8th World Seminar on Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures Yerevan, Armenia, October 6-10, 2003

SEISMIC PROTECTION OF THE RION-ANTIRION BRIDGE

Samuele Infanti[1], P. Papanikolas[2], M.G. Castellano[3]

[1]*FIP Industriale, Via Scapacchiò 41, 35030 Selvazzano Dentro (PD), Italy, infanti.fip@fip-group.it*

[2]*Kinopraxia Gefyra, Antirio Aetolocarnania PC 300 20, Greece , ppapanikolas@gefyra.com*

[3]*FIP Industriale, Via Scapacchiò 41, 35030 Selvazzano Dentro (PD), Italy, castellano.fip@fip-group.it*

ABSTRACT

The Rion-Antirion Bridge, which crosses the homonymous strait in Greece, is located in a region prone to high intensity earthquakes and large tectonic movements generated by local active seismic faults. The deck of the multi-span cable stay bridge is continuous and fully suspended (for its total length of 2,252 meters) from four pylons (with spans 286m + 560m + 560m + 560m + 286m). The approach viaducts to the main bridge comprises for 228m of precast concrete girder decks on the Antirion side and for 990m of steel composite decks on the Rion side. The structures are designed to withstand seismic events with peak ground acceleration of 0.48g (2000 years return period) and tectonic movements between two piers of 2 meters in any direction. This was possible through the use of innovative energy dissipation systems that connect the deck to the top of each pier and limits the movement of the decks during the specified earthquake, while dissipating the seismic energy.

The seismic protection system of the Main Bridge comprises fuse restraints and viscous dampers acting in parallel, connecting the deck to the pylons. The restrainers are designed as a rigid link intended to withstand the high wind loads up to a pre-determined force corresponding to a value slightly higher than the wind load ultimate limit state. Under the specified earthquake, the fuse restrainers are designed to fail, leaving the viscous dampers free to dissipate the energy induced by the earthquake into the structure.

The behavior and the requirements of the dissipation systems were optimized with the help of a non-linear time history numerical analysis on a 3D model. It resulted on seismic devices (viscous dampers and fuse links) characterized by extreme design parameters in terms of force, velocity and stroke, with dimensions and weight never attempted before. The design assumptions and the actual behavior of the seismic protection system had to be confirmed with extensive testing of full-scale prototypes.

The Approach Viaducts are isolated from the ground motion through a system composed of elastomeric isolators designed to provide for the bearing function as well as the required period shift effect and by viscous dampers providing for the energy dissipation. Even in this case, numerical analysis provided the units optimized characteristics and full-scale tests have been performed to verify the design assumptions.

The aim of the present paper is to describe the mentioned seismic protection systems as well as the results of the full-scale prototype testing. The Viscous Damper Prototype tests were

performed at the laboratory of the University of San Diego California (USA), while the Fuse Restraints tests and all the production tests were carried out at the FIP Industriale Testing Laboratory in Italy.

Figure 1. The Rion-Antirion Bridge

1 INTRODUCTION

The Rion-Antirion Bridge (see figure 1), located in the Gulf of Corinth - an area prone to strong seismic events and windstorms -, consists of a cable stayed main bridge 2,252 m long on four large foundations with a span distribution equal to 286m + 560m + 560m + 560m + 560m + 286m and of two approach viaducts (987 m long on the Rion side and 239 m long on the Antirion side).

The cable-stayed deck is a composite steel structure made of two longitudinal plate girders 2.2m high on each side of the deck with transverse plate girders spaced at 4m and a concrete slab, the total width being 27m.

Each pylon is composed of four legs 4x4m, made of high strength concrete, joined at the top to provide the rigidity necessary to support unsymmetrical service loads and seismic forces. The pylons are rigidly embedded in the pier head to form a monolithic structure, up to 230 m high, from the sea bottom to pylon top (see figure 2).

The deck of the main bridge is continuous and fully suspended by means of stay cables for its total length of 2,252m. In the longitudinal direction, the deck is free to accommodate all thermal and tectonic movements.

Figure 2. The main bridge under advanced construction (September 2003)

The bridge is equipped with a damping system that, for its characteristics and for the strict design requirements, entitles to put this structure in the next generation of seismic protected structures.
The seismic protection system of the main bridge comprises viscous dampers connecting in the transverse direction the fully suspended deck to the pylon base.
These viscous dampers are of ever built dimensions and design capacity and shall be installed at the pier to deck interfaces in order to reduce the transverse swing of the deck during a dynamic event.
They are designed to dissipate the energy introduced into the structure by the earthquake. Requirements for a proper and safe seismic behavior are sometimes not in agreement with the everyday service life of the structure. Thus, large structural displacements induced by moderate earthquakes or windstorms are avoided by an additional restraint system, that at the occurrence of a major design event fails allowing the structure free to oscillate with its damping system.
This system is composed by Fuse Restraints installed in parallel to the dampers, so that the deck, when subjected to lateral loads not exceeding their design capacity, is linked rigidly to the substructure, while after failure it leaves the deck free to swing coupled to the dampers.
The design failure force of the fuse restraints is set slightly higher than the maximum expected wind load.

Four viscous dampers (Fmax 3500 kN, Stroke ±1750 mm) and one fuse restrainer (Fmax 10500 kN) shall be installed at each pylons, while at the transition piers two viscous dampers (Fmax 3500 kN, Stroke ±2600 mm) and one Fuse Restrainer (Fmax 3400 kN) shall be considered.

Figure 3 gives the general arrangement of the four viscous dampers and the restraint device at one pylon.

Figure 4 shows the conceptual arrangement of the two viscous dampers installed at the Transition Pier. This pier is composed by a rotating frame pivoting at the base. The mentioned dampers are installed at the deck to substructure interface aligned along the deck transverse center line and rotating with the pier itself. The Fuse Restrainer is installed on one of the two dampers as a component of the damper itself.

