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Agigea Bridge: Comparison of Performance and Economy of a combination of Lead Rubber Bearings and Dampers versus Pendulum Isolators

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ABSTRACT

The Agigea Bridge is a 900m long highway bridge in Romania, located close to the Black Sea, which was opened in 2015. The main span was designed as a cable stayed steel bridge with a length of 360m. The structure is located in a seismic area, therefore a special bearing system with seismic isolation devices was considered, consisting of a combination of lead rubber bearings and hydraulic dampers. In total, 16 lead rubber bearings and 4 hydraulic dampers were implemented in the final design stage. Maurer offered an alternative solution with only 16 sliding isolation pendulum bearings, without any hydraulic dampers. The offered sliding isolation pendulum bearings were designed according to the required performance of the combined system using hydraulic dampers and lead rubber bearings. After comparison, the solution with sliding isolation pendulum bearings, as proposed by Maurer, was realized. All sliding isolation pendulum bearings were designed according to EN 15129. With the presentation the different bearing systems and their performance for the Agigea Bridge will be analysed and the technical and commercial benefits will be explained.

Keywords: Seismic Isolation, Lead Rubber Bearings, Hydraulic Dampers, Pendulum Isolators, Economy, Testing.

INTRODUCTION

Since the Agigea Bridge is located in a seismic area with a seismic acceleration of 0.02g, the choice of a proper bearing system is essential to guarantee the best protection against seismic damage, and to enable a long service life. Therefore, the bearing system of the Agigea main Bridge was planned with 16 nos. of lead rubber bearings in total, for pylon P1 and P2 and for abutment P8 and P9, with 4 lead rubber bearings per axis. An additional 4 nos. of hydraulic dampers at the abutments P8 and P9 were required. The concept of this layout was to transmit the vertical loads at the piers and abutments, and to generate energy dissipation and re-centering after an earthquake. Additional dampers at the abutments were incorporated into the concept to absorb the significant horizontal forces in case of an earthquake. A general view of the main bridge is shown in figure 1.

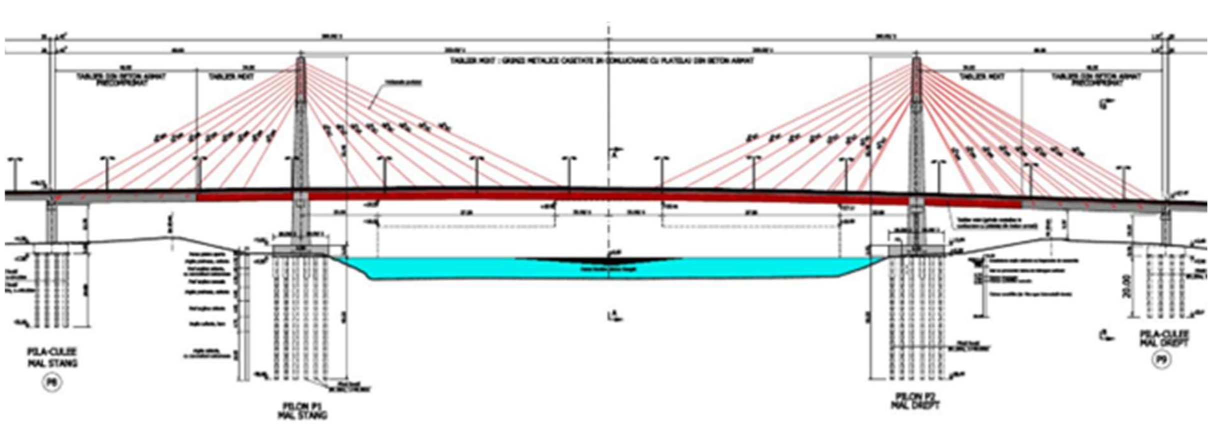

Figure 1 – View of main bridge

PROJECTED BEARING SYSTEM

For abutment P8 and P9, lead rubber bearings with a vertical load of 6,100 kN and a displacement capacity of ±200 mm were considered. For bearings at pylons P1 and P2, the maximum vertical load was 10,000 kN and the displacement capacity was ±260 mm. Additional hydraulic dampers with a response force of 1,200 kN and a stroke of +/-260 mm became necessary to control the displacement in longitudinal direction during an earthquake. The specified G-modulus of the rubber material was 0.4 N/mm² for the abutments and 0.9 N/mm² for the pylons. The system resulted in horizontal forces per bearing of 700 kN at piers and of 430 kN at the abutments. The total design horizontal force in longitudinal direction therefore was 9,320 kN. Figure 2 shows the original planned bearing system.

