16th World Conference on Earthquake, 16WCEE 2017

Santiago Chile, January 9th to 13th 2017

Paper N° 40

Registration Code: S-D1459847475

SEISMIC ISOLATION OF DJAMAÂ EL DJAZÏR MOSQUE IN ALGIERS

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Abstract

The Great Mosque of Algiers (Djamaâ El Djazïr) will be the third largest in the world and shall be completed in 2016/2017. The mosque building has a plan size of 145 x 145 m and a height of 65m while hosting up to 32,000 people. This main building was decided to be placed on 246 nos. seismic curved surface sliding isolators to mitigate the specified seismic PGA of 0.65 g.

The isolation period of the system was chosen to be 3,1 s, to achieve sufficient reduction of incoming ground accelerations. The isolators must carry more than 27,000 kN each. The necessary damping for displacement limitation is provided by approx. 30 % from 3 % sliding friction within the isolators and by approx. 70 % from additional hydraulic dampers. This system limits the horizontal seismic displacements within a specified value of +/-500 mm, which was even magnified by the g_x reliability factor of 1.2 (EC 8) to +/-600 mm.

The additional 80 nos. hydraulic dampers with 2,500 kN capacity not only provide additional damping to limit the max. seismic displacements to 500 mm, but they allow a more smooth damping and shear force depending on the seismic impact. Thus the damping performance can be assumed to be adaptive. The dampers display a soft force development for velocities up to 400mm/s with a damping exponent of 0.4, what creates less response forces for minor to medium earthquakes. This characteristic was also not possible to be created alone – without dampers - by the applied curved surface sliders with defined high friction levels of approx. 8%, as the high friction would be always active – also for minor earthquakes and results in bad re-centring combined with great shear. For the maximum credible earthquake the dampers have been equipped with an integrated force limiter function starting from 1,000mm/s and being active up to 1,200mm/s in order not to overload the damper, the brackets, the anchoring or the structure.

The CE marking and testing according to EN15129 in University of California San Diego and EU Center Pavia was a must for this project. A theoretical service life span of 500 years was proven by wear and fatigue testing.

The author will present in this paper the design considerations and testing of curved surface sliders and hydraulic dampers to be applied within the huge Djamaâ El Djazïr Mosque in Algiers.

Keywords: curved surface sliders, pendulum isolators, hydraulic dampers, structural isolation

1. Introduction

The Great Mosque of Algiers (Djamaâ El Djazïr; Figure 1) will be the world´s third biggest mosque with approx. 120,000 expected daily visitors. The total gross surface is 400,000 m², while the Prayer Hall building itself covers 145 x 145 m with 21,075 m ², which will host up to 37,000 people.

Fig. 1 - Grand Mosque of Algier - Djamaâ El Djazïr Mosque

Due to the severe seismicity in this area (VIII-IX at the modified Mercalli Scale) a PGA of 0.65 g (Figure 2) had to be applied, which is resulting in a maximum elastic response of up to 1.9 g [1]!

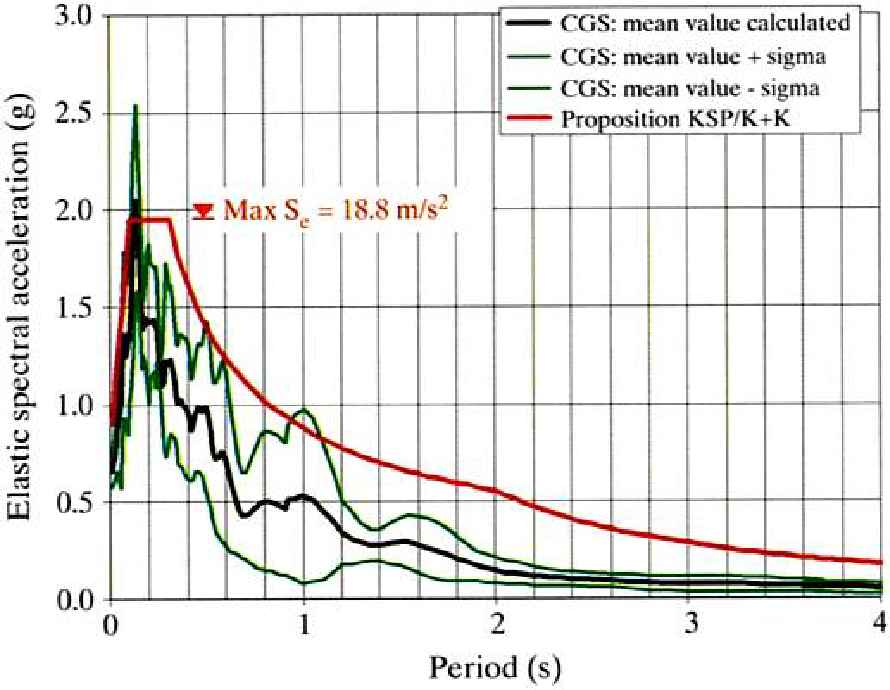


Fig. 2 - Elastic response site spectrum [1]

To reduce significantly the accelerations within the structure the mitigation design approach with seismic isolation combined with energy dissipation was chosen, which allows to go for outstanding structural design with slenderness and transparency. Any structural devices that are appropriately inserted into the structure under the base slab (Figure 3) for seismic isolation shall be robust, shall cause no or easy maintenance and have a theoretically proven service life of 500 years.

