Restoration of Capella da Nossa Senhora do Monte Old Goa

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1. ABSTRACT

The paper presents concepts, methods and details adopted for the restoration of the Capella da Nossa Senhora Do Monte at Old Goa, India as a case study. Capella da Nossa Senhora Do Monte is an early 16th century chapel built by the Portuguese in Old Goa, using laterite stone. The major structural problem was the development of longitudinal cracks at the crown and quarter points in the 21m long vault over the nave. Rehabilitation works involved foundation strengthening, placing 50mm diameter stainless steel ties at intervals, stitching and grouting. The work posed challenges in terms of design of appropriate specifications for plasters, waterproofing materials, lime grouts, mortars, and stitches for specific repairs. The structural solutions and repairs were guided by conservation / architectural requirements and adhered to the principles of minimum intervention, as also use of 'original' materials, as far as possible.

2. LOCATION AND DESCRIPTION OF THE CHAPEL

Capella Da Nossa Senhora do Monte is one of the first churches built by the Portuguese in Old Goa in the 16th Century. This Mannerist style chapel is perched on a small hillock overlooking the Mandovi River, and commands a spectacular view. The approach to the Church is by means of a series of laterite steps cut into the south side of the hillock as seen in Fig.1

'The Capella', can hardly be called a chapel as it is about 33m long and 14m in width, built entirely using laterite stone as a material of construction. Laterite is a derivative rock (secondary rock), a product of weathering of basalt. After weathering for a long time many residual materials get removed leaving behind harder elements like iron and aluminium hydroxides etc. This results in giving laterite its 'sponge – like' look.

Figure 1: View of the Capella De Monte from the South West.

The chapel walls are about 2.7m thick supporting the roof of the nave, which is a barrel vault with a clear span of 9m width and 21m length. The roof of the altar is another vault with a clear span of 5.5m. Both these vaults are covered over by a roof of timber construction resting on laterite pedestals built on top of the vault profile. The roof framework is clad with locally available tiles called, 'Mangalore tiles'. The vault profile also has been constructed using laterite stone and is only 150mm thick at the crown. A number of additions have been made to the church since it was first built. One of the oldest additions is the two storeyed loggia built by the side and attached to the northern wall of the church. Some extensions had also been made to the northeastern end and the eastern face behind the altar.

Figure 2: Interior view of the Nave vault – showing the crack

3. SETTING UP THE TECHNICAL TEAM

Around 1980 it was noticed that the vault had developed a crack in the longitudinal direction. Over time this crack widened causing dislocation of some of the laterite stones and two or three of them separated and fell to the ground. Timely temporary propping of the vault prevented further collapse as seen in Fig.2. It was in this condition that the local parish approached the Fundação Oriente, a Portuguese cultural trust to take up the restoration works. The Fundação Oriente appointed me as the technical director and project responsible after having contacted IPPAR.. Locally, conservation architects (Bombay Collaborative) in association with structural engineers (Sewri Consultants) were commissioned to form a complete technical team to plan and execute the restoration work.

4. PHILOSOPHY OF RESTORATION AND APPROACH STRATEGY

Considering the fact that this was a 16th century monument and was one of the Goa State Archaeological sites, the approach towards its restoration was that of minimum intervention to the old fabric of the church as also a conscious approach of using reversible methods for all new interventions. Special efforts were made to try and match the materials used in the restoration work to the original materials used in its construction. Nevertheless, the use of new materials was not rejected, on the contrary they were regarded since the beginning as important aids.

5. CONDITION OF THE CHURCH

The monument became a topic for discussion and finally a subject for undertaking restoration work when a longitudinal crack (A) as seen in the Fig.3 was noticed. This crack extended longitudinally throughout the length of the vault. The other cracks, at the quarter points of the arch of the vault (B) were also clearly visible. These were seen as hairline cracks from the inner side, whereas the stone had clearly separated at the outer surface, i.e. the barrel arch had developed a central longitudinal crack, where the inner face (interados) was in tension and outer face (exterados) was in compression. In the case of the longitudinal cracks along the quarter points of the barrel vault, however, the interados were in compression and the exterados were in tension. As a result of this cracking pattern, the entire vault was in structural distress. Strengthening and rehabilitation of the vault was one of the main structural design problems to be tackled.

