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Critical discussion about some measurements on a damaged corner of Palazzo Vecchio

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Abstract

A recent work carried out by both the Borough and the University of Florence has stressed the importance of historical investigations and "in situ" measurements in the analysis of the structural damage occurred in some ancient monuments, like Palazzo Vecchio, which in the past were subjected to substantial structural changes. A comparison of the data collected with the ones of other similar historical buildings leads to exclude the possibility that the structural damage, which occurred in one corner of Palazzo Vecchio, depends on increments, or changes of live loads. The dependence of the structural damage surveyed on some structural changes made in the course of the centuries is confirmed by some historical documents and by some experimental tests carried out "in situ".

1 Introduction

The static analysis of a building as structurally complex as The Palazzo della Signoria of Florence requires an accurate historical investigation that indicates the mutations (demolition and/or reconstruction) which have occurred over the centuries. The problem of stability, impossible to confront in its entirety, has been limited therefore to the study of one portion (Fig. 1), which is between Via della Ninna and Via dei Leoni, since on the inside, and in particular on the side facing Via della Ninna, a crack, which is slowly widening, has been observed.

The results of the historical research into this corner have brought to light a disparity in both the type of structure and materials used [1-3]. This meant having to re-examine the pre-existing parts of the building, either Roman or medieval parts, which are to be found in this area and which were included in the extension commissioned in the 15th century by Cosimo I to G B Marco del Tasso and G Vasari. In fact the architectural complex was built on the ruins of the Roman Theatre (1st century AD), which was rediscovered for the first time in the middle of the 19th century. A hypothesis of the historical reconstruction of the development through time of the part of Palazzo Vecchio about which we are concerned is contained in [4].

The relevant crack situated in particular in a part of Via della Ninna would seem therefore to be due to the structural and material differences described above, aggravated by distributive changes carried out in the Renaissance period in order to create more space and characterised by vertical cracks typical of a crush failure. As a matter of fact, the most evident structural anomalies were revealed after the demolition, in the lower floors, of a notably thick wall that divided the corner rooms from the largest room. The Council had decided to contain the damaged pillar by means of a steel structure (Fig. 2). Afterwards, at the request of the writers, in the spring of 1992, a temporary reinforcing wall was built while awaiting a more detailed diagnosis and a more permanent proposal for remedying the fault. The writers then decided to keep the evolution of the crack pattern under observation by measuring the relative displacements of the crack surfaces and by using the topographical and highly accurate level readings described in Section 2.

Based on the results obtained, a research in the Archives was begun, confirmed by the data surveyed "in situ" and quoted in Section 3; it has revealed that the reinforcement steel bars placed by Vasari have been removed during the recent remaking of some floors.

2 Checking the Fault

On account of the crack described above, some calculations were carried out, preceded by an accurate analysis of the loads, which led to a limited execution of provisional works while awaiting more thorough investigations. The analysis of the loads, as often happens in the case of historical monuments, has led to excluding increments and modifications of the live loads as the direct cause of the fault, in so far as the weight of the building itself takes on a predominant importance with respect to the additional loads, which could also be disregarded without stresses undergoing any variations of note.

In order to ascertain the resistance of the supporting structure and to understand the physical and mechanical characteristics of the constituent materials numerous core samples were taken which have excluded the possibility that the masonry walls were of the "a sacco" type. The material of the supporting structure, for the most part stone with small parts of bricks, has proved to be high quality, as has also the mortar. Tests have been carried out to determine the ultimate strength and the elastic properties of the material, which are useful data for subsequent numerical simulations of this portion of the structure.

In order to understand better the static behaviour of this structural complex the evolution of the deformations and displacements have been monitored for about two years. Three types of investigations have been carried out; they are concisely outlined here.

