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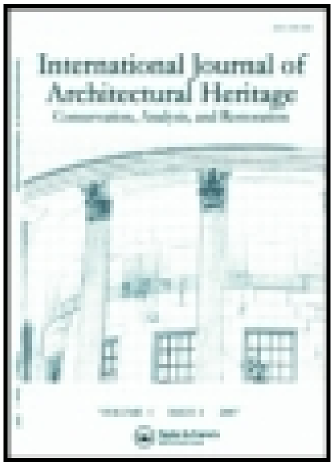

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Preventive Intervention in a Group of Buildings Located in the Historic Centre of Manresa (Barcelona)

C. Diaz[a], C. Cornado[a], A. Griera[b], O. Caselles[c], V. Alegre[d] & P. Santamaria[a]
[a] Universitat Politècnica de Catalunya. Dept. of Architectural Technology I. Barcelona. Spain
[b] Universitat Politècnica de Catalunya. Barcelona. Spain
[c] Universitat Politècnica de Catalunya. Department of Geotechnical Engineering and Geo-Sciences. Barcelona. Spain
[d] Universitat Politècnica de Catalunya. Department of Construction Engineering. Barcelona. Spain

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PREVENTIVE INTERVENTION IN A GROUP OF BUILDINGS LOCATED IN THE HISTORIC CENTRE OF MANRESA (BARCELONA)

Shortened version of the title: PREVENTIVE INTERVENTION IN MANRESA'S OLD TOWN

C. Diaz[a], C. Cornado[a], A. Griera[b], O. Caselles[c], V. Alegre[d], P. Santamaria[a]

[a] Universitat Politècnica de Catalunya. Dept. of Architectural Technology I. Barcelona. Spain.

[b] Universitat Politècnica de Catalunya. Barcelona. Spain.

[c] Universitat Politècnica de Catalunya. Department of Geotechnical Engineering and Geo-Sciences. Barcelona. Spain.

[d] Universitat Politècnica de Catalunya. Department of Construction Engineering. Barcelona. Spain.

cesar.diaz@upc.edu, cossima.cornado@upc.edu, antoni.griera@coac.net,
oriol.caselles@upc.edu, secretaria@cotca.com, pere.s@coac.es

Summary

The preservation of old downtowns has become a necessity of growing interest. New urban policies have been approved in different countries in order to revive the old city centers and make them economically sustainable. In this global trend, the municipality of Manresa (Barcelona) developed an important urban planning operation in the old district that included the demolition of a group of existing buildings and the construction of a new modern one in close proximity to a group of old residential buildings which are cultural heritage of the city. As a consequence, specific areas of risk were generated which lead to the adoption of precautionary measures to ensure safety.

This paper presents the preliminary analysis, diagnostics and monitoring carried out on this group of heterogeneous old buildings, as well as the results and precautionary measures taken to ensure their safety. The paper also provides a translatable methodology that combines qualitative and quantitative aspects.

Keywords: Building pathology, Structural analysis, Non-destructive tests, Geotechnical tools, Crack measurement tools.

1. Introduction

Current policies tend to revitalize historical centers by attracting people towards them in order to make them economically sustainable (Stenberg 1995, Lowing 1994). Within this type of policies, the Manresa City Council has planned to protect the historic centre with the preservation of certain areas that stand out for their urban quality (Ajuntament de Manresa 2012). In other areas of less value, also set in the historic center, the council has chosen some strategic locations to build new buildings that may help to dignify and revitalize some neighborhoods.

The present paper outlines the steps and methodology followed in order to find answers for a specific risk situation that was generated by an urban operation in the historic centre of Manresa, close to the city’s cathedral (figure 1). Such operation involved the construction of a new building allowing a better visibility of a Gothic bridge (S. XIII-XIV) and the preservation of the old buildings in close proximity to the new one.

The preserved buildings form part of an urban block which was partially demolished to allow the construction of the new residential building. Their architectural interest derives from the value of the urban context of which they form part, their location on one edge of the historic centre of the city and by the sense of belonging and strong attachment among the inhabitants of the district. The remaining buildings are residential and date from the end of the eighteenth and beginning of the nineteenth century. For these reasons, the group of buildings studied was declared Cultural Heritage in 1985 (Ajuntament de Manresa 2012) and are protected since then by the current urban planning. These were the most prominent reasons for the municipality to take the decision to conserve the buildings against the alternative solution of demolishing and rebuilding the entire block - an alternative which would have simplified the construction process and reduced the overall costs considerably.

As is mentioned in greater detail in part 3, these buildings are notable for the diversity of materials and construction methods employed. They are also notable for the lack of interlocking between walls and between the infill walls and pilasters that make up the vertical structural elements. The combined presence of stone, rammed earth, adobe and brick walls, together with stone or brick pilasters is a typical feature of the construction of Manresa.

The demolition of half of the urban block had the effect of exposing the rear dividing walls of the remaining buildings and eliminating the contact which had previously existed with the demolished buildings. Due to it, this demolition worsened the initial stability of the buildings (figure 2).

The new residential building was originally planned with three underground storeys for car parking (figures 3, 4) in close proximity to the foundations of the existing buildings. The excavation had to be carried out in a soil formed by an alternation of hard marl and soft conglomerate of the Paleocene (Institut Geològic de Catalunya 2011). Due to the characteristics of the foundation soil, the excavation might create a risky situation due to vibrations. There exists some significant previous research about excavation close to historic buildings (Hanson, Towers, and Meister 2006, Chuaqui, Ford and Janes 2007, Balachandran 1998). However, the present combination of hard-soft soil and brittle buildings caused a specific problem not previously investigated or dealt with in previous research.

2. Aim of the work and methodology

A number of safety measures were adopted in order to safeguard the remaining old buildings. Some of these measures were scheduled for the phase prior to the construction on the new building, while others were to be undertaken during the construction phase. Their aim was to achieve adequate safety levels in the buildings and to limit their residents' exposure to situations that could be objectively described as causing discomfort.

From the very beginning the work progressed in three principal steps with the following aims:

In the first place, it was necessary to evaluate the condition of the buildings as regards their structural characteristics before construction work began. The following actions were carried out:

a) Preliminary documentation about the existing buildings including, in particular, a detailed geotechnical report on the site and a large photographic survey. The latter was oriented to record the condition of the dividing walls and the rear facades before the application of a sprayed polyurethane protection.

b) Drawing up of survey plans of the existing buildings indicating in detail the materials and construction methods used. The inspection carried out for the survey included perforations in the masonry to allow detailed inspection (section 3).

c) Locating and representing graphically the damage visible in the structural elements of those buildings, including cracks and fissures, subsidence and swelling in the walls; sagging in the floors; biological attacks, dampness, etc. (section 3).

d) Carrying out in situ of tests and with the aims of defining the structural characteristics of the walls and the timber beams in the floors. Tests were also carried out to characterize the effects of vibrations on the existing buildings originating from the types of machinery and methods proposed for the excavation in the rocky ground (section 4).

Once all needed information had been gathered, the general condition of the existing buildings was assessed and the precautionary measures to be carried were determined (section 5).

