Agigea Bridge

A cable stayed Motorway Bridge with specific proposal for anti-seismic bearing system

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Abstract The Agigea Bridge is a 900m long motorway bridge in Romania, located close to the black sea. It was opened in 2015. The main bridge is a cable stayed bridge with a length of 360m and its bridge deck is made of steel. The structure is located in a seismic area, therefore a special bearing system with anti-seismic devices was considered, consisting of lead rubber bearings and hydraulic dampers. In total 16 lead rubber bearings and 4 hydraulic dampers were provided 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 mixed system with hydraulic dampers and lead rubber bearings. The construction company decided to use the offered alternative system. All sliding isolation pendulum bearings were strictly designed according to EN 15129. With the presentation the different bearing systems and its function for the Agigea Bridge will be analysed and the technical and commercial benefit will be explained.

1 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 damages and to enable a long service life time. Therefore the bearing system of the Agigea main Bridge was planned with in total 16 nos. of lead rubber bearings for pylon P1 and P2 and abutment P8 and P9. 4 lead rubber bearings per axis. Additional 4 nos. of hydraulic dampers at the abutments P8 and P9 were required. The idea of this system was to transmit the vertical loads at the piers and abutments and to generate energy dissipation and re-centering after an earthquake. To absorb the big horizontal forces in case of earthquake, additional dampers at the abutments were planned to install. A view of the main bridge is shown in figure 1.

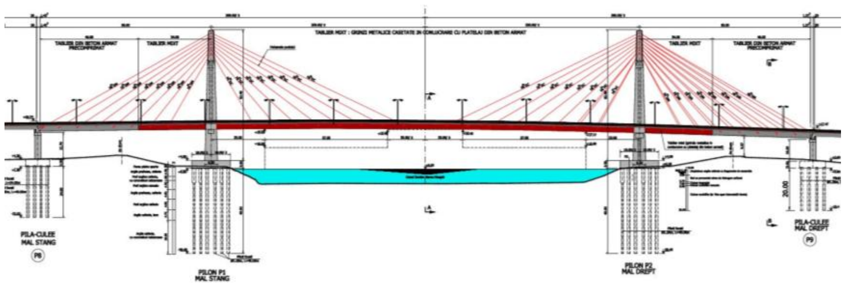

Figure 1 – View of main bridge

3 Planned 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 is 10,000 kN and the displacement capacity with ±260 mm. Additional hydraulic dampers with a response force of 1200 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. This system results in horizontal forces per bearing of 700 kN at piers and of 430 kN at abutment. The total design horizontal force in longitudinal direction therefore is 9,320 kN. Figure 2 shows the original planned bearing system.

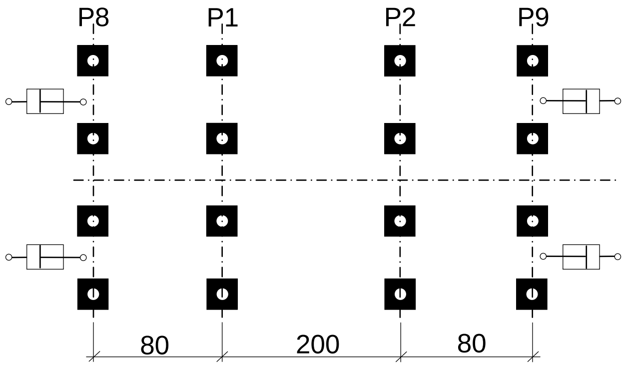

Figure 2 – Bearing layout planned

4 Conducted bearing system

The alternative proposal exists only of 16 nos. Sliding Isolation Pendulum bearings (SIP) with a single curved sliding surface. With the use of SIP's 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 is 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 is 3,636 kN. This force is approximately two times smaller compared to the planned system. But the horizontal stiffness of the complete system is nearly the same as planned from the beginning.
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 certificated material, a long service life time without any maintenance will be 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.