i) Deformation Readings

After an accurate graphic restitution of the fault thirty reading points were fixed, an operation which was not without difficulty, taking into consideration the fact that the majority of the inner walls are frescoed (Fig. 3). The apparatus used for the deformation reading is a "Pizzi" analogical deformometer with a measuring base equivalent to 20 cm and an approximation of 1/1000 mm. The first reading is of 25/5/1992 while the last one is of 28/10/1994. In this period of time twenty three readings were taken, of which twenty one with an interval of twenty days between each one, the last two in 1994 at a distance of six months one from the other. From an examination of the time-displacement diagram it as clear that the alternate movement of the readings corresponds to the opening and closing of the cracks. This movement has been related to the amount of rainfall monitored by the Ximeniano Observatory of Florence and to the level of the River Arno, the values of which were obtained from the "Ufficio Idrografico e Mereografico" of Pisa. From a comparison it is clear that the level of the water bearing stratum influences the extent of the displacements noted by the deformometer. The building was also under observation in May 1993, the period in which the bomb exploded in Via Georgofili, a street very close to Palazzo Vecchio. The explosion did not produce any notable variations in the patterns of the diagrams, as can be seen in Fig. 4.

ii) Triangulations and forward intersections

In order to measure the movements of the façade facing Via della Ninna a triangulation of topographical type was carried out (Fig. 6A). Four placings were chosen which are reciprocally visible, as indicated in the attached planimetre with the letters A.B.C.D (Fig. 6B). Nineteen square plaques of teflon with a width of 10 cm were fixed onto the façade under examination. Because we are dealing with precision work this material was chosen for its low coefficient of thermic working. The plaques were laid on the diagonals with brass listels, the crossing points of which gave the points to be picked up by the theodolite. The plaques were positioned four per floor approximately, half way between one level and the other. The displacements which were measured proved to be of an extent that is impossible to overlook, and suggested the need to carry out the investigations of the archives as described in the following Section.

iii) Highly accurate readings

In support of the deformation readings described in point *i)* other highly accurate readings were taken which confirmed the hypothesis that the "fluctuations" recorded in the diagrams of Fig. 5 are to be attributed, to the most part, to the movements of the stratum. After choosing a datum point from which to start, (a plaque put up by the Military Geographic Institute) the bases and the positions were identified, seven in number (two in Via dei Leoni, four in Via della Ninna and one on the corner). The results are shown on the diagrams of Fig. 5. It is opportune to compare also these readings with the pluvimeter data and the levels of the River Arno.

3 Vasari's Reinforcements

The evolution of the deformation of the walls being concerned (Fig. 6A) has clearly indicated the limited efficiency of the floors as instruments of horizontal connection and has led to the carrying out of an accurate investigation at the State Archives of Florence, in the course of which a handwritten invoice was found,

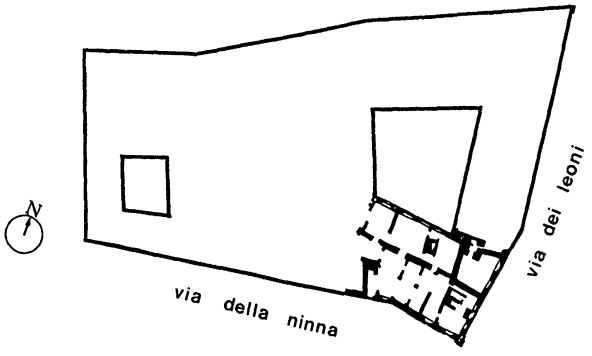


Figure 1: ground floor plan.

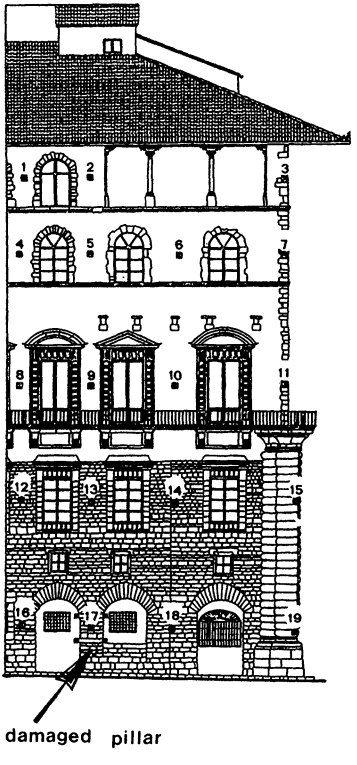


Figure 2: façade on via della Ninna.

