SEISMIC ISOLATION AND POST-TENSIONING: A COMPLETE SOLUTION FOR THE NEW TRIESTE HARBOR LOGISTIC PLATFORM

**DOI 10.37153/2686-7974-2019-16-672-683**

Mauro SARTORI[[1]](#footnote-1), Stefano BARONE[[2]](#footnote-2), Giulio CAMOSSI[[3]](#footnote-3), Ivica ZIVANOVIC[[4]](#footnote-4)

ABSTRACT

The growing of the goods traffic by shipping in Northern Italy stressed the need of having wide logistic platforms for the management of the goods, organizing their stock, ships docking and link with infrastructures. The new logistic platform based in Trieste will improve the movement of goods from central Europe and Turkey with an estimated yearly turnover of 15 million euros. It is made by a 50 cm thick post-tensioned concrete slab. Base isolation was chosen to fully protect the structure from strong earthquakes. For this purpose, 850 CE marked curved surface sliders were supplied by Freyssinet. These anti-seismic devices allow large relative displacements through sliding on special frictional surfaces. Moreover, the double surface configuration allowed to significantly reduce the overall dimensions of the device while maintaining high displacement capacity.

This paper describes the isolation system from the seismic analysis of the overall structure to the tests performed on the devices as well as the post-tensioning system and the expansion joints. This project is a great example of application of post-tensioning and seismic isolation techniques, a complete solution that allows to drastically reduce shear demand at the foundation level, a fundamental target for marine structures that require deep foundations.

*Keywords: Harbor Logistic Platform; Post-Tensioning; Base Isolation; Curved Surface Sliders; Full-Scale Tests*

**1. INTRODUCTION**

The last decades showed a growing of the international goods traffic through Northern Italy, from Europe to middle and far East. This growing is due to the key location of this side of the Country, especially of its harbors when shipping goods from and to Europe. To manage the goods coming from and to be shipped all over the world, wide logistic areas are required to stock them, to dock ships and to connect routes and railways to the sea ways. Trieste is a town located in the middle of this area, Northern Italy, at the end of the Adriatic Sea, within the Mediterranean Sea. Its location is strategic for the movement of goods and for this reason its harbor is one of the most popular. To improve its capacity of managing the goods traffic, a new huge platform has been built over the water to increase the space available for stocking, docking and links. The platform has also been declared duty-free zone by the Italian government to ease the commercial relationship between international shipping companies. The new investment in Trieste harbor with its irregular plan will cover around 70.000 square meters of the existing bay and will improve the movement of goods from central Europe and Turkey for an estimated yearly turnover of 15 million Euros. The platform has been constructed by a joint-venture of Italian contractors composed by I.Co.P. s.p.a, Interporto Bologna S.p.a., Cosmo Ambiente s.r.l. and Francesco Parisi S.p.a. The design has been carried out by the Italian design companies Studio Altieri S.p.a. and ALPE Progetti s.r.l. Figure 1 shows the area of the new logistic platform.

|  |
| --- |
|  |

Figure 1. View of the platform area

**2. THE HARBOR PLATFORM**

The new logistic platform is 470 meters long and 275 meters wide and it is composed by three main elements:

• The superstructure

• The seismic isolation system composed by Curved Surface Sliders (CSS), located under the slab

• The column-piles drilled into the ground on which the isolators are installed

The superstructure is composed by pre-casted and prestressed concrete beams with rectangular cross section 1.8 m wide and 1 m height and by a post-tensioned concrete slab 50 cm thick built on a prestressed concrete self-supporting formwork. The slab follows the coast profile and it has a global surface of 70.000 m2 with a structural gridwork of 10 x 10 m2 (see Figure 2).

|  |
| --- |
|  |

Figure 2. The structural gridwork of the plaform

The geological and orographic configuration of the bay bring to variable stiffness of the column-piles which can vary over time when the space below the slab is filled by the sea water. Moreover, there is a huge variability both in amount and position of the live loads over the slab which could represent up to 75% of the global load. The column-piles, with 1270 mm diameter, were drilled into the ground and are composed by a steel cylinder 10 mm thick filled with reinforced concrete.