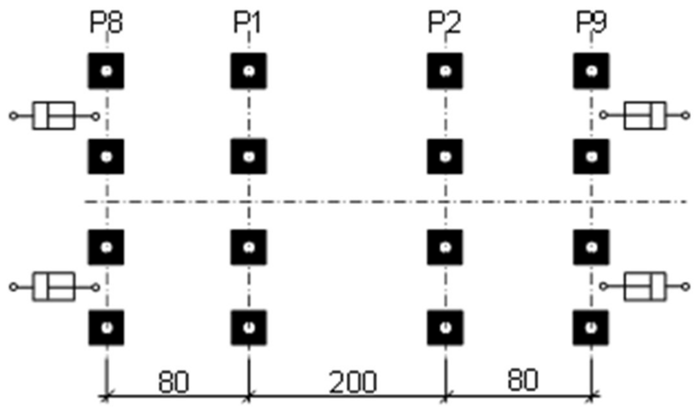

Figure 2 – Intended bearing layout

PROPOSED ALTERNATIVE BEARING SYSTEM

The alternative proposal consists only of 16 nos. of Sliding Isolation Pendulum bearings (SIP) with a single curved sliding surface. With the use of SIPs it was possible to reduce the maximum displacement to ±170 mm for pier P8 and P9 and to ±140 mm for pylon P1 and P2.

The maximum horizontal force at maximum movement was 726 kN for pylon P1 and P2 and 183 kN for abutment P8 und P9. The total design horizontal force in longitudinal direction for the main bridge was 3,636 kN. This force is approximately two times smaller compared to the previously projected system. But the horizontal stiffness of the complete system is nearly the same as calculated for the LRB option.

All isolators are made of steel by using a special and non-lubricated sliding material MSM® (Maurer Sliding Material), to allow the superstructure to move and rotate easily, especially under service conditions. By using this certificated material, a long service life time without any maintenance is guaranteed. All Sliding Isolation Pendulum bearings were designed and manufactured strictly according to EN 15129. Figure 3 illustrates the executed and already installed bearing system with only Sliding Isolation Pendulum bearings.

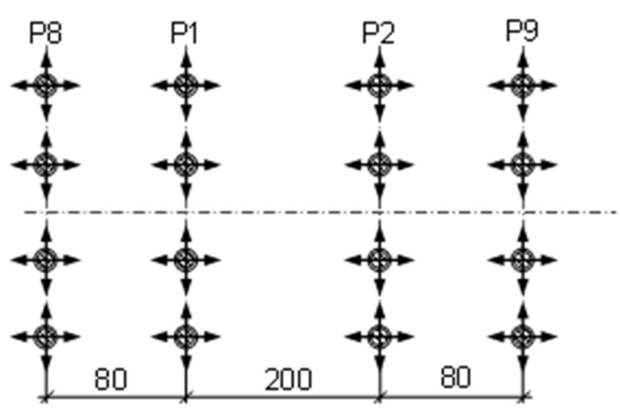

Figure 3 – Proposed alternative and executed bearing layout

WORKING PRINCIPLE OF PROPOSED SLIDING ISOLATION PENDULUM BEARINGS (SIP)

The Sliding Isolation Pendulum (SIP-S) consists of three main steel parts with inner sliding surfaces. The shape of the internal part is always spherical and allows rotations and horizontal sliding displacements as well. The device transmits the vertical loads (W) and provides free horizontal flexibility (D), while dissipating energy[1].

Compared to flat sliders, the SIP-S type inherently incorporates the re-centering capability. The purpose of the self-centering capability– return of the structure to former neutral centre position – is not so much to limit residual displacements at the end of a seismic event, but rather, to prevent cumulative displacements during the seismic event. Self-centering is very important to keep the structure in position during any possible load case to avoid uncontrolled shifting in one certain direction. While the isolator is moving due to relative displacements between the ground and the building during an earthquake, the friction between the sliding surfaces creates energy dissipation.