Finally and during the construction of the new building, control measures were recommended consisting of the monitoring of the effects of vibrations during the construction phase (section 6).

3. The buildings and their condition

The group of buildings studied date from the early nineteenth century, although some parts were built before that time and some of them are more recent. At present, there are buildings of between two and five storeys aligned along *Escodines* street and *Sant Antoni* street. Almost all of the buildings on *Escodines* street have a basement at the rear, far from the street. The basement allows to support the buildings on a strata of bedrock. The ground floors of the buildings are mostly devoted to commercial use, while the upper floors are dwellings.

The construction methods used are traditional ones involving stone blocks, adobe blocks, rammed earth, and to a lesser extent ceramic bricks. Floors are made up of timber beams and joists with vaults of ceramic material or wooden boards between beams (figures 5, 6). The stone walls are more common in the basements and ground floors, but can also be found here and there in the rest of the stories. The parts built recently stand out due to the use of perforated or hollow bricks and reinforced concrete joists. The construction is heterogeneous owing largely to the different constructions stages experienced and to the variety of traditional construction techniques utilized, most of which are traditional in the area (figure 7).

Remarkably, a serious lack of connection between the different structural members was observed. The addition of new parts to the older construction without any consideration on the structural behavior has worsened the initial characteristics of many of the buildings. It is also worth mentioning that many of the buildings had undergone some form of strengthening in the past, especially in the timber joists and beams and, in some cases, the walls.

Despite the diversity of the buildings, some general rules were found. Ground floor walls are built of stone (ordinary masonry or random rubble masonry) with thicknesses ranging between 45 and 62 cm. On the contrary, walls in the upper floors are mostly built of adobe blocks (the “tovot” adobe traditional in Manresa) or rammed earth walls with thicknesses ranging between 20 and 50 cm. In some buildings there are stone pillars that rise up from the stone walls of the ground floor to the top of the buildings. Spanning between them are wooden beams to receive the joists. The pillars are combined with load-bearing walls made of adobe or rammed earth which also support the timber beams that receive the joists. Floors are made up of timber joists and vaults formed with ceramic tiles or bricks. In the basements and ground floors there are some larger stone and ceramic vaults.

The types of damage visible in the buildings are a result of diverse causes. In some cases, they were directly related to the lack of connection in the overall structural system as mentioned previously, especially, when the pillars were showing significant lateral deformation due to the lack of confinement from other parts of the structure (figure 7). In other cases, damage was seen in the form of cracks marking the join between materials behaving differently under vertical loads. Cracking due to concentrated loads were also observed. Other alterations, like the progressive sagging of wooden floors, were due to ageing. Damage due to a lack of maintenance, to dampness or to a combination of the two was also noted, as is the case, in many instances, of rot and other biological attacks on timber elements (figure 8).

Some cracks that had appeared more recently in two of the buildings were directly caused by the mechanical effects of the demolition of neighboring buildings.

Notably, there was a complete absence of damage caused by settlement or ground movement, owing to the fact that the buildings are located on a stable and stiff stratum of bedrock.

The information collected about the construction techniques of each of the eleven buildings, the systematic visual recognition and mapping of damage and the subsequent diagnosis allowed the final set of recommendations listed in section 5, regarding preventive measures, control and monitoring to adopt in the new building project and during its construction.

4. Tests and trials carried out

An experimental plan was laid out, including a number of tests and experiments, to be carried out before the beginning of the construction of the new building. The plan was aimed to the following purposes:

1. Study of the structural parameters of the walls.

2. Study of the structural parameters of the wooden floors.

3. Verification of the levels of vibration caused by possible types of machinery to be used for the excavation of the rocky ground at the site of the new building.

4.1 Determining the structural characteristics of the walls

Presiometric tests were carried out in a sample of walls of the old buildings, including rammed earth, adobe and stone rubble masonry ones. The aim of these tests was the estimation of reference levels of their respective compressive strengths (Binda, 2003).

The locations to carry the tests were chosen by prioritizing the most heterogeneous and loaded zones (figure 9). The total number of valid tests was 15, of which 2 were carried out in 2 adobe block walls, 7 in rammed earth walls and 6 in random rubble masonry walls. The location and number of tests was greatly constrained by the ability to access to the dwellings and the difficulties in manipulating the tools necessary to carry out the drilling (Binda, 2003, Clarke, 1994). Tests were not carried out in brick masonry walls because of their relative scarcity and their non-critical placement.

The testing method used (known as PiD) consists of the perforation of the wall with drills of a diameter of between 70 and 80 mm and the subsequent fitting of a probe of expandable material with the same diameter as the hole (figure 10). Knowing the surface of the probe in contact with the wall and the pressure-stress values generated in the contact between the probe and the wall under successive levels of loading, allows the stress–strain values of the wall to be graphed and the ultimate strength to be estimated. This method is explained in greater detail in Díaz et al. (2008). The PiD has a precedent in the method described in the regulation ASTM D4719-87R94 (American Society for Testing and Materials 1994) applicable to ground testing. The method has been modified for its application to earthen or masonry wall testing.

The following table (table 1) shows the ultimate strengths and the moduli of elasticity found for the stone walls, adobe and rammed earth walls.

It is worth noting that the compressive strengths obtained (table 1 and figures 11, 12 and 13) are in the range of the standard values of walls with similar characteristics. Also, the results for the random rubble masonry walls (with the random nature of the mortar joints) reflect both the lack of gaps in the stonework and the quality of the lime mortar (figure 13). If there had been any major deterioration in its cohesion, this would have damaged the probe and invalidated the test. On the other hand, the slightly higher ultimate strengths of the adobe block walls (figure 12) with respect to the rammed earth walls (figure 11) can be interpreted as being due to the contribution of the lime mortar joints to the overall strength. Moreover, the comparison of the stress-strain graphs of the different types of walls (figures 11, 12 and 13) indicates a greater stiffness of the stone walls compared to those of adobe blocks or rammed earth. These graphs include a first almost horizontal branch which corresponds to the free expansion of the device until it contacts the perforation surface.

4.2 Measurement of the mechanical properties of the floors

For the study of the timber floors tests were carried out in three different locations chosen according to their accessibility and to their level of dampness. These different locations are designated as LOT 1, LOT 2 and LOT 3 in figure 14 and table 2. Samples were taken and tests carried out on joists that showed signs of dampness and also in joists located in dry environment with no sign of dampness.

Two tests were carried out on the timber joists. The first involved the extraction of small cylindrical test specimens perpendicular to the grain to be tested in the laboratory in order to identify the wooed species and to obtain the mechanical properties. This method was combined with non-destructive penetration tests with a special drill linked to a computer (Lozano, 2006). The drills were made close to the location of the extractions of cylindrical specimens in order to allow a correlation between the results of both tests. Such approach permitted a more certain estimation of the wood strength values. Three groups of timber joists were tested. The estimated average compressive strength, taking into account both types of tests, is resented in table 2.

Recommendations for the replacement, strengthening or propping up of various parts of the floors were based on the assessment of those groups of timber floors with the data obtained from the tests. The recommendations also considered the need to intervene in areas showing excessive deformation.