The isolation system is installed between the column-piles and the beams supporting the slab and it is composed by more than 850 CE marked double CSS capable to provide high lateral flexibility, supplemental structural damping and limited torsional effects. All the anti-seismic devices have been designed, manufactured, tested and supplied by Freyssinet Product Company Italia, branch of Freyssinet Group, as well as the Freyssinet post-tensioning system including 750 tons of strand, about 2000 anchorages and 3900 couplers. Moreover, Freyssinet Product Company Italia supplied 1250 m rubber expansion joints to cover the gap between the platform and the dry land, thus allowing seismic movements without damages to adjacent structures. This is a great example of Freyssinet’s capacity to provide a reliable complete solution to construction companies and to supply a huge number of devices in a short time, thanks to the big portfolio of products and expertise.

**3. SEISMIC INPUT**

The structure is designed with a nominal life of 100 years and a reference period of 200 years for the seismic actions. Base isolation is an advanced technique that allows to limit structural damage concentrating the seismic displacement demand into anti-seismic devices properly installed in the structural system and capable to increase the lateral flexibility of the structure (period elongation function) and to dissipate the energy transmitted by the ground shaking (damping function). Figure 3 illustrates the effects of base isolation in terms of acceleration and displacement demand.

|  |
| --- |
|  |

Figure 3. Effects of base isolation

The isolation system allows to drastically limit the shear seismic forces transmitted to the superstructure; for this reason, the slab-beams system was designed in elastic condition, thus reducing the overall costs of the platform (compared to non-isolated solution).

The platform was designed (according to Italian Standard NTC 2008) considering the following seismic limit states:

• Operability Limit State (SLO): after the earthquake, the structure shall not show damages and important breakdowns;

• Damage Limit State (SLD): after the earthquake, the structure can show damages that do not represent a risk for people and the structure keep its characteristics of resistance and stiffness for vertical and horizontal loads. The structure is still working even if its content could be out of order

• Life Safety Limit State (SLV): the substructure works in elastic field; the superstructure does not present signs of important damages and the isolation system maintains its operability;

• Collapse Limit State (SLC): after the earthquake, the structure shows structural damages even if it presents enough safety margin for the vertical loads.

Based on the latitude and longitude of the site, the Italian code provides values of Peak Ground Acceleration (PGA) for different levels of earthquake shaking (i.e. return period). In the case of Trieste platform, the reference period of 200 years leads to a return period of 1898 years for SLV (10% probability of exceedance within 200 years) and 2475 years for SLC (5% probability of exceedance within 200 years). Figure 4 shows the design spectra for each limit state, according to local ground characteristics and topography.

|  |
| --- |
|  |

Figure 4. Design acceleration (left) and displacement (right) spectra for each limit state (5% damping)

**4. THE ISOLATION SYSTEM**

***4.1 Seismic analysis***

To respect the above-mentioned limit states, the final choice for the isolation system foresees CSSs with double sliding surface (details in Section 4.2). Due to the highly nonlinear behavior of these devices, time-history analysis were performed using 7 natural accelerograms, properly scaled and adapted to obtain an average spectrum matching the design one (Figure 5). Table 2 lists the selected natural records.

Table 2. Natural accelerograms selected for the seismic analysis

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **ID** | **Station** | **Earthquake** | **Year** | **Mw** | **Fault mechanism** | **Epic. distance [km]** | **PGAX**  **[m/s2]** | **PGAY**  **[m/s2]** | **PGVX**  **[m/s2]** | **PGVY**  **[m/s2]** |
| 149 | ROLC | Christchurch | 2011 | 6 | reverse | 29,44 | 0,456 | 0,450 | 0,046 | 0,063 |
| 30 | IWT021 | N Iwate Prefecture | 1998 | 5,9 | reverse | 19,32 | 0,405 | 0,367 | 0,045 | 0,035 |
| 83 | ST\_36445 | Parkfield | 2004 | 6 | strike-­‐slip | 15,23 | 1,386 | 2,24 | 0,229 | 0,184 |
| 133 | MODE | EMILIA  Pianura  Padana | 2012 | 6 | reverse | 26,82 | 0,439 | 0,216 | 0,037 | 0,031 |
| 27 | KGS010 | NW  Kagoshima  Prefecture | 1997 | 6 | strike-­‐slip | 26,81 | 1,89 | 2,055 | 0,212 | 0,230 |
| 81 | AI\_013\_CER | Duzce 2 | 2000 | 6 | normal | 15,23 | 0,629 | 0,623 | 0,061 | 0,079 |

|  |  |
| --- | --- |
|  |  |

Figure 5. Target spectrum and spectra of scaled accelerograms and Design and average spectra (SLC limit state)