Structural control is provided by a well-defined coefficient of friction between the special sliding elements (MSM® and stainless steel) which grants the transformation of kinetic energy into heat. In figure 4 the main functionality of a Sliding Isolation Pendulum bearing, here at maximum displacement position, is illustrated.

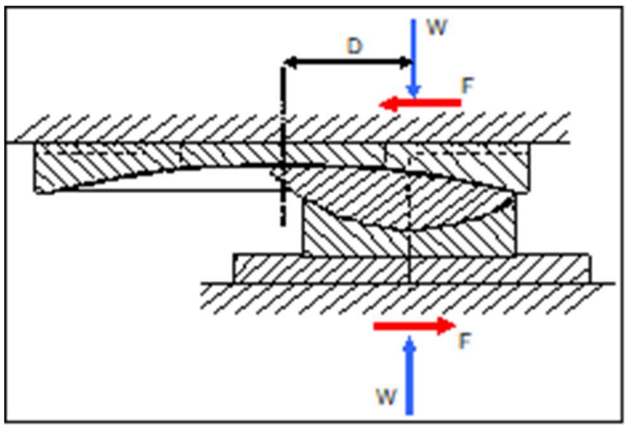

Figure 4 – Working principle of a Sliding Isolation Pendulum bearing (SIP)

In a Single Sliding Isolation Pendulum (SIP-S) device, movement is enabled by a single concave sliding plate with a stainless steel sheet as mating surface for the MSM® slider. The concave stainless steel sheet is firmly held in the structural steel housing by a proprietary design of the recess.

For dust protection, an elastic rubber apron is installed around the upper part, protecting the sliding surface against major dust and other potential contaminants. Figure 5 shows the main elements of a Sliding Isolation Pendulum bearing.

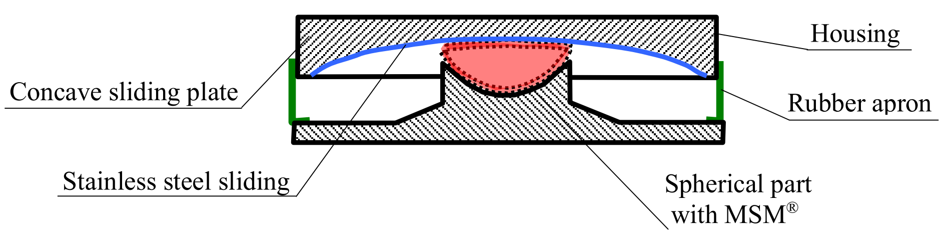

Figure 5 – Elements of a Sliding Isolation Pendulum bearing

One of the main aspects, engineers have to consider for the design of the superstructure and the piers are the response horizontal forces due to the movement of the bearings. These forces have a significant effect on the dimensions of the piers, superstructure, abutments, and even on the foundation. Therefore, these effects need to be taken into consideration when the bearing system is selected. The horizontal response force depends on the vertical load, the radius, the displacement, the horizontal displacement velocity, and the friction. This force could be determined with the following formula, Eq. (1).

$$F = \frac{W}{R} \cdot D + \mu \cdot W \cdot (\operatorname{sgn} v) \tag{1}$$

SLIDING ISOLATION PENDULUM BEARINGS FOR THE AGIGEA BRIDGE

For the Agigea Bridge, two types of isolators were designed and manufactured. Type 1 (8 nos.) with an effective radius of 1080 mm and type 2 (8 nos.) with an effective radius of 2280 mm. Dynamic friction of type 1 was 4.5% and of type 2 it was 3.3%. Both types were connected to the steel superstructure and to the steel anchor plates at substructure by welding on site. Figure 6 and 7 show the cross section of the supplied pendulum bearings type 1 and type 2.