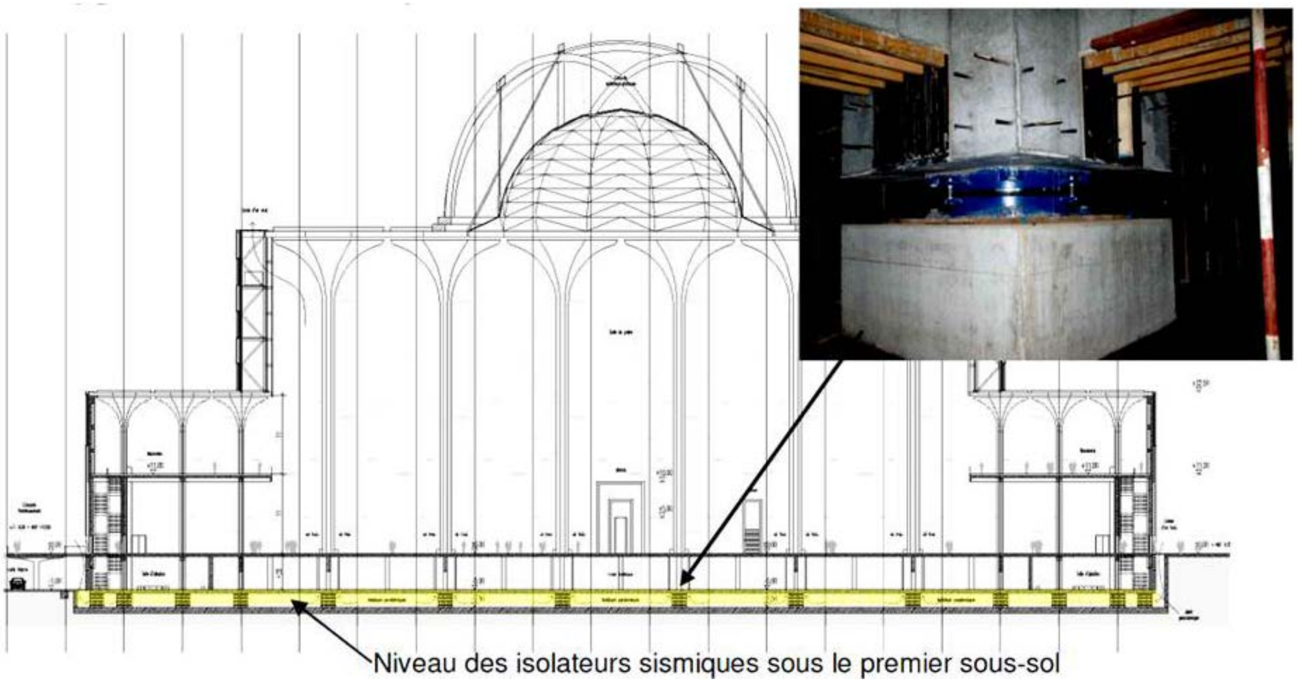


Fig.3 - Seismic isolators under base slab with picture of installed device

The location of the isolators and horizontally acting additional hydraulic dampers was mainly based on the column axes grid (Fig. 4, 5, 9).

2. Design considerations and devices

2.1 General considerations about applied devices

The tender specified to apply curved surface sliders with double sliding surfaces and internal hinge system to accommodate service rotations due to ground setting effects and structural tolerances. The finally applied MAURER SIP DR type of devices comply with standard EN15129 chapter 8.3 [5]. They must provide the required lengthened system period and partly the damping what shall be realized by the radius (green in Fig. 4) in the concave sliding surfaces and friction within the sliding couples (red in Fig. 4).

These devices are absolutely resistant to ageing as only steel and polyethylene parts are installed and rubber components are not applied at all. A fire protection coat is not necessary for the steel made curved surface sliders, but would had been necessary in case of rubber bearings to achieve the specification of the project.

The required damping forces of max. 160,000 kN [2] in total, are not only provided by the friction within the isolators but by additional 80 nos. horizontally acting hydraulic dampers of MHD type. Each of these dampers provides 2,500 kN necessary damping forces and is designed for max. 3,065 kN force response (Fig. 5 (a), (b)).

Having in mind the desired 500 years of service life span the SIP DR and the MHD devices are suitable as ageing is not occurring, for both products. The wear testing was carried out for 10,000 m according to EN1337 [6] and the dynamic testing according to EN15129 [5] showed stable performance for many MCE earthquake events.

The applied corrosion protection system for the isolators and the dampers was 80 µm zinc phosphate plus 180 µm epoxy iron oxide and 80 µm PU blue glossy cover what satisfies even severe marine requirements – even these are not occurring in the cellar of the prayer hall.