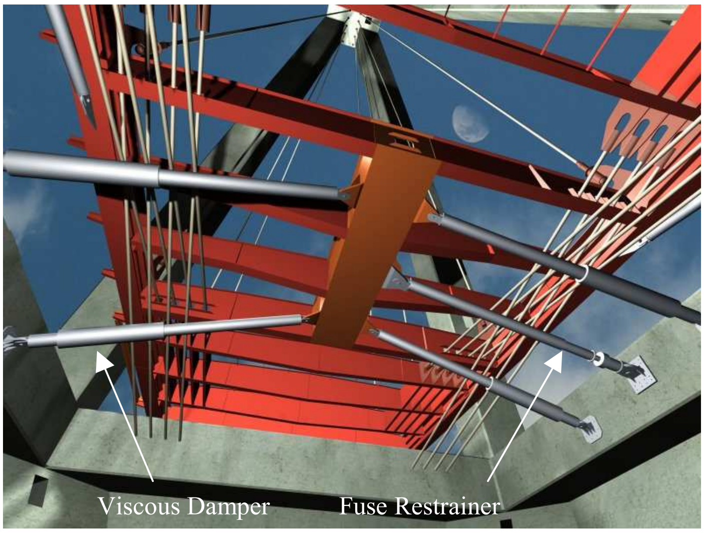


Figure 3. Rion Antirion Main Bridge: arrangement of viscous dampers on the main piers

The Approach Viaducts are seismically isolated through a system composed of elastomeric isolators designed to provide for the bearing function as well as the required period shift effect and by viscous dampers providing for the energy dissipation.
Even in this case, numerical analysis provided the units optimized characteristics and full-scale tests have been performed to verify the design assumptions.

This paper describes the different seismic devices to be applied to the Rion-Antirion Bridge, focusing on the full-scale tests carried out for qualification and acceptance purposes. General information about non-linear viscous dampers are also given below.

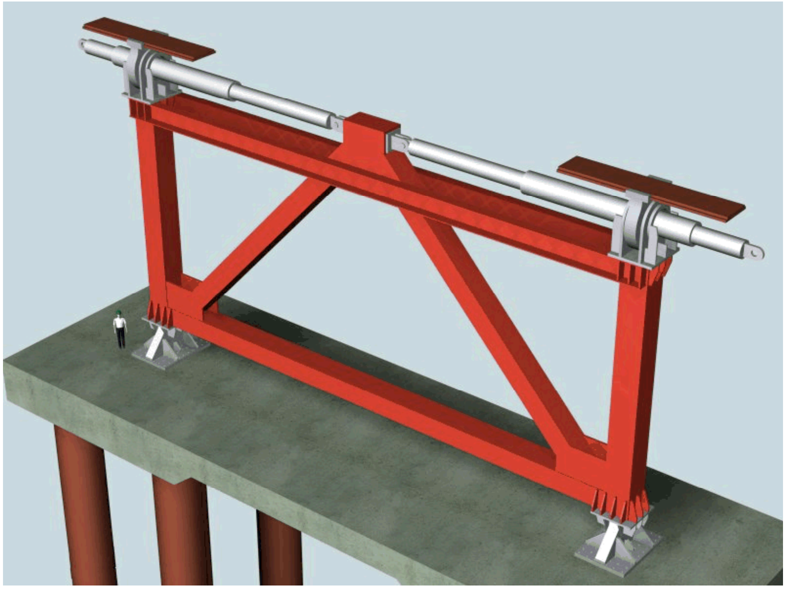


Figure 4. Transition pier configuration

2 NON-LINEAR VISCOUS DAMPERS

FIP fluid viscous dampers are piston/cylinder devices that utilize fluid flow through orifices to absorb energy. Orifices are situated in the piston head, which allow the fluid to move back and forth between the two chambers. The force generated by these devices is the result of a pressure differential across the piston head. These devices are equipped with two spherical hinges at both ends that keep the transmitted load aligned along their main axis. This detail is of major importance to provide a reliable performance: it prevents the piston rod from bending and thus the sealing system from failing. High strength steel components are used for the vessel and the plated piston rod so as to withstand the actions imposed by a dynamic load. The anchoring details depend only on the structure to which they are anchored: for example, the tang plate/clevis system illustrated in Figure 5.

In the last few years, FIP dampers have undergone major testing programs at FIP laboratory as well as at independent facilities (Earthquake Engineering Research Center, Berkeley CA – USA, Boeing Testing Facility, Canoga Park CA – USA and Caltrans SRMD Testing Laboratory at the University of California – San Diego - USA), which has entitled the company to be a pre-qualified damper manufacturer for the Golden Gate Bridge Retrofit project as well as to enter the CALTRANS (California Department of Transportation) list of pre-qualified damper manufacturers. It should be noted that remarkable reaction stability has been achieved by dynamically cycling within a very wide temperature range (-40°C ÷ +50°C) that guarantees proper behavior under any type of environmental conditions.

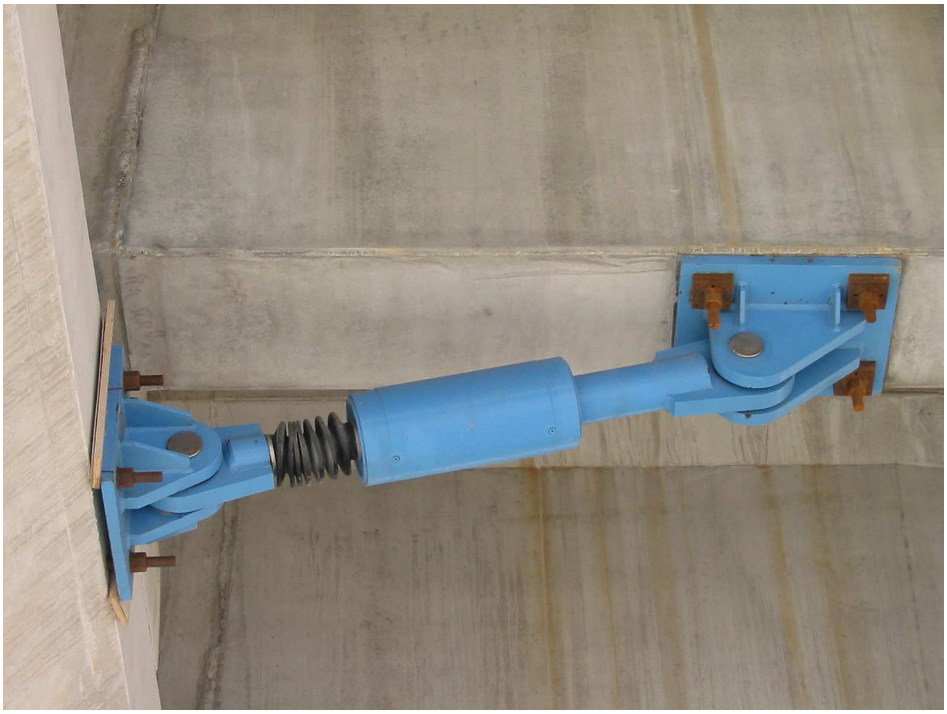
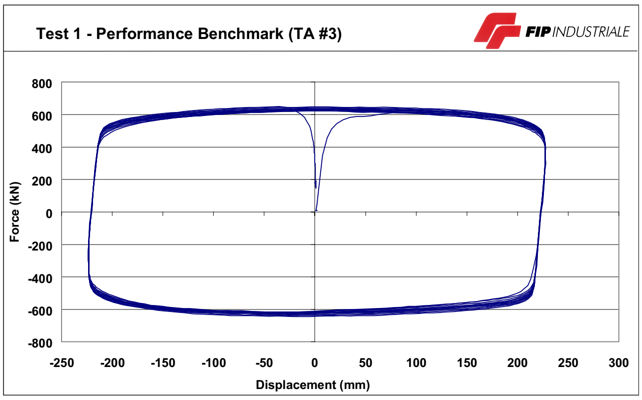