The analysis has been carried out using the commercial software SAP 2000, modeling the column-piles with linear links fixed at the base while the curved surface sliders through non-linear links (see Figure 6 for details).

|  |
| --- |
|  |

Figure 6. Finite element model of the platform and properties of the friction isolators

Figure 7 shows main results of the nonlinear dynamic analysis. Five check points have been selected to monitor displacements of the isolators.

|  |
| --- |
|  |

Figure 7. Results of dynamic analysis performed with SAP2000

Table 3 lists the final numerical results used for the design of the anti-seismic devices.

Table 3. Dynamic analysis results.

|  |  |  |  |
| --- | --- | --- | --- |
| **Data** | **Mark** | **Value** | |
| Maximum Isolator Displacement | dE | | 0.20 m |
| Maximum vertical non-seismic load - ULS | Nsd ULS | | 116000 kN |
| Maximum vertical non-seismic load - SLS | Nsd SLS | | 8000 kN |
| Minimum seismic vertical load | NEd,min | | 1900 kN |
| Maximum seismic vertical load | NEd,max | | 8000 kN |
| Maximum horizontal load | VEd | | 531 kN |
| Equivalent radius | Req | | 8.7 m |
| Dynamic friction coefficient | µdyn | | 4.0% |
| Isolation period | T0 | | 5.91 s |
| Maximum design velocity | vED | | 0.244 m/s |

***4.2 Curved Surface Sliders: a complete device for seismic isolation and dissipation***

The basic components of double curved surface slider are shown in Figure 8.

|  |
| --- |
|  |

Figure 8. Double curved surface slider

In Figure 8:

1. Top sliding plate
2. Primary sliding surface
3. Sliding material
4. Median plate
5. Secondary sliding surface
6. Bottom plate

The choice of double concave surface sliders with identical frictional surfaces allowed to reduce the overall dimension of the device (compared to CSS with one sliding surface only), which was a great benefit for the limited space available for the installation. In fact, with double surface configuration, the displacement is shared by the two sliding surfaces (Figure 9), limiting at the same time P-∆ effects on the column-piers.

|  |
| --- |
|  |

Figure 9. CSS in static (left) and seismic (right) condition

Their main characteristics of double curved surface sliders can be summarized below:

* They allow the relative displacement of the structure with respect to the substructure following one or two spherical surfaces
* The equivalent radius of the device determines the natural period of the structure
* The frictional sliding determines the damping mechanism
* The sliding period is independent from the mass of the structure
* They are self-centering after a seismic event

All the devices of the project have been designed, manufactured, tested and supplied by Freyssinet Product Company Italia and are all provided with CE mark, which is nowadays mandatory within CEN countries.

Special care has been considered to protect the device from corrosion caused the very severe environmental working conditions. In fact, even if the devices are installed on top of the column-piles drilled into the sea bottom of the bay, and hence the water level will lay just below the isolation level, the salinity of the sea makes the environment very aggressive. To protect all the steel elements, a corrosion protection according to class C5M-H of EN 12944 has been applied, which includes 4 metallic layers and epoxy paint applied and rigorously checked by inspections and tests to ensure the high level of reliability. Moreover, to avoid any contamination of the internal elements, a hermetic cover has been installed all around the device (Figure 10). Finally, all the anchor bolt heads were covered by plastic caps filled with grease to increase the durability of the hot dip galvanized bolts.

|  |
| --- |
|  |

Figure 10. Double curved surface slider equipped with hermetic protection

***4.3 Testing of the devices***

The CE mark, given by an independent Notified Body, certifies the constancy of performances through audits aimed to verify the quality production process and that the performances of the isolators matches those assumed in the design phase. According to the harmonized standard for anti-seismic devices EN 15129, this is obtained by performing Type Tests on full-scale prototypes and by Factory Production Control (FPC) tests, to verify the constancy of performances on a percentage of the mass production.