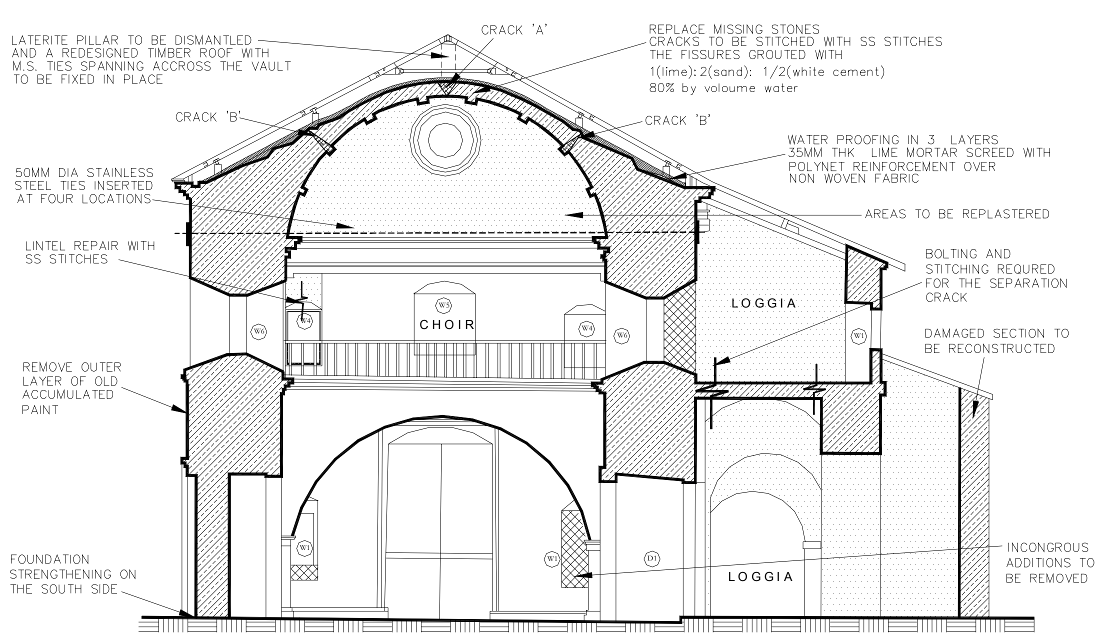

Figure 3: Section showing the cracking of vault schematically and all the other Structurally distressed areas

The other structural distress areas are enumerated below:

It was noticed that the south wall was out of plumb by nearly 100mm.

The gable ends on either side of the nave had separated.

The lintels of the windows on the west façade had cracked due to a lateral crack running across the façade.

The Loggia, which was a later addition, showed signs of separation from the main building.

The restoration works had to address all the issues listed above, (as seen in Fig. 3).

6. REASONS FOR THE STRUCTURAL DISTRESS

From all the signs of structural distress it was clear that there had been some movement caused to the foundations. The exact reason why this had occurred could not be ascertained. The reason for this foundation movement could be settlement of foundations, deterioration of laterite rock used as the material of construction in the foundation work over a period of time, or even effects of earthquake tremors. Sliding of the hillock slope as a possible reason was examined but discarded, as no distress was seen in the laterite steps leading to the Chapel. In any case, if such a phenomenon had occurred, the slope of the hill must have achieved its residual angle over a period of the last 450 years. Be that as it may, the wall had lost its plumb for one of the reasons cited above and the vault had consequently opened like a cracked nut. The structural rehabilitation of the vault therefore meant, initially the foundations had to be strengthened, before the other structural restoration works were undertaken.

