EUROPEAN COMMISSION 7th EURATOM
FRAMEWORK PROGRAMME 2007-2013

THEME [Fission-2011-2.3.1]

SILER
Seismic-Initiated events risk mitigation in LEad-cooled Reactors

Grant Agreement N°: 295485

Deliverable title: Development of full scale prototypes of Lead Rubber Bearings and experimental validation

Work Package	Deliverable number	Lead contractor	Date
4	D4.2	FIP Industriale S.p.A.	

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Starting date	Due date	Actual date	Delay*	Nature
01/06/2012	30/09/2013	31/03/2014		R

Description of the activities:

This report summarizes the activities carried out in Task 4.3 of the SILER project, i.e. the design, manufacturing and testing of full scale prototypes of Lead Rubber Bearings (LRB).

SIGNATURES

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1. Introduction

The activities of WP4, Task 4.3, were based on input from WP 2, in particular on Deliverable D2.2, titled “Description of the design of seismic isolator”, as well as on continous interaction of the WP Leader FIP Industriale with partners ENEA and NUMERIA, in particular with the latter. Said interaction was needed for the detailed design of the isolators. NUMERIA was more involved than ENEA in task 4.3, because since the beginning of the activities it was decided that the LRB prototypes to be designed, manufactured and tested would have been related to MYRRHA reactor, that was modeled by NUMERIA.

2. Design of Lead Rubber Bearings

The design of LRB-based isolation system for MYRRHA, reported in Chapter 5 of D2.2-Part 2, foresees two types of LRB, type A with higher horizontal stiffness and type B with lower horizontal stiffness. The total number of isolators is 339, 80 of which type A and 259 type B. Type A isolators are placed at the slab corners and type B isolators in the middle. Isolators type and locations were chosen to have a coincidence of the centre of mass with the centre of stiffness of the isolators. Table 1 summarises the main input parameters received from WP2 to design the LRB for MYRRHA.

Table 1 – Preliminary input data to design LRB for MYRRHA.

	Type A	**Type B**
Horizontal stiffness (kN/mm)	15	4.5
Equivalent viscous damping (%)	25	25
Vertical stiffness (kN/mm)	15000	4500
Maximum vertical load in seismic conditions (kN)	20123	11878
Displacement in seismic conditions at DBE d_{bd} (mm)	216	207

It can be noted in Table 1 that the vertical stiffness used in the structural model, and given as an input to design the LRB, is exactly 1000 times the horizontal stiffness. The preliminary design of LRB carried out by FIP Industriale based on this input showed that said values of vertical stiffness are too high and cannot be obtained. The parameters given in Table 2 and Figures 1 and 2 are the results of the first design of LRB for MYRRHA.

Table 2 – LRB main parameters obtained in the first design.

	Type A	Type B
Plan size	1350 mm x 1350 mm	Diam. 900 mm
Horizontal stiffness (kN/mm) at d_{bd}	15.57	4.55
Equivalent viscous damping (%) at d_{bd}	27	26.7
Vertical stiffness (kN/mm)	7706	2840