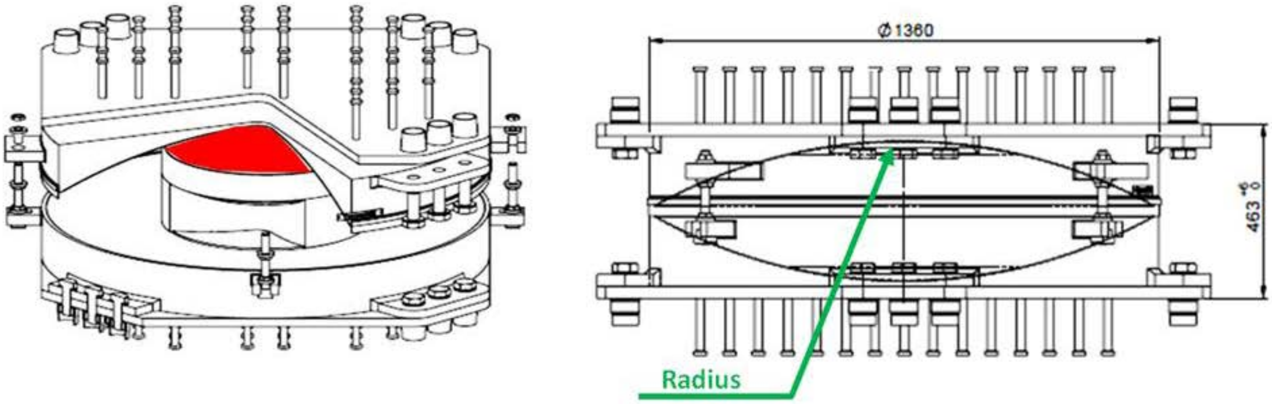
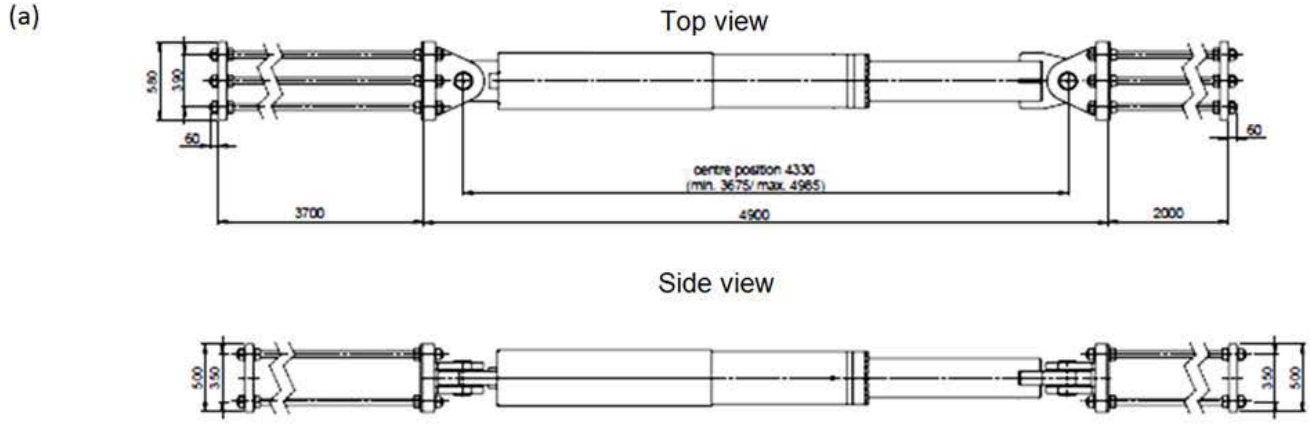


Fig. 4 - Seismic isolator of type SIP DR providing damping and lengthened system period

The SIP DR isolators are anchored by massive anchor plates to the concrete which are designed to transmit a max. shear force of 5,536 kN by 52 nos. shot-welded concrete anchor dowels to the structure.
The MHDs are fitted with 6 nos. up to 3,700 mm long tension-shear anchors with 48 mm diameter at both ends (Fig. 5 (a)).



(b)

Inside view - principle

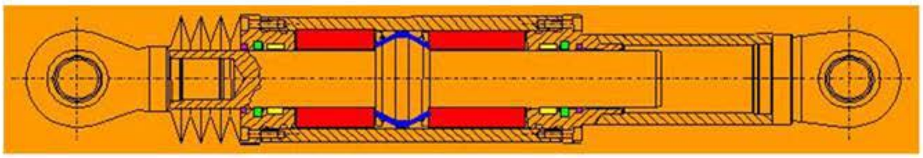


Fig. 5 - Hydraulic dampers of MHD type with max. 3,065 kN force response: (a) Damper for the project and (b) inside view with a special anti-leaking triple-seal-guide system

2.2 Required damping within the isolation system

The structural calculations were performed by the designer KREBS+KIEFER according to EN1998-1 [4] and required 160,000 kN [2, 3] max. damping forces to achieve +/-500 mm [1] real seismic displacement combined with 30 % [1] equivalent system damping. These damping forces would require more than 8 % dynamic friction within the isolators considering approx. 195.000 t structural mass for the seismic load. For the isolation system the specified 30 % equivalent system damping is a rather important value. Especially for smaller earthquakes in case of 8 % friction within the isolators no or only small displacements will occur. These will be combined with relatively big horizontal response forces and accelerations within the mosque for these small to medium seismic events with a lack of re-centring.

