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THE SEISMIC PATHOLOGY OF RELIGION-RELATED BUILDINGS IN ROMANIA AND THEIR TREATMENT ACCORDING TO ARTICLE 10 OF THE VENICE CHART.

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ABSTRACT

" The only focus of deep earthquakes in Europe is situated in the Vrancea mountains"

Acad. G. Demetrescu

" Nowhere else in the world is a center of populations so exposed to Earthquakes originating Repeatedly from the same source....."
I feel that there is not much anyone can teach the seismologist in Romania about their special problem. They have understood it and are well aware of their Unique situation"

Charles Richter

Venice Chart Article 10

" Where traditional techniques prove to be inadequate, the consolidation of a monument can be achieved by the use of any Modern Techniques for the conservation and construction, the efficiency of which has been shown by scientific data and proved by experience".

In the very special seismic conditions of the Romanian territory, where thousands of historical monuments were lost forever, a consolidation strategy to save whatever buildings survived, was imperiously necessary. In a last analysis, this meant renouncing strict traditional techniques and making use, in a discerning manner, of the large variety of methods by Article 10 of the Venice Chart. Founded on the bases of Seismic Damage Mechanics, this strategy includes, in a unifying system : the study of structural morphology of religious monuments, the seismicity of zones rich in monuments, the restoring of material continuity in a damaged structure, the upgrading of existing materials with new compatible materials, the choice of strengthening structures deeply embedded in the initial structure, special structural analyses, etc. All these are carried out without changes in sizes, shapes, proportions, or requested architectural rhythm and style. This complex process was, from the very start, always a multidisciplinar one, beginning with the archeologist and ending with the restoring painter of original frescoes, many of them UNESCO protected.

KEYWORDS

Historical Monument; Venice Chart art. 10; Seismic Pathology; Mechanics of Damages; Consolidation Strategy; Embedded Spatial Skeleton (ESS); Attic Macro-structure; Vertical Member; Horizontal Spandrel; Supplementary Infra-structure.

FOREWORD. SEISMIC PATHOLOGY.

A strategy for the strengthening and restoration of monuments implies the prior definition of scientific base:

(a)- definition and zoning of the mechanical and climatic environment; this concept covers all solid, liquid and gaseous matter interacting with a specific monument during its life;
(b)- experimental testing of mechanical properties of aged materials, as regards strength, deformability and cycling degradation,
(c)- the morphologic analysis and classification of monuments and their specific typology;
(d)- mechanics of seismic damage; specific damage;
(e)- mechanics of degradation phenomena, due to long-lasting action of physical and chemical factors; specific degradation.

THE SEISMOGENESIS OF ROMANIA. THE VRANCEA FOCUS.

The foci of strong earthquakes, affecting periodically most of historical monuments in Romania, lie to the external part of the Carpathian bend, as a consequence of a gigantic subduction at the converging point of four tectonic micro plates. The Vrancea earthquakes have a millennium-long recorded history; referring only to events recorded in the last two centuries, the list is as follows(dr. V. Marza);

Table 1. Strong Vrancea Earthquakes in the XIXth and XXth centuries

Year	H (km)	M (Richter)	Imax (MKS)	Year	H (km)	M (Richter)	Imax (MKS)
1802	--	7.5	X	1908	125	6.8	VIII
1829	--	7.0	VIII 1/2	1940	135	7.4	IX
1838	--	7.3	IX	1977	94	7.2	IX
1894	--	6.8	VIII	1986	145	7.0	VIII 1/2

The 1802 catastrophic event, affected all historical monuments in Moldavia and Valachia; available documents mention innumerable partial or generalized callapses; almost no church tower survived. Considering the above data, it is obvious that in Romania the seismic risk constitutes a natural reality and should be perceived as an intrinsic parameter, to be accepted both for the historic past and for the future.

