BIENNALE DEL RESTAURO ARCHITETTONICO E URBANO

PANAGIA MELANDRINA CHURCH

Structural Assessment And Design Of Emergency Repairs And Supporting Measures

BIENNIAL OF ARCHITECTURAL AND URBAN RESTORATION,

15-16-17 APRIL 2018

Famagusta Gate - Nicosia

BIENNALE DEL RESTAURO ARCHITETTONICO E URBANO

Structural Engineers

Eur. Ing. Platonas Stylianou

B.Eng. (Hons), MSc, MCS, MICE, CEng, FCIArb.

Alberto Farinola

M.Eng. (Hons) in Architectural Eng. CARDIFF,
M.Eng. in Civil Eng. NTUA

Architects

Marilia Christodoulou

Architect

Zoi Lavrentaki

Architect

* All photos and drawings are part of UNDP's Study

** The contents of this presentation are abstracts from a EU funded and UNDP commissioned study

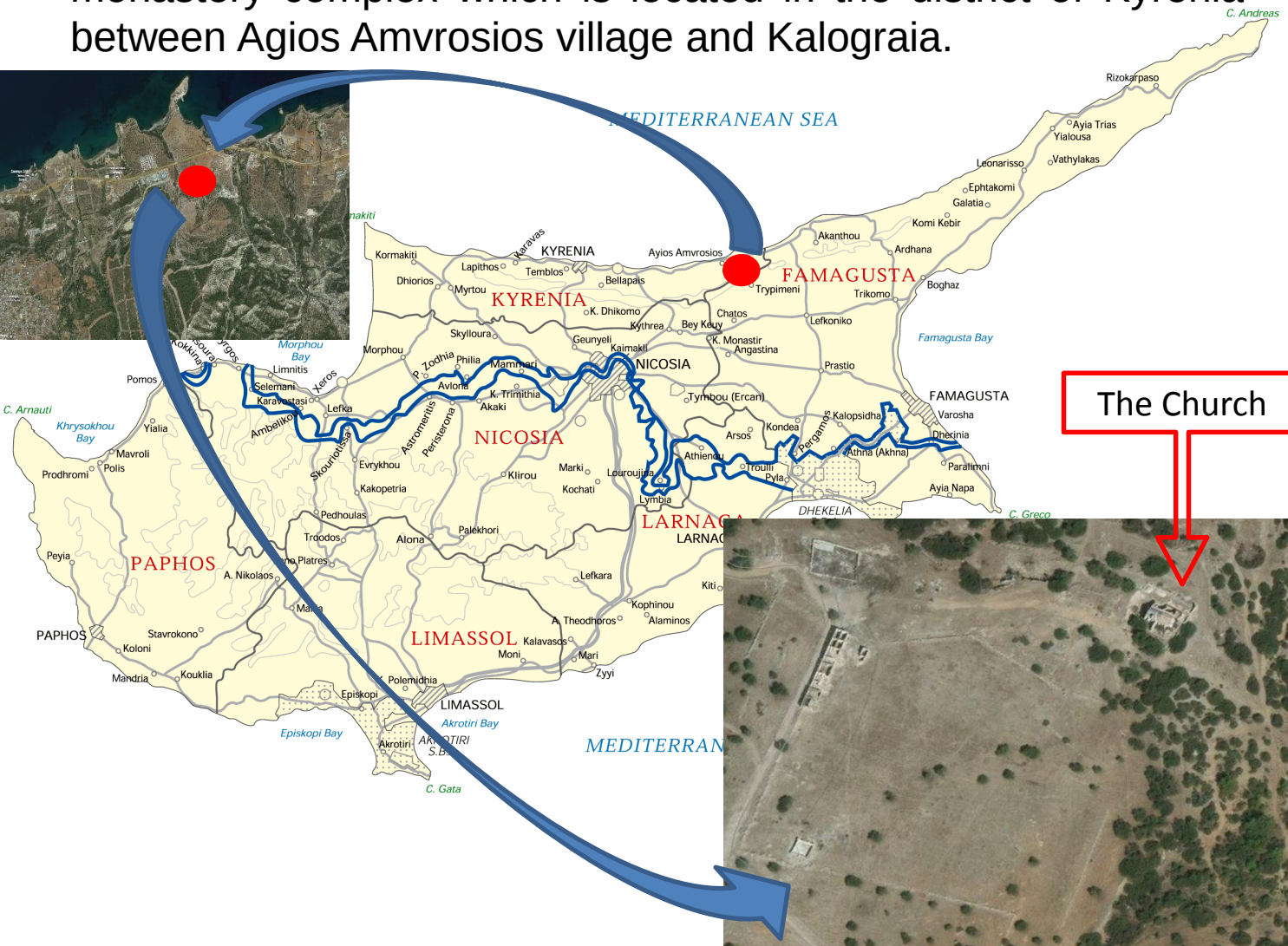
BIENNALE DEL RESTAURO ARCHITETTONICO E URBANO