4.3 Assessment of the structural elements

Given the heterogeneity of the buildings, for the structural verification it was essential to take into account their heterogeneity and the variety of conditions regarding the connection and the interlocking between different parts. Particular attention was allocated to the study of wall-to-wall connection as well to the connection between pilasters and walls. The details of the supports of wooden beams on pilasters and joists on walls were also carefully analyzed. The fact that most of the buildings have experienced partial demolitions, reconstructions or additions adds further uncertainty to the overall characterization and modeling.

Due to the heterogeneity and the variety of conditions regarding the connection between the parts, the application of numerical simulation methods has not been considered appropriate as to obtain accurate results. A proper numerical modeling would require a higher level of certainty and knowledge about the mechanical properties and the connection between the different members. It should be mentioned that in the ICOMOS Charters (ICOMOS 2003), qualitative analysis, direct observation and historical research are taken into account along with the experiments and quantitative structural analysis.

The structural verification of walls was carried out on a set of selected wall panels encompassing the main existing materials (rubble stone masonry, adobe and rammed earth). The selected set of walls panels included the most critical cases according to the stress levels, the thickness and the connection to the timber floors. The calculation method adopted for walls subjected to compression forces was the one proposed by the standard NBE-FL90 (Ministerio de Obras Públicas y Urbanismo 1990), which was in force at the time of the study and is based on the same principles as the current EC6 standard (European Committee for Standardization 2004). The calculation took into account the connection between walls and floor slabs according to the construction details corresponding to each different case. In particular the stiffness of the connection between the joists and the walls was estimated based on the embedment length of the joists into the walls.

Three groups of timber floors chosen to be sufficiently representative of the entire group of buildings were selected for structural verification. The study was based on the French code for timber structures (Commission des règles de calcul et de conceptión des charpentes en bois 1994) and the wood was classified according to the Spanish regulation (Asociación Española de Normalización 2003).

It was found that timber joists in group 1 were under the expected safety levels while safety in groups 2 and 3 was acceptable. It was also found that humidity had no influence in the mechanical behavior of the timber floors. Based on these results, recommendations were derived on the need for safety measures and the strengthening of the timber floor slabs.

4.4 Experimental investigation of vibration levels

The effects of vibration were examined by means of a set of tests carried out before the excavation works needed for the new building. As mentioned, these excavation works were carried out on a rocky type of substratum.

For this purpose, an excavator with a hydraulic percussion hammer with operating weight from 780 to 1500 kg was brought to the site. Measurements were taken in the foundations, floors and walls of the buildings close to the drilling zones with piezoresistive accelerometers fixed to selected points. Tests were also carried out on the floor slabs to identify their resonating frequencies (figure 14).

The accelerations measured with the percussion hammer were found in wide range between 0.02g and 0.75g. As a result, in some buildings they exceeded the recommended values of human exposure to vibration listed by some international institutions (British Standards Institution, 1984) (International Standard Organization, 1987).

Regarding the resonating frequencies of the floors – all of which are made of timber joists - they were found to oscillate between 14 and 50Hz, with the majority occurring at around 20Hz. The use of the machine was not inducing any significant risk because its working frequency, which was of the order of 6Hz, was under the previous values.

This data led to the discovery of excessive levels of vibration in the walls of two of the buildings. Because of it, it was considered that the proposed excavation system should be changed for a different one causing a lesser vibration. It was also proposed to move the position of the retaining wall to be excavated to a more distant position with respect to the existing buildings. At the same time, it was recommended that the level of vibrations should be monitored by means of seismographs during the construction of the new building.

5. Proposed recommendations

The recommendations derive from the study of the buildings' typology and damage and the results of the different tests carried out have been subdivided in two different phases according to the order in which they should be implemented.

5.1. Initial safety measures

It was clear from the initial survey of the building that some safety measures needed to be taken before the diagnosis tasks could be completed and the final recommendations drawn up. These initial measures consisted of the shoring of the rear parts of three of the existing buildings, as it was considered that their level of safety had been severely diminished by the demolition of neighboring buildings whose walls had been providing a structural connection. It was also decided to spray what had been the dividing walls - and any others that had become exposed to the elements by the demolitions - with polyurethane to improve their weathering performance.

5.2. Recommendations regarding the construction phase of the new building

Based on the test results on the vibration effects of on the users of the buildings, it was considered advisable to evacuate the buildings during the period of excavation works programmed in the project. Nevertheless, this precaution could have been avoided by the use of slower methods of excavation capable of maintaining levels of vibration below those considered excessive.

In particular, the following actions were recommended and carried out:

- Setting up of a plan to monitor the vibration levels to be carried out during the entire excavation phase and the construction of the retaining wall for the basement floors of the new building. Maximum permitted levels were defined in that plan (see section 6.1). Such levels were drawn from different documents (Asociación Española de Normalización, 1993, Colegio de Ingenieros de Caminos, Canales y Puertos. 2001, and Bachman, 1987).

- Checking for any evolution in the damage in critical points, such as structural connections and other places particularly sensitive to vibration (see section 6.2).

- Propping of several timber beams with evident deflection.

6. Safety measures carried out during the construction phase

The following paragraphs review and comment the details of each of the actions addressed during the construction. These actions refer respectively to the effects of vibrations during the excavation process and the monitoring of any evolution of the cracks.

6.1. Control and evaluation of vibration levels

During the process of excavating and constructing the foundations of the new building (figure 15), tests were carried out with two different objectives. Firstly, finding out the vibration levels generated by the different excavation processes in order to evaluate their potential effects on the existing buildings; and secondly, monitor the level of vibrations in the base of the existing buildings, in order to make sure that they stayed below the established limits throughout the building of the concrete retaining wall and the excavation.

Regarding the first objective cited, and before their systematic implementation on site, three excavation methods were tested: hydraulic wedge, proposed for the majority of the building site; depth hammer or Down-The-Hole (DTH) hammer drill, proposed for the piling at the perimeter; and finally, the 270Kg (410J) hydraulic hammer proposed for excavating close to the rear facades, between the provisional structures and the rests of walls that prop up the existing buildings. In all three cases, triaxial seismographs were used for measurement.

The maximum vibrations recorded in each one of the tests carried out with the pneumatic hammer were respectively 0.44, 0.75, 1.78 and 10.35 mm/s with predominant frequencies above 100 Hz. The last value exceeds the maximum amount of vibration permitted for buildings classified level III according to the standard regulation UNE 22.381(Asociación Española de Normalización, 1993). These measurements led to the recommendation of a different drilling method in the areas close to the existing buildings.

The first excavation method tested was the hydraulic wedge. This method requires the monitoring of the preliminary drilling and of the hydraulic wedge itself (Persin, 1997). The maximum vibrations measured in the two tests using the hydraulic wedge were 0.21 and 0.35 mm/s with predominant frequencies above 100Hz. These values are well below levels that could cause discomfort to people (Asociación Española de Normalización, 1993).

The second process that was subjected to testing was the construction of the perimeter retaining wall with micro-piles using a Down-The-Hole (DTH) drill. Test areas close to the old buildings were chosen to check the vibration levels in them.