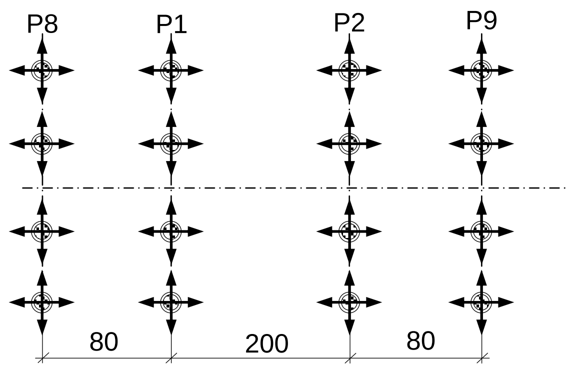

Figure 3 – Bearing layout executed

5 Sliding Isolation Pendulum Bearings (SIP) - general notes

The Sliding Isolation Pendulum (SIP-S) is consisting of three main steel parts with inner sliding surfaces. The shape of the internal part is always spherical and allowing rotations and horizontal sliding displacements as well. The device is transmitting the vertical loads (W) and is providing free horizontal flexibility (D), while dissipating energy.

Compared to flat sliders the SIP-S type provides re-centering capability. The purpose of the self-centering capability requirement – return of the structure to former neutral mid position – is not so much to limit residual displacements at the end of a seismic attack, but rather, 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 partners creates energy dissipation.

The structural control is provided by a well defined coefficient of friction between the special sliding partners (MSM® and stainless steel) which grants for the transformation of displacements energy into heat energy. In figure 4 the main function of a Sliding Isolation Pendulum bearing even at maximum displacement position, is illustrated.

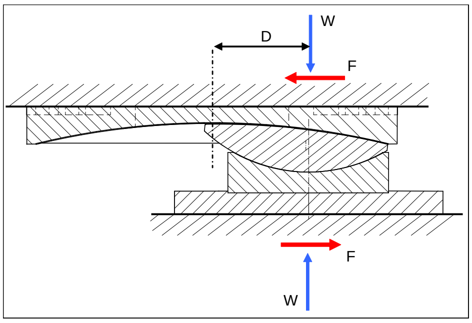

Figure 4 – Function of Sliding Isolation Pendulum bearing

Movement is enabled by a single concave sliding plate with a stainless steel sheet on the surface. Against this the liner material MSM® is sliding. The liner material is fixed by a special recess construction to the spherical part.

For dust protection an elastic rubber apron is fixed to the upper part and protecting the sliding surface against major dust. Figure 5 shows the main elements of a Sliding Isolation Pendulum bearing.

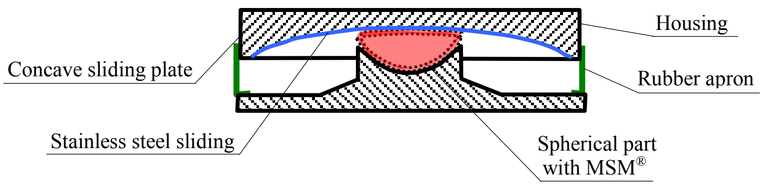

Figure 5 – Elements of a Sliding Isolation Pendulum bearing

The main point, designer have to consider for the design of the superstructure and the piers are the response horizontal forces due to movement of the bearings. These forces have a big effect in the dimensions of the piers, Superstructure, abutments and even on the foundation. Therefore the bearing system should be chosen under this aspect. 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.

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

6 Sliding Isolation Pendulum for Agigea Bridge

For 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 is 4,5% and of type 2 it is 3,3%. Both types were connected by welding at site to the steel superstructure and to a steel anchor plate at substructure. Figure 6 and 7 shows the cross section of executed Pendulum bearings type 1 and type 2.