7. RESTORATION WORK

Having identified the areas of structural distress, structural engineering design solutions compatible with conservation principles and techniques, had to be evolved for the individual components of the Chapel as listed below:

- Foundation strengthening of the south wall as well as north side buttresses of the Chapel
- Structural consolidation of the vault over the nave and the altar
- Ties for strengthening of the vault
- Structural consolidation of the cracks in lintels, separation cracks between the vault and the gable ends and between the nave and the loggia, by means of stitching and bolting
- Designing appropriate grouts, plasters and mortars to match the old grouts, plasters and mortars
- Re-design of roof over the vault, to minimize vibratory loads on the vault profile.

7.1 Foundation strengthening south wall as well as north side buttresses

The design concept to strengthen and buttress the existing foundations was to add extra mass by the side of the existing foundation, attach the new mass to the old foundation by means of S.S, anchor bolts and ties and create a foundation system, such that the entire foundation does not move laterally. As far as vertical settlement of the Chapel wall is concerned, it was assumed that since the foundation has been constructed on laterite rock of the hillock, vertical settlement is not the main issue and whatever vertical settlement was to take place, has already occurred. Adopting a cautious approach underpinning of the existing foundation was thus not attempted. The original laterite rock, of which the foundation was constructed, appeared to be fairly intact and had not crushed or deteriorated over time. In keeping with this design philosophy, the foundation design system as seen in Fig. 4 was adopted for the south wall. A similar system was adopted for the two buttresses on the north wall.

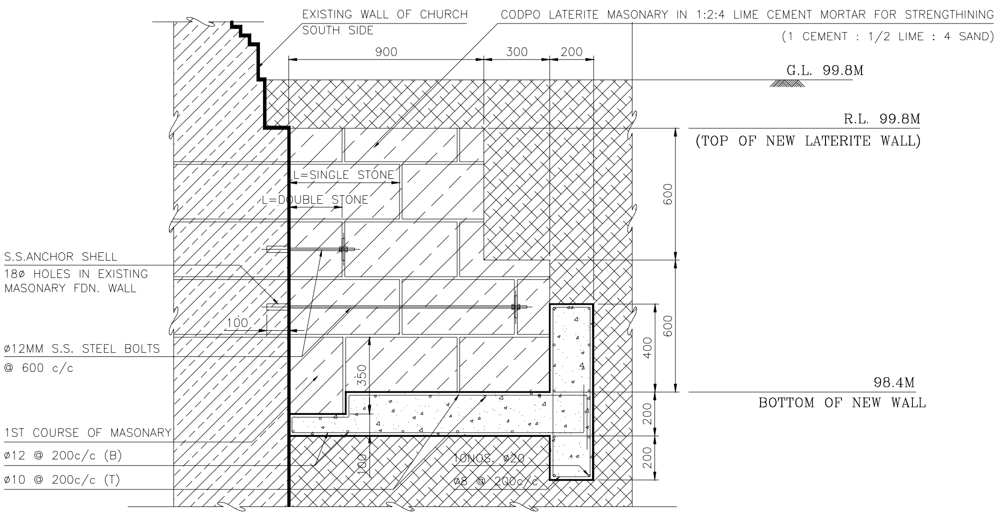

Figure 4: Drawing showing the foundation strengthening detail wall.

7.2 Structural Consolidation Of The Vault

Fig. 5 shows the temporary supporting system designed to support the vault during the process of vault structural consolidation. The system consists of structural steel trestles, on which structural steel arch trusses were erected. The trusses had a provision for attaching, adjustable stirrup head jacks in which timber scantlings, could be placed. These timber scantlings supported plywood formwork plates. Between the vault underface and the plywood formwork plates was sandwiched a layer of 100mm thick foam. The stirrup head jacks were adjusted so that the plywood formwork plates supported the load of the vault surface, with the foam sandwiched in between. The reason for introducing the foam layer, was to ensure that the offsets of the coffers on the underside of the vault, are not damaged.