In this case, the maximum vibration level, produced at the closest point (1.7 m), was of 6.35 mm/s and the predominant frequency of 135 Hz. These values were well below the maximum permitted in the standard regulation UNE 22.381 (Asociación Española de Normalización, 1993), so the use of the proposed method was approved.

The third excavation method analyzed was the 410 J hydraulic hammer. The maximum vibration reached values of 5.5 mm/s with frequencies of around 100 Hz (figure 16). These values remained four times below the maximum permitted by the standard regulation UNE22.381 (Asociación Española de Normalización, 1993). Therefore, the use of this type of hammer was deemed acceptable.

The control of vibration levels in the base of the buildings during the excavation of the piled retaining wall was carried out by a system of permanent electronic seismic monitoring. The system included an alarm and warning lights that would be activated for levels of vibration exceeding pre-established limits. For this purpose, six small concrete tanks with an interior volume of 70x70x70 cm, with watertight lids were distributed along the dividing walls of the buildings (figure 17). In each one of the tanks, a Geosource SM-6 geophone was installed and its response corrected to comply with the standard regulation UNE22.381 (Asociación Española de Normalización, 1993). The geophones were connected to an Instantel Minimate Plus seismograph, using highly shielded cables. The alarm and light were installed on a box containing the seismograph. The geophones were placed in accessible locations, in the upper part of the foundations of six of the buildings. They were placed evenly spaced to minimize the distances between the measurement points and the area of generation of vibrations.

Based on data from the tests previously carried out (using the hydraulic wedge and DTH drill) an alarm level of 14 mm/s was established. This level represents 75% of the maximum level permitted according to UNE22.381 (Asociación Española de Normalización, 1993) for the frequencies measured and using the different excavation methods. The monitoring carried out confirmed that vibrations did not exceed 20 mm/s for frequencies above 100 Hz (figure 18). It also confirmed that the machines used never generated vibrations with frequencies below 50 Hz, vindicating the choice of the alert level established.

The monitoring and alert system installed led to the halting of certain actions whose vibration levels had been approaching the reference limits of regulation UNE 22.381 (Asociación Española de Normalización, 1993) but without exceeding them.

Some conclusions on the excavation methods can be derived from the measurements carried out:

a) Although it is verified that excavation using the hydraulic wedge creates very small vibrations, the necessary preliminary drilling has to be controlled when carried out close to existing buildings (at a distance less than 3 m in this case) This control becomes particularly important when the drilling is undertaken close to buildings showing a delicate condition due to their structural vulnerability or their heritage value.

b) The DTH drill generates a very high level of vibrations over a short distance (above 6 mm/s in this project). However, these vibrations occur with very high predominant frequencies, which according to all the studies and existing regulations are found not to be harmful to adjacent constructions in rocky conditions as is the case in this site. This study makes clear that the vibrations and predominant frequencies are very much related not only to the type of rock or soil but also to the quality and degree of rock breakage.

c) The hydraulic hammer can be utilized in specific circumstances where the vibrations generated are in the high frequency range for which the buildings are less vulnerable, and accordingly the regulations are less demanding.

6.2. Tracking of the fissures and cracks with tell-tales and comparative measurement

As mentioned, the buildings were continuously inspected to collect data about the evolution of damage during the excavation works and the construction of the new building. In this way, precise information about the direct effects on the buildings (which were still occupied during the construction) could be obtained.

For that purpose, the set of the cracks deemed more representative and meaningful were chosen to detect movements in the structural elements. This involved cracks in the form of relieving arches, separation between load bearing elements, and other damage. The procedure consisted of placing a total of 29 tell-tales and 15 calibrated datum points in the cracks selected. In total 24 sets of readings were taken – approximately one every three weeks – over the 18 month duration of the excavation and the construction of the basement floors of the new building. The tool used to take the measurements was a digital caliper with reading accuracy of 0.2 mm and an instrument accuracy of 0.01mm.

The maximum movements measured were in the order of 1.4 mm, and their appearance coincided with the production of the maximum vibration levels. Apart from this incident, the measurements taken did not detect any other notable events during the building process (figure 19).

7. Final conclusions

The buildings analyzed show the usual characteristics of urban aggregates in historic urban centers such as great variety and heterogeneity of materials, structural members and connections between their different parts. The case analyzed also shows the diversified succession of construction phases that may affect ancient buildings, including operations such as partial demolitions, structural substitutions and addition of new storeys.

The approach applied for the structural verification of the structures has involved the combination of in-situ experimental methods to estimate the strength of the materials (adobe, rammed earth, rubble stone masonry and timber) on a selective sample of structural members. In turn, and based on these values, the verification has been carried out on a sample of sections of walls and floor slabs subjected to comparatively high-load levels.

The study and the safeguarding of old buildings affected by the construction of new ones in its immediate environment requires a global and comprehensive knowledge of the structural characteristics of the buildings concerned, along with their damage, their reserve of mechanical strength and the effects of the construction procedures intended for the new buildings.

Nevertheless, there is a lack of regulations on temporary risk situations on existing buildings which leaves full responsibility on the technician committed with the protection of the buildings.

The control of the vibration levels has been found particularly important for the determination of the excavation methods compatible with the safeguarding of the old buildings. In the case analyzed, the only damage appeared in the buildings during the construction of the new building occurred as a consequence of exceeding the vibration levels allowed, due to the excessive power of the machinery used for excavation of rock.

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Figure 1: Location of the city block in the historical centre of Manresa.

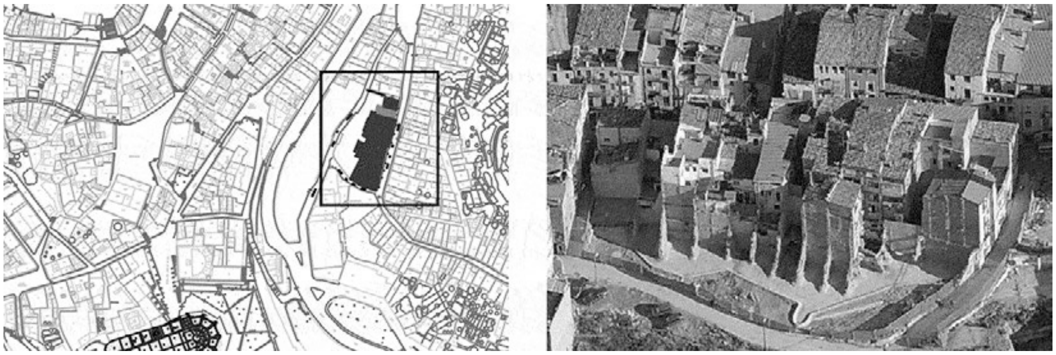

Figure 2: Facades of the buildings and rear view after demolitions had taken place.

Figure 3: Sections of the existing buildings and the proposed new building with its basement parking floors.