Type Tests have been performed at EUCENTRE (European Center for Training and Research in Earthquake Engineering) in Pavia, Italy, on two devices following a severe protocol aimed to full characterize the static and sliding behavior under different conditions of vertical load, displacement and sliding velocity. The protocol, reported in Table 4, is defined according to EN 15129 prescriptions for Type Test of Curved Surface Sliders.

Table 4. Type Test protocol.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **test** | **test name** | **label** | **dof** | **amplitude**  **[mm]** | **max velocity [mm/s]** | **frequency**  **[Hz]** | **load shape** | **vertical load**  **[kN]** |
| **1** | *Pre-test* |  | vert | - | - | - | - | 8000 |
| **2** | *Load bearing capacity* |  | vert | - | - | - | - | 16000 |
| **3** | *Frictional resistance*  *force test* | FR | long | - | 0.1 | - | ramp | 8000 |
| **4** | *Service condition test* | S | long | 45 | 5 | 0.02 | sine | 8000 |
| **5** | *Benchmark* | P1 | long | 145 | 50 | 0.05 | sine | 8000 |
| **6** | *Dynamic test D1* | D1 | long | 36 | 257 | 1.13 | sine | 8000 |
| **7** | *Dynamic test D2* | D2 | long | 73 | 257 | 0.57 | sine | 8000 |
| **8** | *Dynamic test D3* | D3 | long | 145 | 257 | 0.28 | sine | 8000 |
| **9** | *Seismic test E* | E | long | 145 | 257 | 0.28 | sine | 1900 |
| **10** | *Seismic test E* | E | long | 145 | 257 | 0.28 | sine | 8000 |
| **11** | *Bidirectional*  *test B1* | B1 | long | 145 | 257 | 0.28 | sine | 8000 |
| **12** | *Property verification P2* | P2 | long | 145 | 257 | 0.28 | sine | 8000 |
| **13** | *Ageing P3* | P3 | long | 145 | 50.0 | 0.05 | sine | 8000 |

Factory Production Control tests have been performed both at ISOLAB (Freyssinet testing facility) in Montebello della Battaglia, Italy and at SISMALAB, Crispiano, Italy. Table 5 illustrates the protocol.

Table 5. Factory Production Control test protocol.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **test** | **test name** | **label** | **dof** | **amplitude [mm]** | **max velocity [mm/s]** | **frequency [Hz]** | **load shape** | **vertical load**  **[kN]** |
| **1** | *Load bearing capacity* |  | vert | - | - | - | - | 16000 |
| **2** | *Frictional resistance force test* | FR | long | - | 0.1 | - | ramp | 8000 |
| **3** | *Benchmark* | P1 | long | ±145 | 50 | 0.0549 | sine | 8000 |

Tests at ISOLAB were performed on the new 70 MN testing machine able to test devices up to 70.000 kN static vertical load and up to 20.000 kN static horizontal load. The testing bench can develop a vertical dynamic force up to 18.000 kN and a horizontal dynamic force up to 5.000 kN with 1000 mm maximum stroke and 1000 mm/s peak velocity. Figure 11 shows the 70 MN machine.

|  |
| --- |
|  |

Figure 11. The 70 MN press of ISOLAB

The experimental response of the prototypes, in terms of energy dissipated, friction coefficient and horizontal force is compared with the expected design values at the design displacement (see Table 6); the values are perfectly aligned with the theoretical ones.

Table 6. Experimental and design properties of the devices.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Dynamic friction**  **[%]** | **Maximum horizontal force**  **[kN]** | **Energy Dissipated**  **[kNm]** |
| Design | 4.0 | 453 | 185 |
| Experimental | 3.9 | 415 | 179 |
| Deviation | -2.5% | -8.4% | -3.6% |

Finally, Figure 11 and 12 show Type Testing of the device at EUCENTRE and SISMALAB, respectively.