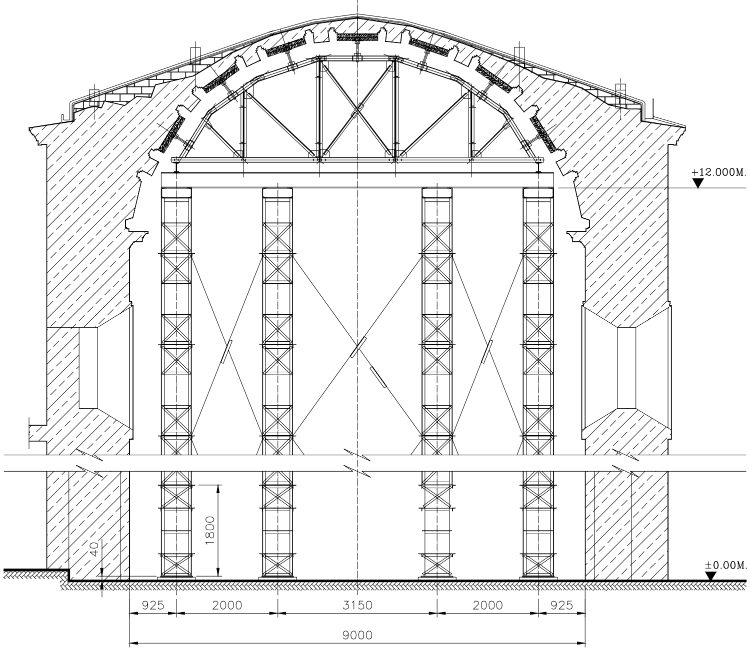

Figure 5: Drawing showing the temporary supporting system

With the vault firmly supported, the next step was to grout and stitch the cracks from above. To achieve this, the entire timber roof above the vault was dismantled and the upper surface of the vault exposed as seen in Fig. 6. The exterior surface of the vault was cleaned and the cracks were located and exposed. It was observed that the cracks ranged from 20mm to 50mm in width. The first step was to refix the dislocated stones. Then the cracks in the vault and the portion which had separated from the gable walls were stitched, with the use of stainless steel stitches. (The various types of stainless steel stitches used in this rehabilitation work are described later in the paper.) Subsequently a pointing mix of [1 part lime: 3 parts sand + 5% Acrylic resin] was used to fill the cracks.

Having restored the vault to this extent, further strengthening was carried out by means of general overall grouting of the vault surface / profile by means of drilling holes, fixing an appropriate nipple and attaching a grout feeder pipe to pass the grout into the main body of the vault. Various mixes of the grout were experimented and tested earlier in the laboratory and later verified for site conditions by means of field tests, before being adopted for work at site. The grout mix finally used was [1 part lime: 2 part sand passing 600 microns: ½ part white cement: 80% water by volume (Unit volume = lime + sand + white cement)] The grouting operation was carried out under a very low gravity feed pressure (maximum 0.1N/mm2). The entire vault consumed nearly 5m3 of grout. After the consolidation of the vault it was necessary to load it with the appropriate weight. In that order, a sandwich of the following materials was executed:

- 50mm thick lime mortar (thicker where there were depressions
- geotextile (non-woven fabric)

- 50mm thick lime mortar [1part lime: 3 parts sand]
- fiber mesh with 3mm thick epoxy resin

Figure 6: Photograph showing the vault surface when exposed with the timber roof dismantled

7.3 Ties for Strengthening of the Vault

While this process was in progress, four horizontal holes were drilled through the 2.7m thick north and south walls exactly opposite each other, to place stainless steel ties as tension members, to prevent any lateral movement of the walls. The detailed design of the S.S. ties is shown in Fig. 7.

