Degradati on of Romanian Cultural Heritage in Surrounding Environment

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1. ABSTRACT

The oldest monumental buildings preserved in the Carpatho-Danubian-Pontic region are churches. For centuries they were the most representative creations of ecclesiastic and monumental architecture. More specifically, they have always represented typical orthodox churches since Romanians are the only Latin nation of orthodox religion, while all the other peoples of Latin origin are catholic. Erected with stone and brick masonry, these Eastern Churches of Balkan-Byzantine style were always an evidence of the level of technical knowledge, cultural receptivity and artistic refinement reached during their époques. As a rule, they followed the Byzantine pattern based on the standard scheme of the Greek Church, the straight cross inscribed in a rectangle and the dome supported on pendentives or on piers. However, they are creatively adapted to the regional traditions of the secular architecture. These Orthodox Churches also reflect the foreign influences on the autochthonous art of building. The paper also presents old and new methods for repairing three-lobed churches made of stone and brick masonry. The innovation consists in reinforcing, coating or confining masonry structural members with the aid of polymer grids of high density and strength. The results obtained by static and dynamic tests on reduced and full scale models show that the method is reliable and worth to be applied.

2. INTRODUCTION

The monastic establishments of Romania suffered in time major damages provoked or amplified by the earthquakes, even if, until the 17th century inclusively, the building technique was very good, implying also some elements with anti-seismic character. Thus, bricks had the dimensions 4x14x28 cm, being made of well washed and mixed clay, the paste exposure to several freeze-thaw cycles contributing also to this. Compared to a modern brick, double pressed, a medieval brick is about 4-5 times more resistant, both to compression and traction. The mortars were also prepared very carefully, of well-washed sand and high quality lime. The addition of gravel and crushed brick provided medieval mortars with hydraulic qualities, and tow or chopped straws contributed to the elasticity and the resistance of the plasters.

In the spirit of the Byzantine building tradition, the walls were consolidated by a system of belts made of oak beams, surrounding the edifices at various levels. Even the foundations were reinforced sometimes with oak beam belts. For not exposing the buildings to supplementary loads, the vaults and the crowning elements (towers, etc.) were made of volcanic tuff (the so-called siga), very resistant and light.

This emphasises the medieval masters' concern for ensuring the necessary resistance for the buildings. Unfortunately, in the 18th and 19th centuries, after the disintegration of the handicraft brotherhoods and the apparition of capitalist type property speculation, the building technique decayed significantly. The brick, until then prepared by skilful masters, began to be made by Gypsies, the care for mortar preparation disappeared, the beam belts were not used anymore, the quality and the resistance of the buildings being severely harmed.

For these reasons, for the accurate evaluation of the effects produced by the earthquakes on the historical monuments, we must take also into account the evolution of the building technique.

Among the monastic establishments in our country that suffered destructions during the earthquakes there is also Caldarusani, prince Matei Basarab’s most important foundation, built during 1637-1638. This monastic complex is situated about 45 km north of Bucharest, on the north-western shore of the Calsarusani Lake, in the Snagov Plain (Fig. 1). The enclosure of the monastery, rectangular, 93 m long, 67 in wide and about 6 m high, with walls one meter thick, is built of ancient brick. This monastery was erected on the monastic settlement existing before 1637, fact proven by the archaeological discoveries made on the occasion of the restoration of the fortified enclosure in 1950-1967, as by some drillings made by us.

The construction plan of the Caldarusani Monastery is specific for the 17th century, trilobite, with lateral apses. It has two small towers and the third, much higher, dominates the whole edifice. The belfry tower from the entrance gate, having also a strategic function, fell during some earthquakes, so at the restoration during 1775-1778 it was completed by an oak wood structure, having a guard room on the top. This addition was removed during the recovery works during 1908-1915, the tower remaining at the enclosure’s height. The powerful earthquake in 1802 demolished the small church outside the monastic enclosure, which at that moment was under construction. The 1940 earthquake made the big tower to collapse and the church building was severely cracked. The tower rebuilding and the church repairing were carried out in 1943. The tower at the entrance gate, fallen at the same earthquake was restored in 1956 in the present form. The 1977 earthquakes, as the 1986 one, produced some damages, enlarging some cracks and provoking new ones.

Romania – Physic Map

The establishment has a particular historical importance, due to its cultural role during the centuries. A medieval art museum was set up inside the Monastery’s enclosure, containing several icons painted by Nicolae Grigorescu (the greatest Romanian painter), garments, cult objects and manuscripts of particular value (Gherasim Cristea, 1997).

The Caldarusani Geodynamic Observatory, an observation point of international interest was fitted out in a building outside the enclosure of the Monastery and is operating since 1961.

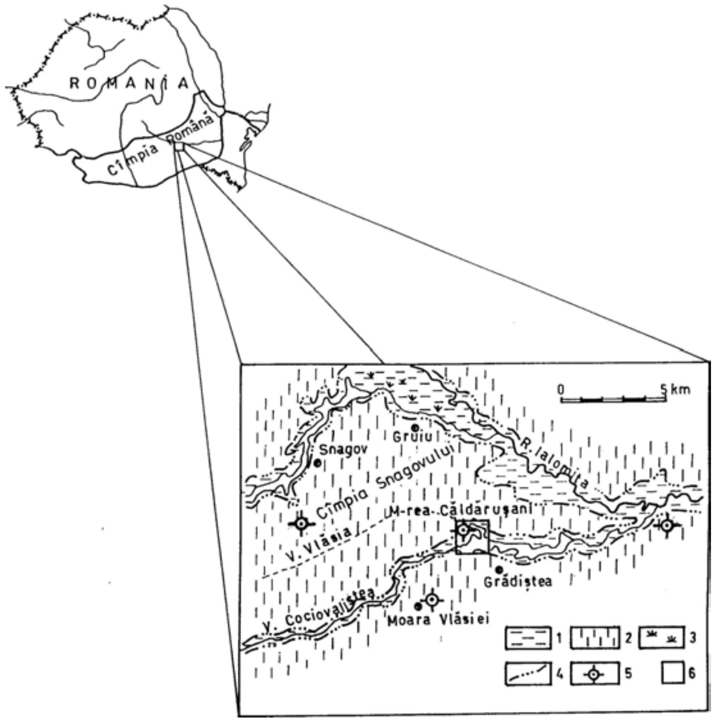


Fig.1 – Location of the studied perimeter (Geological map of Romania, scale: 1/200.000). Genetic types of the Quaternary deposits: 1. alluvial – proluvial; 2. diluvial – proluvial; 3. swamp deposits; 4. geological – morphological limit; 5. Geological drilling; 6. Limit of the studied perimeter.

3. GEOMORPHOLOGICAL AND HYDROLOGICAL DATA OF CALDARUSANI SITE

Geological, hydrological, meteorological and related natural processes and factors should be monitored. This would include water courses and levels, soil characteristics and subsurface geology, whose behaviour and interaction in the event of disaster could have an impact on property, lives and cultural heritage.

The Caldarusani monastic complex is situated on an earth limb, surrounded on three sides by the waters of the lake with the same name. Westwards, it is directly linked with the Snagov Plain, important subunit of the Romanian Plain. The Snagov Plain has a medium altitude of 85 m, with shallow valleys, its main feature being the system of lagoon type lakes (Balteni, Snagov, Caldarusani). From the geotechnical point of view, the Snagov Plain represents the southward continuation of the Ialomita River debris cone, covered by deluvial-proluvial deposits (loess-like deposits). The thickness of these deposits is growing southwards and eastwards. Throughout the plain, numerous loess-like deposits settlements develop, created by densification and clastocarst phenomena (Cotet, 1976). The mentioned processes were favoured by the reduced thickness of the loess-like deposits and especially by the presence of the sands and gravels immediately at their basis. The high permeability of the deposits allowed the underground water to travel with high speed and to transport a large quantity of fine material. As the deposits texture modified, the process amplified, carrying away larger quantities of matter.

Thus, underground cavities were formed, having more or less important sizes, which, chained, gave birth to the densification valleys. Sometimes, the underground voids determined a slow sinking, favouring the development of settlements. These sinking were produced under the action both of external forces and of their own weight. The water dissolves the calcium carbonate skeleton (carrying it downwards and depositing it in the form of limestone concretions in the inferior layers), reduces the cohesion, changes the consistence state, increasing the apparent density, provoking or amplifying the sinking process.

The river lagoons of the medium and inferior Ialomita course are the best represented in the Romanian Plain. Thus, beginning downstream of the confluence of Cricovul Dulce with Iabomita, the river lagoons are found first on the right riverside - Balteni, Snagov, Balta Neagra, Caldarusani, Comana -then on the left side, downstream of Urziceni - Cotorca, Rogozului, Fundata, Ezerul, Ograda and Strachina. There are also a series of less important river lagoons, both on the right and on the left riverside. Genetically, the most studied lakes were Snagov and Caldarusani. G.Valsan (1915) thinks these valleys and lakes are ancient courses of Ialomita which withdrawed successively from southeast towards northwest. P.Cotet (1976) thinks the Burdufului and Colceagului valleys with Mostistea, forming one basin, linked the hydrographical net of the Balteni, Snagov and Caldantsani lakes. The pushing of Ialomita southwards by the dejection cone of Cricovul Dulce obliged this river to penetrate, by successive catchingss, in the southern part, taking over all these lacustrine valleys.

According to Gastescu (1971), the valleys on which the lakes of the Snagov-Caldarusani group are found were initially erosion valleys, formed in the conditions of a greater relief energy, that afterwards, through the subsidence movements, were invaded by the waters and barred by the collecting river. According to Murgoci (1907), in the Upper Hoolocene the whole region was affected by a negative movement, so the rivers having their origin in the Carpathians changed their basic level, triggering upwards an intense erosion action. The matter carried away was deposited on the riverbeds, in the sunken zone, making them higher. In the case of the tributaries of these valleys from the plain, it was remarked that the erosion, transport and accumulation action was insignificant compared to the similar processes on the main rivers. For this reason, they kept their slope profiles almost unchanged. Due to the alluvia barrage created at these tributaries' estuary, their course was transformed into real river lagoons.