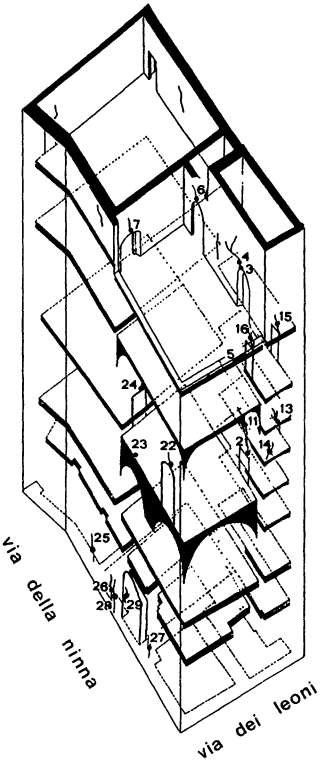


Figure 3: isometric view.

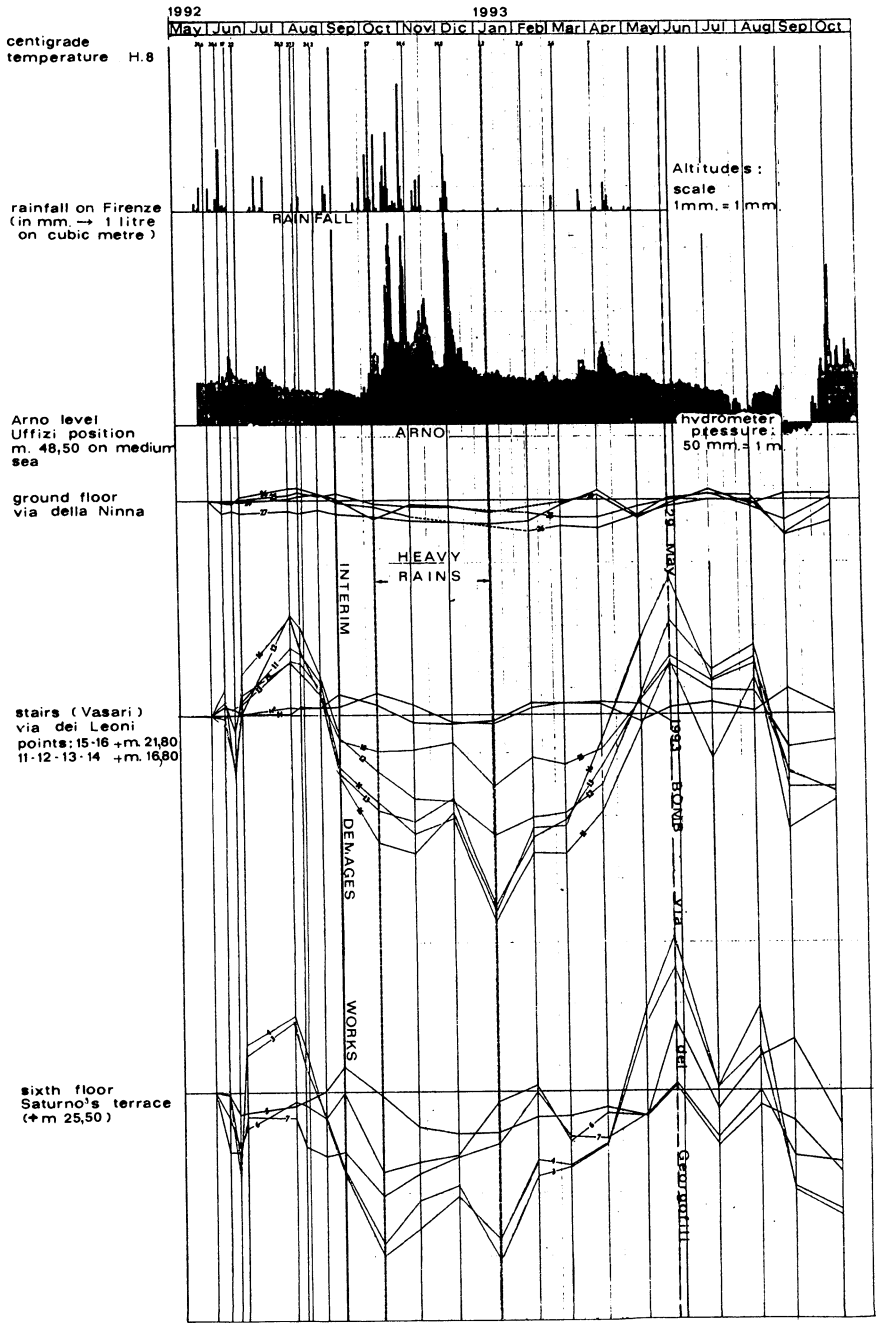


Figure 4: deformation readings.