Therefore the designer requested a hybrid system to achieve smooth sliding combined with perfect re-centering capabilities for frequently occurring earthquakes and the high damping demand for the MCE earthquake event. Thus one part of the damping is coming from 3 % dynamic sliding friction within the SIP DR devices and the other part from the hydraulic dampers (MHD). The 3 % dynamic friction damping is always available during any earthquake – independent from the displacement velocity. This is the basic system damping, while the structure is held in position for wind impacts. The MHDs provide a damping force which is dependent on the velocity with a damping exponent of 0.4 up to 1m/s what is the specified project design velocity (Fig. 6) with a corresponding regular max. seismic response force of 2,500 kN.

$$Damper\ force = C \cdot v^{\alpha} \qquad (1)$$

The hydraulic dampers enable better re-centring of the prayer hall during and after an earthquake as their maximum forces during oscillations occur with phase-shift to the re-centring forces and their forces are low for small displacements or velocities respectively.

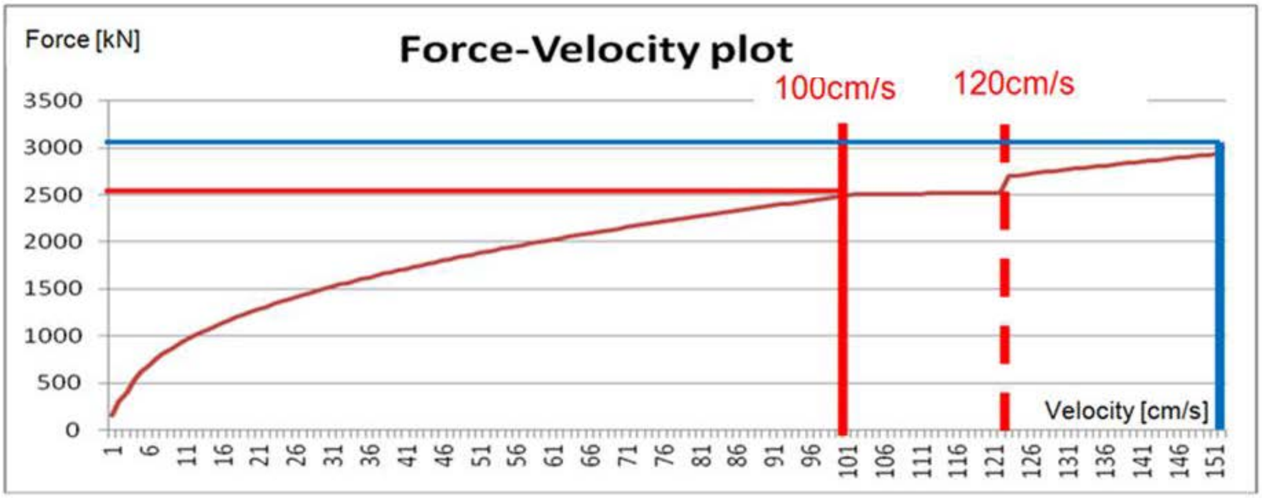


Fig. 6 - Specified force-velocity-plot of MHD type [1]

The rather large damping exponent of 0.4 up to 1 m/s grants for smaller and medium seismic events with small displacement velocities smooth and small response forces. In addition MAURER proposed and designed from 1 m/s to 1.2 m/s a damping exponent of 0.05, i.e. this is a force limiter mechanism within the MHD to protect the structure and itself from overload effects. To satisfy the over-velocity safety demand a reliability factor of 1.5 for dampers according to EN15129 [5] was applied. Therefore the MHD design is even considering a max. design velocity of 1.5 m/s. Within 1.2m/s to 1.5m/s the damping exponent is again 0.4 (Fig. 6). Finally the upper design force level for the hydraulic damper was 3,065 kN and not like originally specified 2,500 kN only.

This system is a good back-up as approximately 30% of the damping is coming from the isolators (246 nos.) with lower friction level and approximately 70 % of the damping is provided by hydraulic devices (80 nos.) achieving a big safety with regard to reliability and possible failures. The prayer hall behaves smoothly for small to medium earthquakes but the isolation system will increase the damping rapidly to the required level of 30% for the MCE event with effective displacement limitation.

2.3 Required displacement capability within the isolation system

The calculated pure seismic displacement from the FE time history analysis is +/-500 mm [2], what was multiplied with a reliability factor of g_x = 1.2 according to EUROCODE 8 [4] resulting in +/-600 mm [1] seismic displacement demand. In addition to these displacements it was decided to consider - due to the big plan area size of 145 x145 m of the structure - creep/shrinkage with +/-40 mm and 50 % of the thermal displacements with +/-15 mm. Thus the final design displacement capacity for all devices was defined to be +/-655 mm.

The lead rubber bearings were rejected besides of ageing and fire resistance due to buckling stability problems for the maximum design displacement amplitude combined with the required corresponding vertical loads. The SIP DR isolator is extremely stable even at maximum displacement position combined with max. load of 27,000 kN (Fig. 7).