In the case of the river lagoons, the passing from the bank to the bottom of the lake is made directly, through the lake slope. The longitudinal profile has the aspect of the valleys they occupied. The maximum depth is registered towards the middle of the lake, as a consequence of the sinking processes which acted after the lake formation (Gastescu, 1960).

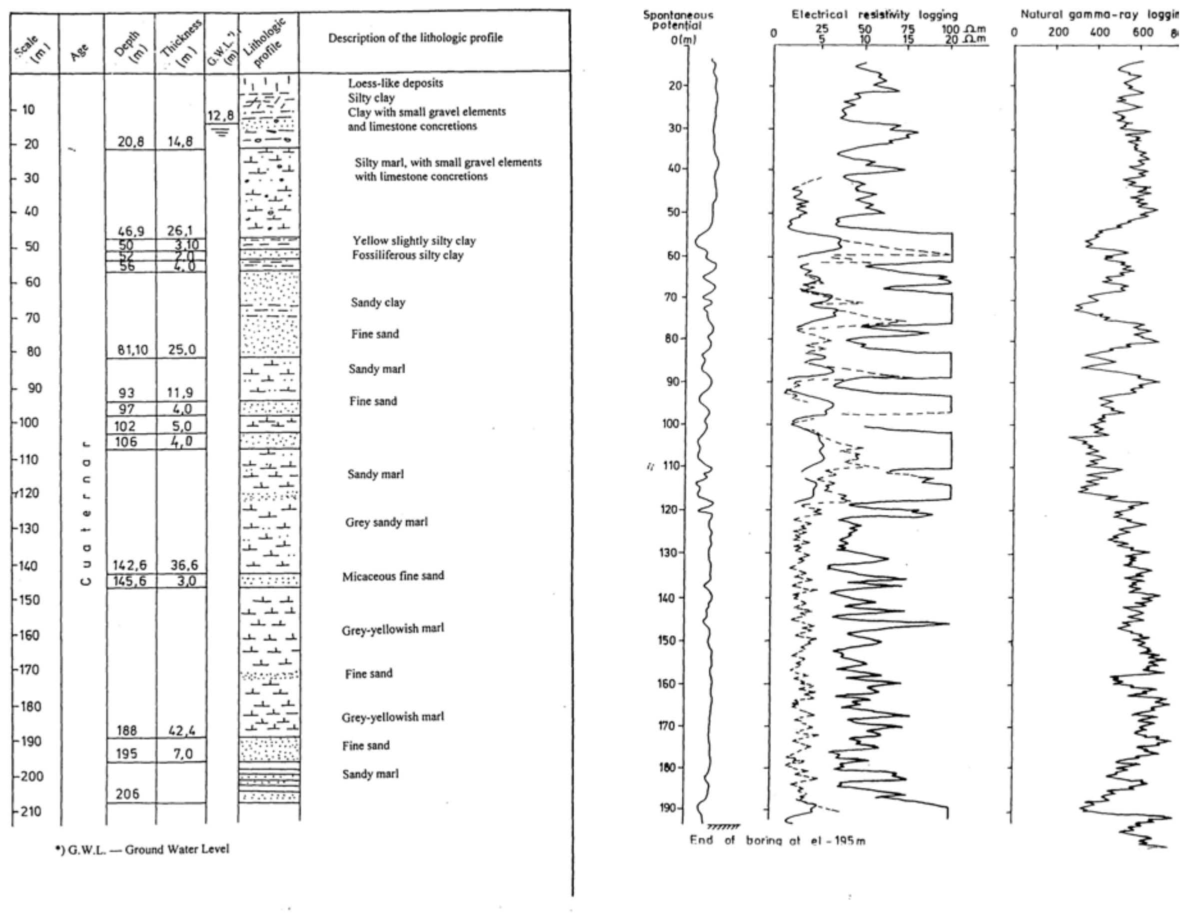
The Caldarusani Lake, formed at the confluence of the Cociovalistea Valley with Vlasia Valley (Fig. 1) is 4 km long and has a water surface of 150 hectares (the surface of the lake was continually reduced by colmatation; for example, in 1857 it had 280 hectares and over 6 km in length). The maximum depth is 5m. At the high freshets of Ialomita, such as those of 1970, the flooding waters may affect it. The lake is linked with Ialomita by the Fierbinti derivation, 7 km long.

4. GEOLOGY OF CALDARUSANI SITE

Stratigraphy. The perimeter the monastic complex Caldarusani is situated in is a part of the large structural unit of the Moesian Platform. This is made up of a folded basement, Assyntic or Caledonian and a very thick cover of sedimentary Palaeozoic formations (Upper Cambrian, Ordovician, Silurian, Devonian, Carboniferous and Pennian), Mesozoic (Triassic, Medium and Upper Jurassic, Cretacic), Tertiary (Eocene, Miocene, Pliocene) and Quaternary formations (Paraschiv, 1979). We do not insist upon the succession of all the deep formations of the sedimentary cover of the platform, but we shall mention only the formations met in the geological drilling in the Moara Vlasiei locality, situated about 4 km southwest of the investigated perimeter (fig. 1).

The probe reached the depth of 2235 m, being stopped in formations belonging to the Tortonian. In Fig.2 we are showing the litho logic column of this borehole. The Tortonian is represented by greyish-whitish marls limestone, and by slightly chalky compact sandstones. Over these, the Medium Sarmatian is transposed transgressively, a succession of grey mans with thin intercalations of micaceous sands, 570 m thick. Continuing the sedimentation, there are marts, sandy marts with micaceous sands intercalations. The thickness of these deposits, belonging to the Meotian, is of about 370 m. And marts, sandy compact marls also represent the Pontian, about 140 in thick. The Dacian formations about 600 m thick cover transgressively the Pontian marts.

Fine micaceous sands, grey-yellowish, with scarce intercalations of marts and sandy marts, represent them. Clays, sandy clays with sands intercalations, represent the Levantine. The thickness of these deposits is approximately 150 m. Over the Levantine deposits there is a gravels and sands horizon, the so-called *Fratesti Layers,* having a thickness of about 150 in. These layers, belonging to the Lower Pleistocene, are covered by a succession of marts, clays and sands, known as *the marl complex,* about 130 in thick. This complex belongs to the Medium Pleistocene. The Pleistocene deposits series is completed by a pack of clays and sandy clays, having loess-like deposits in their upper part. The Holocene is represented by loess-like deposits, sand and gravel (Liteanu, 1956).



a b

Fig.2a. Lithostratigraphic column of the Moara Vlasiei geological drillings

Structure. The sedimentary cover of the Moesian Platform shows a gradual sinking south-northwards, with a relatively smooth slope up to the proximity of the investigated perimeter. Following towards the North, its sinking accentuates, making thus the passing to the Carpathian Fore deep. The Miocene and Pliocene deposits keep the same general tilt, their thickening being also noted on the same direction (Geological map, scale 1: 200.000). The tabular structure of the platform, the sinking of the sedimentary cover and the growing of its thickness on the mentioned direction is well reflected in the Bouguer gravimetric anomaly map, on which a south-northwards decrease of the isogals values can be noticed (Figs. 3 and 3a). The same fact is emphasised also by the magnetic map, the vertical component

(AZ), on which the relatively smooth grow of the isodynamics values towards the North can be noted, in relation to the 100 gamma isodynamic line, conventionally established for the Surlari geophysical observatory (Figs. 4 and 4a).

According to the seismic data (Enescu, 1992; Enescu *et al.,* 1992) the medium crust thickness in the investigated area is about 33 km and the one of the lithosphere is approximately 72 km.

The sedimentary cover has a rupture tectonic, with vertical or very tilted faults, oriented in two dominant directions: one, east-westwards, affecting the whole sedimentary, including the Pliocene, and the second, oriented approximately perpendicularly on the first. The first represents the faults oriented parallel to the structural elements of the Carpathian Orogene; the northward sinking in steps of the platform occurs along these faults. This group of fractures is the youngest, generated and partially reactivated in the Neogene, simultaneously with the fore deep subsidence. Among the northwest-southeast oriented faults, there is firstly the intramoesian fault (TinosuFierbinti-Calarasi). This fault suffered successive translations, first to the right, then to the left (Sandulescu, 1984). Among the major faults there are also Peceneaga-Camena, as well as the westward prolongation of the CapidavaOvidiu fault (Fig. 5).

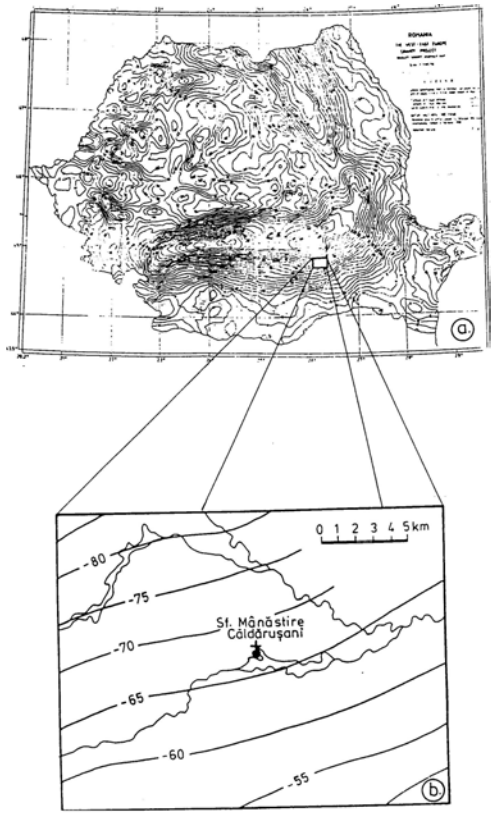


Fig.3 Romania - Gravimetric map (a).