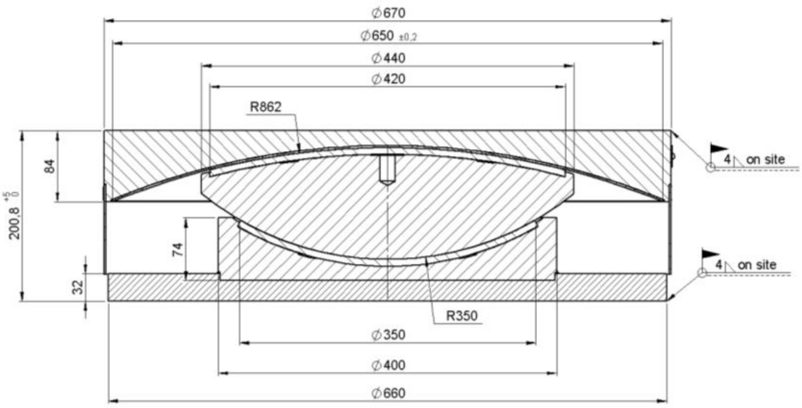

Figure 6 – SIP-S type 1

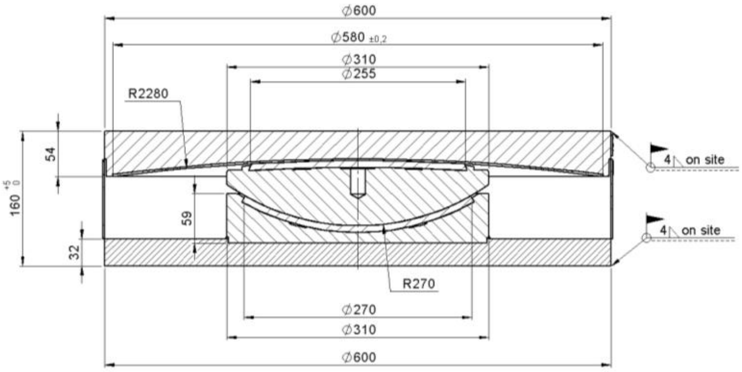

Figure 7 – SIP-S type 2

6 Testing

The sliding isolation pendulum bearings were strictly designed in accordance to EN 15129, the European standard for Anti Seismic Devices. According to this standard, prototype tests have to be done to prove the theoretical 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.

Figure 8 – SIP-S installed in test machine

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

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 written by Ruhr University Bochum. The real test plot in figure 9 is an example of the typical behaviour of the pendulums.

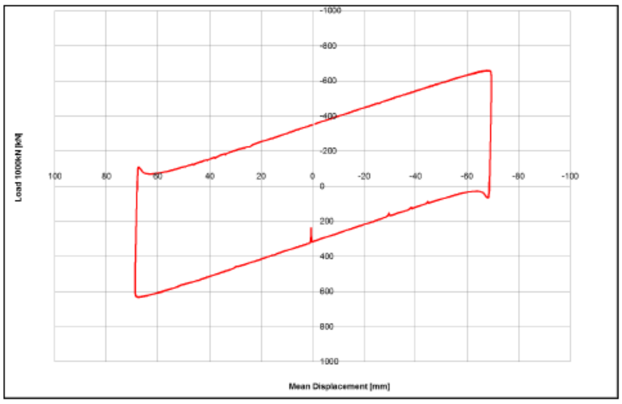

Figure 9 – Test plot of load/ displacement hysteresis loop

4 Conclusions

With alternative isolation system, the Agigea Bridge is very well protected against damages due to service and 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 life time 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 characteristic of the Sliding Isolation Pendulum bearing devices will be the same over the whole life time. There will be no negative effect of aging and hardening as it will happen with rubber material.
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.

References

1. Huber P, (2007) MAURER Premium Seismic Isolation with Sliding Isolation Pendulums
2. Holterman L, (2015) MAURER Technical Drawing, 665502-01 and 665502-02
3. Dr.-Ing. H. Alawieh, (2015) Ruhr-Universität Bochum, Certification Tests on four Sliding Isolation Pendulum Bearings, Report