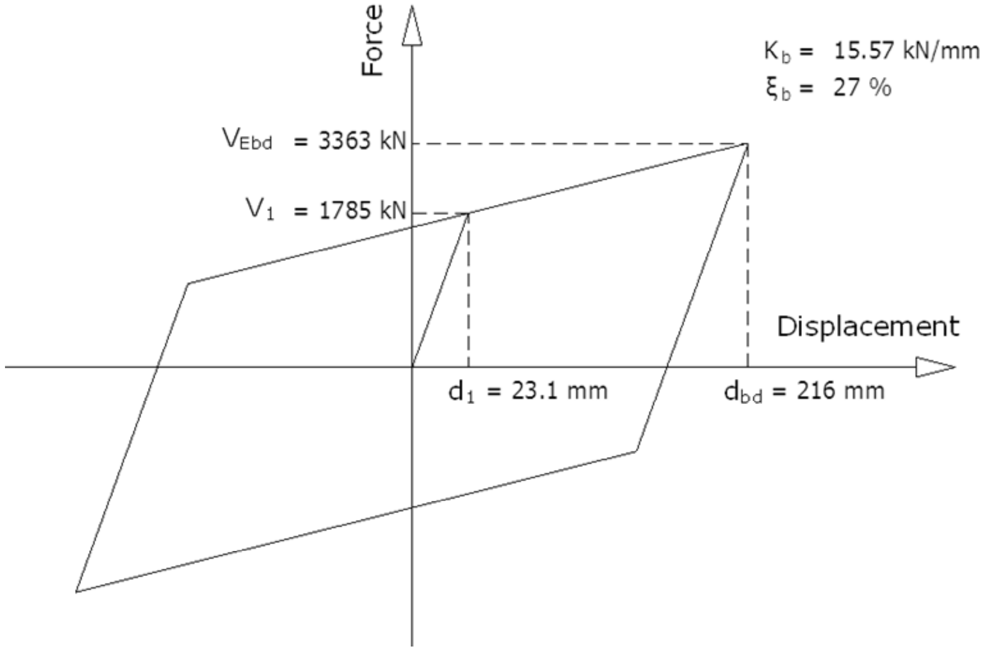


Figure 1 – Bilinear curve at DBE of LRB type A (first design).

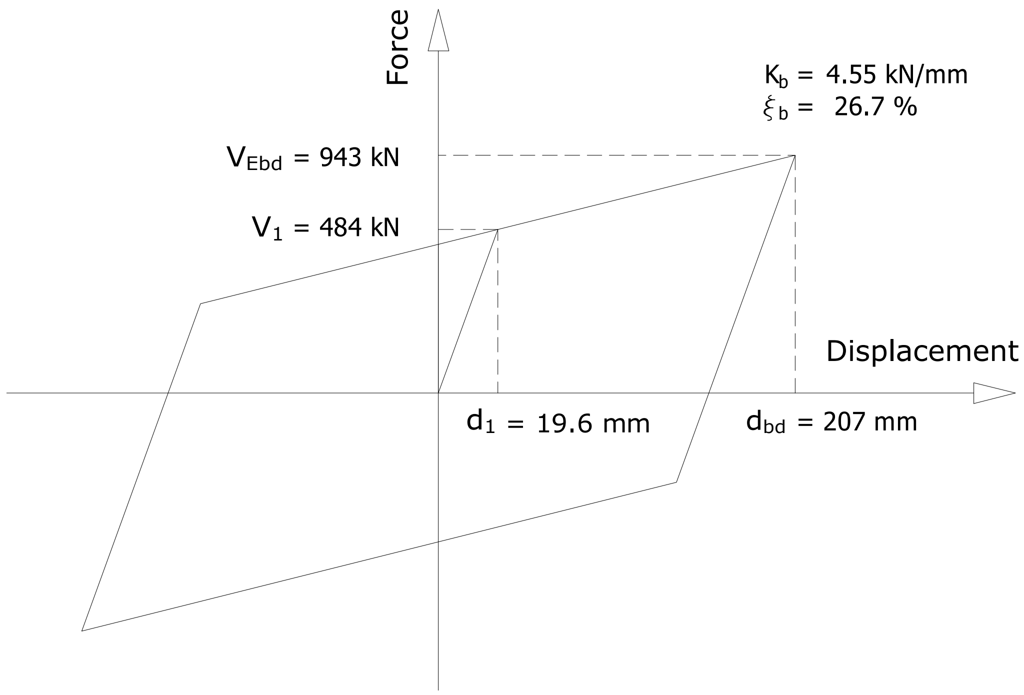


Figure 2 – Bilinear curve at DBE of LRB type B (first design).