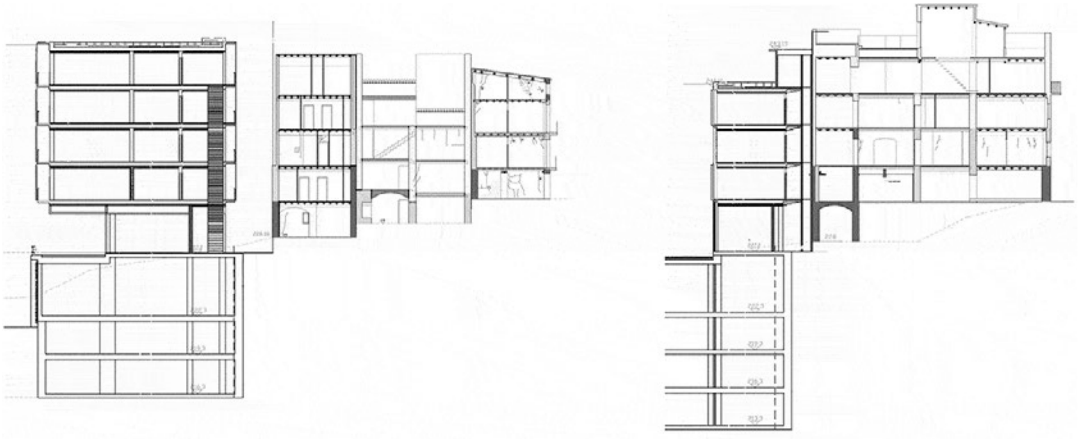

Figure 4: First floor plan of the existing buildings and proposed new building.

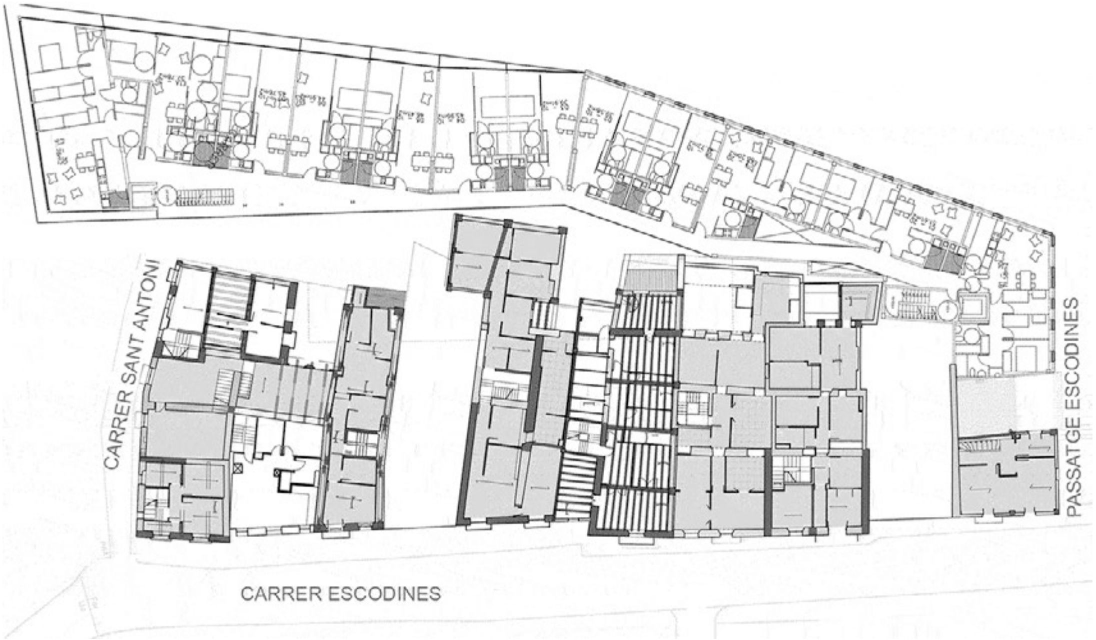

Figure 5: Plan of the ground floor.

Figure 6: Plan of the first floor.

Figure 7: Existing damage and condition of the buildings.

Figure 8: Damage survey showing the trial openings carried out.

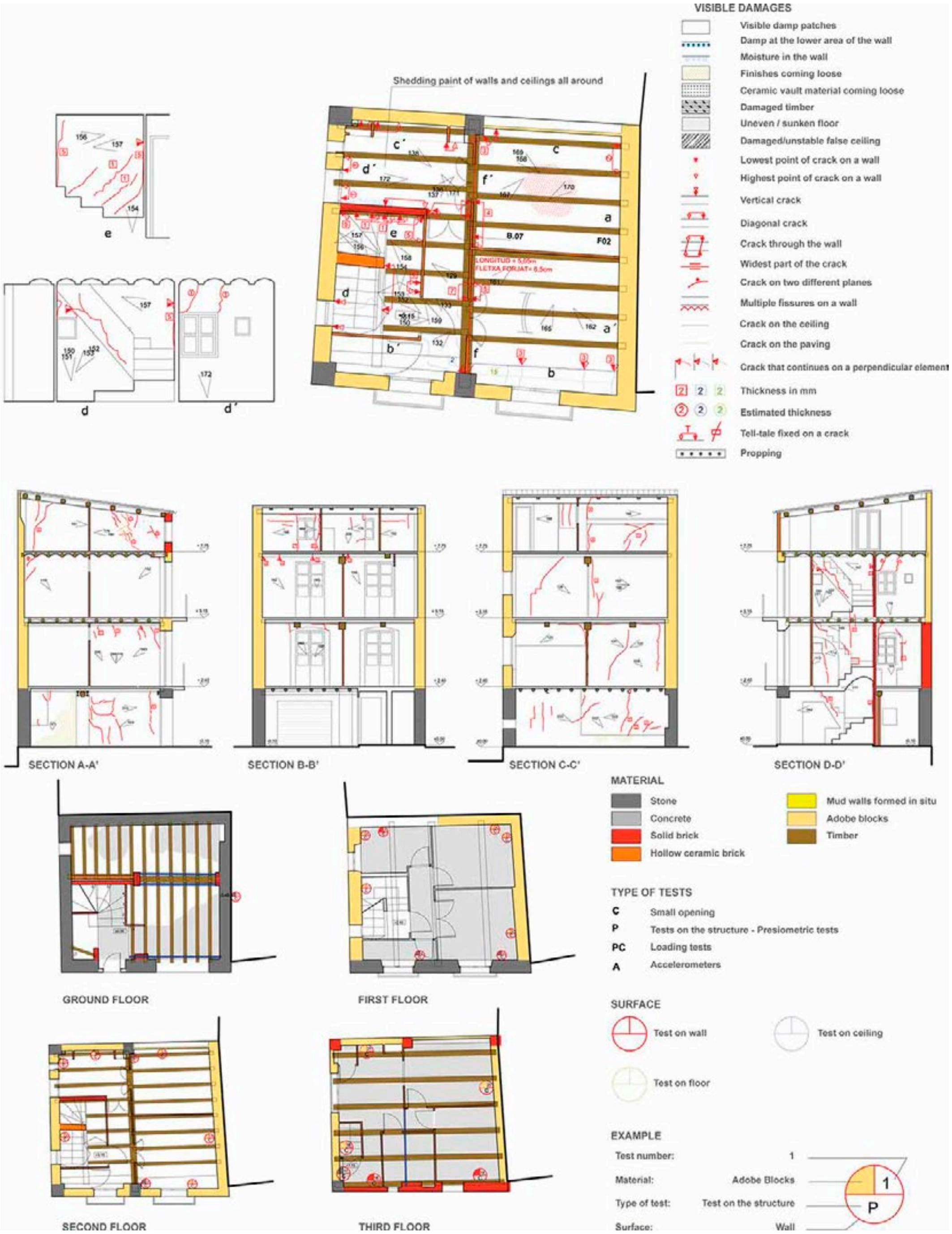

Figure 9: Location of the various wall tests.