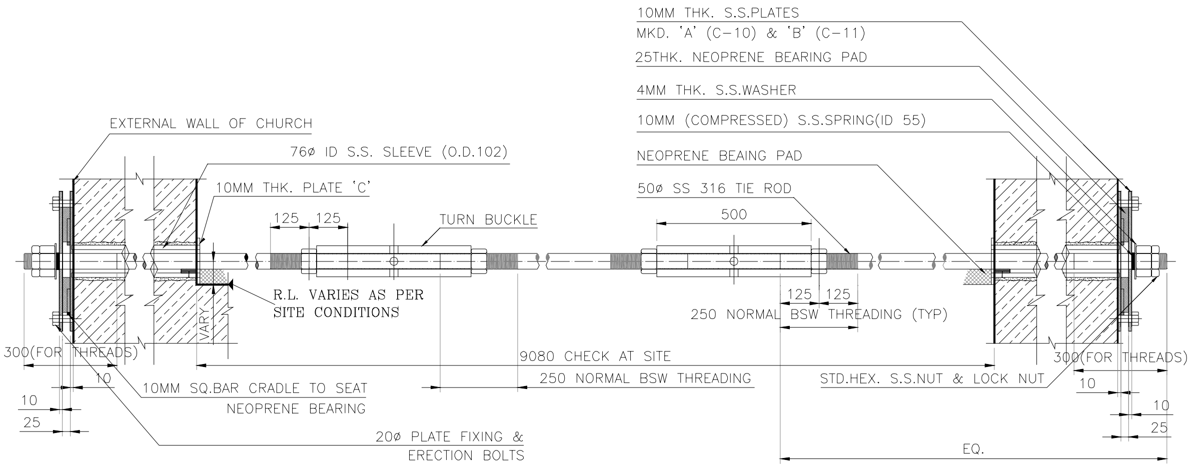

Figure 7: Detail of the ties

The ties mainly consist of a stainless steel bolt SS 316, 50mm in diameter in three parts joined by two intermediate turnbuckles. The holes drilled, were lined by a stainless steel pipe 6mm thick as a liner. The ends of the ties abutted against the wall face by means of two stainless steel plates 8mm thick, with neoprene bearing pads as a sandwich layer. The neoprene pads were placed to permit slight movement in the system / bolt, that might occur due to difference in temperature, or lateral forces like earthquake tremors etc. The end of the bolt was anchored by means of a hexagonal nut, tightened till refusal and followed by a lock nut. The entire bolt / tie assembly is as erected and placed under the vault is shown in detail in Fig. 8.

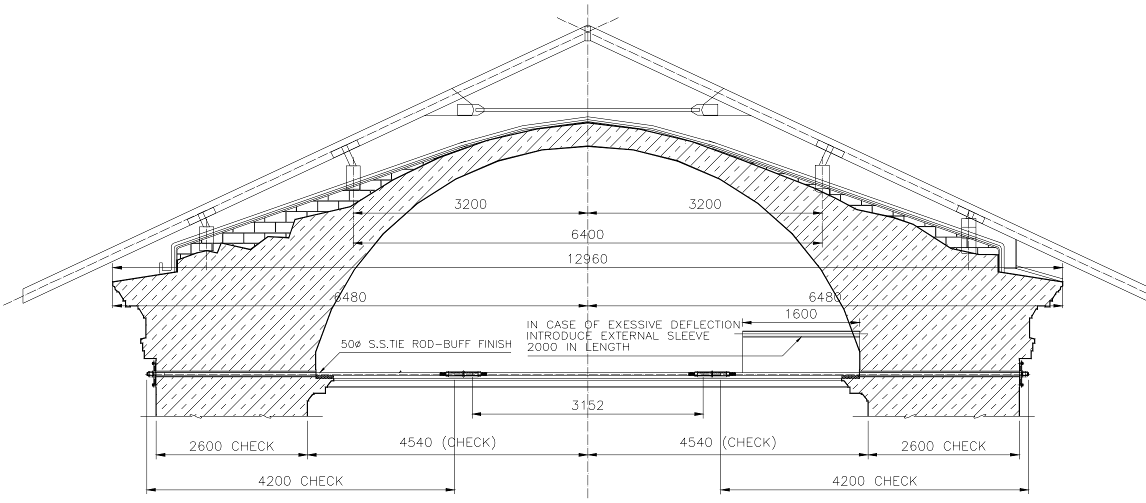

Figure 8: Entire S.S. Tie Assembly as erected and placed under the vault

Four such ties were placed in the entire vault, at convenient locations as seen in the key diagram as shown in Fig. 9.