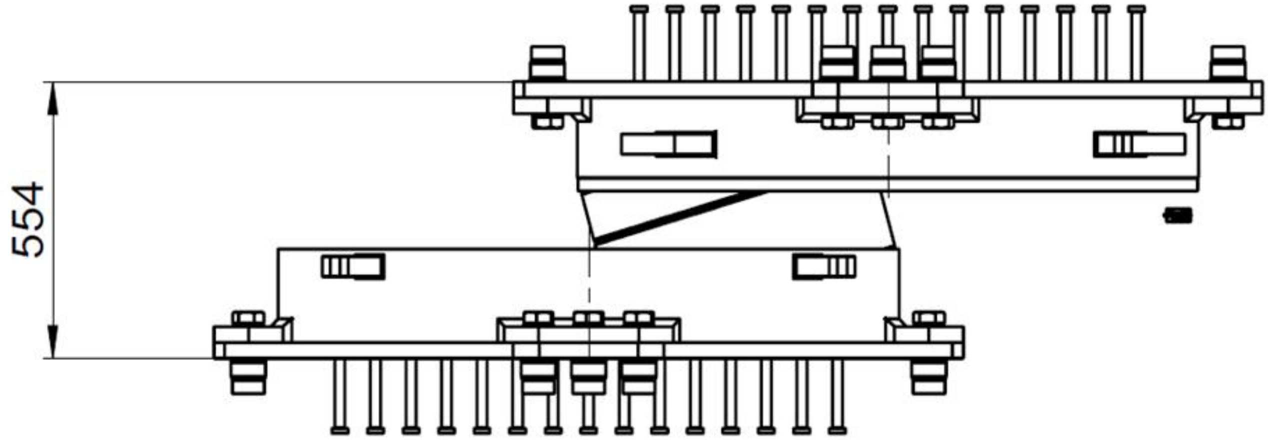


Fig. 7 - Seismic isolator of SIP DR type at max. displacement of +/-655 mm

2.4 Required stiffness within the isolation system

The intention was to shift the first natural period of the non-isolated structure from T = 0.85 s to T1 = 3.1 s to achieve a significant decrease in response acceleration in the design spectrum (Fig 2). Therefore the elastic system stiffness k (without friction or damper participation) was specified to be 750,000-850,000kN/m [2] - corresponding to 3.1 s structural period - and was realized with 2.4m effective radius within the curved surface sliders when considering 195,000 t structural mass for the seismic design. The re-centring of the system is ensured with this system stiffness k.

$$k = \frac{(195{,}000t \cdot g)}{2.4m} \tag{2}$$

The effective system period with consideration of friction and hydraulic dampers is then in the range of 2.6 s.

2.5 Arrangement and layout of isolation and dampers

The SIP DR isolators (green and blue in Figure 8) were placed under any main column of the prayer hall to allow good vertical load transmission. The distance between the single isolators varies between approx. 6-15 m (Fig. 8, 9).

40 nos. dampers (red in Fig. 8) are arranged in X- and 40 nos. dampers are acting in Y-direction (Fig. 8, 9), as the hydraulic piston dampers can act in one certain direction only. The spherical plain bearings between both damper body ends and the support brackets towards the structure allow the rotation of the damper occurring when simultaneous displacements in X- and Y-direction happen.

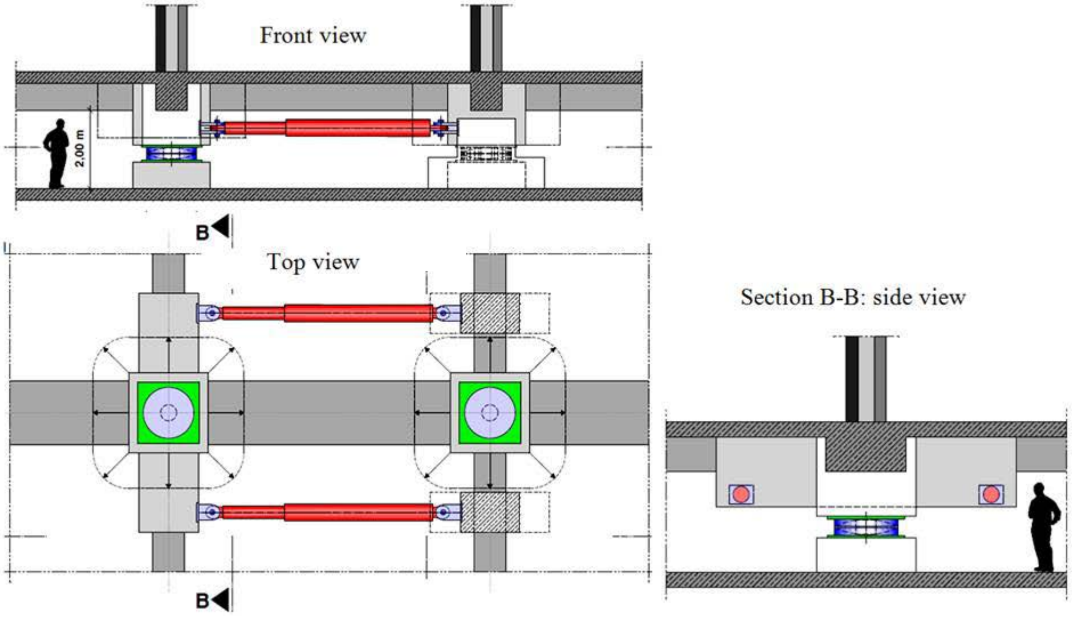


Fig. 8 - Arrangement of dampers and isolators [1]

