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Strengthening of Pisa Tower by External Post-Tensioning

Renforcement de la Tour de Pise par précontrainte extérieure

Verstärkung des Turmes zu Pisa mittels externer Vorspannung

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In 1991, VSL International Ltd. was entrusted with a study of the temporary circumferential prestressing of the Pisa Tower.

The job was to present a solution with temporary hoop prestressing tendons at the first level "Loggia" of the Tower. Those tendons were intended to prevent buckling of the masonry on the South Side of the Tower.

The idea was to wrap a number of prestressing strands around the circumference of the tower in the area of the first loggia as shown in Fig. 1. It was decided to place monostrands distributed over the height of the loggia wall. In addition, 8 monostrands were placed above the arches of the lowest level columns. The tendons were initially stressed to 50 % of their guaranteed ultimate strength. Very strict requirements with regard to the visual and functional effect on the tower were set:

- temporary tendons
- small visual impact on the tower
- no detrimental effects on the marble surface
- long term corrosion protection
- no grease in the monostrand
- strand overlength nicely hidden
- resistance against microorganisms and similar
- resistance against UV-radiation
- proven technology must be used
- stressing system insensitive to human error

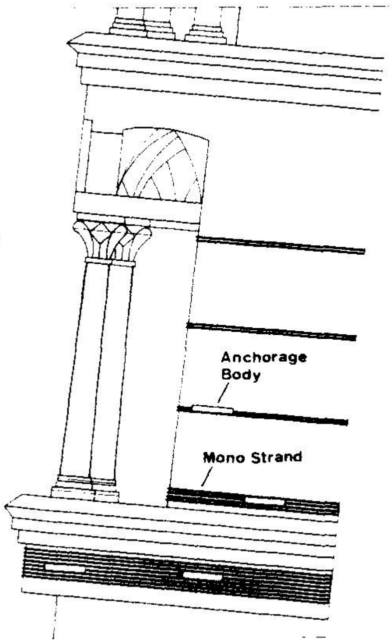

Fig. 1: Tendon Lay-Out at First Loggia

These requirements called for a design which allows the tendons to be force-monitored, retensioned, detensioned and removed. The chosen prestressing system does not interfere with existing materials. The tendons are finally held in place by their prestressing force.

The anchorage bodies were machined out of full material St 52-3 and then hot dip galvanized with a zinc thickness of min 80 μm.

The 7-wire prestressing strand according to Euronorm 138-79 is hot dip galvanized after drawing of wire with a zinc coating of min. 50 μm.
The strand is sheathed by a sleeve made of PVDF (Polivinylidenflouride), diameter 20/16.2 mm. This material is highly resistant against chemicals and weathering, and allows low-friction sliding of the strand in the sleeve inspite of the absence of any grease. The wedges were treated with a new corrosion protection method called "Dacromet 320", similar to hot-dip galvanizing but 2.5 times more effective for the same coating thickness. Because of the requirement that there must not be any interference with existing materials the anchorage had to be a "flying" anchorage, i.e. it slides with respect to the marble surface while stressing. A special PVDF pad was therefore provided between the anchorage body and the structure. This pad allowed low friction sliding, at the same time protecting the marble.

The anchorage system has minimized outside dimensions, thus causing hardly any visual impact on the structure. After stressing, the strand overlength is hidden in the anchorage body and covered by closing the lid as shown in Fig. 2.

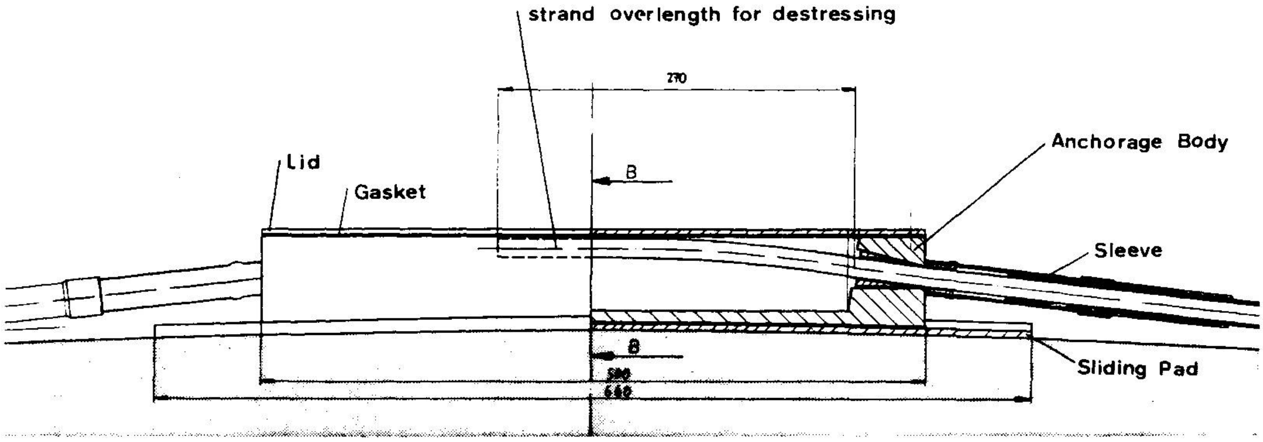

Fig. 2: Specially Designed Monostrand Anchorage Body on Sliding Pad

Although "proven technology" was used, the importance of the structure justified the execution of extensive testing. A full-scale stressing test was carried out on a circular silo structure with a radius similar to that of the Pisa Tower. The aim of the test was to demonstrate the adequacy of the entire system, in particular the anchorage body and the PVDF sliding pad. The experience gained during the installation and stressing confirmed that the special anchorage body, and the stressing procedures work as intended. The friction coefficient of the assembly of non greased strands was approximately $\mu = 0.11$.

The installation of the hoop tendons was executed in June 1992 by the VSL licensee PRECO.