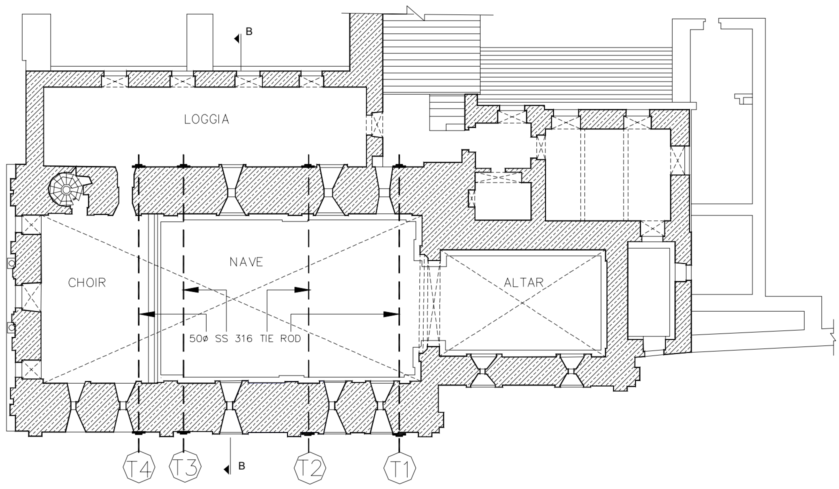

Figure 9: Key plan showing location of the ties

7.4 Consolidation of the cracks in lintels, between vault profile and gable ends and loggia, by means of stitching and bolting

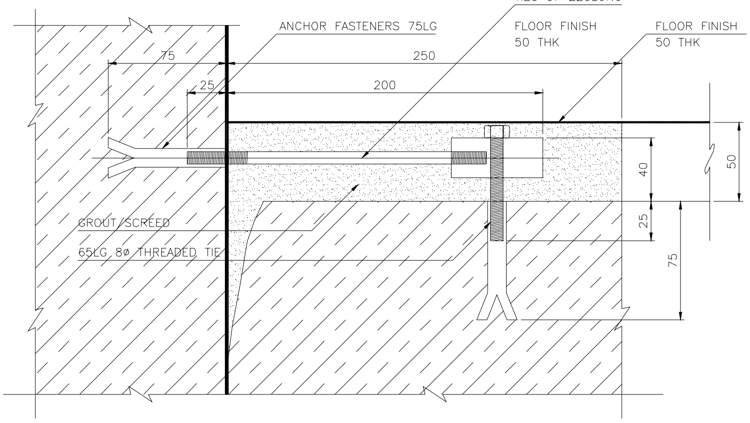

Figure 10: Detail of stitch between a vertical wall and the Horizontal plane

Different stitches were designed for appropriate locations, as required. The stitch as shown in Fig. 10 was necessary where the vertical walls and the horizontal planes of the vault or the floor slab had separated. This had occurred where later additions like the loggia had separated from the main Chapel. Due to the movement in the foundations the gable walls showed signs of separating from the vault profile.

To describe the stitch, an anchor fastener is placed in a vertical wall and a tie is screwed in to it. The end of the tie has a flat plate with an eyehole drilled into it. An anchor fastener is then drilled in to the horizontal surface in alignment with the eyehole of the flat plate. A vertical tie is now threaded through the eyehole and a nut is tightened on the faceplate by means of a hexagonal nut. Thus a vertical surface gets anchored to a horizontal surface.