THE MORPHOLOGY OF RELIGIOUSE MONUMENTS

The pathology of religious monuments requires advanced knowledge on structural members and components and their specific interactions; the authors, together with Arch. S. Miclescu, worked out a methodology to describe and examine in-depth the morphology of sacred monuments, conceived into three steps(Fig.1-abcd).
Step 1: Simple structural members and components.
Step 2: Structural complexes of the 1-st order.
Step 3: Structural complexes of the 2-nd order.
Examples in (Fig. 1- a, b, c, d) refer to classical orthodox churches; based on the shape of components and on transfer of forces and couples; catholic churches have a different morphology, although shape, forces and couples transport criteria was the same.

MECHANICS OF SEIMIC DAMAGE

Damage in old sacred buildings is always 3D. Consequently, design of strengthening should mandatory reflect this spatial character.

Damages in Church Nave. Systematic damage, in all examined churches (over 100), can be summarized as follows:

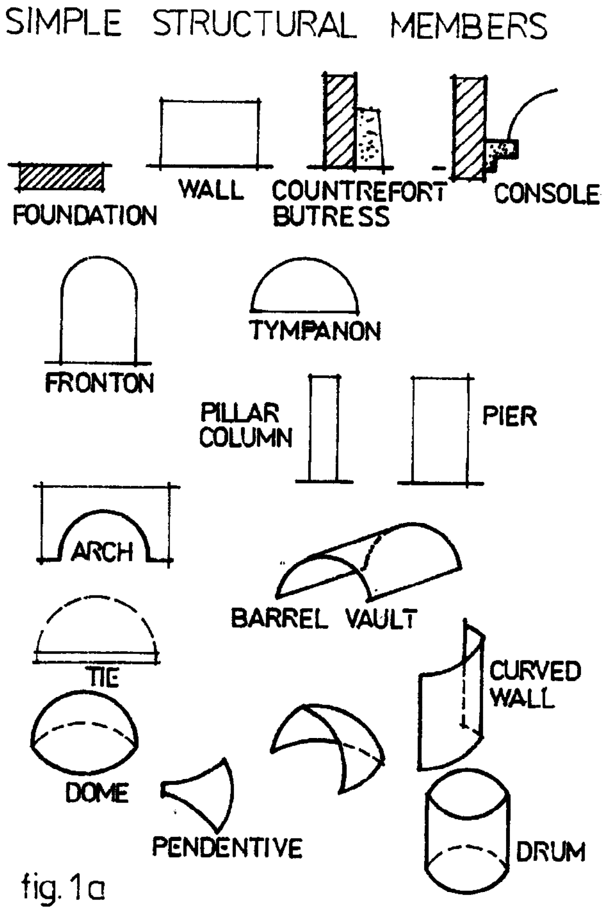


fig. 1a

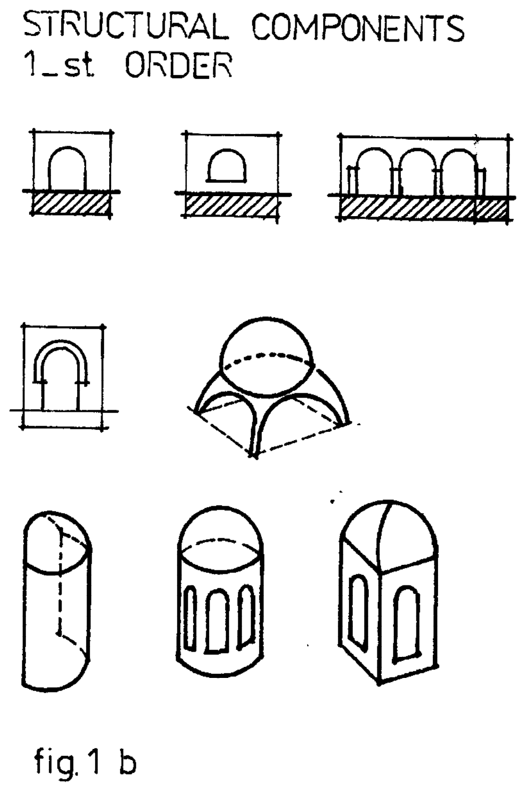


fig. 1 b

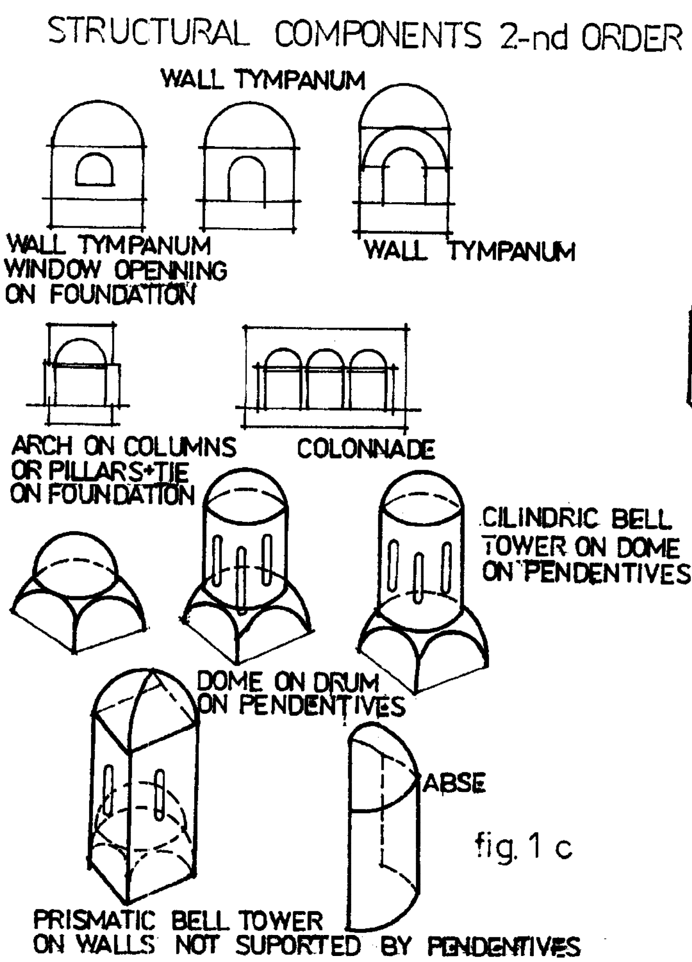


fig. 1 c

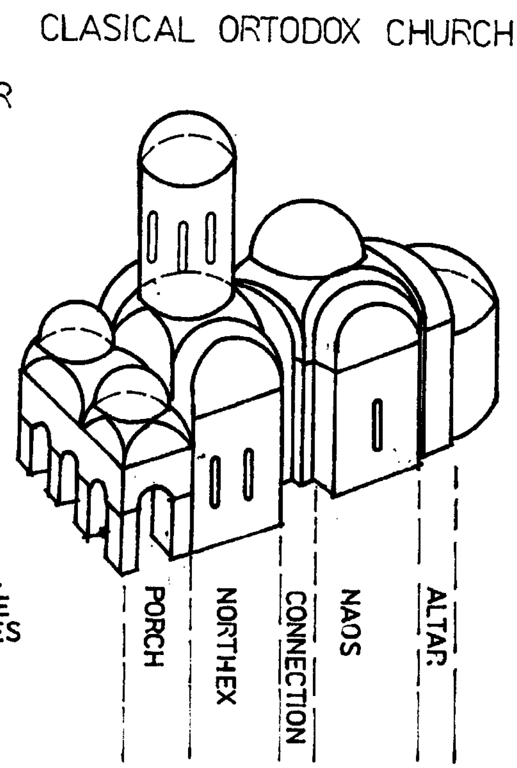


FIG. 1

(a)- a longitudinal dislocation(LGD), almost always extending from the altar to the porch, tending to cut the Church Nave in two halves;

(b)- transverse dislocations(TRD) and fractures in the axes of the naos, nortex and the porch, Systematically in the Weaker Parts of the Nave Walls, i. e., the vertical narrow window openings.

These two types of associated dislocations fractures transform the main body in an Assembly of almost Independent Blocks, each behaving separately(Fig. 2).