On the basis of said first design, and subsequent interaction between FIP Industriale and NUMERIA, the design of LRB was finalised by FIP Industriale. Subsequently, non-linear dynamic analyses were carried out by NUMERIA using different groups of time-histories related to different design spectrums. Table 3 and Figures 3 and 4 summarises the main design parameters of type A and type B LRB as per their final design, and the main results of time-history analyses, in terms of maximum horizontal displacement and vertical load. As expected, the maximum displacement d_{bd} obtained with non-linear time history analyses resulted lower than that obtained with linear equivalent analysis.

Table 3 – LRB main parameters obtained in the final design
and main results of non-linear dynamic analyses at DBE.

	Type A	**Type B**
Mark	LRB 1250x1250/192-200q	LRB 900/189-210
Plan size	1250 mm x 1250 mm	Diam. 900 mm
Minimum vertical load in seismic conditions (kN)	-879 (tension)	581
Maximum vertical load in seismic conditions (kN)	28165	21384
Displacement at DBE d_{bd} (mm)	161	161
Horizontal stiffness (kN/mm) at d_{bd}	16.43	4.81
Equivalent viscous damping (%) at d_{bd}	28.7	27.1
Vertical stiffness (kN/mm)	9105	3404

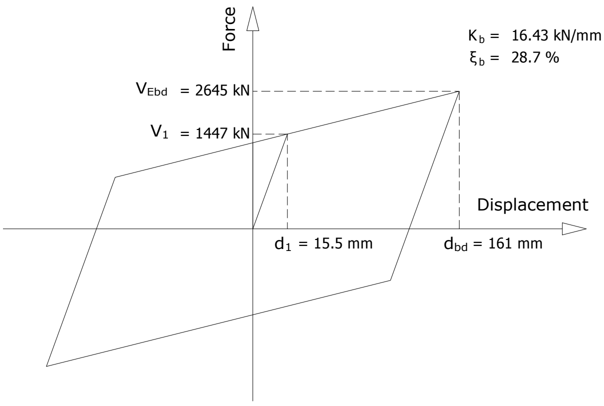


Figure 3 – Bilinear curve at DBE of LRB type A– LRB 1250x1250/192-200q (final design).

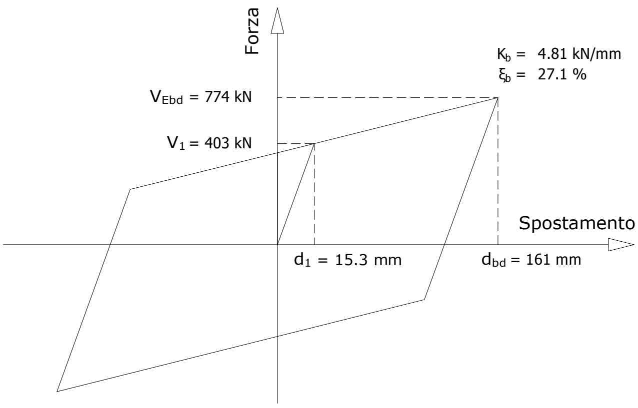


Figure 4 – Bilinear curve at DBE of LRB type B (final design).

The LRBs have been designed according to EN15129:2009, with additional prescriptions established within SILER project, for example to design the isolators with shear strain at design displacement at DBE not higher than 100 %. Other additional prescriptions were related to the verification against buckling stability, not always mandatory for LRB in EN 15129, and to the fixing methods as discussed in D4.1.

The final design of LRB type A has the mark LRB 1250x1250/192-200q. It is a square isolator, with a side of 1250 mm, and 4 lead cores, each with diameter 200 mm. Total rubber thickness is 192 mm.

Annex I shows the drawing of LRB 1250x1250/192-200q, including anchorage plates as well as counterplates.

The final design of LRB type B has the mark LRB 900/189-210. It has a diameter of 900 mm, a lead core with diameter 210 mm, and total rubber height of 189 mm.

Table 4 shows the maximum shear strain values of the two types of isolators at DBE. Amongst the different set of time histories considered, the maximum displacements were obtained with those corresponding to RG spectrum.

Table 4 – Shear strain on LRBs calculated at DBE.