Investigated perimeter (b)

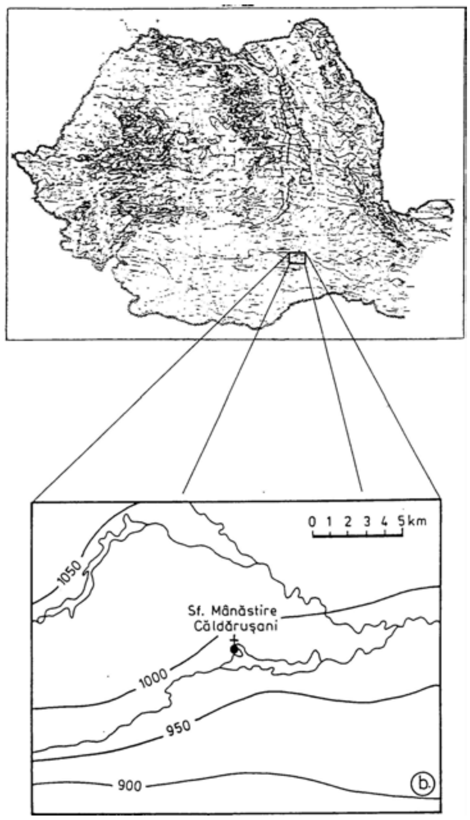


Fig.4 Romania – Magnetic map (a).

Investigated perimeter (b)

The complete succession of the Pliocene and Quaternary deposits, up to the beginning of the Upper Pleistocene shows that negative vertical movements continuously affected the region. This fact is reflected also by the modification of the main rivers coming down from the Wallachian Sub Carpathians, such as the Ialomita river.

After a north-south course as far as the Targoviste locality, this becomes northwest - southeast and afterwards, beginning in the proximity of the Balciuresti locality, approximately east-westwards. Obviously, besides the pronounced subsidence of the area in front of the Carpathian Arc Bend (the area of confluence of the Siret river with the Danube, towards which all the rivers of the Eastern Wallachian Sub Carpathians were attracted), the basic level lowering, after the retreat of the Pleistocene lake, had also a major contribution.

General seismic, meteorological, hydrological and geological data relevant to assessing the vulnerability of property in general (and cultural heritage specifically) to hazard and probable damage or loss should be systematically collected and analysed.

Analysis of the above conditions will improve the ability to provide accurate early warning of the intensity and frequency of earthquakes. Such analysis should also contribute to general preparedness planning for earthquakes, including efforts to:

- minimize vulnerability by developing and implementing measures for assistance (technical and financial) for the strengthening, repair and maintenance of cultural property;
- control use of historic properties and related alterations where risk is high and alterations might increase risk; and
- control proposed alterations to the use of land in the vicinity (local and regional) of significant cultural property, where that land practice demonstrably increases risk.

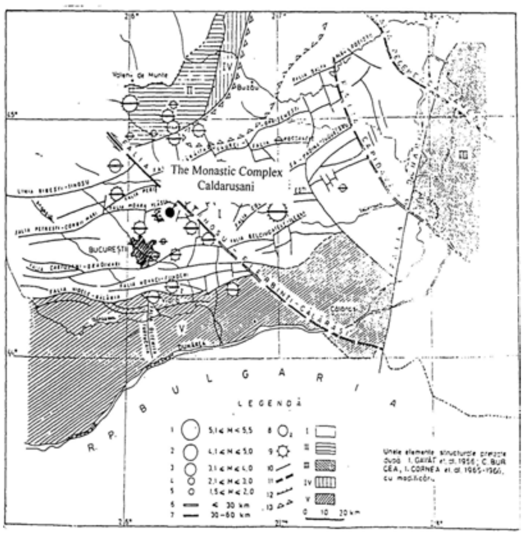


Fig. 5 Seismotectonic map of the eastern Moesian Platform

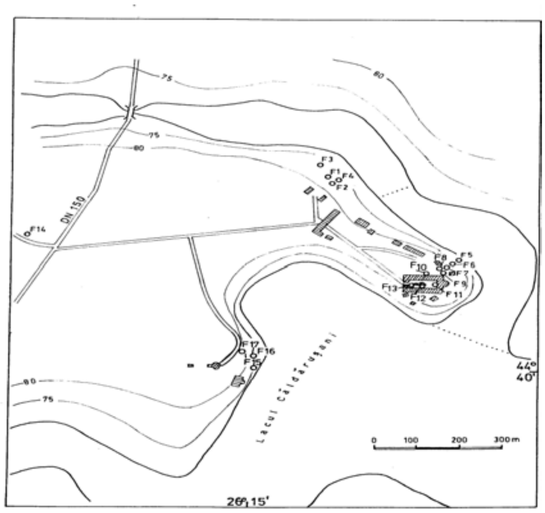


Fig. 6. Location in plan of the drillings carried out in the Caldarusani perimeter

5. GEOTECHNICAL CONDITIONS OF CALDARUSANI SITE

Sixteen geotechnic drillings and one geological drilling 2235 in deep were carried out in the investigated perimeter. Information concerning the geological conditions of a greater ground surface, in extent of the perimeter was obtained from four hydro geological drillings more than 300 in deep.

In the northwestern part of the monastic complex, four bore-holes (FIF4) were carried out, three more than 10 in deep and one 20 m deep (Fig. 6). Six bore-holes (F5-F10) were dug outside the monastery’s enclosure and three (FI 1-F 13) inside the enclosure. These manual bore-holes were 2-3 in deep. Three manual bore-holes (F15, F16, F17), ~ in deep were also carried out on the lake-shore. A geological drilling 206 in deep (F 14) was performed in the western part of the perimeter, near the DN 150 road. The hydro geological drillings carried out outside the perimeter made possible the drawing up of the litho logical section (Fig. 7).

Lithological columns and geophysical diagraphies were made for some of the drillings *(e.g.,* Figs.2a and 2b).

According to the agreement made on the basis of the discussions with our partners Dr. D. Rozos and Dr. N. Nikolaou in December 1998, in Bucharest, at present a ditch is being dug up perpendicularly on the slope, in front of the wall of the monastery. This ditch is 25 in long and about 3m deep. A geological-engineering map is also being elaborated, as well as a hydro geological map of the investigated perimeter.

Next, we present a brief characterization of the geotechnical conditions in the investigated perimeter, on the basis of the data obtained from F1-F4 geotechnical drillings. The drillings penetrated through the Upper Pleistocene Holocene deposits, represented by a clayish-silt complex with numerous lime concretions.

In some drillings near the monastery and inside the enclosure, some traces of old foundations were found (brick fragments, debris, etc.).

The ground water level was met at depths from 7.0 to 9.7 in. The aquifer layer lies at the basis of the clayish-silt deposits, being fed by lateral infiltration of the lake waters and by rainfall.

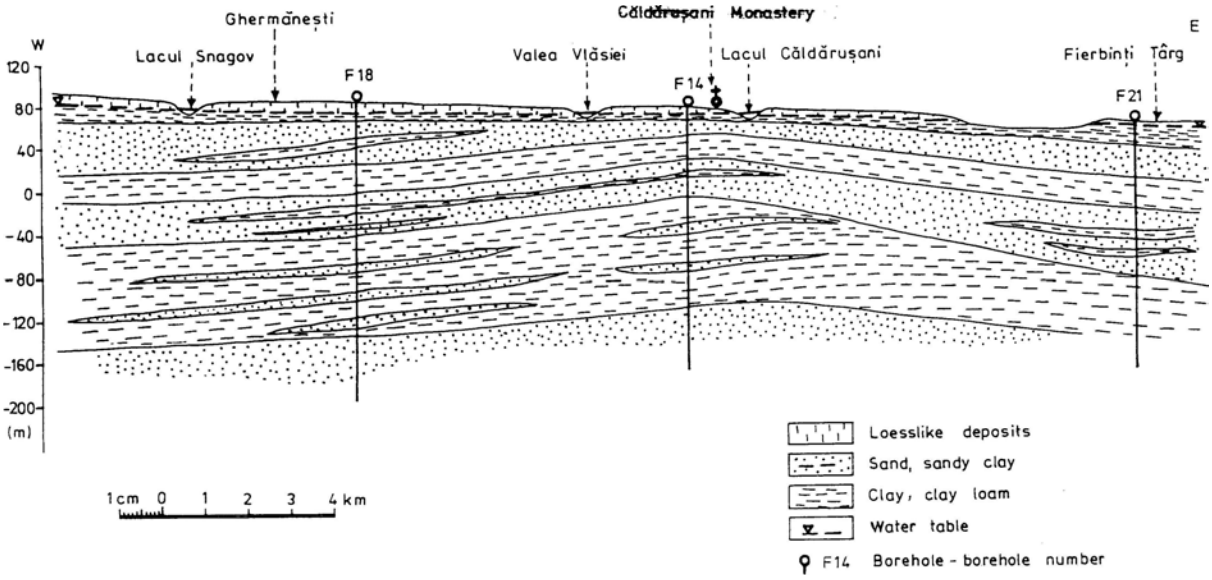


Fig. 7 Caldarusani area. Lithological cross section

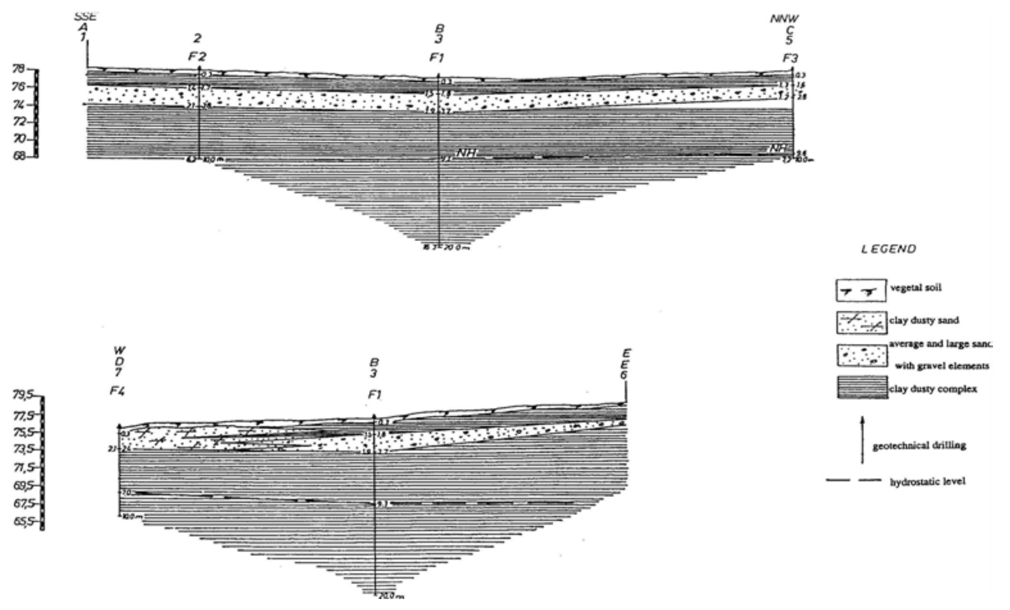


Fig.8 Caldarusani area. Geological profiles across the drillings

In the frame of the clayish-silt complex, constituting the foundation ground, three litho logical types were separated, on the basis of the granulometric structure:

- a type - clay and clay marl, with a rock mass medium content of 67% clay, 27% silt and 6% sand;
- b type - silt clay and clayish silt with a medium content of 32% clay, 55% silt and 13% sand;
- c type - coarse-medium sand, constituted of 14% fine sand, 29% medium sand, 41% coarse sand and 16% small gravel.

The c type (the sand layer, having 1,2 - 2,1 in thicknesses) was met in the drillings 1, 2 and 3, at depths from 1.7 to 3.7 in.

In every mentioned litho logical type there are numerous limestone concretions.

Because the first two litho logical types appear in a multiple alternation, with gradual passing from one type to another, the analyses and geotechnical laboratory test results shall be treated together.

Thus, according to the degree of saturation (Sr=0.82%-0.84%), the two litho logical types are included in the *very wet* soils category. From the plasticity point of view, the foundation ground is included in the *very high* plasticity (a type; Ip= 39,6%) and in the “high” plasticity (b type; Ip= 30.6%) soils categories. From the consistency point of view, both types are classified in the *plastic stiff* category (Ic= 0.84-0.94). The density has values between 1.95 g/cm^3 (a type) and 1.89 g/cm^3 (b type), in a dry state the values being 1.55 g/cm^3 (a type) and 1.52 g/cm^3 (b type).

For both types the angle of the internal friction has values that range from 14º to 15º.

The compressibility index has an average value a_v=1.56 .10^{-4} kPa for the a type, while a_v= 1.89. 10^{-4} kPa for the b type. Thus, from the deformability point of view, the a type is included in the *high* compressibility soils category and the b type, in the *medium* compressibility category.

For the c type, medium-coarse sand, we appreciate a medium compacting state with *1.95-2.0* g/cm^3 densities in a natural state. The angle of internal friction has values between 25º and 30º.

The determinations, the analyses and the geotechnical laboratory tests are carried out according to the Romanian standards and norms in force (standards equivalent or adaptable to the international standards - British Standard or ASTM).

6. SEISMICITY OF CALDARUSANI SITE

Precise data should be collected and collated on the probability of occurrence of earthquakes within the geographic region, including type, location, probable intensity and likely frequency. This must be undertaken not only based on present-day and long-term scientific research and monitoring of future causes and events, but also on the basis of an analysis of the documentation available on past disasters. Information should be published in map form, with data maintained in digital format.

The seismicity of the perimeter is determined mainly by the activity of the Vrancea deep hypo central area, site of the most devastating earthquakes affecting the territory of Romania. The evaluation of the effects of the most powerful Vrancea earthquakes is materialized in various maps: macro seismic, of the maximum observed seismic intensity, of the maximum acceleration and in the seismic zoning map of Romania. The analysis of the information offered by these maps concerning the position of the investigated perimeter will allow establishing its characteristic intensity/acceleration.

Thus, according to the 10/11/1940 earthquake (M=7.4) macro seismic map, made by Demetrescu (Fig. 10), the perimeter is situated in the 8 degree macro seismic area, value noted in several neighbouring localities, while according to the macro seismic map elaborated by Atanasiu (Fig. 11) for the same earthquake, the seismic intensity should be 6^{+} ÷ 7 degrees. Concerning the two maps, we should specify the following: the greater detail degree offered by Atanasiu's map is due to the fact that for its elaboration were used questionnaires from about 5000 localities, the information included being corroborated by field verifications, while Demetrescu had at his disposal only 200 questionnaires. On the other side, the field work aimed at the verification of the various information determined Atanasiu to consider that the seismic intensity values established by Demetrescu were overestimated with one degree (Atanasiu, 1961).

According to the isoseists map pf the 4/03/1977 earthquake (M=7.2), the Caldarusani perimeter is situated in the VII degree macro seismic area (Fig.12).

On the maximum observed seismic intensity map (Fig. 13) the perimeter is also situated in the VII degree macro seismic area. This map was elaborated by taking into consideration the macro seismic maps of the most powerful Vrancea earthquakes produced during 1894-1984 (Mãndrescu *et al.,* 1988). They used the maps of the earthquakes of 17/08/1893 (M6.1); 31/08/1894 (M=6.1); 13/09/1903 *(M=5.7);* 6/10/1908 (M=6.8); 22/10/1940 (M=6.2); 10/11/1940 (M=7.4) and 4/03/1977 (M7.2).

According to the isoaccelerations map (Fig. 14) elaborated (Mândrescu *et al.,* 1995) on the basis of the acceleration values recorded by the national accelerographs net during the 30/08/1986 earthquake (M7.0), inside the investigated perimeter the acceleration should have reached the value of 100 cm/s^2, corresponding to the 7 degree of seismic intensity (STAS 11100/1-91).

According to the isoaccelerations map (fig. *15)* elaborated (Mândrescu *et al., 1995)* on the basis of the instrumental records obtained during the 30/05/1990 earthquake (M=6.7), the perimeter is placed on the 150 m/s^2 isoacceleration, respectively the 7-8 degree of seismic activity. This map such as the macro seismic map (Fig. 16) emphasises the preferential distribution of the seismic energy flow, south-south-westwards for this earthquake.

On the seismic zoning map of the Romanian territory (Fig. 17) proposed as a State standard, the perimeter is situated in the 8 degree macro seismic area, with a return period of 50 years.

The local seismic activity is well described by the study elaborated by Cornea and Polonic (1979). According to the map accompanying the study (see fig.5), the crustal earthquakes produced in the proximity of the perimeter had magnitudes between 2.4 and 3.8. The most powerful crustal earthquake produced in this part of the Moesian Platform had the magnitude *5.4.* This earthquake's epicentre was established near the Cazanesti locality, situated about 60 km east of the investigated perimeter. From the reported data, it can be noticed that the local seismic activity does not constitute a threat to the behaviour in time of the Caldarusani Monastic Complex buildings.

7. SEISMIC DAMAGES

The Eastern Churches shaped according to the three-cusped plan seeming to show an intrinsic sensibility to earthquake actions. In the course of time some of them were completely destroyed. Others survived being, however, more or less damaged. Often by strengthening parts of original work were altered or even definitely sacrificed.

As concerns the damages caused by earthquakes, first should be mentioned the steeples. As a rule the masonry columns of steeples horizontally sheared at their bottoms and tops. The steeples of Wallachian Churches yielded easier to shearing than those of Moldavian Churches. Consequently, nowadays in Bucharest e.g. one church out of three is provided with false, wooden steeples.

Apse walls of the nave and altar were also severely damaged. The typical damages consist either in vertical cracks, showing the some settlements have had also occurred, and cracks inclined with 45° developed around the openings for windows or doors. The same two types of cracks have been developed in the straight walls of the ante-naves, especially when they were not braced at their tops.

The semi-circular arches as integral parts of the surrounding walls, designed to narrow the vaulted space and to support the cupola or steeples have also been damaged by earthquakes. Generally, the cracks appear at the arch crown as well as at the quarter of free spans. Such damages are often produced with the aid of arch ties. They are developing horizontal concentrated forces, always acting more or less eccentrically. A faulty foundation also favoured apse walls and transverse arches to be damaged. This is the particular case of churches rebuilt in a new masonry style over the ancient foundations of wooden churches burnt or stone masonry churches destroyed by earthquakes or settlements.