The LGD is accompanied by cracks and dislocations in the altar vault, large tronconic fractures in all the arches, in the barrel vault between the naos and the nortex, etc. Cracks and fractures were frequently around doors and windows openings, (lines of weaker strength). Openings in walls generally constitute sources of stress concentrations and brittle fracture(Fig. 3-a, b, c, d). Cornices, frontons, terminal parts of the nave without transverse ties, may be also damaged; these members exhibit innumerable transverse cracks and degradation's, up to friability of the material, caused by climatic effects.

Damages in Domes, Drums, and the Bell towers. Such prominence always constitute highly sensitive elements to earthquake action. Built in brittle materials, with low tensile and shear strength, these are exposed to high overturning moments and shears due to dynamic amplification from the Prominence Effect. Damage patterns exhibit a large variety: total collapse, partial collapse, shear of drum base above the roof, shear at the base of the tower at it support on the drum and the pendentives, inclined cracks sometimes caused by torsion, cracking and dislocations of the window lintels(Fig. 3-a, b, c, d).

Damage in the Infrastructure. Longitudinal and transverse fractures of the nave sometimes propagate to the foundation. This happens almost systematically in the case of the window in the axis of the altar. In some cases, two inclined fractures which intersect in the window opening, outlining a gigantic X, continued down to foundations, were observed.

CHOICE OF MATERIALS

This is a very important design process; philosophically speaking, Matter and the Mechanical-Climatic Milieu are primary data; the monument, which its dimensions, shape, proportions and architectural style of the epoch, is a Product, conditioned by forces of nature and by the physical-mechanical of materials at the date of construction. In most cases, our monuments are built in brick or stone masonry, both exposed to explosive crushing caused by earthquake action, by soil sliding or uneven settlements typical for loessoid soils, etc.

Our monuments were built by Christian Dukes, disposing of limited means, at the gates of an Eastern Europe more hostile than earthquakes. For this reason, our monuments possess the proportions of miniature jewels, bearing the scars both of earthquakes and successive devastation's. In many cases, actual foundations lie over much older infra-structures, as discovered in archaeological investigations: such Traces possess the status of historical roots and are protected as such.

New materials become now available; however, the problem remains excessively difficult when a new material is combined with an old one. In this case, the choice of materials is chiefly determined by the compatibility of the time-degraded materials with the new ones; Rejection is real. In spite of its excellent properties, of being molded when poured, common RC is not extempt from Rejection, when coming into contact to very weak masonry or large stone block masonry. Also the harmful phenomena, of chemical migration of substances contained in cement, towards painted surfaces, is a very subtle rejection, determining certain specific strategies to protect old paintings and frescoes.