	TYPE A LRB 1250x1250/192-200q	TYPE B LRB 900/189-210
DBE	**84 %**	**85 %**

The displacements corresponding to EC8 spectrum were smaller. As an example, Figure 5 shows the force vs. displacement curve obtained as a result of a non-linear dynamic analysis with one time-history generated from EC8 spectrum. The maximum displacement obtained is about one half of the maximum displacement obtained with RG spectrum. Consequently, the use of EC8 spectrum instead of RG spectrum would allow to design smaller isolators.

Figure 6 shows the comparison of force vs. displacement curves obtained on the same isolator at DBE and BDBE, with the same time history generated from EC8 spectrum. The maximum displacement corresponds to a shear strain of about 210 %.

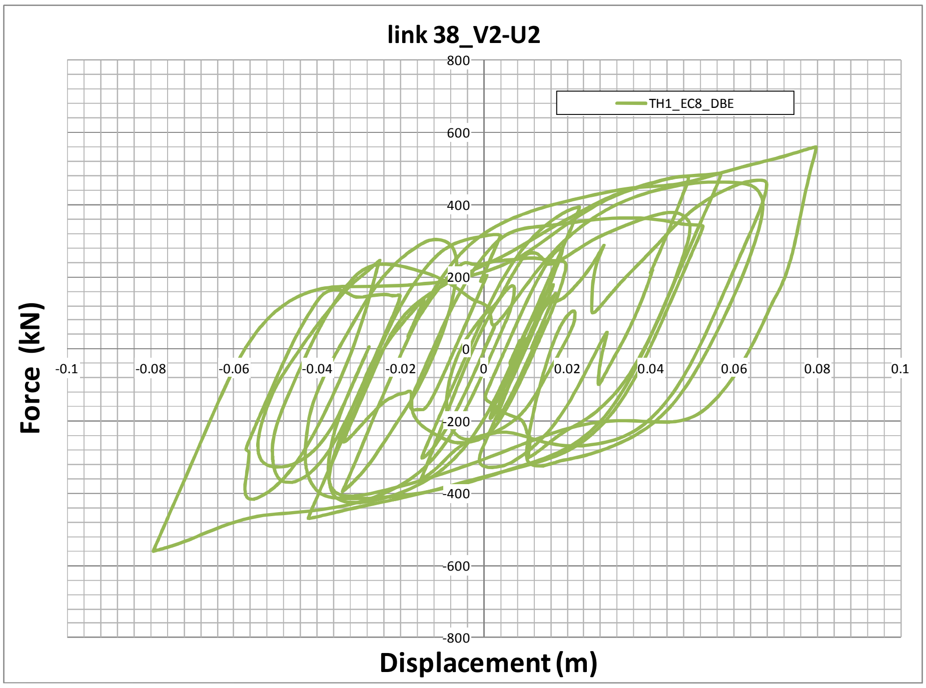


Figure 5 – Force vs. displacement curve at DBE on a LRB type B (with time history No. 1 generated from EC8 spectrum).