7.5 Designing Grouts, Plasters and Mortars

Considerable amount of laboratory testing (sieve analysis, particle size distribution, angle of repose etc.) was conducted on the locally available sand before arriving at the various mixes for grouts, plasters and mortars. In the case of the grout its viscosity was also tested to arrive at a mix that would flow easily. In all cases, the original samples of plaster, mortar etc. were analysed for their composition, and new samples were tested in the laboratory to arrive at a similar match. The site was instructed to conduct field tests to ensure the suitability of the mixes specified. The tables below show mixes for grouts plasters and mortars finalised.

Table 1 : Grouts

Mark No	Lime	Sand passing 600 microns	White Cement	Water
G 1*	1	2	1/2	80% by volume
G2 *	1	3	-	80% by volume

* G1 was the grout mix utilised to grout the vault profile in an overall manner. To the mixing water was added a water based acrylic emulsion NAFUFIL a product of 'Bauchemie', the concentration being maximum 5% by volume.

*G2 was the grout mix utilised to grout vertical fissures and cracks.

Table 2 : Plasters

Mark No.	Lime	Sand	Additive
P 1- External Plaster	1	3 (up to 118 microns)	Nil
P 2– Internal Plaster	1	1.5	Nil

Table 3 : Pointing mortar

Lime	Sand	Laterite	Additives
1	3	-	5% acrylic resin

Maximum size of sand particle to be 0.64 mm.

Table 4 : Levelling mortars

Mark No	*Lime*	*Sand*	*Laterite*
LM 1	*1*	*1.5 (well graded)*	*1.5 large grain particles*
LM 2	*1*	*2 – well graded*	*1 – No.1 Stone Metal (max.size 10mm)*

Levelling mortars were used in areas like the vault, where the mortar was required as a filling material to correct the geometry of the profile of the vault.

7.6 Design Of The Roof Over The Vault

In the case of the original roof, the main rafters spanned from laterite pedestals placed on the crown of the vault to those on the side. Thus, vibrations induced into the roof structure due to wind load were transmitted on to the vault. While redesigning the roof framework, the laterite pedestals on the crown of the vault were eliminated and instead, a horizontal mild steel tie was introduced to span across. Thus the wind load is transmitted to the sidewalls of the Chapel which are about 2.7m thick. The barrel of the vault, hence, is protected from unnecessary vibratory loads. All nails and screws piercing the timber, are of S.S. 316 grade, to avoid any splitting of the timber due to corrosion. Fig. 8 also shows the arrangement of the timber truss forming the new roof design.

8. CONCLUSIONS

The work was of a unique nature, providing wide opportunities in conservation, engineering and architecture. The highlights of the restoration work were items such as structural-strengthening (design of SS ties, and of various types of stitches), selection of grouts, plasters and mortars and plaster conservation. Minimum intervention and as far as possible, use of original materials, remained the cardinal principles in involving the restoration designs. Respect for the historicity of the monument was kept paramount in planning the design strategy.

The intervention above described was brought to you as a typical example of a thorough conservation / rehabilitation project and also because it involved the most common applications of new materials.

In this chapel we find some of the main areas where new materials for safeguarding architectural heritage are most used:

- structural
  - SS ties, stiches
  - Fiber meshes
  - Epoxy resins
- additives
  - for mortars (acrylics)
- stone, brick, masonry and plaster treatment
  - consolidants*
  - hydro-repellents*
  - fixatives
  - resins*
  - isolations
  - stone repair*
- pest control
  - bird control*
  - insect control
  - plants control

* not used in this project

As a footnote I must refer another important field where new technologies have seen a great development which is the diagnosis methods. This is a privileged area for new technologies such as the evaluation of stress in a masonry wall or the monitoring of crack evolution. However those were not used here because they just weren’t available. We based our diagnosis in empiric methods, brainstorming and in low technology tools.