LONGITUDINAL / TRANSVERSE
FRAGMENTATION OF THE CHURCH BODY IN DISTINCT BLOCKS

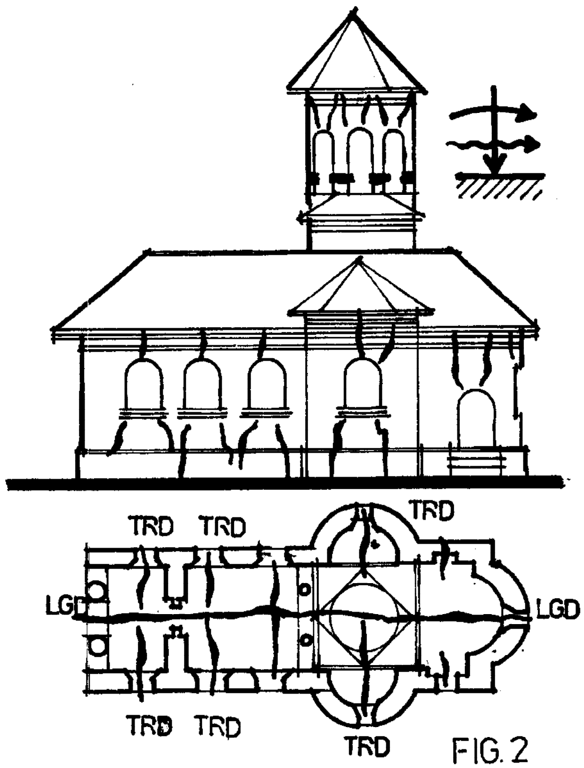


FIG. 2

DAMAGE MECHANISM OF THE ALTAR ZONE INCLUDING THE TRIUMPHAL ARCH

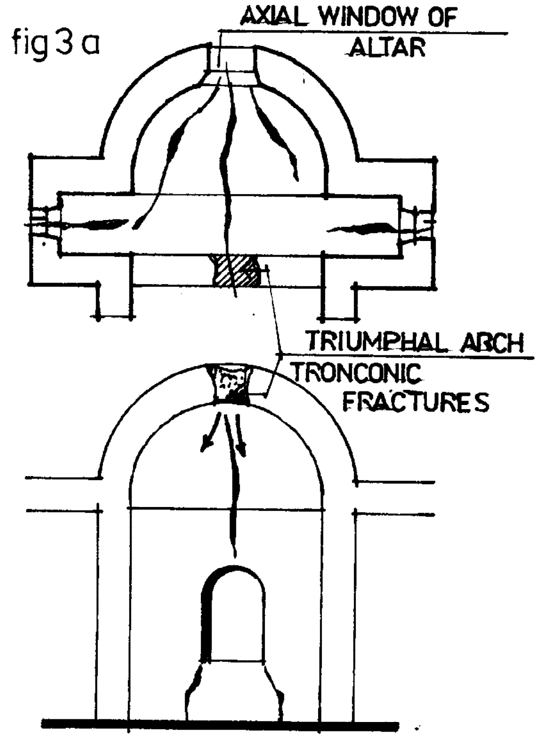
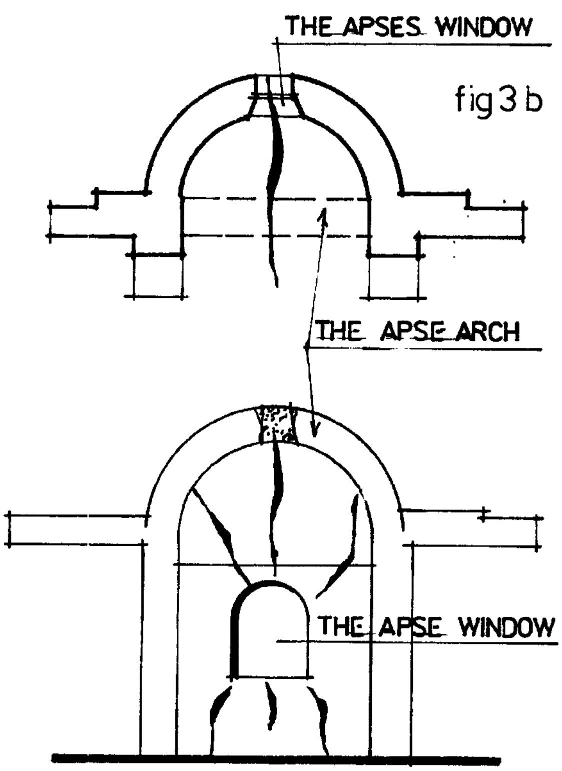
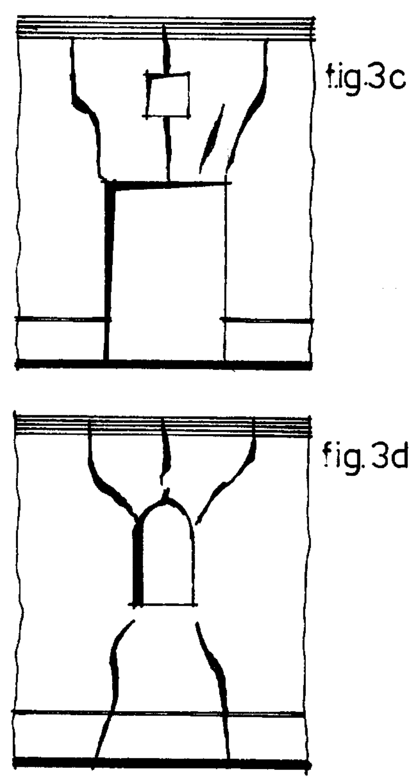