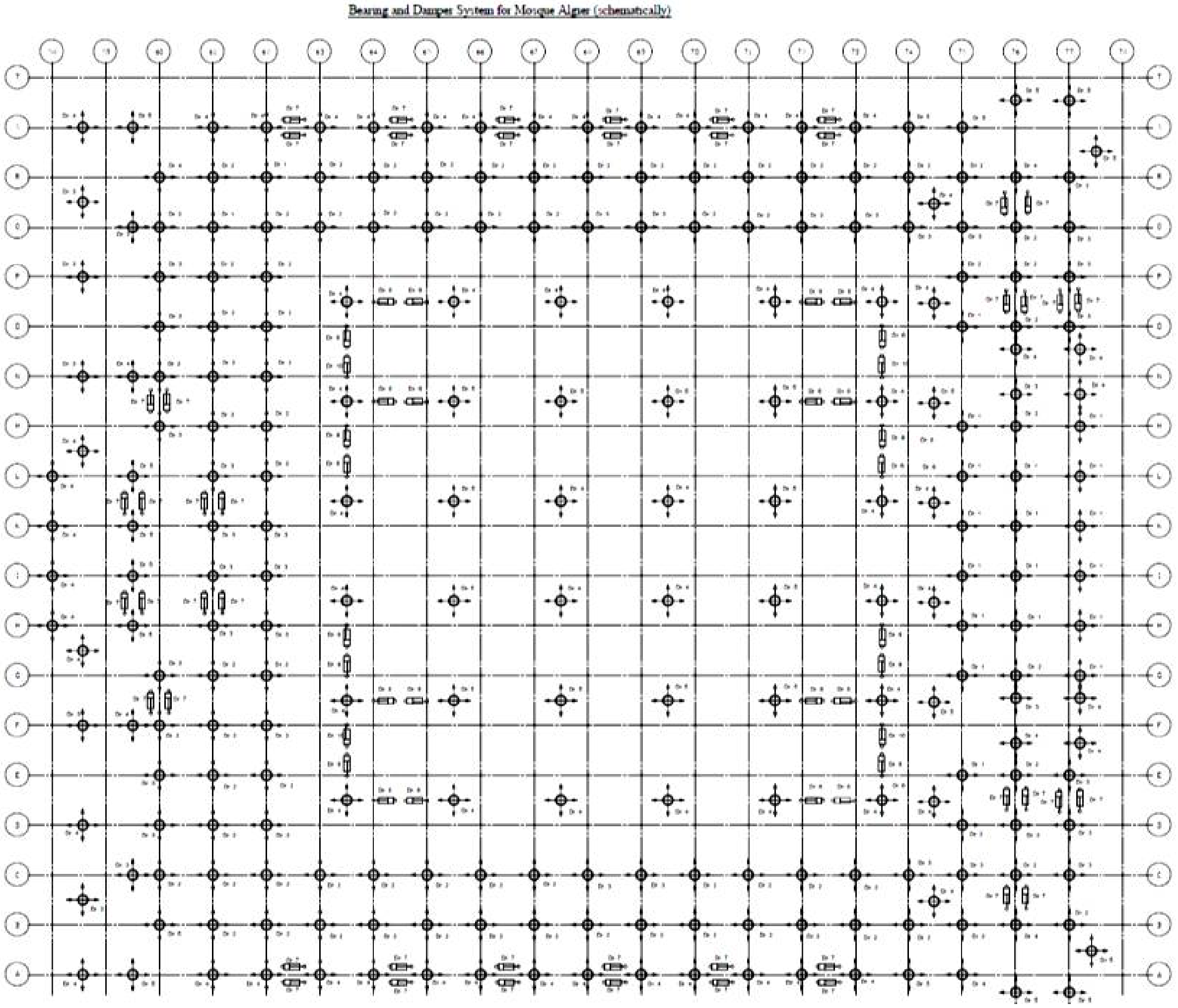


Fig. 9 - Layout of dampers and isolators [1]

3. Testing for CE marking

3.1 Isolators - SIP DR

The prototype and production testing was performed at the University of California in San Diego/USA within the CALTRANS SRMD Test Facility. The first prototype testing of the SIP DR devices were in Nov. 2012 (Fig. 10, 11) including eight devices. In August 2013 the second part for the production testing was carried out. Within the testing the compliance to EN15129 [5] was investigated and achieved with 3 % average dynamic friction for the specified seismic design loads.