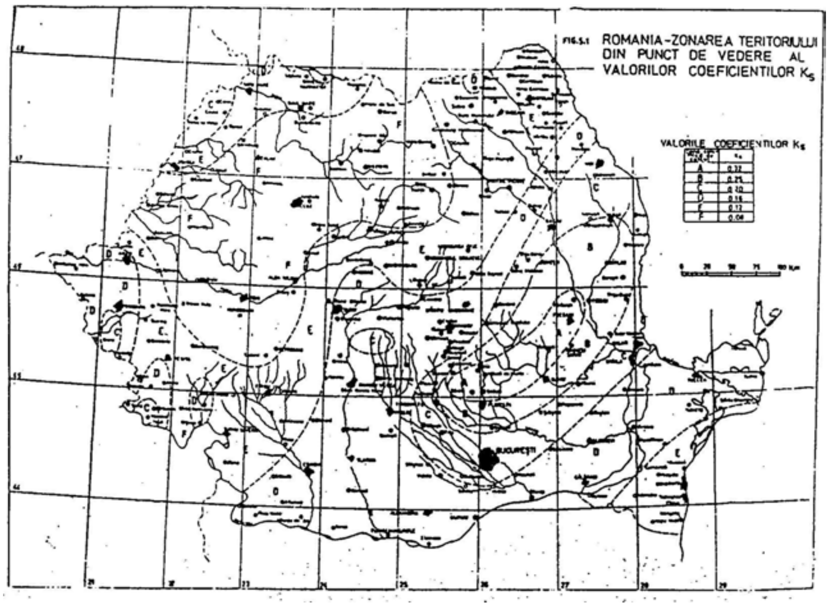


Fig.9 – map of Romania with seismic zones

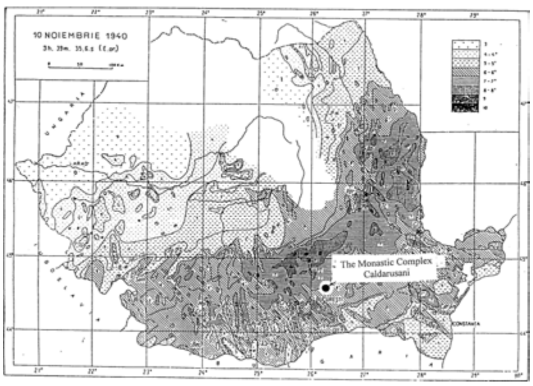


Fig. 10 – Iso-accelerations map of 1940 earthquake

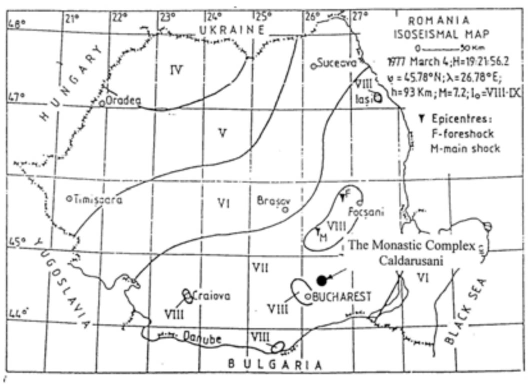


Fig. 11- Iso-accelerations map of 1977 earthquake

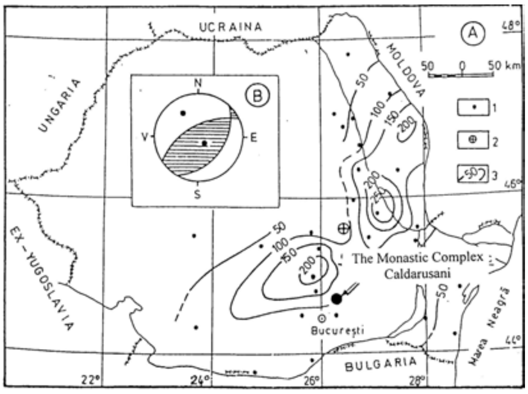


Fig. 12 Iso-accelerations map of 1986 earthquake

Fig. 13 Iso-accelerations map of 1990 earthquake

Earthquakes can cause damage both directly and indirectly to property and cultural heritage, resulting in a variety of types of damage, some of which are noted below.

Buildings and their contents are especially liable to structural collapse and damage related to lateral forces transmitted to buildings. Thus:

- walls, unreinforced vertical components (e.g., chimneys) and unsecured standing objects may topple;
- horizontal and vertical joint fasteners and connections may be severed or broken;
- building components may shift laterally and permanently relative to each other;
- building components may collapse on and crush objects and collections;
- structural cracks may appear in building elements which have absorbed lateral forces;
- building stability and resistance to future shocks may be reduced;
- freestanding items may be displaced;
- suspended items may become dislodged;
- service supply lines – water, sewerage, electricity, telephone, fuel supply lines (e.g., natural gas) – to properties may be blocked or severed, in turn increasing risk of secondary damage from fire or water;
- property alarm, early warning and communication system may be damaged, slowing effective response;
- humidity and temperature monitoring and control systems for museums, collections, galleries may be lost; and
- access to and from properties may be impeded by collapse or damage of landscape elements such as trees and roads.

Historic districts, in addition to damage to component structures and objects, may also suffer damage to their system as noted below.

- destruction of municipal infrastructure systems, particularly electrical and communications systems, and water, gas and sewerage systems. Damage to such systems can increase the potential for collateral water and fire damage, and reduce the ability to communicate effectively in an emergency – response situation; and
- damage to transport infrastructure – roads, railways, waterways, airport – including bridges, underpasses, culverts, elevated passageways and vehicles, potentially impairing effective movement of citizens and access by emergency – response vehicles to threatened or damaged areas;

Cultural landscapes and ***archaeological sites*** may suffer the types of damage noted above for individual monuments and groups of buildings, as well as the following:

- toppling or damage to landscape features such as trees, fences or unstabilized wall fragments;
- liquefaction of soil, which can happen under certain circumstances, and lead to landslides or subsidence;
- increased risk of secondary damage from fire, or from flooding resulting from damage to hydro-electric installations or to dams;
- destruction of animal and plant life, and loss of habitat for various species, resulting in erosion of biodiversity;
- damage to transport infrastructure, impairing effective response by citizens and impeding access by emergency-response vehicles to threatened or damaged sites.

An earthquake-preparedness strategy include elements which both reduce the potential for damage to cultural heritage, and establish clear modalities for reaction to an emergency. It requires mutual commitment on the part of those responsible for earthquake preparedness and those responsible for cultural heritage to work together in developing a balanced strategy to improve care for human life, property and heritage.

Unlike the provisions usually in place for fire protection, rarely do measures for earthquake protection for specific properties assign responsibility to a single officer, even in zones of high earthquake risk. Attention is most often given to earthquake-readiness concerns only when individual their owners renovate properties. Most contemporary building codes require that buildings being renovated meet contemporary requirements for all aspects of public safety, namely fire, earthquake prospecting, etc. At that point, the building's earthquake readiness is assessed.

While municipalities in areas of high earthquake potential frequently make systematic efforts to evaluate the risk to structures, and to upgrade structures to better withstand risk, such studies do not always result in adoption of overall strategies to upgrade earthquake preparedness for individual properties.

Even though the risk of earthquake may seem less immediate than that of fire, it is important that responsibility for a property's earthquake protection be permanently assigned to an individual or team who can continuously review and upgrade earthquake-related provisions. The property earthquake officer should work closely with municipal and state officials in devising an earthquake strategy appropriate for the property, its occupants, its contents and its heritage values.

Earthquake protection strategies will differ from those devised for fire in two major respects:

- earthquakes - unlike fire - cannot be prevented;
- the event itself - also unlike a fire - is relatively brief, and cannot be controlled.

These differences suggest the importance of focusing effective earthquake-protection strategies on preparation and on response: on measures aimed particularly at reducing risk, at enhancing earthquake resistance, at improving earthquake detection and monitoring, and at developing a response plan.

The strategy should suggest ways in which its various measures should respect heritage values, while improving earthquake protection.

In earthquake zones, some attention is likely to have been given to increasing the earthquake resistance of particular buildings. Such efforts, however, only address part of an effective property-specific, earthquake-protection strategy.

Those areas to be addressed in developing a complete and effective earthquake-protection strategy for a heritage property include:

- ***reducing risks***, which could involve efforts to reduce the impact of earthquakes on particular properties through:
  - *ensuring high levels of property maintenance;*
  - *reducing sources of ignition, to reduce likelihood and consequences of secondary fire*; and

- *ensuring suitable property uses in high-risk zones*.
- *for historic properties in particular, maintenance should pay particular attention to the state of older electrical or fuel supply systems, to reduce the likelihood that fire may break out following an earthquake*

- **increasing earthquake resistance**, covering
  - *efforts to strengthen the resistance of a building or its components to earthquake damage*;
  - *risk analysis to determine the likely intensity and frequency of earthquakes*;
  - *analysis of the structure's response to previous seismic events;*
  - *reinforcement of structural systems to increase the ability of a building to meet an earthquake's lateral forces;*
  - *isolation of the building from the ground in order to interrupt or divert the lateral thrust of an earthquake*.
  - *for historic properties in particular, measures to reinforce or isolate structures should be undertaken in ways have minimal impact on the property's heritage values.*
- **earthquake detection and monitoring** through efforts to provide adequate early warning of an earthquake, and knowledge of the event's critical parameters:
  - *in-ground sensors and communications systems capable of providing advance warning of the arrival of an e*arthquake; and
  - *systems for measuring the intensity and location of an earthquake and for ensuring transmission of this information to emergency-response centres.*
- **earthquake - response planning,** encompassing:
  - *Preparation efforts by occupants and emergency-response officials in anticipation of earthquakes;*
  - *involvement of occupants and earthquake-response officials in risk analysis for particular properties and zones, and in identification of needs to improve earthquake protection*;
  - *ensuring that municipal and regional plans indicate properties and structures serving special care in the event of an earthquake;*
  - *development of a comprehensive earthquake-response plan; and*
  - *earthquake-reaction training and drills for occupants and earthquake-response officials.*

in addition, **for historic properties**:

- *the response plan should include an inventory and full documentation of fragile and significant building elements, objects and fittings which deserve special attention and possibly salvage removal and conservation) in the aftermath of an earthquake;*
- *provision, on site, of an adequate supply of materials for salvage, protection, restoration, etc*;
- *provision for removal of threatened or damaged materials to a secure storage or conservation facility*;
- *identifying emergency teams of trained and experienced conservation professionals (architects, engineers, surveyors, planners, archaeologists, historians, etc.), craftspeople, builders and responsible members of the local community, available and able to respond during emergencies; and*
- *earthquake-protection training should sensitize officials to the nature of*
- *heritage buildings and objects, and indicate appropriate salvage care.*

A property's earthquake-protection strategy should be the subject of continuous monitoring and review, in order to identify and introduce possible improvements.

It is important to ensure that a historic property's earthquake-protection strategy is applied flexibly. The package of measures adopted should be designed to meet basic safety and stability requirements, with least harm to the character of the historic property. Structural alterations should be the minimum necessary to enhance earthquake protection to an acceptable level.

The best earthquake protection strategy for a particular property will meet all defined standards of safety and security for people, property and objects, with least harm to heritage values, and at least cost.

