Zeitschrift: IABSE reports of the working commissions = Rapports des commissions de travail AIPC = IVBH Berichte der Arbeitskommissionen

Band: 30 (1978)

Artikel: Structural repair of monumental masonry buildings

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DOI: https://doi.org/10.5169/seals-24173

IABSE / ISMES — SEMINAR ON CONSTRUCTIONS IN SEISMIC ZONES
Session: Repairs and reconstruction of the structures

STRUCTURAL REPAIR OF MONUMENTAL MASONRY BUILDINGS

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SUMMARY.
This report deals with some structural repairs performed on monumental and historical buildings in the Marche district (Italy). The structural repairs deal particularly with floors, masonry walls, foundations, arches, vaults and domes.

RESUME. RESTAURATION STRUCTURALE SUR DES BATIMENTS MONUMENTALS
Dans cette communication sont illustrées quelques techniciens de restauration structurale réalisée sur des bâtiments monumentals de la région Marche. En particuler les interventions concernent: les planchers, les murs, les fondations, les arcs, les voutes et les dômes.

ZUSAMMENFASSUNG. STRUKTURALE RESTAURATION VON MONUMENTAL GEBÄUDEN - In dieser pubblikation werden einige technische Restaurations arbeiten an Monumental gebäuden - insbesondere an Decken, Maüern, Fundamenten, Bögen, Gewölben und Kuppeln - erläutert.

1. INTRODUCTION

The repair and strenghthening of a masonry construction damaged by an earthquake have the intention of restoring the building to the previous service and, at the same time, to assure the resistance of the whole and of each part against seismic forces of fixed intensity.

This report deals with some structural repairs performed on monumental and historical buildings in the Marche district (Italy).

The general criteria and some specific techniques of structural repairs against earthquake are emphasized. At the same time the remarkable difficulties that arise when dealing with very old and sometimes crumpling buildings are pointed out. We underline the difficulties of having to work in the presence of imposed structural solutions, patterns and technologies associated with dimensional problems which imposed the employment of the tools as well as the mobility of the workmen and, sometimes, the type of reinforcement.

2. GENERAL CRITERIA OF STRUCTURAL REPAIR

The chosen structural repair techniques are founded on the employment of concrete with ordinary tensile strength reinforcing or prestressing steel and fundamentally result in microsewing, binding, bracing, cages, etc. . In special cases steel frameworks and lattices mashed in a suitable way are employed.

The architectonic requirement of preserving, almost everywhere, the original patterns of the skin-walls of the enclosures and the partitions, has prevented the choice of repairing the structure by covering the masonry.

However, the remarkable geometrical consistency of the structures, typical for the buildings under consideration, has allowed us to obtain the reinforcement of the masonry making use of the hollow spaces. In this manner a repair that leaves all cultural values of the building unaltered in obtained.

3. EXAMPLES OF STRUCTURAL REPAIRS

3.1 Foundations

When a change of the foundation ground associated with reduced consistency in the foundation masonry due to the mortar alteration is verified, it is sometimes found necessary to use vertically-inclined micropoles in a fan-shaped arrangement in order to affect a wide area of ground. At this stage the problems connected with the interaction ground-foundation should obviously be taken into account.

These micropoles should be drilled with machines of moderate dimensions which are able to be introduced easily in closed spaces through normal openings and which have no height problems.

The micropoles diameter, range $8 \div 14$ cm, can be variable (as a spyglass) while the length is connected with the stress-working values of the ground and obviously limited by the highest allowable loads for each diameter.

After the arrangement of the reinforcement with steel bars, the casting takes place with a mortar injection under pressure so that an improvement of the foundation masonry is obtained too.

In the foundation the manufacture of the reinforced concrete lintols in made with full cuts of the masonry for a height equal to that of the lintol to be inserted. During such a stage the overhanging wall is supported with casting-embodied steel jacks provided with a screw and put into action with a torque wrench in order to check the applied stresses. Then dihedral-shaped formwork is applied to facilitate the performance of the casting. Finally the filling up of the whole space is obtained with pressurising starting from the top making use of suitable vibrators.

During these works there aren't any structural movements, in contrast to the traditional arrangements of lintol erecting done step-by-step without any supports.