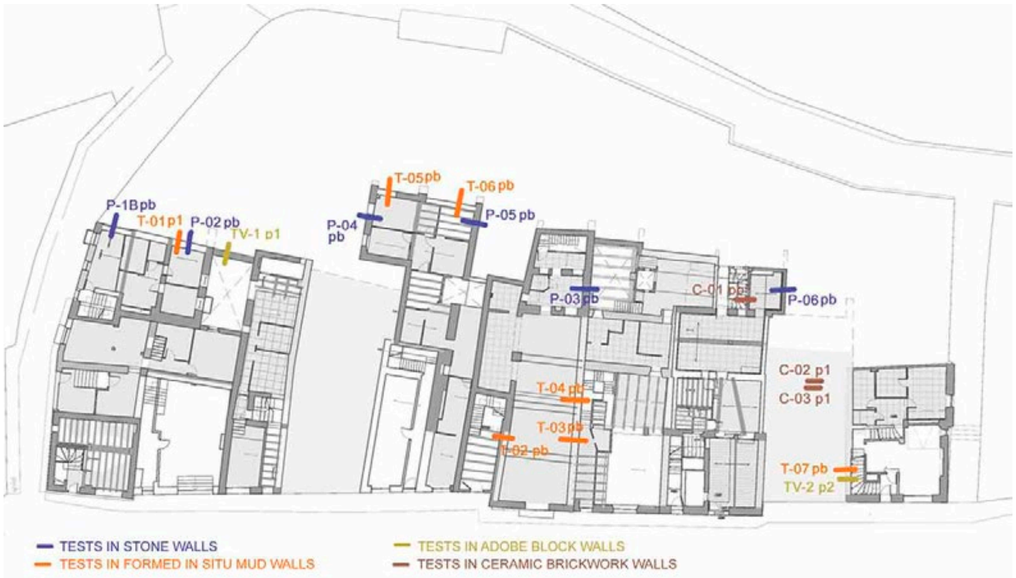

Figure 10: The process of setting up the probe in a Wall of ordinary masonry: Making the hole (left), nserting the probe (centre) and adding pressure (right).

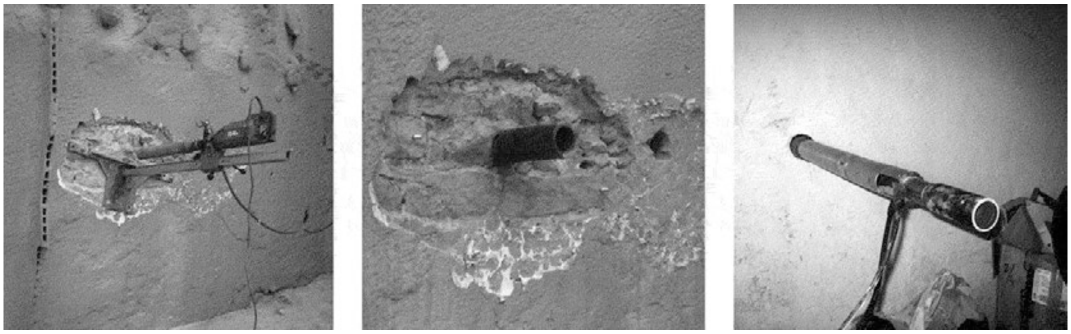

Figure 11: Graphs of stress - strain carried out on rammed earth walls.

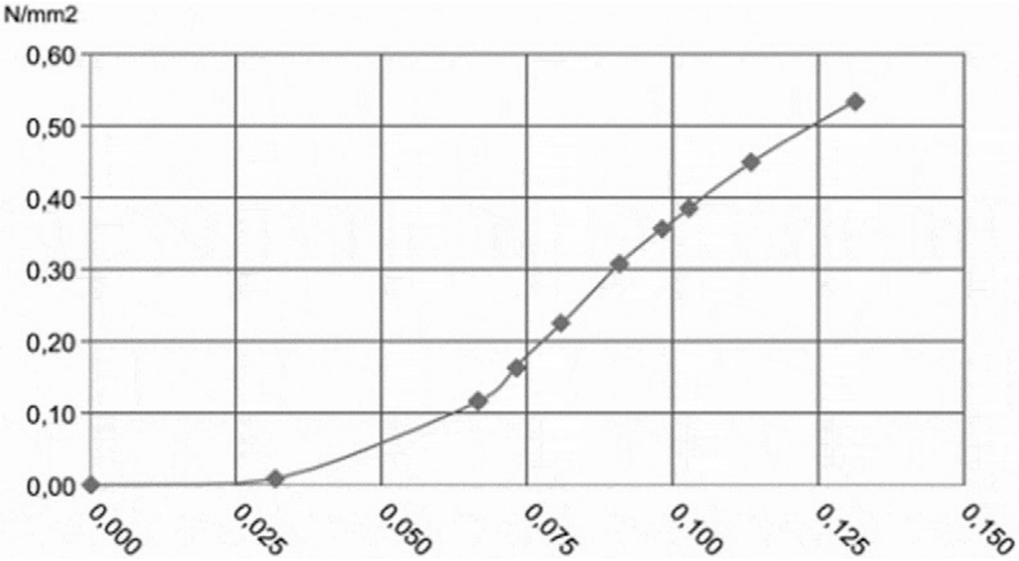

Figure 12: Graphs of stress - strain carried out on adobe block walls.

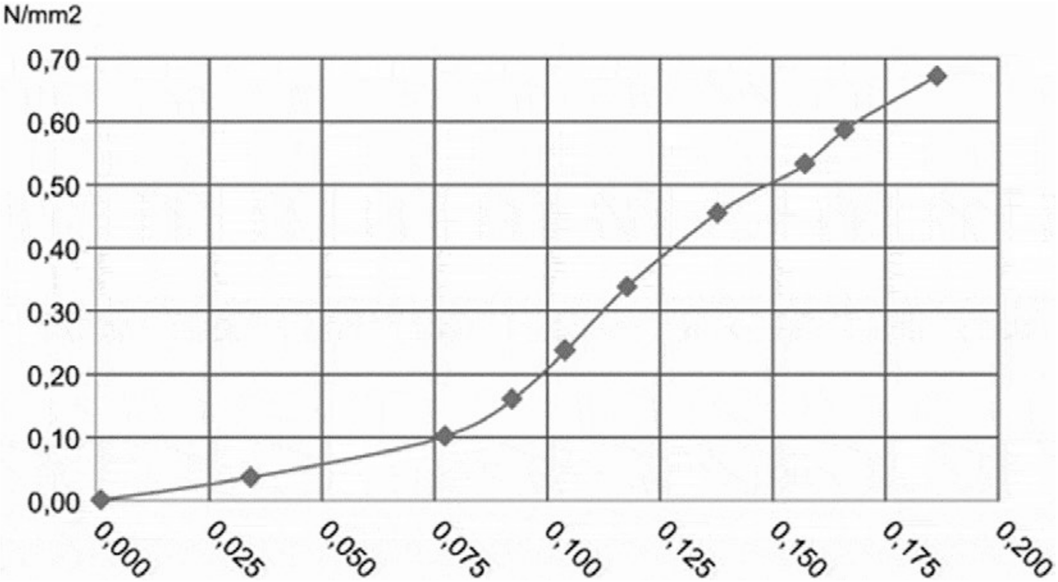

Figure 13: Graphs of stress - strain carried out on masonry walls.