* UNDP Photos

* UNDP Photos

LOCATION

- Panagia Melandrina Church is part of the Melandrina monastery complex which is located in the district of Kyrenia between Agios Amvrosios village and Kalograia.



* UNDP Photos

* UNDP Photos

OBJECTIVE

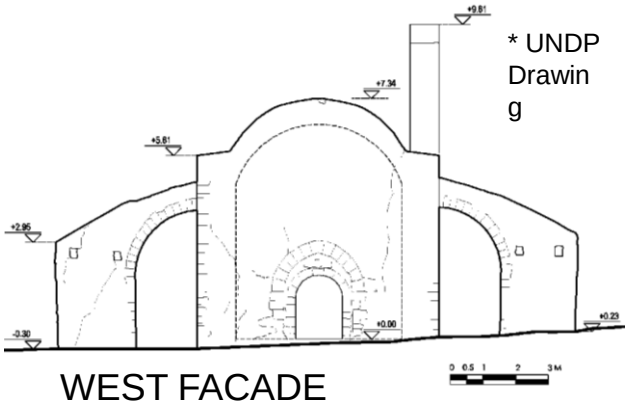
- Abandonment & lack of regular maintenance work and protection over the years are the main problems of the site.
- In 2011, a number of site inspections took place to observe & record the current condition of the structure and the site.
- Our team was responsible to investigate the structure's pathologies, assess the safety of the church and design emergency repair & supporting measures that would prevent the structure from further damage without distorting its architectural and monumental character.
- One of the most challenging parts of the project was the fact that all proposed interventions should be reversible and help / facilitate the execution of any future restoration works.