3.2 Masonry walls

The masonry mesh with bearing functions, of closed quadrilateral shape possibly regular and balanced is selected in the plan of the building. Then it is propped up with a vertical and horizontal reinforcing mesh using prestressed concrete tendons.

The perforation performed by rotation is obtained with a hydraulic engine working to a low number of revolutions in order to avoid excessive vibrations that are harmful for the masonry. The hydraulic engine is of limited dimensions so that it is possible to arrange a remarkable handling of the drill and there is the possibility of working to different heights placing the oil-dynamic station on the soil level. Therefore the transmission of the fluid takes place with rubber pipes over ten metres in length. The holes, $5 \div 6$ cm in diameter, are made up to 50 m long and with any position.

Then the tendons for prestressed concrete are inserted into the hole. These tendons are prestressed or protected by an oiled plastic sheath inside and afterwards post-tensioned.

In this latter case the steel of the unbounded tendons is protected against the oxidization independently of the external mortar injection reliability. Moreover it is possible to perform the post-tensioning after the external mortar injection and therefore when the masonry has stiffened.

Additives are added to the mortar to prevent shrinkage.

In this manner a local improvement of the crossing masonry is obtained. In fact the fluid mortar saturates the exsistent spaces between the constitutive elements and the wide hollows unfortunately always present in this particular type of stone masonry.

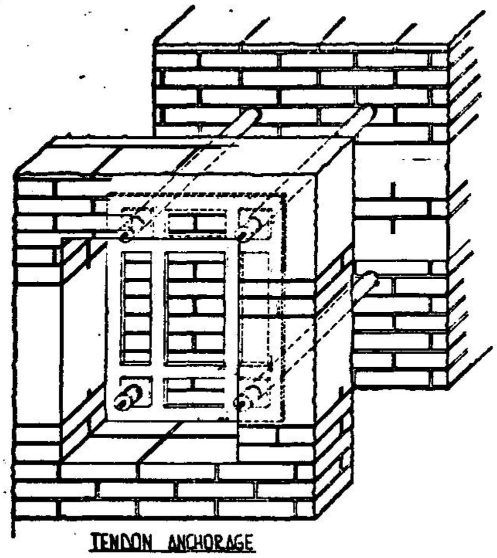

Fig. 1

In order to have a hooped lintol (fig. 1), sewings with a group of four tendons are arranged. Before the tensioning the tendons of the group are stirruped with Ø 12 ÷ 14 welded crop-ends, with 150 ÷ 200 cm centres. These stirrups join in a whole the four tendons and play the important role of preventing the transverse vibrations that any tendon may exhibit following the sudden tensile stresses produced by earthquake shock effects.

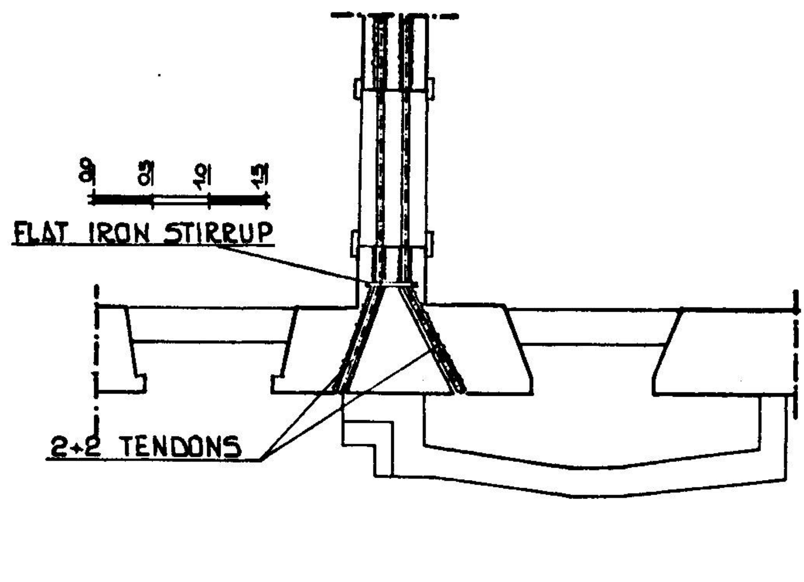

Fig. 2

There is the possibility of changing the direction of the four tendons locally on the condition that the axial simmetry is respected. Particularly the solution of fig. 2 is feasible when a structural element lies in the area of the anchorage of the tendons.