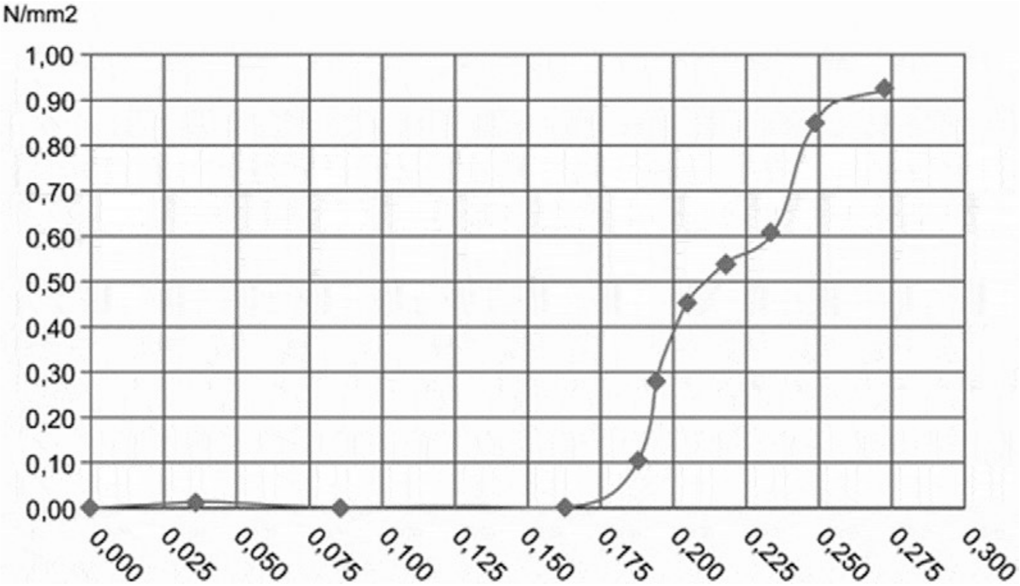

Figure 14: Positions of the accelerometer tests and the tests on timber floors.

Figure 15: Excavation and the construction of the piled perimeter retaining wall.

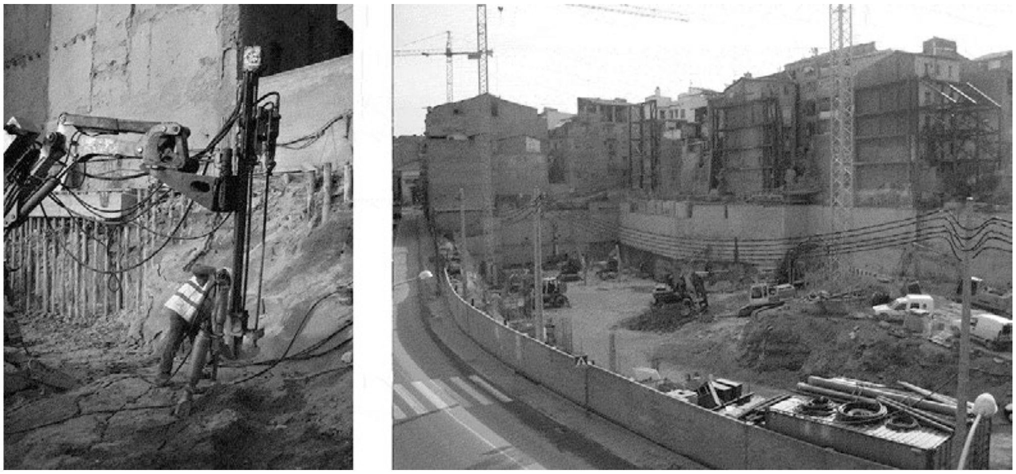

Figure 16: a) Grafic of velocity over time. b) Criterion for compliance with the standard regulation UNE22.381 during the excavation with the 410 J hydraulic hammer.

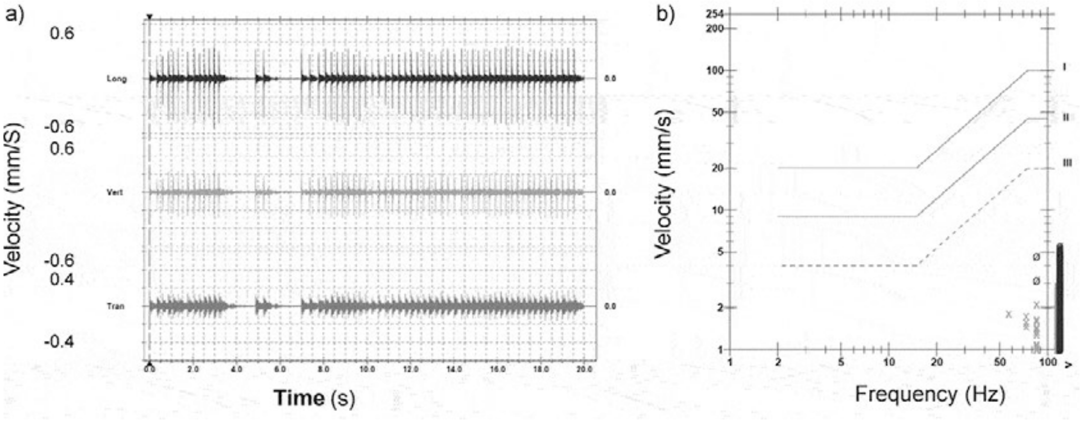

Figure 17: Site plan showing the seismograph, the geophones, the inclinometers, the tell-tales and the calibrated datum points.

Figure 18: Example of one measurement of the daily variation of the vibration velocity and detection of maximum values.

