MEASURES TO STRENGTHEN THE REMAINS OF THE *DOMUS TIBERII* IN ROME

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SUMMARY

The integration between static studies and archaeological and geothecnical data has allowed to carry out a minimal strengthen work in the ruins of one of the Caesar's Palaces in Rome.
The overturning of the front wall has been prevented by an array of post-tensioned tie bars equipped with an innovative elastic restraints, that has been calibrated with data acquired through a long period of in situ measurements. These spring devices allow both the respect of the present static behaviour and the drastic reduction of the constraint due to the seasonal displacements.

1. THE DOMUS TIBERII

The ruins of the *Domus Tiberii*, one of the Caesar's Palaces in the ancient Rome, occupy the north-west corner of the Palatine hill, the site of the primitive roman settlement, that became in time the exclusive residence of the highest nobility and then of the Emperors.
The built of the first nucleus of the Palace began in the second half of the 1st century on a rectangular podium (135x120 meters), whose external retaining walls were strengthen by a tier of masonry arcades disposed on one or two orders.
Subsequently the emperors Domitian and Hadrian extended the Palace, widening the first podium with vast substructures set to the existing buttresses and based on the lower slopes of the hill.
Today the ruins of Hadrian's substructures, overlooking the Forum, consist of a range of rooms, with wall 15 meters high, closed by barrel vault (Fig. 1). These structures artificially extended

beyond and against the north side of the hill and, becoming part in a whole of juxtaposed buildings, they created a connection between the Palace and the Forum.

Figure 1

Figure 2

2. THE HISTORY OF DAMAGE

The static disarrangement of the substructures of the Hadrian's building has been revealed until their construction, at the beginning of the II century. Many signs attest the damage and the repair works of the structures already in ancient age. Besides some irregularity in the brickwork of the surviving walls highlight the settlements in the first phase of building works.
It is like that the Roman builders know the softness of the soil and therefore the difficulty to wide the palace. Therefore they adopted an ingenious building system: the slope of the hill was terraced and propped with retaining walls and substructures, whose cross walls constituted effective buttresses, forming a whole of structures along the slopes of the hill. This was certainly the only way to widen the Palace assuring the stability to the new constructions.
However the internal stresses, due to the soil softness, weakened in time the retaining structures, that became particularly sensitive to exceptional actions. Therefore the intense seismic activity, that interested Rome between the 5^{th} and the 9^{th} century, produced remarkable collapses in substructures and perhaps the full destruction of the Palace. After that the progressive covering of the rubbles, formed a slope that settled in the centuries and provided an adequate maintenance for the surviving structures.
The ruins of the Domus were therefore abandoned or used to agricultural purpose and, finally, after the half of the XVI century, included in the Garden established by the Farnese family on the Palatine hill. At the end of the 19^{th} century, before the excavation works, the remains of the Hadrian's substructures, overlooking the Forum, were partially covered with earth, the arcades closed by walls and lacking in some portions of the vaults and internal walls and with large gaps in the original brick face (Fig. 2).
The excavation work and the demolition of the Renaissance superstructure gave back the imposing ruins marked by the signs of serious collapses and damage due both to the natural calamities and to the long exposure to the weathering. Only ten years later the remains were completely disinterred and deprived of the slope that had assured their stability, they became isolated and "suspended" on a clay terrace over the Forum. The front wall overlooking the

Forum, which was originally built as an internal wall, showed a relevant leaning and large cracks disconnecting it from the rear structures.
When the excavation works was completed, the need to oppose the tilting of the front wall was evident. The first repair measures assured the stability of the front, restoring the brickwork of the wall faces and building some masonry buttresses, that were based on the ancient footing of the collapsed structures. These repair works were carried out by P. Rosa and G. Boni respectively at the end of the 19th century and at the beginning of the 20th.
The strengthening of the front wall has been tackled at least two times again. At the end of fifties some steel bars to tie the front to the rear structures have been laid, the missing internal walls restored and the ruins covered. At the beginning of seventies the evolution of the settlements increased the damage on the front. In this circumstance two further pairs of steel tie-bars with large diameter were disposed to prevent sudden collapse. Nevertheless the scientific approach to design the repair works required a full knowledge of damage, so that a complete plan of studies and observations started.