FIG. 3

DAMAGE MECHANISM OF LATERAL APSES



FRACTURES IN AREAS WEAKENED BY OPENINGS



New Materials:

(a)- New Materials coming in direct contact with old materials, to achieve Perfect and Permanent bond and mechanical binding, bond being the primary factor of intimate association; this category includes: reinforced fine grout; reinforced and confined coarse grout; cement milk for grouting in massifs, away from painted surfaces; lime milk for completion of enclaves and grouting in massifs; calcium caseinate, used in contact with painted surfaces.

(b)- New Materials used strictly in zones where the contact new/old is not so important: plain concrete and common RC, ductile steel(round bars or shapes), composite steel RC.

Table 2. Mix Proportion of main bonding materials

Coarse grout	Fine grout	Calcium Caseinate (CC)
1 part Portland Cement 2.5 p Coarse Sand 1.5 p Fine Gravel 0.5 p Lime Water in excess to allow placing by simple pouring	1 p Portland Cement 2.5 p Sand + very fine gravel (3-5mm) Water enough to allow bond with the Bed	CC Paste 1 p old lime 2 p fat-free cow cheese CC Mortar 2 p CC paste 3 p (or 2 p) sand

CHOICE OF STRUCTURES. SPECIFIC DETAILS

Basic Concept

The consolidation concept introduces in the mass of the existing structure a new skeleton, intimately embedded by Bond and mechanical Binding to the initial structure, thus obtaining a stable composite up to the ultimate stage of seismic behavior. This new spatial carcass implies a previous restoration of apparent continuity of old materials, the introduction of a macro-structure in the roof and upper part of the monument, a supplementary infra-structure associated with the existing one, a system of embedded vertical members connecting the two macro-structures and some embedded horizontal spandrels. A distinct problem refers to strengthening and anchoring the towers to the main church structure.

Existing Congenital Seismic Sensitiveness to be mastered

Main Seismic Sensitiveness are: excessive brittleness of old masonry, i.e. their very small capacity for post elastic adaptation, except by brittle fracture and dry friction along fracture lines; the existence of frequent openings, the percentage of which sometimes exceed 20% of the wall area; low strength of old masonry in direct shear, in tension, along normal and inclined sections; scarce transverse structural walls, to achieve the large space required by the specifics of Orthodox Church architecture; the presence of important prominences(towers, etc.); asymmetric arrangement of masses, generating seismic torsion.

Restoration of Apparent Continuity in the old Material

Solutions: bonding-in with cement mortar of inert masonry, using old-type bricks or blocks of stone of a related quality with the initial ones; grouting of cracks with cement milk, except in painting areas; grouting of wide cracks, dislocations or gaps, with lime milk with sand added, in painted areas; fine cracks grouting with fluid calcium caseinate paste; filling of wide cracks with calcium caseinate mortar; fields of X cramps in dislocated-grouted areas; spatial Mending of grouted dislocations with steel incisions; completion of large dislocations with reinforced Filons of coarse grout. Note: Painters-restaurateurs recommend calcium caseinate as an excellent barrier against migration of salt in cement milk.