Efforts to increase earthquake resistance must be based on adequate understanding of a building, its structural systems, construction materials and techniques, its evolution, history and conservation, its condition, its heritage values and its likely earthquake performance.

All physical alterations to improve resistance must be based upon an adequate survey and must meet requirements for earthquake resistance established by local authorities. Studies to produce recommendations should take into account the seismic history of the region and of particular properties, in order to improve understanding of measures previously taken. Such an analysis requires looking closely at:

- The existing resistance of historic structures and materials to earthquakes

Builders have devised a variety of Ingenious means to minimize human injury and structural damage from earthquakes. An excellent example is the construction technology developed in Chilca, Peru, in an area of high seismic risk. Instead of massive, traditional masonry constructions, they built wooden frameworks which were then covered with waffle-and-daub and plastered with lime mortar While resembling ordinary masonry, These structures respond to earthquakes by losing theft coating in a relatively harmless shower of dust, leaving the basic framework intact (Photo by Alejandro Alva, IccRoM)

- The effectiveness of traditional concepts and methods of improving resistance.
- The variable behaviour of different structures and materials – timber frame, rubble or ashlars masonry, earth structures, etc. - in the face of seismic activity.
- The implications for behaviour in the event of a disaster of building defects, both intrinsic and extrinsic.
- Evaluation of the effectiveness of previous modern strengthening practices and techniques.
- Assessment of different levels of earthquake intensity, and of past and expected frequency of occurrence.
- Experiences from previous seismic events in the area or of such events in comparable circumstances elsewhere.

Design criteria and reinforcement recommendations sensitive to the values of historic properties should ensure that:

- The works proposed will not result in the loss or impairment of the special interest or integrity of the historic property.
- Preference is given to respecting, retaining and enhancing existing structural systems and materials where possible; in other words, the emphasis is on performance-based analysis. This means recognizing the adequacy of the performance of existing structural systems and members as a means of evaluating the overall effectiveness of structural systems (rather than relying exclusively on the numerical computations, or ability of constituent members or assemblies to meet code requirements).
- Preference is given to use of traditional materials and techniques in reinforcement.
- Where new materials and reinforcement techniques are proposed, these are compatible with those already existing, and are durable and reversible, as far as is practicable; if these conditions cannot be met, alternative proposals should be commissioned and evaluated.

- Each building and any proposed works are assessed on their own merits.
- Earthquake-reinforcement analysis is based on building performance, rather than on simple application of code requirements, with due consideration given to improvements offered by technical developments.
- Proposed works are designed against realistic probability assessments of disaster occurrence, intensity, and associated risk levels.

The opportunity to upgrade earthquake resistance should always be pursued when a building is the subject of a major programme of repair, alteration or extension. Existing inappropriate or unauthorized forms of construction, extensions or alterations should be removed where possible.

All improvements and strengthening work should be fully documented allowing for long-term review with the aim of contributing to establishing appropriate international standards.

8. Construction Materials

It seems that the art walling brick masonry on Romanian territories lasts from Roman invasion at the beginning of the second century A.D. Since then it was known to use the plumb-bob wire and to successively laid the bricks, with the aid of gravity field, in horizontal layers according to the principle *full on joint.*

For all the above mentioned monuments only solid bricks were used. They are made from ordinary red clay, manually shaped in wooden casings and burned out in brick fields. Brick dimensions differ in time and places. Between centuries X and XV it was used for length 280-350 mm, width 160-200 mm and thickness 40-50 mm, while between XVI-XVIII the dimensions were accordingly reduced to 250-260 mm, 120-140 mm and *35-40* mm, probably to enhance labour productivity and masonry quality.

Checking the strength of bricks to free falling carried out quality control. Six by six bricks randomly collected were let to successively fall from increasing heights of 0.25, *0.50,* 0.75 and 1.00 in on and wooden platform laid on a sandy bed. At least 4 of 6 bricks should resist to the falling from 1.0 *in,* and the rest of 2 bricks to the falling from 0.75 m. Laboratory tests on bricks selected in this way have shown strengths in the range from 5 to *7.5* MPa.

For mortar only lime binding matter was used in that period. Two qualities of lime were known: high-calcium or rich lime and hydraulic lime. The last one is obtained from marl, with a clay content varying between 8% to 40*%,* burned in lime kilns up to calcinations temperature of 1100-1200 ^{0}C. When the clay content is limited to 24%-40% then the so called Roman lime is obtained. It has hydraulic qualities and by laboratory tests there were found strengths up to M12.

As a rule the sand for mortar was obtained from rivers as quartz, siliceous sand. Three ratios in volumes lime: sand were used: 1:1.4, 1: 2,2 and 1:3. The specific weight of mortar was found between 15.2 — 18.0 kN/m^3, and the apparent porosity 27%-37%. The thickness of bed joints as well as of perpendicular ones was the same with brick thickness.

Often church foundations have been made also from brick masonry. In those cases only the so-called Roman lime was used. Sometimes the masonry was reinforced with wooden bars. The bars have been firstly protected against decaying with milk of lime and then inserted in horizontal layers, especially near corners and crossings.

Finally, it should be mentioned that for the bearing-out masonry glazed bricks were used.

9. Climatic data

The climatologic data are issued from the Climatologic Atlas of Romania, built up on a 60 years observation work (1896 - *1955).* We consider this period to be more relevant for the lifetime of the studied monuments, than the standard reference period (1950 - 1989). Two zones were considered: Valcea zone, characterising the climate for the Hurezi and Arnota churches, and Bucharest zone, for the Caldarusani monastery and the other churches located in this area.

Air temperature: the mean, maximal and minimal monthly values are represented in Figs. 2.1 and 2.2, for the Caldarusani area and Valcea county, respectively.

There are differences also for the absolute values (lower for Valcea) and for the amplitudes (both monthly and annual), more important at Caldarusani The absolute maximal and minimal values are: *(41.1^{0}C;-35.1^{0}C)* for Caldarusani, and (38.6^{0}C; -25.8^{0}C) for Horezu station (near Hurezi and Arnota churches). The annual mean temperatures are, respectively 10.7 ^{0}C and 7.1 ^{0}C.

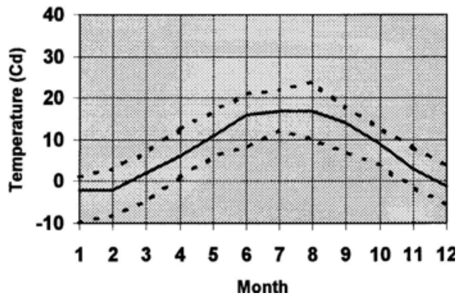


Fig. 14 Air temperature values for Valcea zone

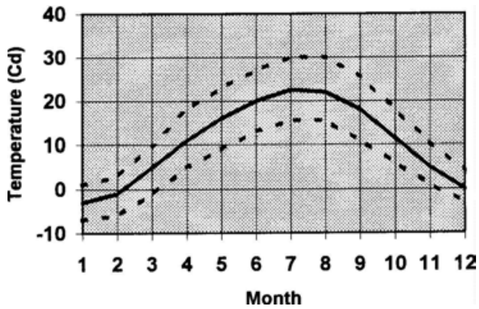


Fig.15 Air temperature values for Caldarusani zone

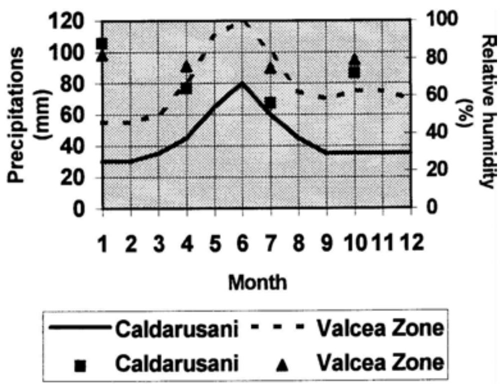


Fig. 16 Atmospheric precipitation and relative air humidity

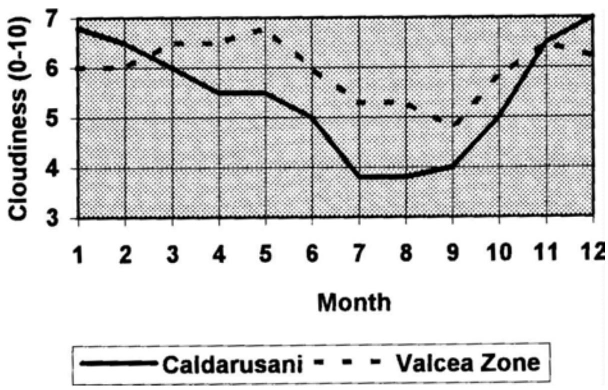


Fig.17 Monthly mean cloudiness

The annual temperature sums (basis 0 ^{0}C) are, respectively, 4,000 and 3,000 degree - days. At Caldarusani, the air - temperatures below 0 ^{0}C occur during the period 15 December - 25 February, and at Horezu, between I December and I March.

The atmospheric precipitation and relative air humidity are represented in Fig. 2.4. The radiative regime is represented by the cloudiness, in Fig. *2.5.*

10. THE IMPORTANCE OF RISK-PREPAREDNESS FOR CULTURAL HERITAGE

Current initiatives at international, regional and local levels to improve risk-preparedness for cultural heritage are a response to the outpourings of concern coming from professionals in the early l990s, looking for improved channels for professional involvement. These initiatives strengthen existing frameworks for preparedness, response and recovery, and put in place a number of useful mechanisms for practical assistance at site level.

At the same time, these efforts have helped identify some of the key obstacles to achieving desired improvements. Many of these barriers are attitudinal in nature, rooted in perceptions prevalent among professionals dealing with heritage and, to a lesser extent, those in the disaster-preparedness field. Considerable ‘passive’ resistance can be found in the conservation community, which while always moved to respond in the moment of emergency, appears less interested in planning for preparedness than in pursuing involvement in the field’s perceived current ‘central’ themes (authenticity, conservation of modem buildings, conservation of cultural landscapes, etc.). The focus of the 1996-99 ICOMOS triennium - The wise use of heritage — offers an admirable framework for increasing the attention given to cultural heritage at risk.