Figure 5. Typical damper anchoring configuration (photo taken during the installation)

A very important issue related to the utilization of the technology entails the correct numerical modeling of the devices as integrated into the structural model and the performance verification of the finished product.
The latter topic will be amply discussed in the following paragraphs.
.The most appropriate mathematical model to represent the behavior of an FIP viscous damper is to use a Maxwell constitutive law characterized by a linear spring in series to a non-linear dash-pot element (see Figure 6). The first element represents the elasticity of the system that is mainly due to the compressibility of the silicon fluid, while the second depicts its damping properties. The exponent that characterizes the non-linearity of the response as a function of the velocity, is particularly important. Positive effects are undoubtedly related to low exponent dampers: e.g. in bridge applications, reduced pier deformation, lower expansion joint costs and cost effective bearings or in buildings, maximum reduction of relative displacement at the isolation interface or in the braces.
FIP viscous dampers are designed to guarantee a 0.15 exponent so that, within a wide velocity range, reaction is expected to be almost constant. This performance characteristic permits the devices to initiate their damping reaction at low velocities, providing the maximum reduction of the superstructure displacement.
Total system elasticity, mathematically represented by the stiffness K, depends on the compressibility of the fluid and it is particularly evident at the point of motion reversal, or at any rate, at the point of transitory phases: commonly, it is a secondary effect and often it is not even computed.



Maxwell Model

$$x = x_0 \, sin(\omega t)$$

$$F = C\left(\dot{x} - \frac{\dot{F}}{K}\right)^{\alpha}$$

$$\alpha = 0.15$$

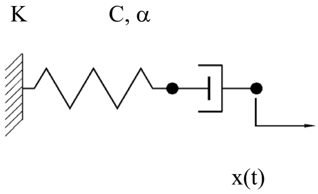


Figure 6. Damper constitutive law equation and hysteresis loop

To evaluate the response of such a system, the differential non-linear equation representing its constitutive law needs to be integrated.
Looking at the plot in Figure 6, it can be noted that this typical hysteresis loop looks almost rectangular even if the displacement time–history is sinusoidal (thus velocity dependent). This is due to the damper characteristic exponent (0.15). In fact, the behavior is almost independent from velocity. Thus total damper behavior can be similar to that of a spring in series to a ”perfectly plastic” element characterized by a constant threshold force.

3 MAIN BRIDGE SEISMIC ISOLATION SYSTEM

As above anticipated, the seismic isolation system of the main bridge comprises fluid viscous dampers and fuse restraints.
The behavior and the requirements of the viscous dampers were optimized by means of non-linear time-history analyses on a 3-D model of the entire bridge. Strict specifications were imposed with regards to the behavior of the seismic protection system in order to ensure a stable performance of all the devices: dampers reaction shall be within ±15% of its theoretical constitutive law and Fuse restrainers failure shall be within ±10% of the design value.
Full-scale tests aimed at verifying the design characteristics are described below.

3.1 Viscous Dampers Full-Scale Testing

The following paragraphs present the main result of the testing activities performed at both FIP Industriale Testing Laboratory and at the Seismic Response Modification Device (SRMD) Testing Laboratory of Caltrans at the University of California at San Diego on a full-scale prototype of the viscous dampers to be utilized on the above mentioned bridge.

Figure 7. Production damper under test at FIP laboratory

The prototype, characterized by a 3220 kN reaction at the maximum design velocity of 1.6 m/s (damping constant $C=3000kN\cdot(s/m)^{0.15}$) and by a ±900mm stroke, was submitted by FIP Industriale on February 2002 for evaluation.

This viscous damper is deemed to be the largest ever-built device of its type (6.4 m pin to pin) and was tested up to its maximum design conditions. The prototype is equal in every detail to the dampers designed for final installation with the exception of the length (and consequently of the stroke), which is shorter so as to fit into the existing test rig of the SRMD.

Table 1. Dampers Characteristics

Characteristics	Pylons	Transition Piers	Prototype
Damper Series	OTP350/3500	OTP350/5200	OTP350/1800
Stroke (mm)	-1650/+1850	± 2600	± 900
Pin-to-Pin Length (mm)	10520	11320	6140
Total Length (mm)	11310	12025	6930
Maximum Diameter (mm)	500	550	500
Damper Weight (kg)	6500	8500	3300
Total Weight (kg)	9000	11000	5500

3.1.1 Prototype Full-scale testing at FIP Industriale Laboratory – Italy

The above mentioned prototype underwent to two series of tests. The first one was performed at FIP Industriale Testing Laboratory, where the unit was tested for final tuning of its damping characteristics before shipment to the UCSD laboratory for official testing in presence of the client (Kinopraxia Gefyra - Greece) and of the bridge design checker (Buckland & Taylor - Canada).

FIP Industriale Testing Laboratory is equipped with a power system providing for 630 kW at 1200l/min thus resulting to be the most powerful in Europe for full-scale dynamic testing of seismic devices.
Being the above unit of exceptional characteristics, the prototype was tested up to the maximum velocity provided by the available system, which resulted to be 0.2 m/s.