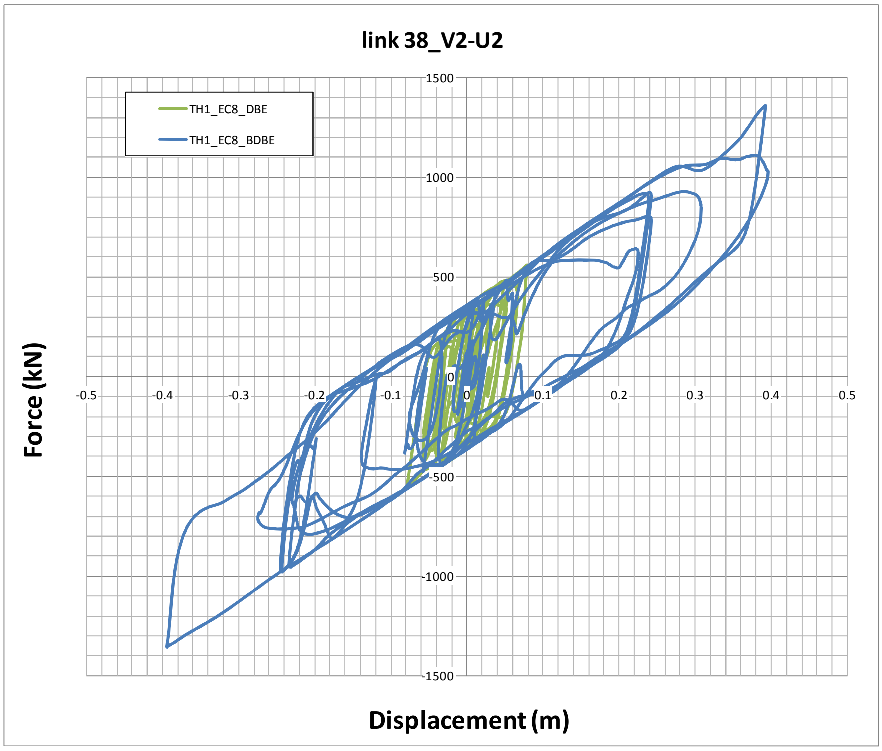


Figure 6 – Force vs. displacement curves at DBE and BDEon a LRB type B (with time history No. 1 generated from EC8 spectrum).

3. Manufacture of Lead Rubber Bearings Prototypes

Amongst type A and type B isolators designed for MYRRHA, type A (LRB 1250x1250/192-200q) was selected as the prototype to be manufactured and tested within SILER project. This selection was made because type A was the biggest and thus the most difficult to be manufactured, and consequently the most critical in terms of test results.

The design of LRB 1250x1250/192-200q made use of a new low damping rubber compound developed within the framework of Task 4.1. It is a compound based on natural rubber, with effective dynamic shear modulus G=1.4 MPa at shear strain 100% and frequency 0.5 Hz.

Two full-scale prototypes of LRB 1250x1250/192-200q have been manufactured, with serial numbers IT1730I and IT1731I. Due to the big dimensions of the prototypes (1250 mm x 1250 mm in plan, height of vulcanized part 367 mm), special care was necessary both in the design and construction of the mould and in vulcanization of the prototypes.

4. Testing of Lead Rubber Bearings Prototypes

Both full-scale prototypes of LRB 1250x1250/192-200q have been tested (Figures 7 – 10).

Figure 7 – Prototype IT1730I under testing.

Figure 8 – Prototype IT1730I under testing.

Figure 9 – Prototype IT1730I under testing.

Figure 10 – Prototype IT1731I under testing.

The combined compression-shear tests have been carried out up to the limits of the biggest testing rig of FIP Laboratory in terms of horizontal force (2000 kN), under a vertical load equivalent to an average pressure of 6 MPa, according to EN 15129:2009. This limit was enough to measure the bilinear behaviour of LRBs and check it in comparison with the theoretical bilinear curve. Figures 11 and 12 show that the experimental behaviour is fully in agreement with the expected theoretical behaviour.

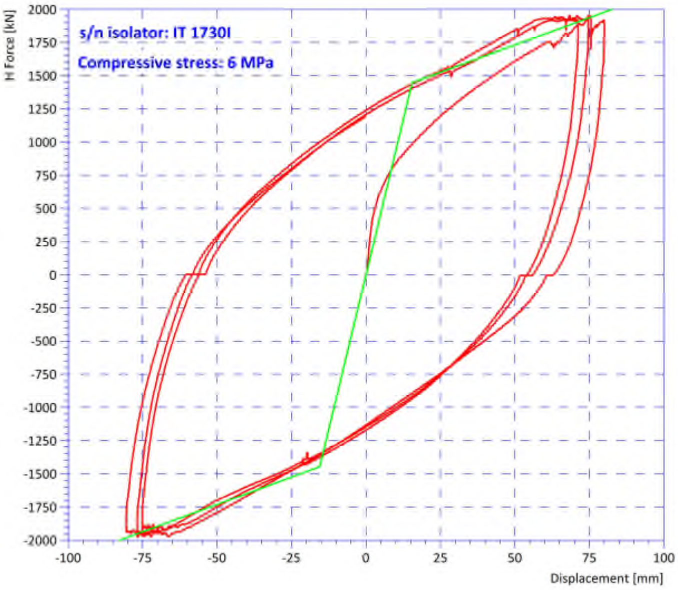


Figure 11 – Comparison of theoretical (green) and experimental (red) force vs. displacement curve for LRB prototype LRB 1250x1250/192-200q (serial number IT1730I).