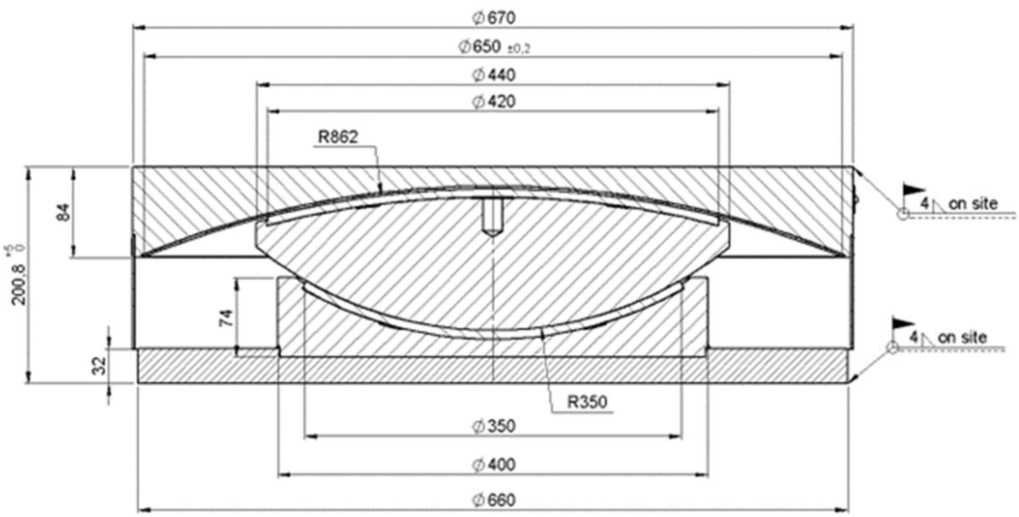

Figure 6 – SIP-S type 1[2]

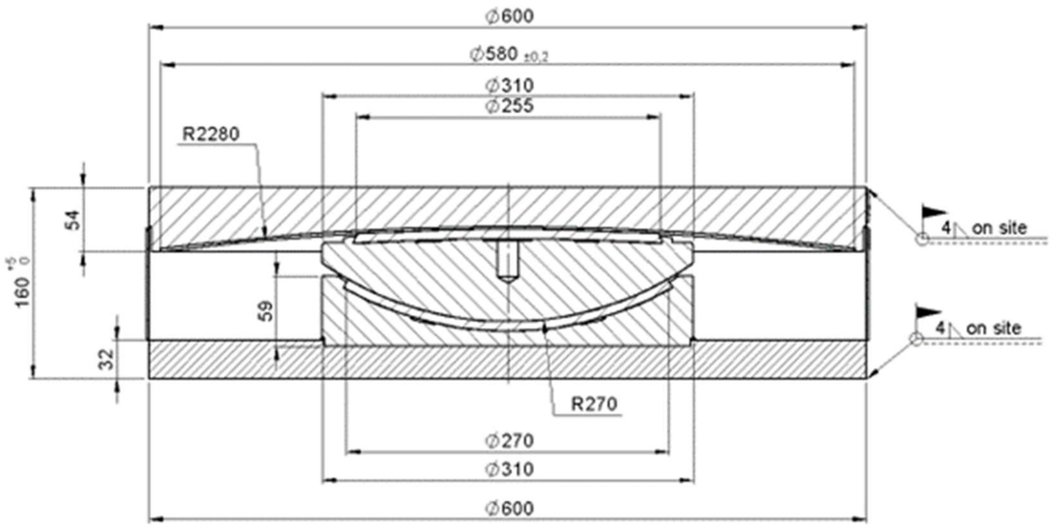

Figure 7 – SIP-S type 2[2]

TESTING

The sliding isolation pendulum bearings were strictly designed in accordance with EN 15129, the European standard for Anti Seismic Devices. According to this standard, prototype tests must be done to prove the calculated performance. For the Agigea Bridge project, 4 prototype tests (two of each type) became necessary and were executed at Ruhr University Bochum, an independent and approved test laboratory[3].

Figure 8 – SIP-S installed in test machine

The prototype tests have been supervised by MPA Stuttgart, an independent and approved third party institute. All tests have been successfully executed according to the below shown test matrix (table 1).