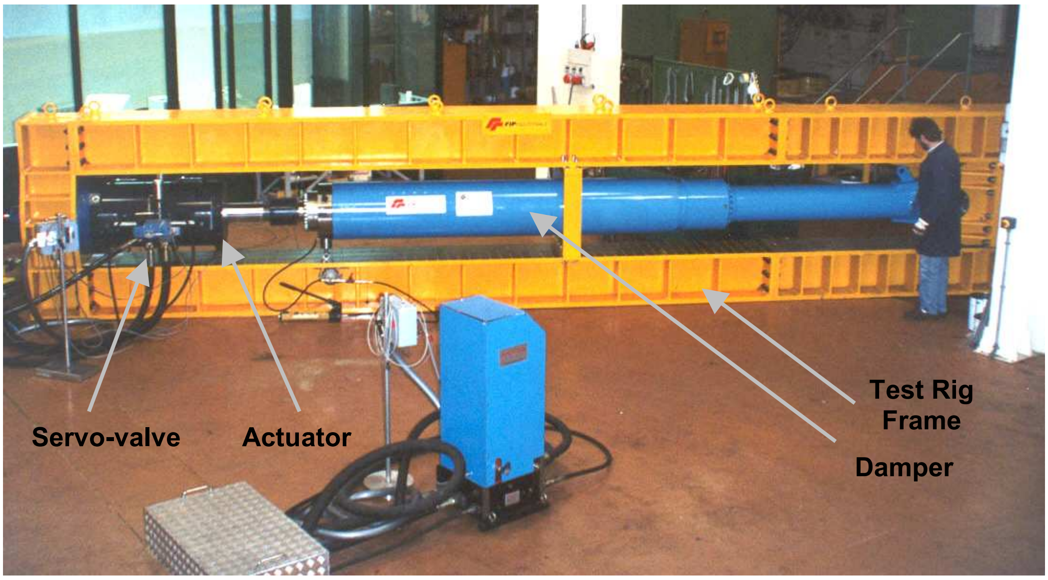


Figure 8. Viscous Damper Prototype during testing at FIP Laboratory

In Figure 8, the prototype is shown during dynamic testing at FIP testing Laboratory.

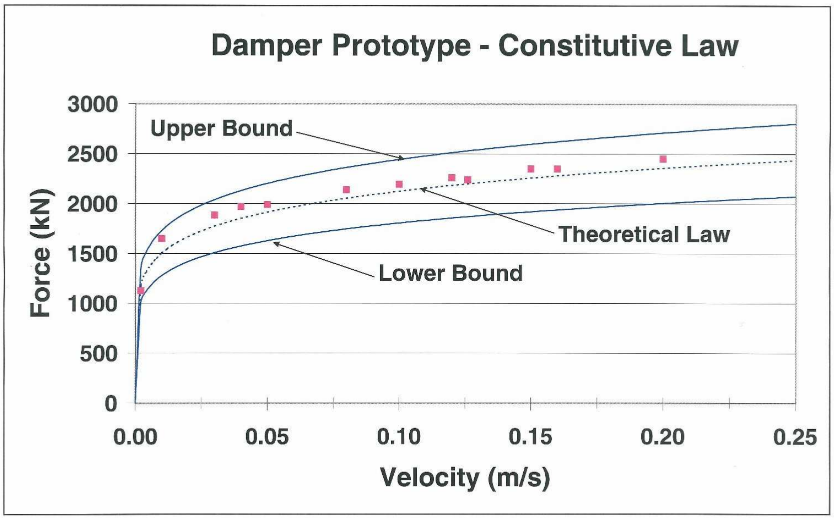


Figure 9. Experimental measurements vs. damper constitutive law

For testing purposes, the unit was pinned at one end to the test rig (yellow colored) while its piston rod was connected directly to the actuator through a 3000kN capacity load cell. The damper reaction was measured through the mentioned load cell as well as indirectly from the pressure detected on the actuator through a pressure gauge. The displacement was measured through a magneto-strictive displacement transducer. In figure 9, the test results are reassumed and it is evident how the damper behavior follows the theoretical constitutive law with a minimal deviation.

3.1.2 Full-scale testing at SRMD Testing facility – California, USA

The damper OTP 350/1800 was tested at the Seismic Response Modification Device (SRMD) testing facility of the University of California San Diego. The test matrix is reported in Table 2 (tests are listed in the same order they were carried out).
It is worth noting that the tests were performed up to the maximum design velocity equal to 1.6m/s. It was the first time that a damper of a so high load capacity was tested at such a high velocity.
The specimen was horizontally installed in the testing rig, connected at one end to a reaction wall and at the other end to the movable platen. The six degrees of freedom table is capable of unique level of displacement, forces and velocities. For this specific application the platen was moved in the longitudinal direction, with a displacement control loop able to maintain the components of motion in the other directions at negligible level. Figure 10 shows the damper installed on the testing frame.

Figure 10. Prototype testing at SRMD Facility (UCSD)

Peak forces measured at different velocity levels are reported in Figure 11.

Table 2 Test Protocol Prototype FIP OTP 350/1800

Test #	Test Name	Input	Number of cycles	Stroke	Testing conditions (V = Peak Velocity)
1	Thermal	Linear	1	± 895 mm	V<0.05 mm/s for 5 minutes Increase velocity to 1mm/s up to completion of the displacement.
2	Velocity Variation	Sinusoidal	5 5 5 3 2	± 300 mm	V=0.13 m/s V=0.40 m/s V=0.80 m/s V=1.20 m/s V=1.60 m/s
3	Full stroke & Velocity	Sinusoidal or step loading	1	± 850 mm	V_{max}=1.6 m/s
4	Wear	Linear	20000	± 5 mm	V=15 mm/s Every hour change position of the piston of about 100 mm
5	Velocity variation	Sinusoidal	2	± 300 mm	V_{max}=1.6 m/s

Maximum forces appear to be very symmetric in the all range of velocity. A difference of 7% was recorded at maximum speed (1.6 m/s) only for the first cycle. The second cycle of the same test shows instead a deviation of 1.6%. The comparison among peak forces of different cycles shows a reduction of the peak force of 3.8% between fifth cycle and first cycle for test Velocity A (0.13 m/s). For the high speed tests the maximum force reduction is equal to 10.4%.