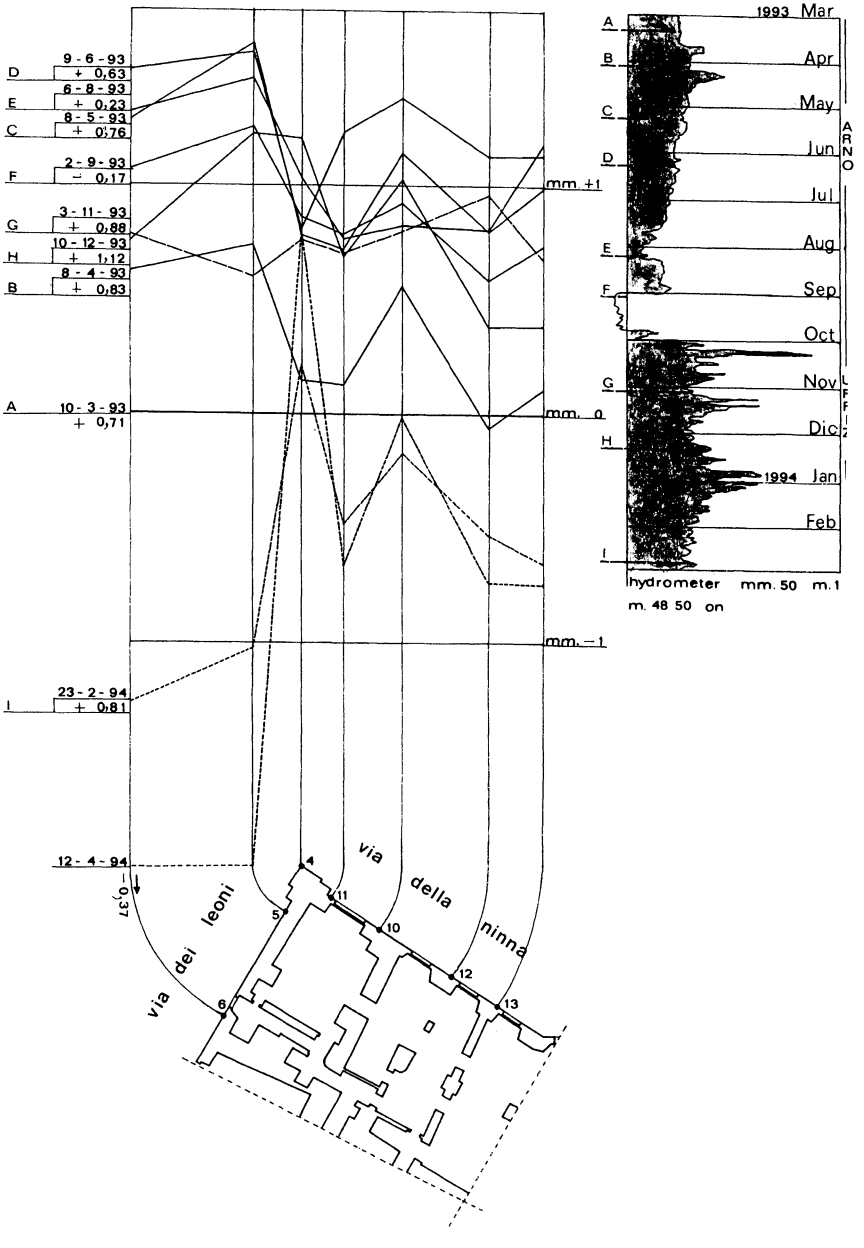


Figure 5: diagrams of vertical displacement.