3. THE PRESENT SITUATION

The analysis of the damage has been carried out with the contribution of the archaeological, geothecnical and static studies. This task has been based on deepen in situ investigations and on a long time monitoring of the relative and absolute displacements of the structures.
The cracks pattern on the internal walls showed the presence of three principal cracks plain: close to the front wall, corresponding of the inside openings and finally between the front and the external buttresses. The trend of the front wall to detach and to overturn was particularly worrying owing to the increase of the "historical" off plumb that already overcame 15 centimetres.
The masonry of the front, besides, showed a diffused micro-cracks pattern that mainly touched the restored face, but they locally stretched to the ancient masonry that showed a marked detachment between the brick face and the concrete nucleus.
The archaeological and geothecnical studies have linked the damage both to the kind of soil and to the lacks in the ancient retaining structures. The geothecnical studies have shown the stratigraphy of the soil under the foundations: the primary Palace is based on a tuff formation, while the Hadrian’s building is based on a fluvio-marshy recent drift, made of slime and clay (Fig. 3). The clay stratum, that formed the natural slope of the hill, presents an increasing thickness toward the Forum valley and it reaches the highest thickness below the northeaster corner of the front wall.
The measurements to monitor the widening of the main cracks and the evolution of the displacements in the structure have been performed during ten years. These measurements highlight a relevant movement, directly connected to the seasonal climatic variations, that nevertheless shows a little annual increase. The levelling measurements point out, in detail, the correlation between the displacements and both the seasonal change in the soil characteristics and the shrinkage and expansion of the masonry due to the fluctuation of the water content in the concrete masonry nucleus.

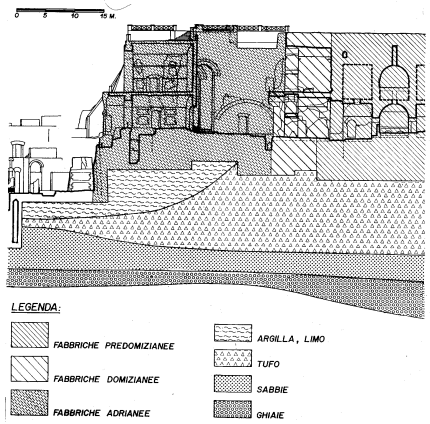


Figure 3

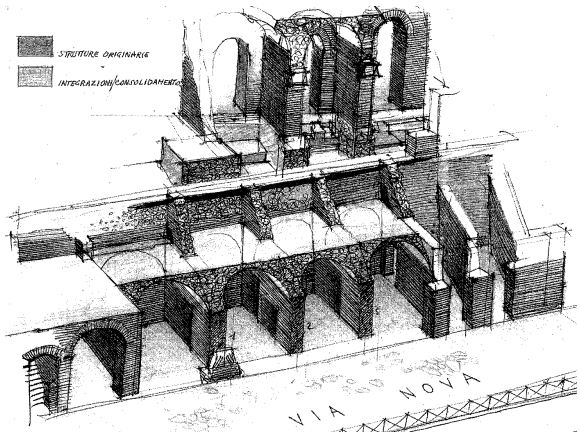


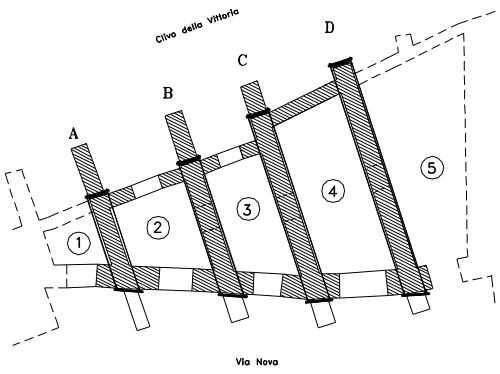
Figure 4

4. THE REPAIR WORKS

The deepen studies and investigations, carried out on the monument in the last decades, have therefore highlighted the need to integrate the repair of damaged masonry with an organic plan to stabilize the front wall.
The needs of preservation excluded an underpinning work to avoid settlements. This work would have altered the monument in a not reversible way, twisting the more ancient archaeological strata.
Two different repair methods have been then evaluated. The first way, agreeing on the first repair works, are based on the rebuilding, in a philological way, of the ancient structures below the Domus and on the widening the actual buttresses (Fig. 4).
The way chosen is the second one, that consists on replacing the passive tie-bars system with an active diffused one, able to ensure an action opposing to the front tilting and reducing the high pressure eccentricity on the footing. Although this is a more unobtrusive and less onerous solution, it needs to take in account the conspicuous seasonal movement of the structures, which would have caused harmful internal stresses in the masonry already weaken.
Following this purpose a tie-bar restraint which includes an innovative elastic device has been set up. This device gives to the masonry structures not only a simple translational restrain, but a constant applied force, also in case of settlements and creep.
This system is able both to guarantee the static behaviour of the building and to take up the settlements of the ground without further damage. Using this elastic restraint it is also possible to follow the change in the building dimensions due to the fluctuation of moisture and temperature, keeping steady the system efficiency and avoiding harmful internal stresses in the structures.