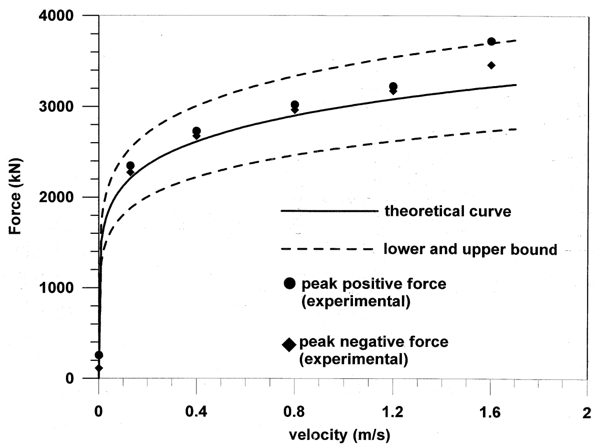


Figure 11. Experimental vs.theoretical – damper constitutive law

The calculated energy dissipated per cycle (EDC) for the Full Stroke and Velocity Test was 11035 MNm (+6% of the theoretical EDC). In order to perform this test a 3.3 MW power input was required.
Wear tests were completed with 10 sets of 2250 cycles, at constant velocity of 0.015 m/s and 10 mm total stroke.

Figure 12. Experimental damper hysteresis loop

The force vs. displacement response of the damper is reported in Figure 12 for the test at 1.2 m/s peak velocity.
Thermocouples were installed both internally and externally the damper body in order to monitor temperature rise during and after the motions. Air and nitrogen gas was used, in a cooling box, to restore the ambient temperature on the damper before a new test.
Temperature rise was recorded for each test. The maximum increase took place at the end of the test Velocity Variation B, with 40 degrees Celsius recorded from the sensor installed internally to the damper.
All the test results were deemed to be in agreement with the design specifications.
It is worth to stress how the test results obtained at the SRMD facility agreed very well with the measurements performed at FIP testing laboratory and how the damper behavior resulted to provide for stable reaction in a very wide velocity range (0.002 – 1.6 m/s).
The extrapolation of the damper reaction in the range of velocity 0.13-1.6 m/s from the test performed at FIP laboratory up to 0.2 m/s differed from the measured reaction at the SRMD facility by only few percent point. This result demonstrates how much predictable is the damper behavior within the full test range.
The test aimed at verifying the damper reaction at low velocity (0.1 mm/s) measured a reaction of 200kN.

3.1.3 Quality Control (production) tests at FIP Industriale Laboratory

The aim of the production tests was to verify the compliance of the production units with the contract specification or, in other words, that their reaction and damping characteristics fall within the design tolerance range.
The test is performed on 100% of the produced units and at the current time, two production lots have been already full-scale tested at FIP Industriale Laboratory in Italy (see figure 7 for the testing configuration of a production unit).

The contractual test program requires for the following tests:

- Proof Pressure test: the test is aimed to verify that the damper vessel withstand with no damage or leakage 125% of the design internal pressure.
- Low velocity test: the test is aimed to verify that the damper reaction at low velocity (less than 0.1mm/s) is less than 200kN in order to allow for easy of length adjustment and to avoid fatigue loads on the bridge.
- Dynamic test: the test is aimed to verify that the units provide for a reaction that follows the theoretical constitutive law with a maximum deviation of ±15%.

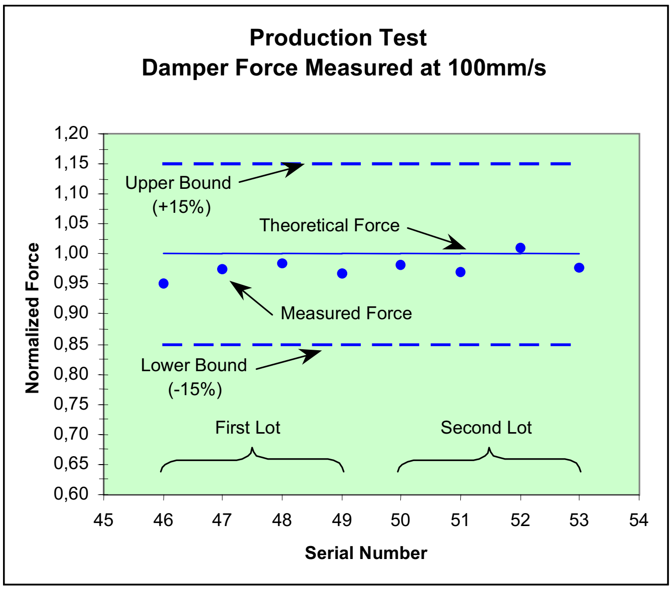


Figure 13. Normalized reaction of the production units

All the above mentioned tests have yielded a positive outcome.
In figure 13, a graph shows for all the units of the first two production lots (serial numbers from 414946 to 414953) the measured reaction, normalized with reference to the theoretical reaction, obtained imposing three sinusoidal cycles of 250mm stroke amplitude and reaching a peak velocity of 100mm/s (see figure 14).

It is worth to note that the maximum measured deviation was -4.8% with respect to the theoretical reaction at 100mm/s (2124kN). The measurements confirmed the results obtained during the prototype testing at the SRMD Facility of the University of California at San Diego.

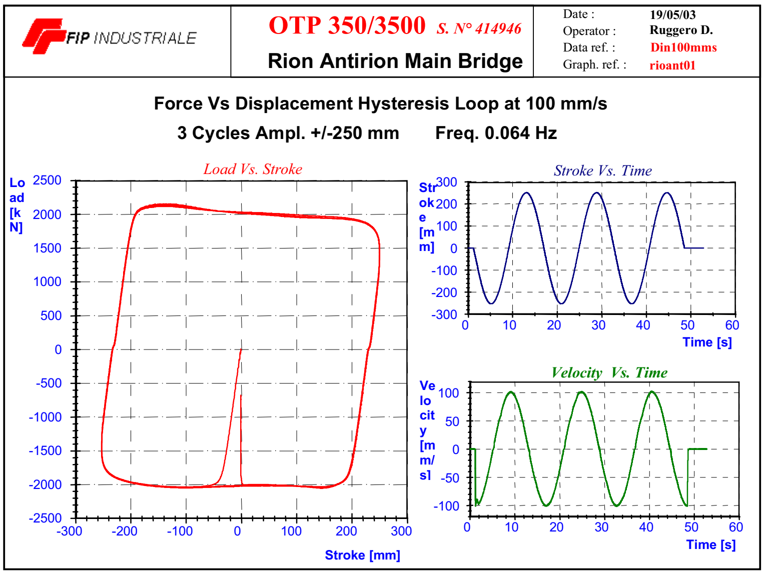


Figure 14. Dynamic test results

4 FUSE RESTRAINTS

Fuse restraints shall provide for a stiff link between the deck and the substructure for the lateral service load as well as for low occurrence high-intensity windstorms. As anticipated, only at the occurrence of high intensity events they are designed to fail allowing the damping system to work properly.