THE ASEISMIC SPATIAL SKELETON-ESS-CASINGS

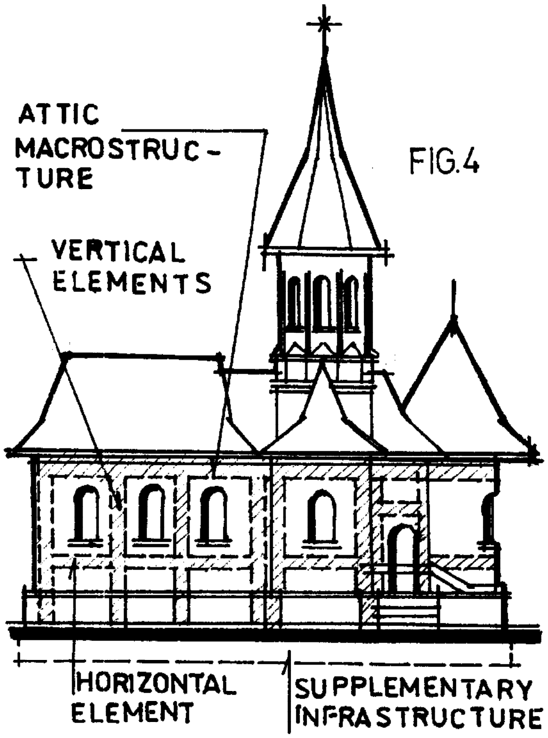
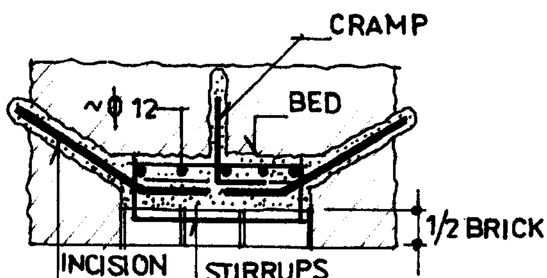
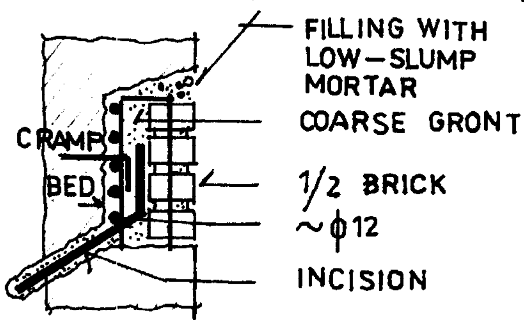