addressed to G. Vasari and concerning the production of thirteen steel bars to reinforce a corner of Palazzo Vecchio [7-13]. The corner, subject to the intervention, turned out to be exactly the one under examination. Thus, already in 1558 signs of a fault had been reported: the causes in that case could be various: the settling of the new masonry in relation to the buildings incorporated into the corner or an incautious intervention by Vasari. It is historically certain that Vasari was forced to insert at least thirteen steel bars into the ceilings of the last three storeys in order to contain the effect of a volume which had become increasingly greater in the course of the centuries (it should be noted that Vasari had also inserted new vaulted and, therefore, straining roofing). In the past it had never been possible to detect any traces of these reinforcements; only those present in the ceilings were identifiable from their "heads" still visible on the façades. By the use of a powerful "metal detector" supplied by the "Genio Militare", capable of picking out the presence of iron substances, all thirteen of Vasari's seel bars were identified. These had been cut in recent times (in the 1950's) for the remaking of some ceilings (Fig. 7).

4 Future Developments of the Investigation

The surveys and the "in situ" tests were completed a few days ago. It is hoped that from these data it will be possible to obtain information in order to define the current depth of the foundations, the possible pre-existing archaeology and the stratigraphy of the ground. Piezometers will be fixed into the holes resulting from the extraction of the core samples in order to carry out a further examination of the stratum and its variations. All of this has, as its aim, the design, if necessary, of an opportune sub-foundation. The analysis of the data collected in the course of the investigation will, in addition, allow the suitability of other interventions to be assessed, such as the reinforcing and/or the substitution of the pillar "at risk", part of the façade of Via della Ninna, and the restoration of Vasari's reinforcements, cut in the 1950's.

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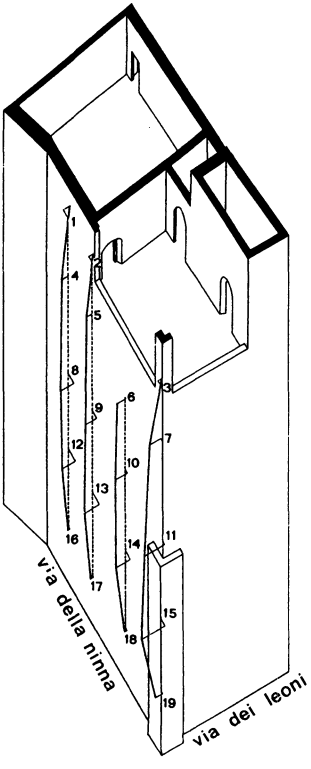


Figure 6A: movements of the façade.

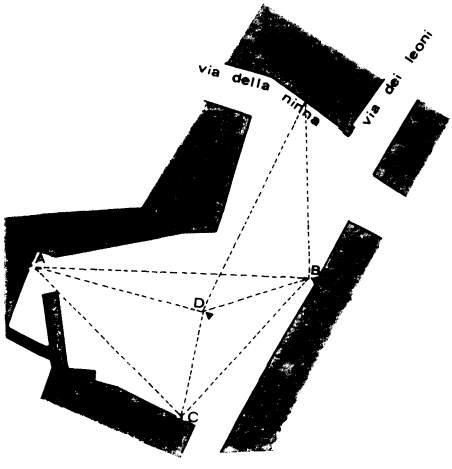
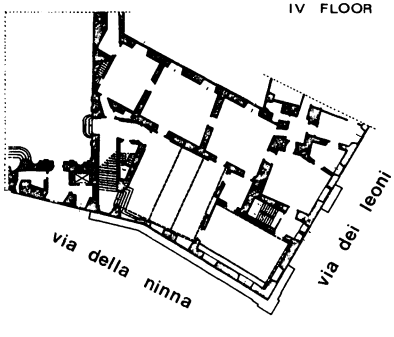


Figure 6B: planimetry.



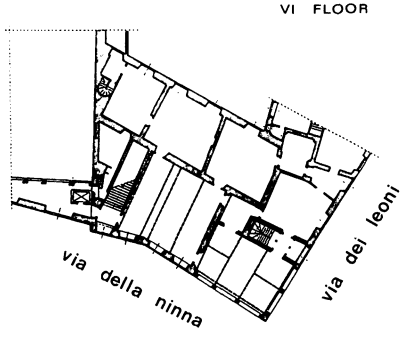


Figure 7: location of Vasari's reinforcements.