They are located at the main piers as well as at the transition piers. The main pier units are designed as single units equipped at their ends with spherical hinges. This configuration allows for the design rotations as well as for a correct alignment of the load along the device axis for any deck position. The element failing at the reaching of the desired design load – the so-called Fuse Element - is installed in the middle of the unit, for a general configuration of the unit see Figure 15.

The units to be installed on the main piers are characterized by a failure load of 10500kN. Similarly the units installed at the transition piers, that are installed as components of the dampers, are characterized by a failure load of 3400kN. The design tolerance on the failure load of the units requires a precision of ±10%: a very strict design performance for such a high capacity units.

Furthermore, a main design complication came from the need of minimizing the internal forces of the laterally restraint deck induced by tectonic movements originated from seismic fault located under the bridge. Thus, the units located on the main piers are equipped with a system designed to allow for length adjustment. This operation is performed when a certain load level is constantly applied to the link, so a load cell monitoring the load on the unit is required. As part of the monitoring system of the bridge, this will allow to identify the moment at which re-adjustment of the deck is required.

Another design requirement was that the units shall not disassemble after failure of the main component, so the units were designed to allow for the same stroke provided by the dampers.

Being the restraints first function to withstand the every day actions (service loads), a test has been required to evaluate the fatigue life as well as any influence on the failure strength.

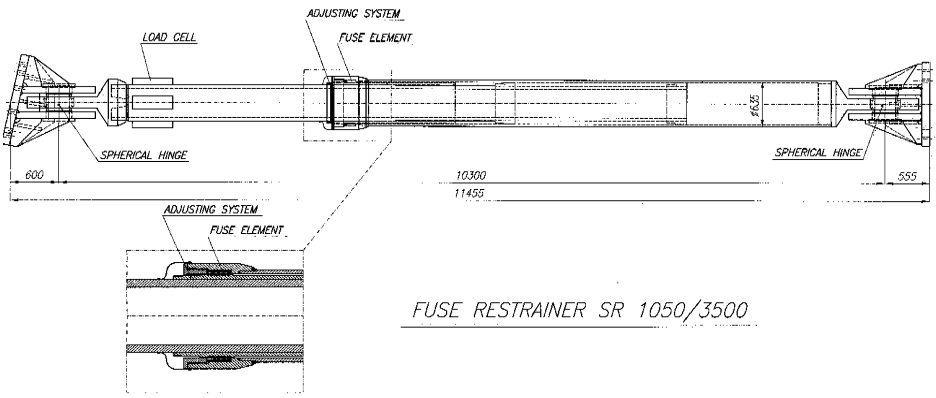


Figure 15. Fuse restraint general configuration

4.1 Testing program

The testing program was carried out on two full-scale prototypes of fuse element for each typology.
It consisted on a first test performed on one unit increasing monotonically the load up to failure, while a second test was performed on the other prototype imposing two millions of cycles at a load level equal to 10% of the design failure load and then increasing monotonically the load up to failure.
Failure test and fatigue test were carried out on different test rigs, the first one is a 8000 kN capacity test rig commonly used for bearing test while the second one is a 3000kN dynamic test rig: the same used for damper testing.
Testing results have shown that both prototypes failed within the design tolerance. The difference between the measured failure loads before and after fatigue test can just confirm that the design fatigue load cannot be considered as effecting the ultimate capacity of the fuse restraints. In the following table, all the testing results are presented. Figure 16 shows typical graphs obtained for both the 3400kN and 10500kN units.

Table 3. Test Results

Device Type	Failure Load Capacity (kN)	Tolerance Range (kN)	Measured Load (kN)	Deviation (%)
SR340	3400	3060-3740	3545	+4.3
SR340	3400 (Fatigue)		3591	+5.6
SR1050	10500	9450-11550	10382	-1.1
SR1050	10500 (Fatigue)		11765	+12.0

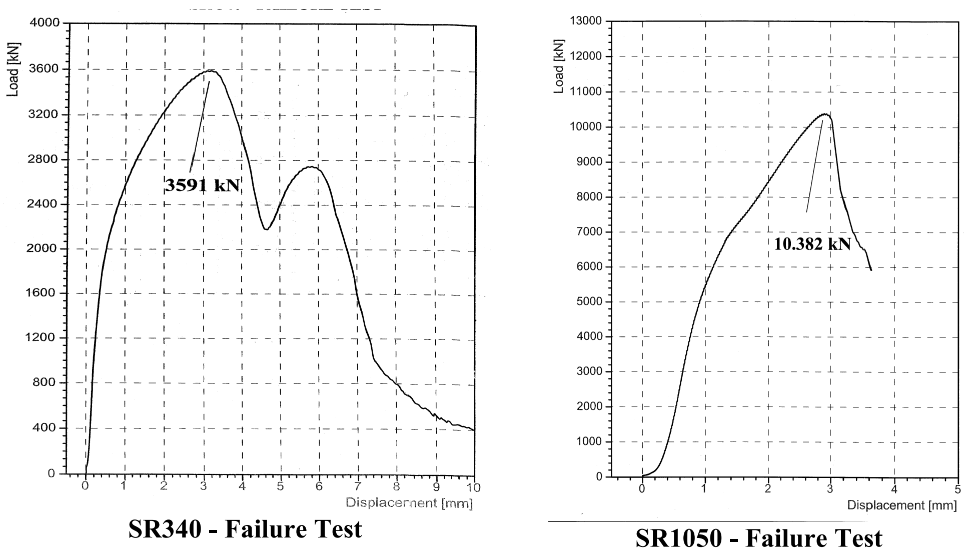


Figure 16. Failure Test

Figure 17 shows the SR1050 fuse element testing configuration during the fatigue test.