FIG.4

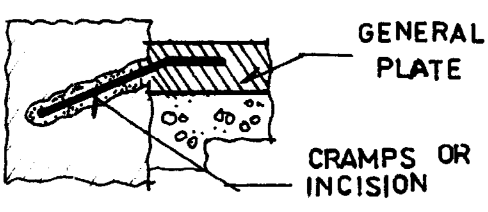
VERTICAL ELEMENT fig.6a



HORIZONTAL ELEMENT fig.6b



GENERAL PLATE fig.7a

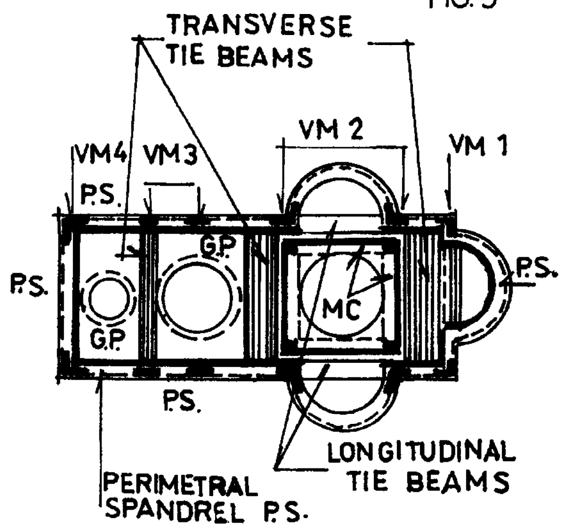


THE ATTIC MACROSTRUCTURE

M.C. = MAJOR CASING OF THE SQUARE BASE

G.P. = GENERALE PLATE

FIG.5



VERTICAL MEMBERS

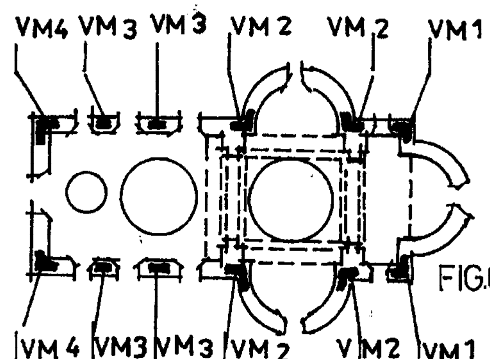
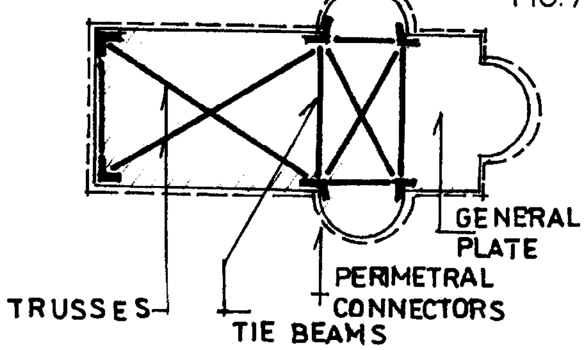


FIG.6

INSIDE INTERVENTION TO THE INFRASTRUCTURE IN THE CASE OF LESSOID OR SLIDING FOUNDATION SOILS

FIG.7



The Embedded Aseismic Spatial Skeleton(ESS).

This is a Skeleton, intimately embedded by natural bonding of grouts and mechanical binding in the existing structure; such ESS ensures: stopping of the LGD/TRD(Fig.4) and the increase of lateral strength, ductility in the energy sense and stability to cyclic degradation.

The Components of an ESS are: a Macro-structure in the roof-attic, a supplementary Infra-structure, a system of Vertical Members and Horizontal Spandrels.

The Attic Macro-structure: a perimetral spandrel; transverse tie-beams; tensile rings at the base of the naos tower(Fig.5). All those components are associated in a single structure of horizontal and vertical rigidity; a true framed shear-wall diaphragm.

The Supplementary Infra-structure is necessary in the following cases: when the foundation system presents major damaged; when the soil is exposed to sliding; when the soil is sensitive to wetting(loessoid soil, frequent in Romania). When possible, the intervention may be carried out both on inside and outside. In the interior, the floor mat is transformed in a system with great horizontal stiffnes; in the exterior, the intervention should be gradually stepped from case to case: a simple perimetral spandrel of RC, a Vierendeel system of RC, a massive bulwark to confine the whole perimeter (Fig. 7, 7a).

The two Macro-structures described above are associated in the frame of ESS by a system on embedded vertical members, placed in vital points of the church body(the inside corner of the abscess, corners, the separation of the entrance and nortex, etc.). The embedding is obtained: by use of reinforced coarse grout, incisions or big cramps, stirrups and external masonry of the original nature. The ESS, vertical members play the role of some macro-stirrups of the corbel type(Fig. 6, 6a).

In the case of Tall Churches, with narrow openings, some intermediate embedded spandrels should be introduced(Fig. 6b).

Strengthening and Anchoring of Towers.

The classical tower consists of 8-12 slender pillars terminated at the top with a painted dome. The original solutions applied involves 8-12 looped bars, anchored with deep incisions, confined with spiral wire and enrobed in coarse grout.

Note. The minimal bond strength between grouts and old matter obtained on real specimens was 20 kg/cm^2 (200 T/m^2); a true index of permanence and durability in time.

IN LIEU OF CONCLUSIONS

The strengthening and restoration of monuments, damaged by systematically repeated strong earthquakes in Romania, constitutes a specific and independent technical endeavor, and has practically no connection with a similar approach being carried out on monuments in a predominantly gravitational field of nature forces. For this reasons Article 10 of the Venice Chart should be considered as a fundamental document for special environments.

The authors wish to emphasize the vision, the unlimited trust as well as the moral and material support in the field, from the Orthodox Church and the Romano-Catholic Church in Romania, for which they want to render their deepest thanks.

To this work contributed Mr. Vlastar Apostolescu, Dan Baciu and Mrs. Ana-Maria Tenea, for which the authors also direct their thanks.