The intersection of bearing walls is propped up with a column-shaped vertical reinforcement firstly to improve the area of the crossing of the level lintols, secondly to effect a better connection between the different floors and finally to inject mortar with additives into the masonry.

In this case the reinforcements are generally made by deformed steel bars which are stirruped every 50 + 60 cm, in the same a way as the lintols.

Repair or anchorage microsewing is arranged on the masonry and on the masonry cornices or friezes where necessary.

The holes, made by chrifters with a drill range 2 + 3 cm, are filled under pressure using mortar with additives after the insertion of deformed steel bars of Ø 6 + 8. These microsewings are efficacious for stone masonry and particularly the connection of a masonry wall with brick masonry.

Sometimes and for small length (50 + 100 cm) the steel bars are replaced by brass threaded ones in order to avoid a possible attack by atmospheric agents.

Finally it makes use sometimes of tendons, each of them running into the masonry wall alternatively crossing from one face to another (fig. 3). The following results are achieved:

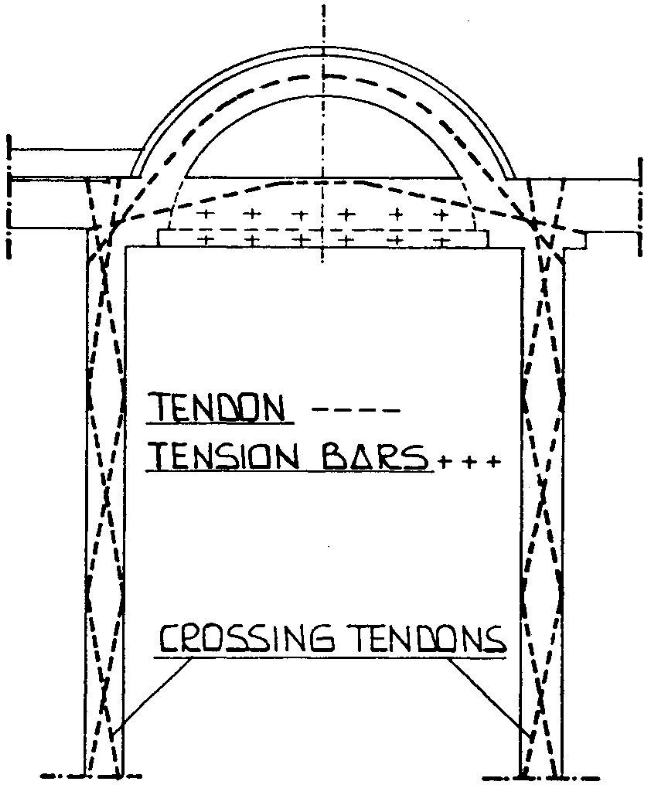

Fig. 3

- a greater setting on the skin-masonry;
- a smaller fatigue of the masonry during the drilling stage;
- a hopping effect of the masonry core;
- the possibility of erecting the lintols with prestressed tendons on walls which are not rectilinear.

3.3 Floors

In structural repairs which require radical change, cast-in-situ partially prestressed floor joists with clay-blocks are chosen. In these cases the question is to make suitable correlations between the floors and the walls.

In the place of the pre-existing wood beam butts, the complete cutting of the masonry to receive a standard reinforced concrete lintol is performed step by step. In the same way as the structural repair to the foundation, during the cutting stage the masonry is supported with casting-embodied jack made by two steel plates connected with a height adjusting rod (fig. 4).