All of the attitudinal obstacles encountered are worth reviewing in some detail, in order to identify possible arguments for challenging underlying perceptions. These are looked at below under six conceptual headings.

1. Reluctance to give serious attention to the loss of cultural heritage during catastrophes that claim human life
2. Need to strengthen collaborative working habits of built-heritage conservation professionals
3. Need to strengthen the visible profile of risk-preparedness in the professional activities of those who work in built-heritage conservation
4. Need for built-heritage conservation professionals to strengthen their collaboration with those involved in conservation of objects, collections, museums and archaeological sites
5. Need to strengthen interest of built-heritage conservation professionals in the value of preventive approaches

Improving risk-preparedness for cultural heritage offers many benefits. It important that site managers use arguments concerning such benefits, thus enhancing their ability to improve the care given to the heritage resources in their car Aspects worth stressing are that:

- the extension of the life of cultural heritage properties, their collections and constituent elements confers a tangible benefit upon these properties;
- adoption of a cultural-heritage-at-risk framework refocuses conservation attention from the curative to the preventive, from the short-term to the long-term, and consequently offers property owners significant opportunities to realize long-term savings;
- a cultural-heritage-at-risk approach may also be seen to offer particular benefits to specific groups. Thus:
- for the heritage professional, disaster-preparedness becomes one extreme, set along a continuum of linked concerns, rather than a special-case scenario;
- for the heritage movement, a continuous-care framework suggests a holistic focus on management of all cultural resources rather than on a defence of what many perceive as elitist values;
- for built-heritage professionals, there is the opportunity to work closely with object- and archaeological-conservation professionals in establishing common approaches and philosophies;
- for risk-preparedness professionals, a continuous-care framework highlights that the heritage community shares common concerns for continued life, security and the various ways that that life is expressed through heritage.

Cultural heritage is always at risk. It is at risk from the depredations of war. It is at risk in the face of nature's occasional eruptions and irruptions. It is at risk from political and economic pressures. It is at risk from the daily forces of slow decay, attrition and neglect. It is even at risk from the hand of the over-zealous conservator!

If the cultural heritage community begins its dialogue based on this premise, then it will be able to make bridges not only to those responsible for planning for disasters, but also to ordinary people whose own vigilance must be stimulated, whose own courage in the face of disaster must be supported. We will be able to deal with catastrophe and its consequences without having to set human life against the worth of cultural heritage; we will recognize that the life and heritage are inextricably linked, part of one indivisible whole, and that efforts to secure one should serve to strengthen the other.

Principles appropriate in improving risk-preparedness for cultural heritage acknowledge the most important ideas to emerge from the recent Blue Shield discussions:

- Given recent international Declarations promoting the integration of improved risk-preparedness for cultural heritage in existing disaster preparedness infrastructures, principles should be placed within the context of existing structures and practices to protect life and property in the face of disaster or armed conflict; and

- as noted in the Introduction to this Manual, built-heritage conservation principles have been developed primarily to guide thinking about *intervention,* i.e., about curative approaches to heritage. Principles relevant to improving risk-preparedness for built cultural heritage need to be devised for *preventive* approaches, concerned with improving the general conditions for the long term survival of cultural heritage and its significant messages.

Salient principles are given in the box. These are the desirable characteristics of approaches for the better management of the heritage attributes of particular properties. Each principle and its implications in risk planning, response and recovery is considered below.

- The key to effective protection of cultural heritage at risk is advance planning and preparation.
- Advance planning for cultural heritage properties should be conceived in terms of the whole property, and provide integrated concern for its buildings, structures, and their associated contents and landscapes.
- Advance planning for the protection of cultural heritage against disasters should integrate relevant heritage considerations within a property's overall disaster prevention strategy.
- Preparedness requirements should be met in heritage buildings by means which will have least impact on heritage values.
- Heritage properties, their significant attributes and the disaster-response history of the property should be clearly documented as a basis for appropriate disaster planning, response and recovery.
- Maintenance programmes for historic properties should integrate a cultural-heritage-at-risk perspective.
- Property occupants and users should be directly involved in development of emergency-response plans.
- Securing heritage features should be a high priority during emergencies.
- Following a disaster, every effort should be made to ensure the retention and repair of structures or features that have suffered damage or loss.
- Conservation principles should be integrated where appropriate in all phases of disaster planning, response and recovery.

1. *The key to effective protection of cultural heritage at risk is advance planning and preparation.*

- The best means to protect cultural heritage at risk is to ensure that adequate attention in advance planning is given to identification of heritage attributes, the risk to these attributes and appropriate response measures for these risks.

2. *Advance planning for cultural heritage properties should be conceived in terms of the whole property, and provide integrated concern for its buildings, structures, and their associated contents and landscapes.*

- No distinction should be made in planning between a property's movable and immovable cultural heritage components; there should be one integrated response plan for the property rather than one for its structures, another for its collections and a third for its landscape.

3. ***Advance planning for the protection of cultural heritage against disasters should integrate relevant heritage considerations within a property's overall disaster-prevention strategy.***

   - A property's disaster-prevention strategy should fully integrate concern for the cultural heritage within it, both in terms of the planning process used to develop and update the strategy, and the particular response plans which might result; there should be one fully integrated response plan for a property.
   - Property managers must be able to work with inhabitants, administrators and planners to resolve conflicts and to develop conservation strategies appropriate to local needs, abilities and resources.

4. ***Preparedness requirements should be met in heritage buildings by means which will have least impact on heritage values.***

   - Requirements to contain risks and hazards should not be reduced in order to maintain heritage character; to heritage purists, a sprinkler system might be offensive in a historic structure, but its effective use can save lives, property and heritage.
   - The key concerns from a heritage perspective should be the design and installation of disaster-protection systems or mechanisms in ways which will *minimize* impact on heritage values. Hence, approaches to preparedness design that remain sensitive to heritage will generally require review of a large range of alternatives, in order to ensure that the least-impact option has been identified.

5. ***Heritage properties, their significant attributes and the disaster-response history of the property should be clearly documented as a basis for appropriate disaster planning, response and recovery.***

   - Analysis should make reference to cultural and use significance, and the relationship of structures or elements to their setting. This information should establish priorities for protection of a property and guide fire brigades civil defence officials to handle sensitive areas with care in responding emergencies. It should also provide a record which would allow the accurate; recovery (if warranted) of lost or damaged elements.
   - Property inventories established to protect heritage should, however, be us carefully. Property elements not listed, or 'low' in priority, should not perceived as disposable. The heritage values of heritage properties are m than the sum of the aggregate values of component parts, and efforts should be made to ensure that disaster-response plans are focused on preserving not only 'significant' elements but the totality of the property.
   - Significant attention in planning for risk-preparedness should be given obtaining and studying documentation of the performance of a structure property during past disasters, in order to benefit fully from lessons relevant for planning for the future. Post-disaster recording can also help clarify property losses and priority needs for stabilizing and securing the property and its constituent elements.
   - The existence of a complete record of the property should not substitute all possible efforts to protect the property from the consequences of decay or disaster, or be permitted to relax vigilance against risk.

6. ***Maintenance programmes for historic properties should integrate a cultural-heritage-at-risk perspective.***

   - Maintenance programmes are often conceived in terms of the daily cause deterioration of a property, e.g., visitor and occupant use and the impact weather conditions (temperature, humidity); this perspective should be expanded to include analysis of all possible human and natural sources of de and loss, the degree of risk associated with each and appropriate measure reduce or mitigate risk.

7. ***Property occupants and users should be directly involved in development emergency-response plans.***

   - The first line of defence and response in urgent situations will always be property occupants and users. Their involvement in planning increases their understanding of the purpose of proposed measures and the likelihood effective response. Their involvement also brings their first-hand knowledge and experience of the property to the process of developing a response plan.

8. ***Securing heritage features should be a high priority during emergencies.***

   - While efforts to preserve heritage should never compromise efforts to preserve human life in an urgent situation, nevertheless, heritage - as the tangible and intangible record of all past and current lives-deserves the utmost care in emergency response.

9. ***Following a disaster, every effort should be made to ensure the retention and repair of structures or features that have suffered damage or loss.***

   - The involvement of qualified conservation professionals, experienced in post-disaster assessments, is critical to retention of damaged buildings and elements. For lay observers, visible damage often appears to be of greater concern than its actual condition warrants, and there is a tendency to believe recovery is either impossible, or too expensive. Condition assessments must come from heritage professionals experienced in looking at similar situations. It is important that the response plan for the property identifies in advance individuals capable of being called upon rapidly for such assessments.
   - Assessment by a qualified specialist should result in recommended measures for immediate and urgent stabilization and protection of cultural heritage. Budget provisions for such stabilization should be part of advance planning for improving property disaster-preparedness.
   - Relevant building codes and standards should be applied flexibly in post-disaster assessments. In the interests of public security, the officials responsible often quickly condemn damaged properties, citing relevant standards and codes. Without compromising public safety, heritage properties should be given the benefit of the doubt until assessment by qualified and experienced professionals can determine the true condition of the site, remedial measures required and their urgency.

10. ***Conservation principles should be integrated where appropriate in all phases of disaster planning, response and recovery.***

    - Conservation principles should be used to guide property documentation before, during and after emergencies: documentation should be *secure* (i.e., stored in several locations), *reliable* (i.e., its accuracy should have been verified independently of those carrying out the initial recording) and *readily accessible.*
    - Conservation principles should be included among the legal and normative instruments applied in actions needed for damaged heritage elements, in order to ensure integrated response to post-disaster needs.

- As with all facets of risk-preparedness, property managers and emergency-response officials should ensure that conservation principles are an integral part of the overall set of principles applied in risk planning, response and recovery. The decisions made should be balanced judgements based on shared principles, accepting responsibility for safeguarding the heritage resource.
- Appropriate expertise should be sought. Managers should recognize when advice must be sought from specialists, such as for wall paintings, sculpture and objects of artistic and historical value, or particular building materials and systems. The experts involved should work as part of multidisciplinary teams.

