± 16 | 0.50 | 50 | sine | 2500 | 3 | 23 |
| 4 | HCC | horizontal | ± 32 | 0.50 | 101 | sine | 2500 | 3 | 23 |
| 5 | HCC | horizontal | ± 80 | 0.50 | 251 | sine | 2500 | 3 | 23 |
| 6 | HCC  TV  FV | horizontal | ± 160 | 0.50 | 503 | sine | 2500 | 3 | 23 |
| 7 | HCC | horizontal | ± 230 | 0.50 | 723 | sine | 2500 | 3 | 23 |
| 8 | FV | horizontal | ± 160 | 0.3125 | 314 | sine | 2500 | 3 | 23 |
| 9 | FV | horizontal | ± 160 | 0.80 | 804 | sine | 2500 | 3 | 23 |
| 10 | HCC | horizontal | ± 240 | 0.50 | 754 | sine | 2500 | 3 | 23 |
| 11 | RC | horizontal | ± 160 | 0.30 | 302 | sine | 2500 | 10 | 23 |
| 12 | CC | vertical | - | - | 400 kN/min | ramp | 4000 | - | 23 |
| 13 | LC | horizontal | 414 | - | 5 | - | 1600 | - | 23 |
| 14 | LC | horizontal | 414 | - | 5 | - | 4200 | - | 23 |
| 15 | TV | horizontal | ± 160 | 0.50 | 503 | sine | 2500 | 3 | 40 |
| 16 | TV | horizontal | ± 160 | 0.50 | 503 | sine | 2500 | 3 | 15 |
| CS = Compression Stiffness LC = Lateral Capacity  HCC = Horizontal Cyclic Characteristics TV = Temperature Variation  FV = Frequency Variation RC = Repeated Cycles | | | | | | | | | |

Figure 7 illustrates the hysteretic shear response of one LRB SE prototype for the RC test while Figure 8 shows some test sequences at ISOLAB.

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Figure 7. Hysteretic shear response of LRB SE prototype (RC test)

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Figure 8. Test sequences at ISOLAB

Table 4 reports the Factory Production Control test protocol for LRB SE.

Table 4. Factory Production Control test protocol of LRB SE according to EN15129:2009.

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **test** | **label** | **direction** | **amplitude**  **[mm]** | **frequency**  **[Hz]** | **peak velocity [mm/s]** | **input load shape** | **vertical load [kN]** | **cycles** |
| 1 | CS | vertical | - | - | 400 kN/min | ramp | 4000 | - |
| 2 | HCC | horizontal | ± 230 | 0.14 | 200 | sine | 2500 | 3 |
| 3 | HCC | horizontal | ± 240 | 0.13 | 200 | sine | 2500 | 3 |

According to the European Standard requirements, at least 20% of the production isolators of each type shall be subjected to Factory Production Control tests; therefore, for this project, 300 devices must be tested before shipping (part of these tests is ongoing at the time of writing this paper).

Type tests for both SE and SD devices have given positive results, thus compliant with design performances and respecting limits and tolerances imposed by EN15129:2009, thanks to the internal production of all the bearings components, mastered by continuous and rigorous checks of the incoming new materials and production process. The Lead Rubber Bearings manufactured by Freyssinet are proven to fully-comply the design specification as well as the European standard and all the bearings were eligible to be CE-marked, providing the assurance that all appropriate qualifications have been approved and satisfied.

**4. CONCLUSION**

Base isolation is among the most advanced and efficient seismic protection solutions, especially in medium and high seismic areas. This technique allows to control the overall dynamic response of the structure through special anti-seismic devices; therefore, such devices should always meet stringent performance requirements. In this context, the European Standard EN15129:2009 is one of the most advanced worldwide code which specifies functional requirements, general design rules of the devices, material characteristics, manufacturing and testing requirements, as wall as assessment and verification of constancy of performance, installation and maintenance requirements. Moreover, the EN15129:2009 is integrated with other harmonized standards for CE marking, which guarantees conformity and quality of the devices within the European community. For these reasons, this Standard is increasingly adopted even beyond Europe.

The new Jakarta-Cikampek elevated toll road is an impressive infrastructure, as well as a modern example of seismic isolation of long viaducts. For this project, the Freyssinet Group designed and supplied 1450 ISOSISM® LRB anti-seismic devices, of which 300 tested in the advanced internal dynamic laboratory of the Company, based in Italy, The isolators were designed and tested according to EN15129:2009, with the requirement to be even CE marked.

This project shows the capacity of the group to provide an end to end service and solution to the final client, assisting it since the design phase optimizing the characteristics of the seismic protection system depending on the ground composition up to the detailed design of the isolators, from manufacturing in a high quality system with internal controls to guarantee the constancy of the performances to the testing of full size devices both for qualification and quality control of the mass production up to the delivery according to the schedule of the client.

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