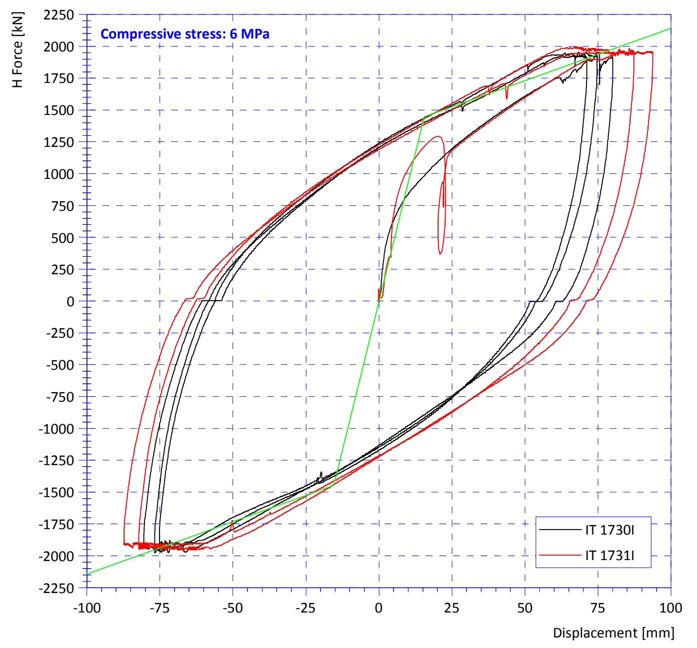
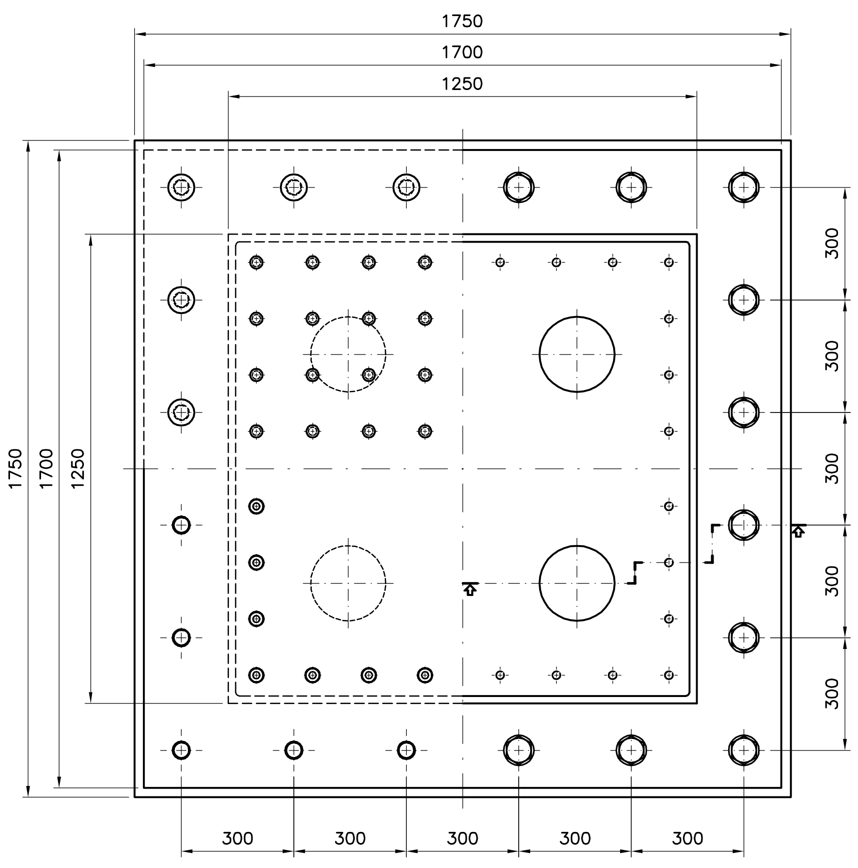
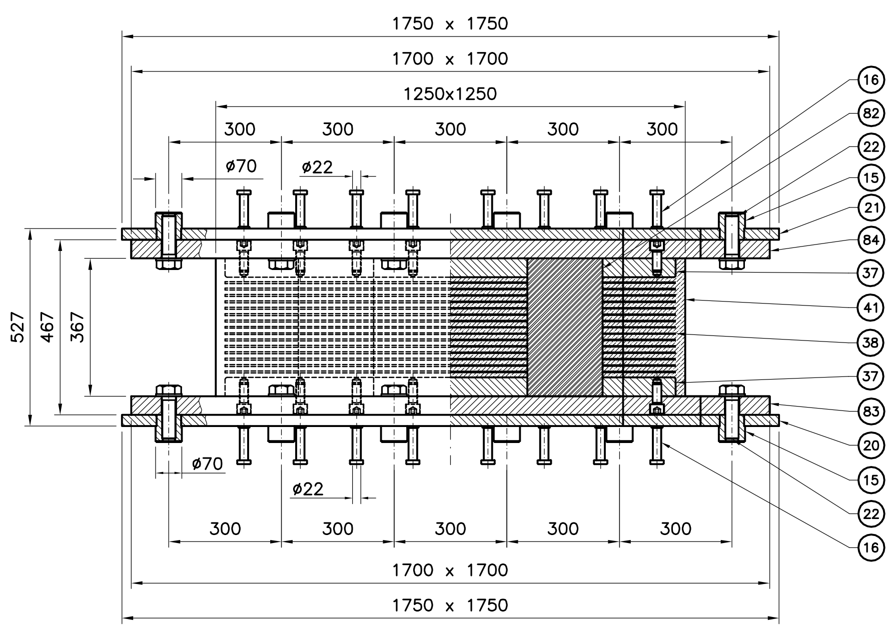