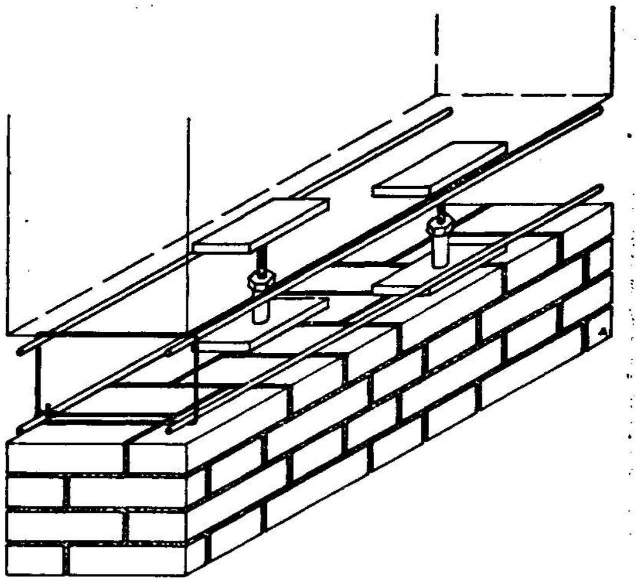

Fig. 4

The casting in done as far as the extrados plane of the slab, then an inclined formwork is arranged for the concrete filling of the hollow that is still in the masonry. This latter part of the casting must be pressurised, carefully vibrated and done using mortar with additives.

3.4 Arches and vaults

The old bracing systems or those which use the ties placed on the extrados, above the crow section so as to hide their presence, are no longer used. Both these devices reduce but do not cancel the harmful effects of the drifts specially when used for rather splender abutments.

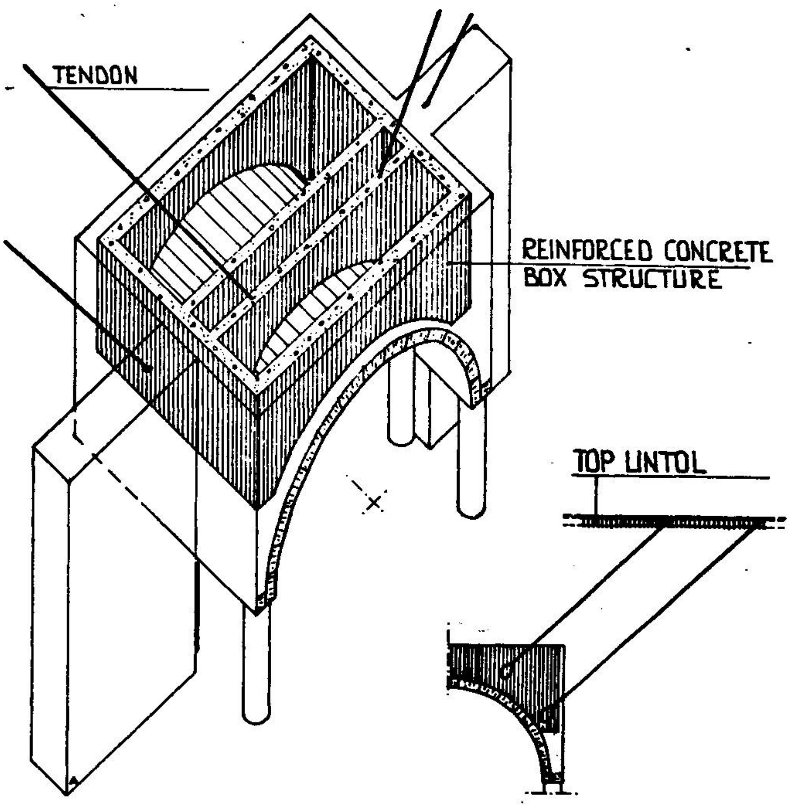

Fig. 5

It is pointed out that when making a repair to curved elements of historical and monumental buildings it is very difficult to find single system doing the job. This arises from the following facts: the inadmissibility of visible metallic ties imposed by aesthetic considerations; the heterogeneousness of the structural performances of the elements to be repaired; the generally limited space available above the extrados; finally, the inconsistency of the support points.

Therefore several structural repair patterns are employed. The following appear as most meaningful.

When enough space at the extrados of the arch to be repaired is available a reinforced concrete box-structure is arranged in the inner part of the arch. Several arch quoins are jointed to this box--structure. In the case of fig. 5 the box--structure is jointed using inclined ties to the reinforced concrete lintol placed on the top of the building so as to transfer the load into the more efficient static areas.