|  |  |
| --- | --- |
|  |  |

Figure 11. Type Test at EUCENTRE

|  |
| --- |
|  |

Figure 12. Type Test at SISMALAB

**5. POST-TENSIONING SYSTEM AND EXPANSION JOINTS**

The platform was built following different steps. For each of them there were two phases: first, a square section with dimension 3 x 3 m2 was casted, second, it was post-tensioned to adjacent elements already manufactured. The complete post-tensioning system, including 750 tons of strand, about 2000 anchorages and 3900 couplers needed to create the structural continuity of the whole platform. The anchor system, shown in Figures 13 to 16, has been developed by Freyssinet Group fulfilling the requirements given into the main international standards and is provided by European Technical Assessment (ETA) and CE mark. The post-tensioning system was optimized to facilitate tension operations, to reduce steel reinforcement, geometrical interferences thus improving the whole behavior.

|  |
| --- |
|  |

Figure 13. Active anchor: C range series

|  |
| --- |
|  |

Figure 14. Multi-strand couplers: CC series

|  |
| --- |
|  |

Figure 15. Fixed anchor: F range series

|  |
| --- |
|  |

Figure 16. Anchor installation on site

The wide platform develops deformations in every direction due to reversible actions, like the environmental temperature. Moreover, in case of earthquake, the isolation system will undergo high displacements Therefore, to allow such deformations, an expansion joint line was installed along the 1250 m long perimeter of the platform. A special expansion joint was installed, capable to cover the gap between two adjacent spans even during seismic events (Figure 17). The joint is made of reinforced rubber with a bridge plate to ensure the continuity above the gap. The reinforcing steel profiles are completely inserted and vulcanized to the rubber. This process represents a suitable solution to ensure efficient protection against corrosion and allows a longer lifetime. The rubber compound has been specifically chemically formulated to resist oil, grease, petrol, salt and sand, without suffering premature ageing phenomena due to sun rays, salt and snow. During an earthquake, it can withstand much higher deformations thanks to the wide bridge plate vulcanized in the central part of the rubber.

|  |
| --- |
|  |

Figure 17. Section of the expansion joint

**6. Conclusions**

To solve the need of improving the capacity of the Trieste harbor a new duty-free, huge platform of 70.000 square meters has been built covering an existing bay. This investment will help the stocking of good transiting through the future main hub at the end of Adriatic Sea and will allow the docking of big ships as well as the link with the main roads and railways. The logistic platform is a 50 cm thick post-tensioned concrete slab isolated by more than 850 double curved surface sliders installed on steel-concrete column-piles drilled directly into the sea bottom. The devices were designed and consequently tested to validate the behavior.

Thanks to Freyssinet portfolio, a complete solution was provided with specific technologies from design level up to test and installation on site. This project shows a complete and integrated solution, capable to ensuring high levels of reliability and quality of the products while respecting the always tight construction schedules.

**7. References**

Barone S., Calvi G.M., Pavese A. (2017) Experimental dynamic response of spherical friction.based isolation devices. *Journal of Earthquake Engineering*, DOI: 10.1080/13632469.2017.1387201.

Constantinou M.C., Mokha, A., Reinhorn A. (1990) Teflon bearings in base isolation. II: Modeling. *ASCE* *Journal of Structural Engineering* 116, 455–474.

European Committee for Standardization (CEN), 2009, EN 15129, Anti-Seismic Devices.

Mokha A., Constantinou M.C, Reinhorn A. (1990) Teflon Bearings in Base Isolation I: Testing. *ASCE Journal of Structural Engineering* 116.2: 438-454.

Quaglini V., Bocciarelli M., Gandelli M., Dubini P. (2014) Numerical Assessment of Frictional Heating in Sliding Bearings for Seismic Isolation. *Journal of Earthquake Engineering*, 18:8, 1198-1216.

1. Technical Manager, Freyssinet Product Company Italia, Milan, Italy, [mauro.sartori@freyssinet.com](mailto:mauro.sartori@freyssinet.com) [↑](#footnote-ref-1)
2. R&D Engineer, Freyssinet Product Company Italia, Milan, Italy, [stefano.barone@freyssinet.com](mailto:stefano.barone@freyssinet.com) [↑](#footnote-ref-2)
3. Engineer, Freyssinet Product Company Italia, Milan, Italy, [giulio.camossi@](mailto:giulio.camossi@)freyssinet.com [↑](#footnote-ref-3)
4. Deputy Technical Director, Freyssinet, Rueil Malmaison, France, [ivica.zivanovic@](mailto:ivica.zivanovic@)freyssinet.com [↑](#footnote-ref-4)