Figure 17. SR1050 Fuse element during fatigue test

5 THE RION-ANTIRION BRIDGE APPROACH VIADUCTS

5.1 Introduction

The approach viaducts, being of critical importance for the functionality of the main bridge after a seismic attack, have been designed to withstand the same earthquake intensity level of the main bridge (PGA=0.48g).
They present different design and construction technology but the same type of seismic isolation system.

The Antirion approach viaduct, located on the mainland Greece side, has a total length of 227.96 m (6 spans: 2 spans of 37.460 m and 4 spans of 38.460 m) and it has been already built as shown by figure 18.

The viaduct is made of pre-cast pre-stressed concrete girders with reinforced concrete deck slab.
Longitudinally, the viaduct consists of simply supported spans linked by continuity deck slabs at the location of supports.

The typical cross section consists of 8 pre-stressed concrete girders with transverse diaphragm cross beams on support.

The piers of the viaduct are reinforced concrete frames in the transverse direction made of four columns connected at their lower part by a pile-cap and at their upper part by a cross head beam.
The abutment consists of bored cast-in-place piles and/or appropriate spread footing on treated soil.

Figure 18. The Antirion Approach Viaduct

The Rion viaduct is located on the Peloponnesus side and has a total length of 986m. It is currently under construction.

The viaduct consists of two independent composite bridges. Each composite structure is made of two girders connected by cross beams.
The bearings of the bridge are elastomeric isolators or sliders and are located under the main steel girders.

The typical cross section consists of a concrete slab connected to the steel beams by connectors.
The piers of the viaduct are reinforced concrete frames in the transverse direction made of two columns connected at their lower part by a pile-cap and at their upper part by a cross head beam.

The piers are founded on piles.

The seismic isolation system used for the protection of all the approaches consists of a combination of elastomeric isolators and viscous dampers.

The isolators provide for the bearing function as well as for the lateral flexibility required to shift the period of the structure and so to reduce the acceleration of the deck.
These bearings are made of alternate layers of natural rubber and steel plates vulcanized together and mechanically anchored to the deck and the substructure.

Figure 19. Approaches isolation system

Viscous dampers, dissipating the energy introduced by the earthquake and so providing for the required damping, are set up in longitudinal and transverse directions between the deck and the pier heads to limit relative displacement.

Isolators and dampers installed on the Antirion Approach Viaduct went through an extensive test program performed at the testing departments of ALGA and FIP Industriale in Italy. The main results are shown in the following paragraphs.

5.2 Seismic hardware tests

5.2.1 Elastomeric Isolators

Tests have been performed to check the quality and the mechanical characteristics of the elastomeric isolators in order to evaluate stability, capacity, resistance to service loads and, of course, the lateral stiffness.
Two typologies have been produced characterized respectively by 500x600x239mm and 500x600x253mm main dimensions and by natural rubber providing for a 1N/mm^2 shear modulus.

In figures 20 and 21, full-scale isolators under testing at ALGA Laboratory in Italy as well as the graph depicting the measured Force vs. Displacement loop are respectively shown.

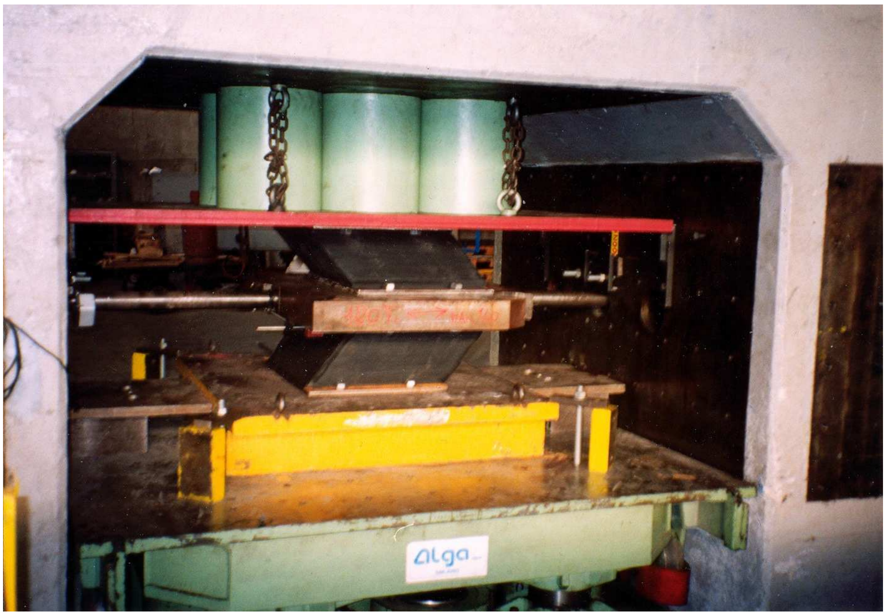


Figure 20. Isolators under tests

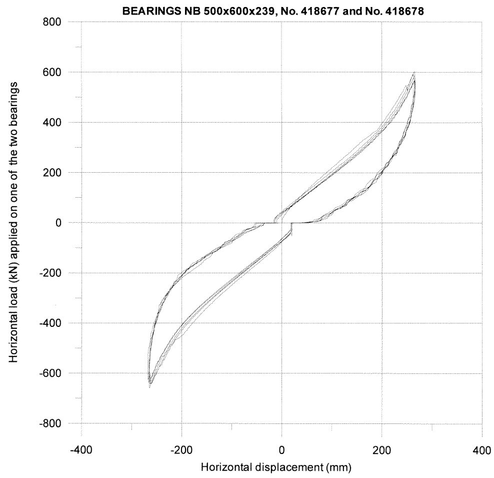


Figure 21. Isolators stiffness characteristics

5.2.2 Viscous Dampers

Tests aimed to verify the effective damping capacity under dynamic loads, the displacement capacity and the accordance with the expected performance law (Force vs. velocity relationship) were performed on full-scale units.
The Antirion Viaduct requires for 44 dampers to be installed both longitudinally and transversally (see figure 22).