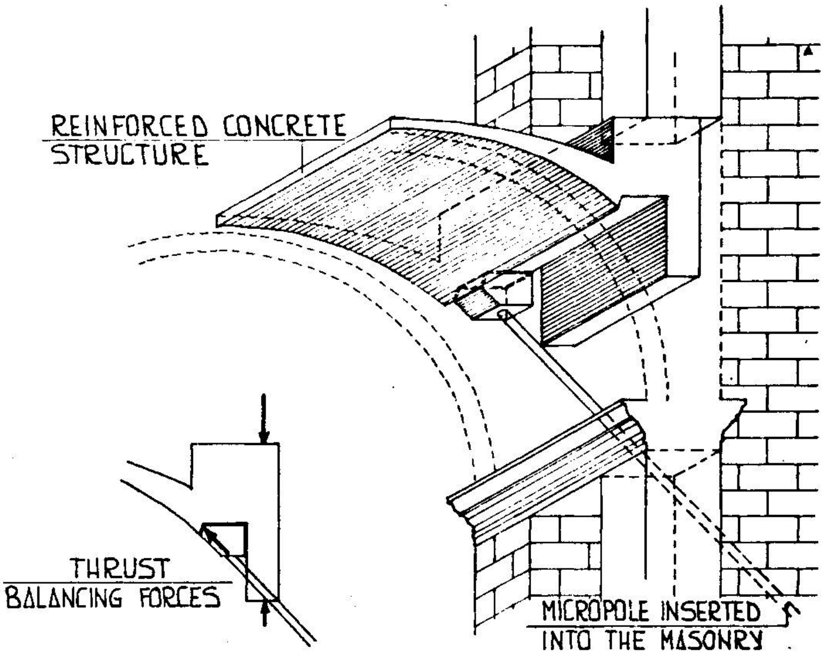

Fig. 6

In the presence of very small crown space above the extrados, a system of reinforced concrete cantilevers is arranged so as to balance the thrust of the vault, using the position of the overhanging column (fig. 6).

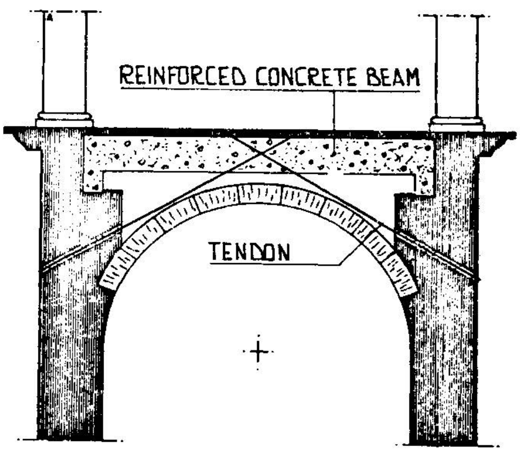

Fig. 7

Sometimes the thrust is eliminated using two inclined ties departing from the springer and anchored in the middle of a rigid reinforced concrete beam. This latter is completely indipendent of the vault and supported on the abutments of the same vault (fig 7).