11. POLYMER GRIDS

Modern masonry was criticised in one of the above chapters for using cement mortars and cored bricks. However, it was not claiming to produce only solid bricks or prepare only lime mortars. The technological progress cannot be denied. The idea is to restore the balance between the elastic and plastic proprieties of the original masonry. For this purpose synthetic reinforcement proved to be the most appropriate. According to Prandtl's Theory three models of reinforcing masonry with polymer grids can be assumed: 1) insertion them in the bed joints (Fig. 10), 2) confining the plain masonry (Fig. 11), and 3) combining the two previous models by confining the reinforced masonry (Fig. 12).

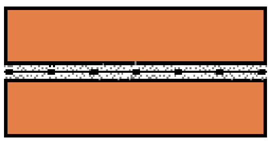


Figure 10 - Insertion

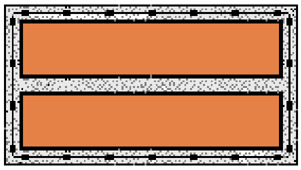


Figure 11 – Confining

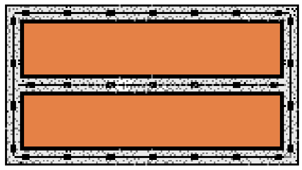


Figure 12 –Combined

There are also three criteria for choosing polymer grids as reinforcement for masonry: 1) high tensile strength at low strains, 2) controlled long-term deformations and 3) integrated solid joints. The reinforcing approach with synthetic grids essentially differs of that known for steel bars. Polymer grids are firmly fixed in mortar by interlocking of their joints. The mechanism of stress transfer from mortar to grids is discontinuous and produces only in the solid joints through normal stresses σ, without any contribution of the tangential ones τ. Only tensile forces are transferred from mortar to grids. This specific mechanism was demonstrated in a pullout test on a grid inserted in sintered glass with glycerine and viewed under polarised light.

12. REINFORCING AND RESTORING TECHNIQUES

For restoring buildings and monuments, reinforcing the masonry structural members with polymer grids shows great potential. This work involves three specific techniques: 1) inserting the grids in the horizontal layers of mortar between bricks (Fig. 13) ; 2) coating the outer surfaces of masonry with reinforced plaster; and 3) confining the structural members with the same reinforced plaster (Fig. 13). In all cases, synthetic reinforcement compensates for masonry's lack of ductility and enhances its natural strength capacity.

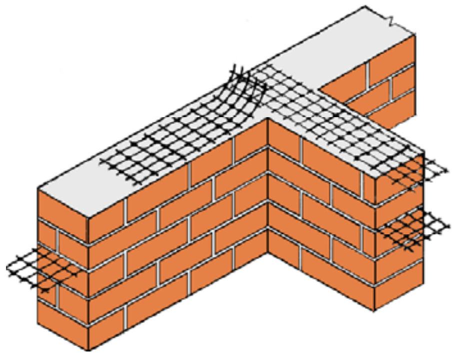


Figure 13: Horizontal reinforcement

The first technique improves load transfer capacity between the masonry units, since the reinforcement prevents horizontal expansion of mortar. It is not necessary to lay the grids in all mortar beds, but only in some of them at vertical distances between 20 cm and 60 cm. The joints of grids are obtained by superposition without any joining devices. Coating the masonry with reinforced plaster improves the shear resistance of the masonry wall, whether or not the horizontal reinforcement is present. This technique is efficient only when the reinforced plaster adheres well to the masonry surface. The effect of this type of reinforcement is bi-directional, in the plane of the wall. Finally, confinement with reinforced plaster improves both compression and shears resistance and is most efficient when combined with the reinforcement in horizontal layers. This type of reinforcement acts in a three-dimensional sense and can be used to increase the bearing capacity of structural members several times.

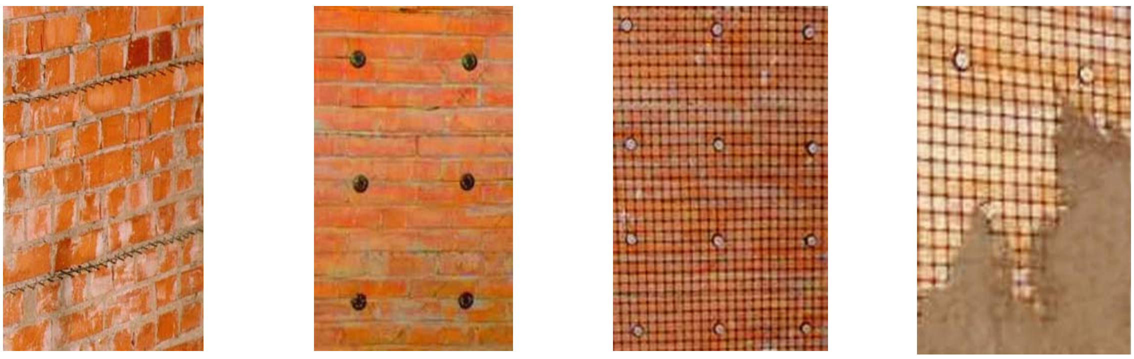


Figure 14: Horizontal and vertical reinforcement

The polymer grids can be used as reinforcement for both engineered and non-engineered masonry within either new or old buildings. Each case should be analysed separately according to the characteristics of the masonry units and the mortar, as well as the type of construction. The importance of workmanship in this context cannot be overstated. Typical masonry configurations are commonly laid in “running” bond, with the units overlapped on half their length. Single-wythe or barrier walls are most common. Multiple-wythe walls are also constructed and can consist of composite brick-block walls. However, cavity walls are not allowed in seismic areas.

All the available masonry units, such as bricks and blocks, can be associated with polymer grids. Clay units, dense or lightweight aggregate concrete units, autoclaved aerated concrete units, calcium silicate units and natural stones can be used in reinforced structural members. Solid clay bricks are the most efficient for use with reinforcing, since they produce a rather uniform pressure on the polymer grids. Vertically perforated bricks are sometimes also admitted in reinforced masonry. However, in seismic areas vertically hollowed bricks are not recommended, while horizontally hollowed ones are prohibited.

13. EXPERIMENTAL VALIDATION

First test on ISMES' shaking table was carried out on a 3D model of a plain masonry building (Fig. 15). The original model was submitted to inputs of increasing intensities up to 10 dB when masonry limit state of cracking was reached. Then, two belts of plaster reinforced with polymer grids confined the damaged model. Submitted again to increasing inputs up to 14 dB the model resisted, the two belts displaying only several thin vertical cracks. The results have been used for continuing the research in the frame of the INCO Copernicus program.

The second test on the same shaking table was carried out on a 3D model of a RC frame with masonry infills reinforced with polymer grids in horizontal layers (Fig. 16). The model was submitted to inputs of increasing intensities up to 8 dB when the joints of RC frame cracked while nothing happened with masonry infills. Then, each masonry panel was confined with reinforced plaster. Submitted again up to a level of 10 dB the model was slightly damaged without reaching the limit state of cracking.

Both tests have shown the capacity of masonry reinforced with polymer grids to dissipate the induced energy without major decay of strength. By this ductile behaviour the damages in structural members was strongly reduced. From the tests on masonry models of panels is known that they suddenly drop in shear strength. The strength decay falls exponentially with the magnitude of deformation. The things are radically changing after reinforcing the panels with polymer grids. The strength is no longer abruptly decaying but follows a linear function of deformation with a rather mild gradient. In this way the limit of deformation remains in the limit fixed by Eurocode 8 for checking the limit state of serviceability.

Finally, both models were provided with openings for windows and doors. According to the same EC8 they are *in plan* irregularities with strong torsion effects. They are infringing upon the seven guiding principles governing the conceptual design against seismic hazard and particularly upon the *uniformity and symmetry.* However, all panel models of masonry reinforced with polymer grids resisted to the shear stresses induced due to the above-mentioned irregularities.

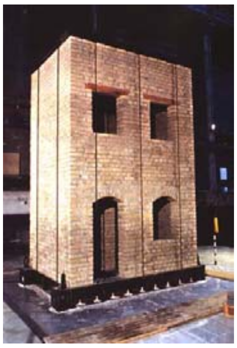


Figure 15 - Plain masonry model

Figure 16- RC frame with masonry infills

14. CONCLUSION

The original masonry, as it was used to ancient structures, satisfies rather well the required conditions of the mathematical model assumed by Prandtl for ductile materials. Indeed, the masonry made by clay bricks well burnt and bound by lime mortar is endowed with elastic and plastic properties simultaneously developing. Beginning with some levels of vertical compression the bricks behave like rigid bodies while the mortar reaches its limit of plastic equilibrium and yields. Masonry lateral deformation by mortar expulsion develops shear stresses. They are due to both mortar internal cohesion and external friction between mortar layers and bricks. The vertical joints between bricks are also helping by a kind of passive resistance. The same mechanism of stress transfer also occurs to some masonry of natural stone. In modern times the weight of tall and industrial buildings have much increased. The bearing capacity of lime mortar became to low for higher compressions. This is why gradually the lime was replaced in mortars by cement. Masonry bearing capacity increased but not as much as expected. Then, to reduce masonry own weight, cored bricks, with holes in either vertical or horizontal directions, were gradually introduced. In this way, after a service of millennia, the original masonry during less than a century was completely replaced. The new one has higher resistances to compression but is extremely brittle. There are strong theoretical background and experimental results to use polymer grids for restoring the masonry in buildings and monuments belonging to architectural heritage. The restoring techniques are simply to apply, do not require qualified labour or advanced technologies and is cost effective. With the aid of this synthetic reinforcement became possible to reach the level of safety as required by the official codes. From historical perspective the masonry reinforced with polymer grids regains its original balance between the elastic and plastic properties.

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