To issue the CE mark (Fig. 12) on the isolators, additionally the EN1337 [6] had to be fulfilled, what requires to have an European Technical Approval (ETA-06/0131 [7]) for the applied high performance MSM® sliding liner material.

Fig. 10 - Prototype isolators installed into CALTRANS test rig in San Diego

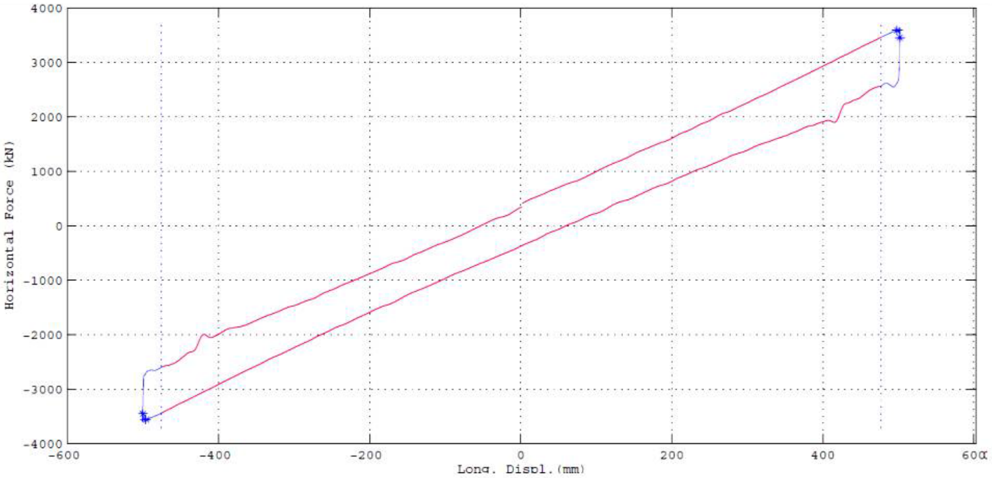
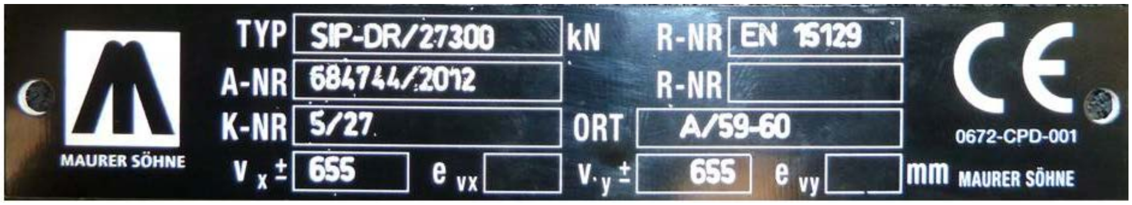


Fig. 11 - Original hysteretic loop of tested SIP DR for 1,000 mm/s velocity and 15.000 kN load [8] resulting in 3,600 kN lateral force due to 3 % friction and 2.4 m system radius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TYP SIP-DR/27300 kN R-NR EN 15129

A-NR 684744/2012 R-NR

K-NR 5/27 ORT A/59-60

V x ± 655 e vx V y ± 655 e vy mm

0672-CPD-001

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Fig. 12 - CE mark for SIP DR