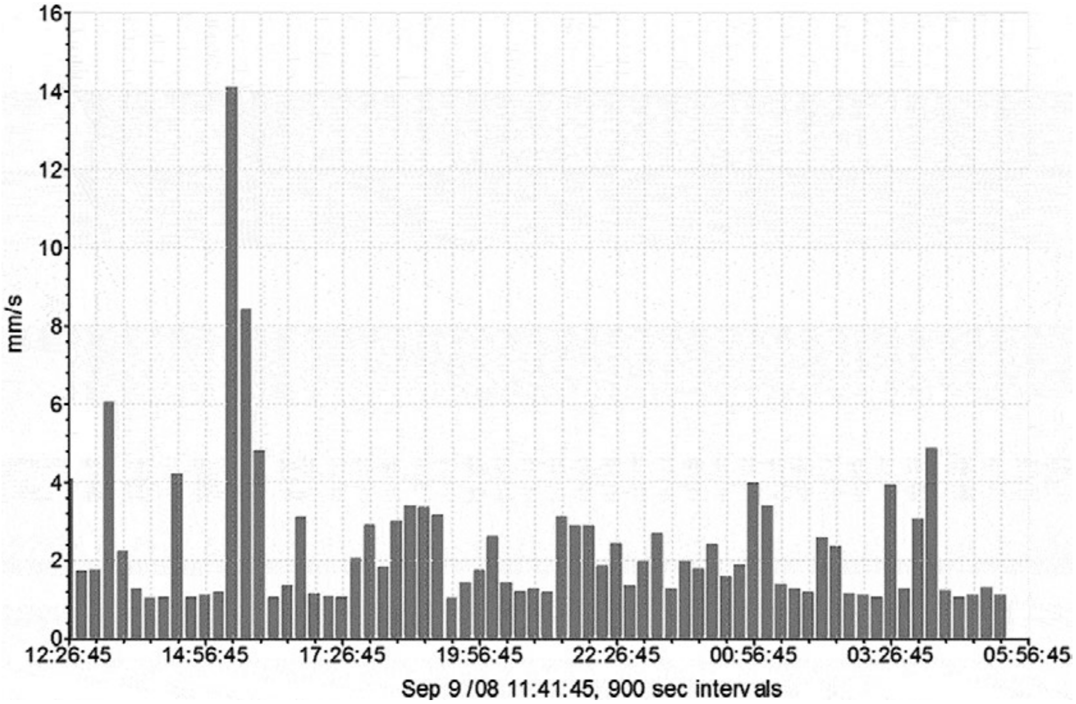

Figure 19: Values from the monitoring of the cracks taken using the calibrated datum points. Escodines 14 up, Escodines 22 down. See figure 17.

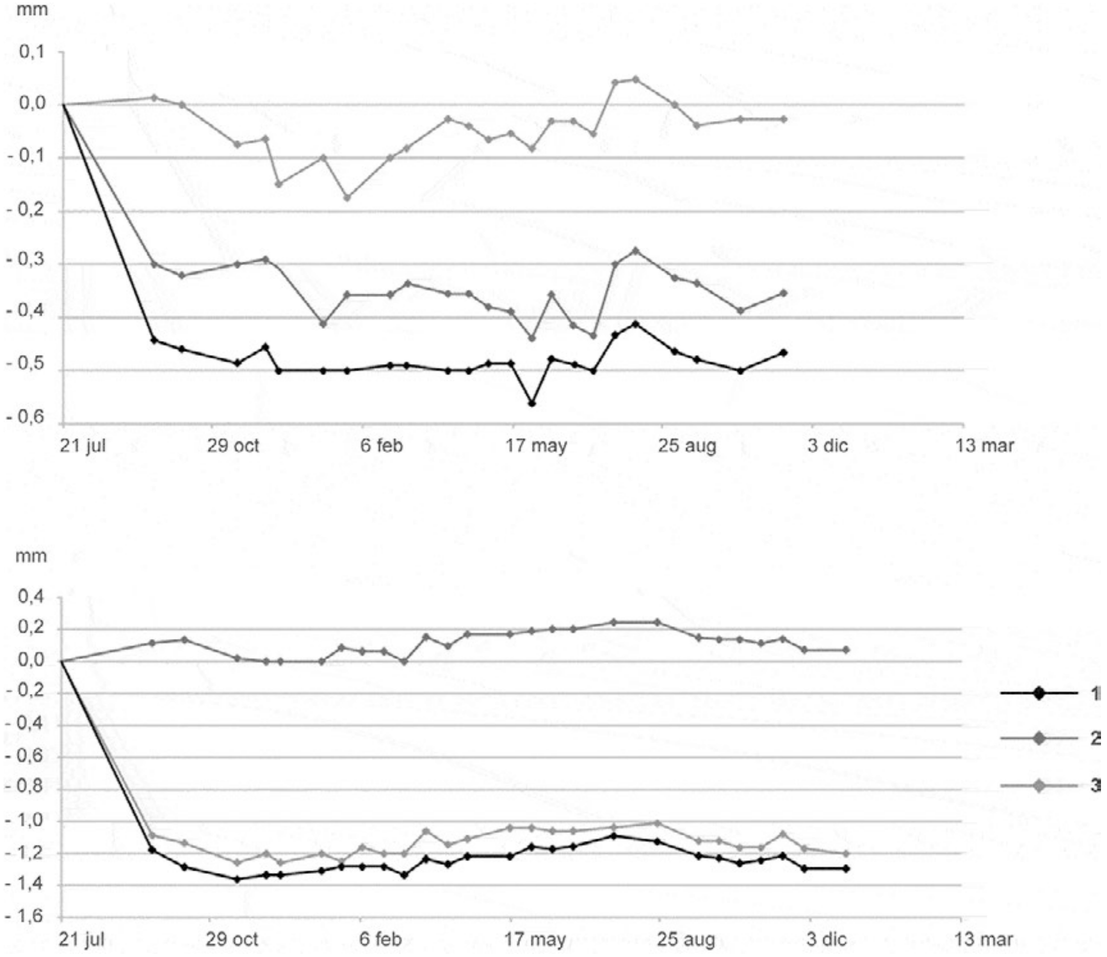

Table 1: Results of the tests on the rammed earth, masonry and adobe block walls.

	KEY	σ_u (N/mm^2)	E (N/mm^2)
Tests in rammed earth walls	T-01	0,810	7,46
	T-03	0,538	7,34
	T-04	0,385	4,12
	T-05	0,602	7,15
	T-06	0,312	2,01
	T-07	0,480	9,24
Tests in stone masonry walls	P-1B	2,696	32,48
	P-02	1,547	21,14
	P-03	0,720	9,49
	P-04	0,798	16,22

	P-05	0,894	20,72
	P-06	0,978	18,62
Tests in adobe walls	TV-01	0,658	6,29
	TV-02	0,596	7,60

Table 2: Results of the tests on the timber joists.

		LOT1		LOT2		LOT3				
humidity		15,50%		17,60%		14,25%				
σ_u (N/mm^2) from tests on cylindrical specimens (PiE) and drill tests (PiR)	PiE	2,93		6,49	3,29	8,88	6,39	7,85	2,19	7,76
						3,65	3,2	-	-	-
	PiR	3,93	3,28	10,2	5,4	8,08	4,56	4,43	2,67	8,04
		2,51	2,55	3,86	4,47	4,25	5,13	7,87	7,06	5,61
		3,86	2,06	5,22	6,82	7,02	7,35	6,78	6,63	-
Average σ_u (N/mm^2)		**3,01**		**5,72**		**5,97**				