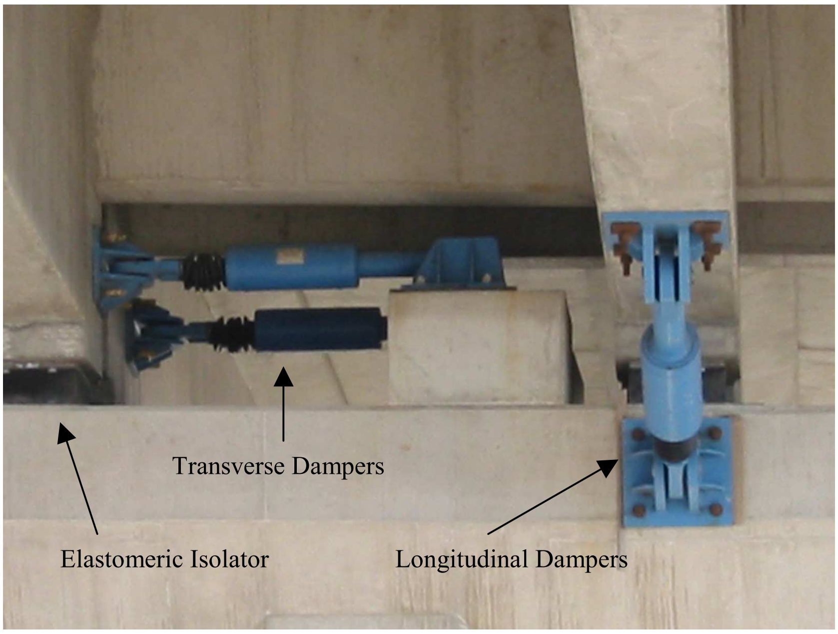


Figure 22. Dampers typical arrangement

The longitudinal dampers (24 units) are characterized by a 1200kN load capacity and by strokes ranging from ±200 to ±250mm, whilst the transverse dampers (20 units) are characterized by an 800kN load capacity and by strokes equal to those used longitudinally.

Being the proposed technology the same used on the main bridge, the dampers are characterized by a 0.15 damping exponent, thus ensuring an effective damping action even for low velocities.

In figure 23, a 1200 kN capacity damper under testing at FIP Industriale Laboratory is shown.

In figure 24, the hysteresis loop obtained testing at constant velocity is presented.

The Rion Viaduct requires for the installation of 134 units characterized by 300, 600, 1200 and 2400kN load capacity and strokes ranging from ±250 to ±405mm that are currently under production.

Figure 23. Production Tests at FIP Laboratory

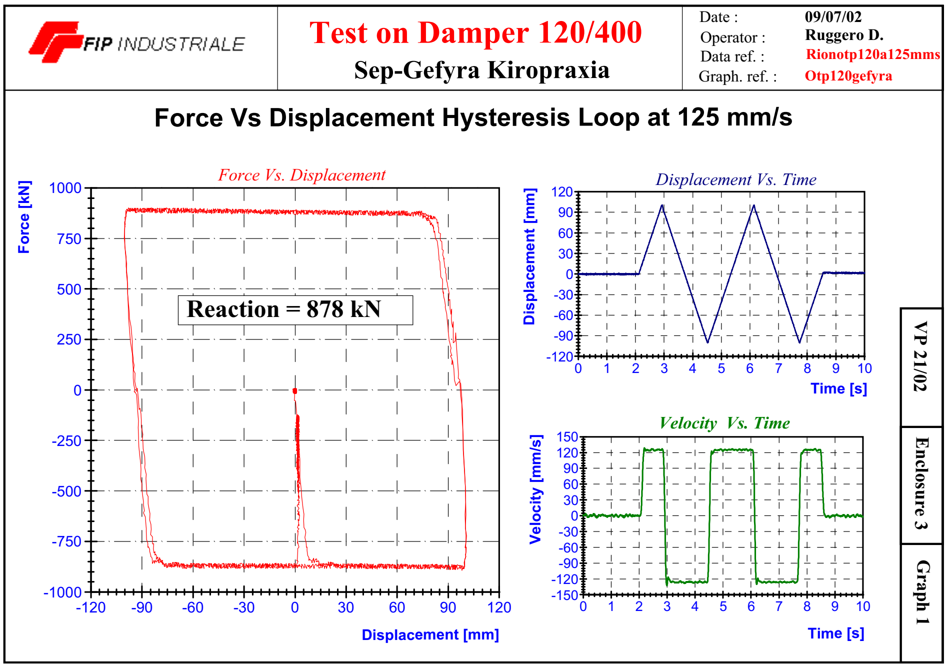


Figure 24. Hysteresis Loop

6 CONCLUSIONS

Testing of full-scale viscous dampers and fuse elements were performed in order to confirm the characteristics and the main design assumptions of the seismic dissipation system used for the Rion-Antirion Cable Stayed Bridge and for the approach viaducts.
Tests performed on Fuse elements verified positively the design assumption showing that it is possible to achieve a very tight tolerance (±10%) on the predicted ultimate capacity even when the units are designed for a very high failure load (10500kN).
The Viscous Damper prototype demonstrated very stable behavior even when tested under dynamic conditions, requiring power dissipation higher than design parameters.
The measured energy dissipation and viscous reaction were always well within the design tolerance of ±15% of the theoretical design parameters.
Testing aimed to represent the effect of structural vibrations induced by traffic and/or of movement induced by structure thermal expansion did not produce any appreciable change in the damper behavior.
The production tests confirmed that the dampers to be installed on the bridge provide for the same characteristics of the prototype with a deviation from the theoretical constitutive law lower than 5%.
Full-scale testing of large size dissipating devices proved to be a real challenge compared to previous testing experiences as it pushed the limits of equipment available worldwide.
Experimental results on full-scale units give a high degree of confidence on seismic devices as a means to protect large and important structures such as the Rion-Antirion Cable Stayed Bridge and its approaches.

ACKNOWLEDGEMENT

The authors wish to express their sincere gratitude for the active and fruitful cooperation rendered by Mr. Gianmario Benzoni of the UCSD Laboratory, as well as the indefatigable support furnished by Mr. Renato Chiarotto of FIP Technical Department, Mr. Pierluigi Galeazzo Testing Laboratory Manager of FIP Industriale and his staff.
A remarkable thank is addressed to Mr. Agostino Marioni (ALGA) and to Mr. Philippe Salmon (Freyssinet) for their cooperation within the JV operations.

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