Test #	test name	label	main dof	stroke [± m]	max vel [m/s]	freq [Hz]	load shape	vertical load [kN]	cycles [#]	µ [-]	test duration [s]	friction force [kN]	energy/ cycle [kJ]
0	Pre-test 0	P0	long	0,045	0,280	0,990	sine	3080	3	0,033	3,0	102	18
1	Pre-test 1	PT1	vert	-	-	-	constant	4860	-	-	600,0	-	-
2	Frictional Resistance	FR	long	0,006	0,0001	-	triangular	4860	0,25	-	1860,0	-	-
3	Benchmark	P1	long	0,090	0,050	0,088	sine	3080	3	0,033	33,9	102	37
4	Dynamic 1	D1	long	0,023	0,280	1,981	sine	3080	3	0,033	1,5	102	9
5	Dynamic 2	D2	long	0,045	0,280	0,990	sine	3080	3	0,033	3,0	102	18
6	Dynamic 3	D3	long	0,090	0,280	0,495	sine	3080	3	0,033	6,1	102	37
7	Seismic 1	E1	long	0,090	0,280	0,495	sine	1750	3	0,059	6,1	103	37
8	Seismic 2	E2	long	0,090	0,280	0,495	sine	3900	3	0,026	6,1	101	36
9	Bi-Directional	B	long	0,090	0,280	0,495	sine	3080	3	0,033	6,1	102	37
10	Property verification	P2	long	0,090	0,280	0,495	sine	3080	3	0,033	6,1	102	37
11	Service	S	long	0,120	0,005	0,007	sine	3550	20	0,029	3015,9	101	49
12	Load Bearing Capacity	BC	vert	-	-	-	constant	9720	-	-	60,0	-	-
13	Post-Test	PT2	vert	-	-	-	constant	4860	-	-	600,0	-	-
14	Ageing	P3	long	0,090	0,050	0,088	sine	3080	3	0,033	33,9	102	37
15	Integrity of overlay	O	long	0,090	0,280	0,495	sine	3080	3	0,033	6,1	102	37

Table 1 – Test matrix for prototype test

All results were recorded, and a comprehensive test report was provided by Ruhr University Bochum. The test plot in figure 9 is a representative example of a typical performance of the pendulums.

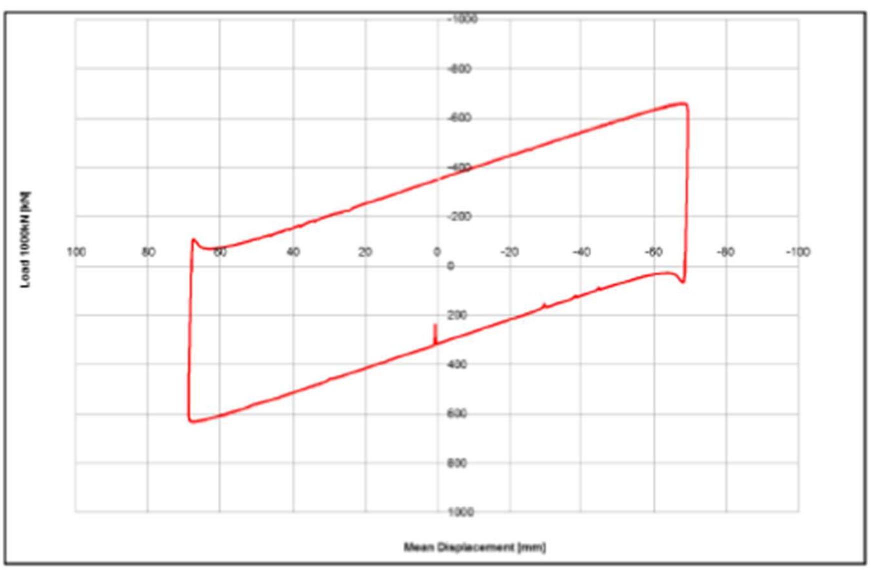

Figure 9 – Test plot of load/ displacement hysteresis loop

CONCLUSIONS

With the proposed alternative isolation system using Sliding Isolation Pendulum Bearings, the Agigea Bridge is well protected against damages from seismic impacts. The response forces of the alternative pendulum bearing system are less than the ones of the original planned system. This results in a more economical design of the structure itself. With the used materials a long service life of the isolation system and therefore also for structure, without any maintenance, is guaranteed. The alternative solution was designed to fulfill the original requirements regarding the stiffness. The behavior and characteristics of the Sliding Isolation Pendulum bearing devices will be the same over the complete lifetime. There will be no negative effect of aging and hardening as it occurs with rubber materials.

In summary, the use of isolators made of steel, for protection of bridges against seismic damages, is the most economical solution, considering also the better performance, regarding the whole lifetime of the structure, compared to a rubber made system.

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