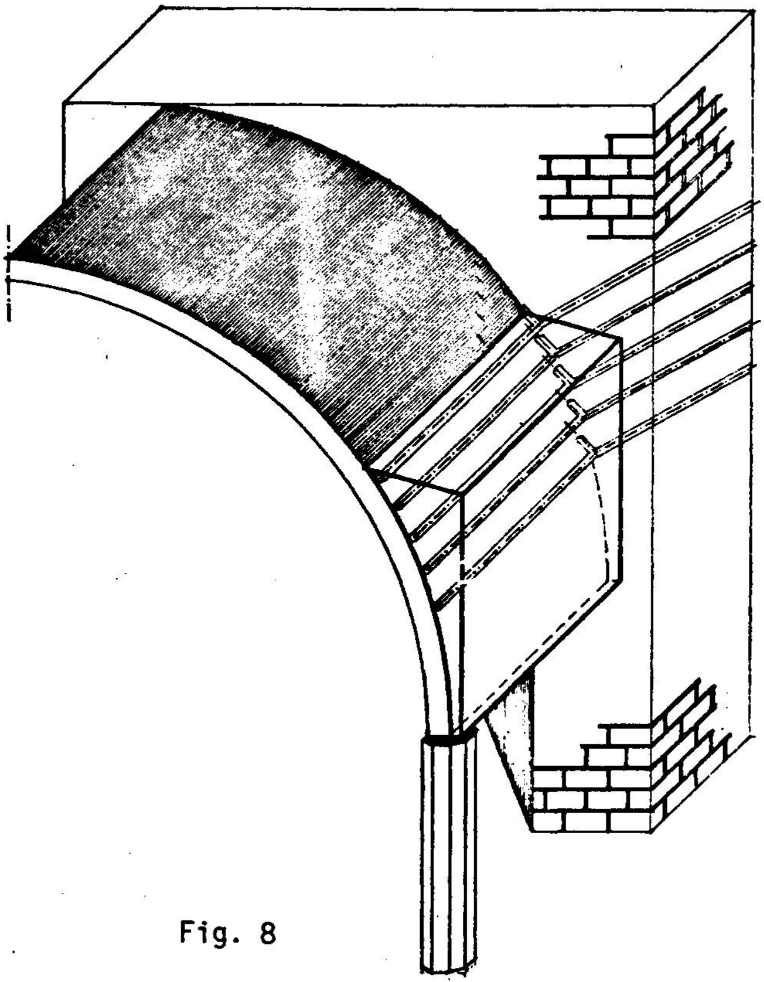

Fig. 8

Non typical structural repair performed on a ogival propless vault deserves a mention. This can be done when the above mentioned techniques and particularly the use of a tie, located in a statically ineffective position for aesthetic reasons, are impractical. In this case the springer pressures should come from two reinforced concrete cantilevers placed at the springer of the vault and arranged with sheated tendons inserted and tensioned when the casting has stiffened. The tendons fasten the cantilever to a facade--wall efficiently (fig. 8).

In the presence of a strain condition produced by an inadequate loading of the curved element (fig. 9), there should be arranged on the extrados artificial massless loads, located at a number of limited points and obtained by tendons tensioned in a suitable way and by screw-jacks embodied afterwards in a reinforced concrete lintol.

3.5 Domes

The analysis for behaviour under static loading required for the structural repair of the domes frequently indicates that the line of pressure comes out of the kernel of the cross section so that, specially near the vertex there arise strained zones. These latter in the primary structural idea, are reduced (never cancelled) by the masonry turrets. Obviously such a device is not feasible as a structural repair especially to hold the entity of the masses which come into play.

Therefore live stresses are to be balanced with the artificial massless loads.

Actually a steel inner-dome made by two elements separated by a joint is arranged. An element is jointed at the bottom to a prestressed concrete ring, the other one is jointed at the top to the vertex of the dome. The joint allows thermal expansions and deformation changes due to shrinkage.

Then a set of steel cables, departing from the top of the dome and separated from the masonry by a truss, loads only the end side of the dome as far as it is necessary for the equilibrium while a forces system which contributes to place the line of pressure in the centre is arranged (fig. 10).