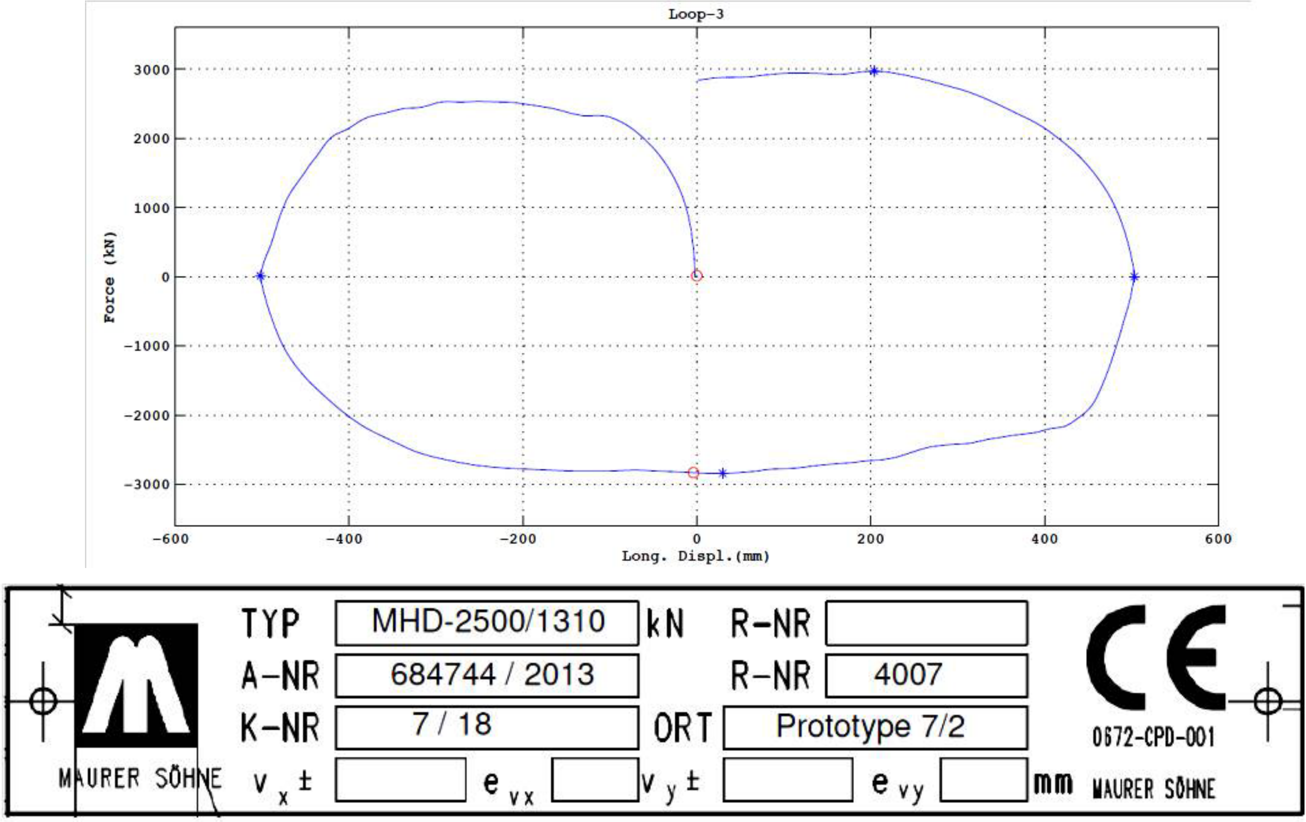
3.2 Hydraulic dampers - MHD

The prototype and production testing was performed at the University of California in San Diego within the CALTRANS SRMD Test Facility end of March 2013 (Table 1, Fig. 13 & 14) including four devices.

For the constant pressure test 50 MPa were induced on every MHD for 120 s. During this test there was a pressure drop of 0.3-0.6 MPa only without leaking effects what is far within the norm and showed no leaking effects. The special triple-seal-guide system within the MHD allows good lubrication to avoid wearing, but is not showing any leaking of the hydraulic oil.

Table 1 - MHD test data and requirement acc. to EN15129 [4]

Test #	Test name	Chapter in EN 15129	d [mm], +/-	v [mm/s]	Excitation	Number of cycles	Expected force [kN]	Actual force [kN]	Δ force [%] max. +/-15%
1	low velocity testing	7.4.2.3	30	<0,1	(0 … +d …-d … 0, const)	1	250	17	-
2	Constitutive law tests	7.4.2.5	500	17	(0…+d…-d…0,sinusoidal)	3	490	425	-13,3
3				250			1436	1539	7,2
4				500			1895	2165	14,3
5				750			2228	2530	13,5
6				1000			2500	2824	13,0
7	Damping efficiency tests	7.4.2.7	200	500	sinusoidal	1	1895	1921	1,4
				500		2	1895	1868	-1,4
				500		3	1895	2120	11,9
				500		4	1895	2130	12,4
				500		5	1895	2140	12,9



TYP MHD-2500/1310 kN

R-NR

A-NR 684744 / 2013

R-NR 4007

K-NR 7 / 18

ORT Prototype 7/2

v x ± e vx v y ± e vy mm

Fig. 13 - Original hysteretic loop of tested MHD for 1,000mm/s velocity [9] on top; CE mark on bottom

Fig. 14 - Damper test at EU Center Pavia on bottom;

The damper tests fulfilled the EN15129 requirements and CE marking was issued (Fig. 13).

4. Conclusions

The applied isolation damping system for the Grand Mosque of Algiers consists of double curved surface sliders combined with horizontally acting hydraulic dampers. These devices - considering the EC8 based design of the structure and the significantly increased PGA of 0.65 g - fulfill the 500 year service life time requirement and provide more than 30 % system damping.

The SIP DR isolators provide together with the European Technical Approval for the MSM® sliding liner, the 10 km wear testing and the excessive high velocity dynamic seismic testing, the best possible reliability and durability combined with constant friction performance characteristics. The MSM® liner material is not showing stick-slip or any wearing effects for any velocity.

The 80 nos. MHD dampers offer redundancy and additional high damping depending on velocity. A special force-velocity characteristic with variable damping exponent was achieved to create smooth forces for the small to medium earthquakes with perfect system re-centring performance. The MHDs ensure a force reduction for the MCE events while fulfilling the damage limitation requirement even beyond the required 1 m/s design velocity up to 1.5 m/s velocity.

The overall isolation system is considering remarkable reliability factors on the basic seismic input data, on the displacement of the devices and on the possible over-velocity. This allows to assume the highest possible probability for continued functionality while fulfilling the damage limitation required for this project.
All devices were successfully tested at University of California in San Diego/U.S.A. and at EU Center in Pavia/Italy.

5. Acknowledgements

The author would like to thank especially the University of California in San Diego/USA., EU Center in Pavia/Italy, Material Testing Institute (MPA) of University Stuttgart/Germany and KREBS+KIEFER/Germany for their co-operation.

6. References

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