Figure 12 – Comparison of theoretical (green) and experimental force vs. displacement curve for LRB prototypes LRB 1250x1250/192-200q
(serial number IT1730I: black curve; serial number IT1731I: red curve).

ANNEX I

DRAWING OF LRB 1250x1250/192-200q





84	1	Upper anchor plate	S355JR EN 10025		
83	1	Lower anchor plate	S355JR EN 10025		
82	4	Lead core	Pb		
41		Vulcanized rubber	G_{din}=1.4 MPa		
38		Reinforcing plate	S355JR EN 10025		
37	2	Vulcanized plate	S355JR EN 10025		
22	40	Bolt TE M36	Grade 8.8 EN 20898		
21	1	Upper counterplate	S275JR EN 10025		
20	1	Lower counterplate	S275JR EN 10025		
16	128	Shear connector	Fe 37-K DIN 17100		
15	40	Anchor dowel	1C40 TQ+T EN 10083		
POS.	QUANT.	DESCRIPTION – DIMENSIONS	MATERIAL	CODE	REV.

FIP INDUSTRIALE S.p.A. Via Scapacchio' Selvazzano D. (PD)

WEIGHT – Kg: 8800

SCALE: 1:10

TITLE: Lead Rubber Bearing series LRB

	DRAWN	APPROVED
DATE	01/10/13	01/10/13
BY	PC	MGC

ITEM IDENTIFICATION: LRB 1250x1250/192–200q

DRAWING N°: 1A38969 REV.: 0

REV	DATE	DESCRIPTION	BY

REVISION

FIP – UNI A2 – 594x420