Into detail, two systems of coupled stainless steel tie-bars with small diameter have been laid close to the wall face. The main system counteracts the displacement of the front wall, while the minor counteracts the buttresses. Altogether coupled tie-bars are disposed on the four internal walls and distributed on four levels (Fig. 5, 6). The separation in two independent system reaches the purpose to make both a smaller restraint on the external front toward the Forum and

a precise and calibrated tie-bars system for the different structures that are already not connected (Fig. 7).
In accord with the forces required in the systems of tie-bars, two different elastic restraints have been designed. The three levels, tying the front wall, employ a device equipped with a calibrated spring leaf (Fig. 8). For each pair of ties, the bars are fixed to the ends of spring, which is inserted in a crossbeam leaning on the inside wall. Instead the tie-bars of the buttresses are equipped by a stack of cup springs fitted in a cylindrical device, that has been inserted in the hole through passes the tie-bar (Fig. 9).
These devices, as well as to apply a constant force, allow to minimize the effect of the different thermal expansion between stainless steel and masonry. In the longest bar (about 16m) the different elongation reaches ± 3.15mm, while the tension in tie fluctuate in a range (±10%), that is bearable by the structure.
The elastic system is of course supplied with suitable restraints to avoid any overturning or displacement. If the front wall move over the safety threshold, the tie-bar system is therefore able to guarantee its stability with forces higher than the post-tension value.
Finally the monitoring of the structural displacements and of the change in the tie-bar loads has been carried out both laying down the strengthening system and later on, giving the experimental auditing of the innovative aspects in the repair work.



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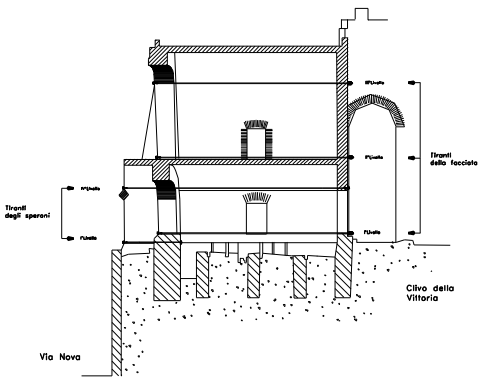
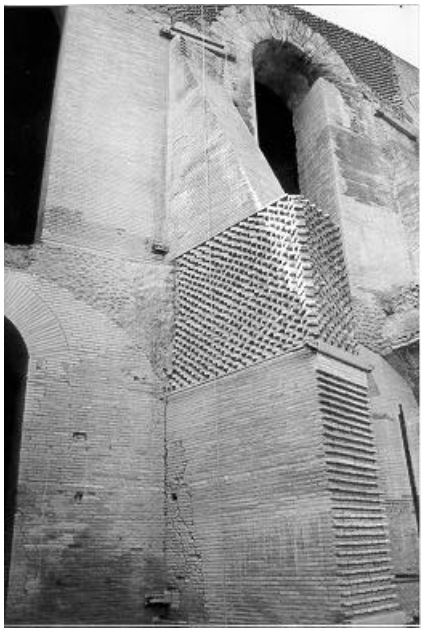


Figure 6

5. ACKNOWLEDGEMENT

The repair design arises from the agreement between the Archaeological Superintendency of Rome and the Interdepartmental Centre for the Science and Technology of Historical and Architectural Conservation, CISTeC, with the scientific supervision of Prof. Giorgio Croci.
The restoration work has been superintended by Arch. Giangiacomo Martines, co-ordinator of the Superintendency Technical Office.



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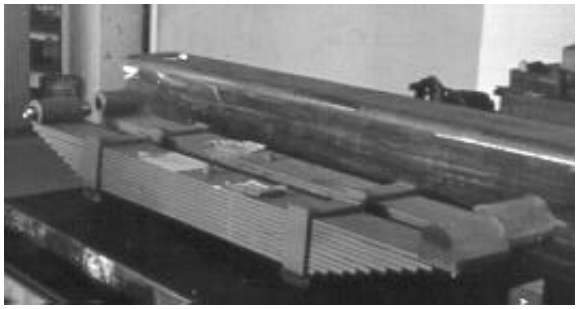

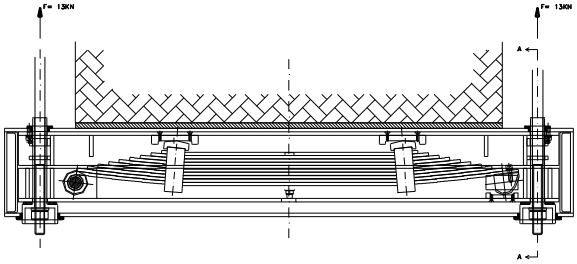

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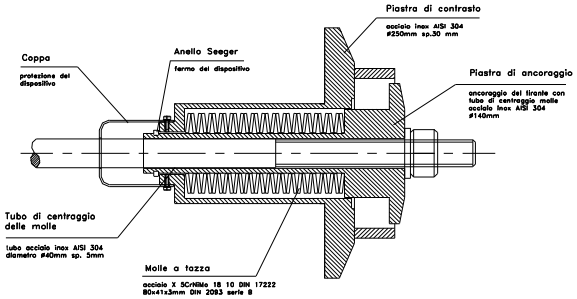

Figure 9

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