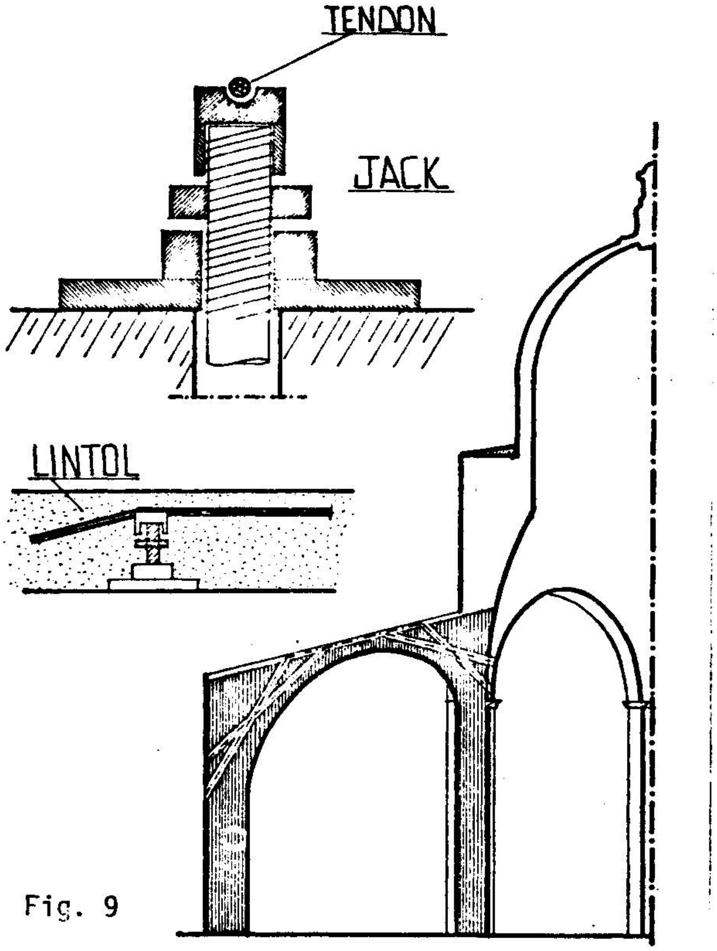

Fig. 9

4. CONCLUSIONS

The illustrated structural repairs have been studied so the strengthening structure, as prestressed, is able to collaborate with the

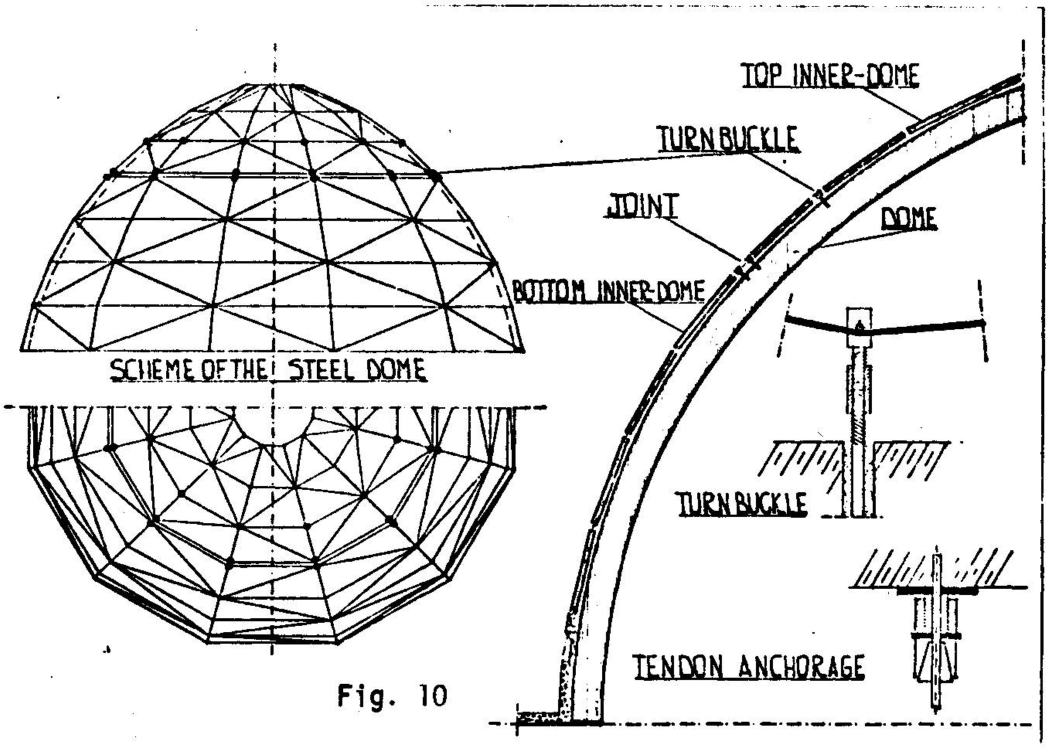

Fig. 10

existant stoneworks right from the beginning.

In this manner structural movements, which are particularly harmful for the masonry structures are avoided.

The architectonic value of the repaired buildings associated with their usage features require non-typical structural repairs generally independent of the costs involved, but carried out to respect and to preserve above all the greatness of the building and, at the same time, to improve its earthquake resistance.