THE STRUCTURE

* UNDP Photos

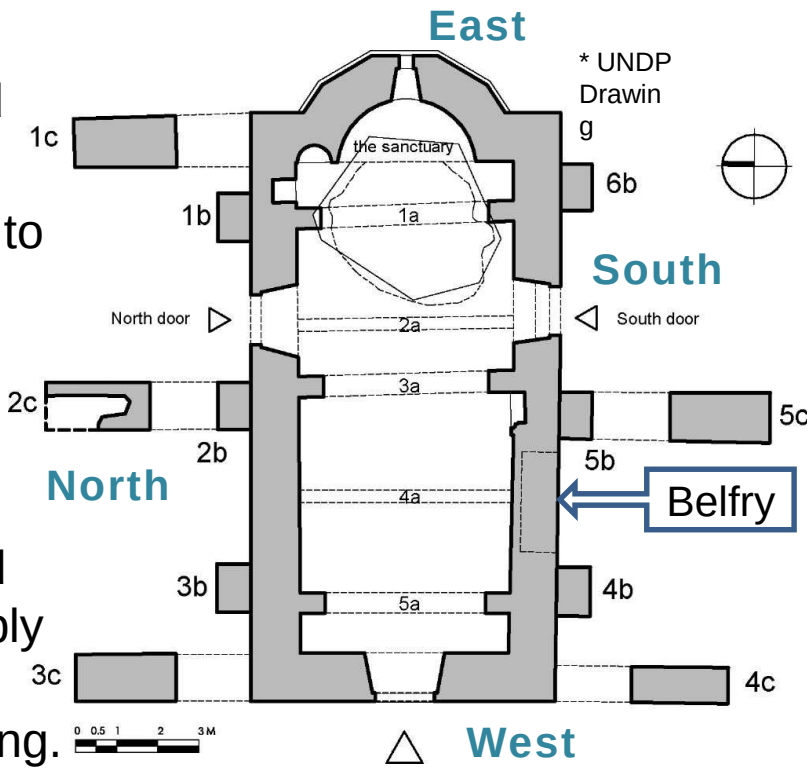
* UNDP Photos

- Late 14th century.
- Single-naved, barrel-vault structure with an apse at the sanctuary & a small belfry on the south façade.
- Three leaf masonry walls with approximate overall thickness of 120cm.
- Mainly lime mortar – Cement mortar plaster in the vault and sanctuary.
- 5 arched masonry beams [1a to 5a].
- 3 steel tie rods – 1 is cut.
- 6 external masonry piers – buttresses [1b to 6b].
- 5 masonry counterforts added around 1731 [1c to 5c] – Simply attached to the structure / Sculptured frame & rubble filling.



* UNDP Drawing

WEST FACADE



PHOTOS – Before Interventions

* UNDP Photos

* UNDP Photos

* UNDP Photo

* UNDP Photo

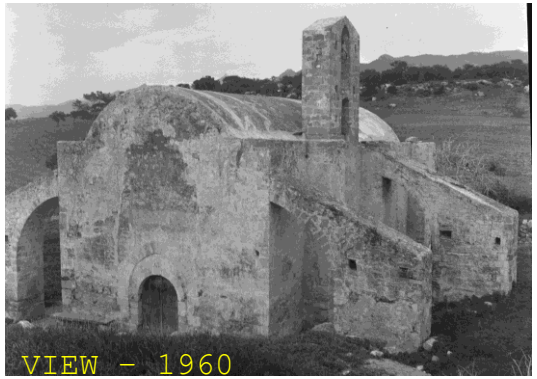
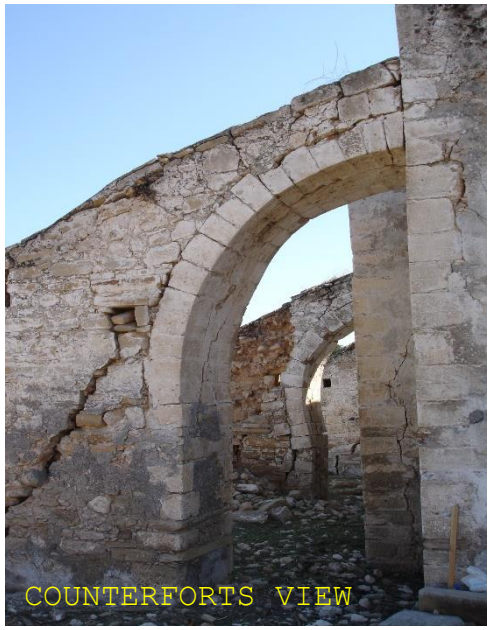


Photo Archives-Department of Antiquities

* UNDP Photo



* UNDP Photo

* UNDP Photo

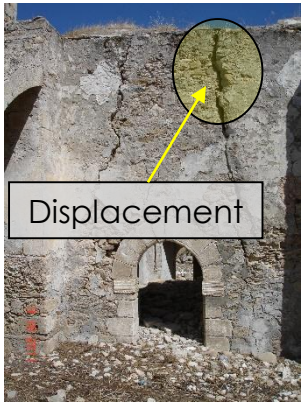
* UNDP Photo

CONDITION ASSESSMENT & PATHOLOGY

* UNDP Photos

* UNDP Photos

- Objective involved the assessment of both the **body of the Church** itself and the added **Counterforts**.
- Very bad structural & general condition - Extensive damages and deformations on the load bearing systems due to:
  - earthquake activity & ground movements
  - lack of regular maintenance / restoration / renovation.
- Very poor or no joining & adhesion of stones leads each structural component to act individually according to its own mechanical / dynamic characteristics – Walls with no monolithic behaviour / Roof with no diaphragmatic action.
- Extensive severe cracks on the load bearing masonry of the Church – Mostly out-of-plane cracking patterns.



* UNDP Photo

* UNDP Photo

* UNDP Photo

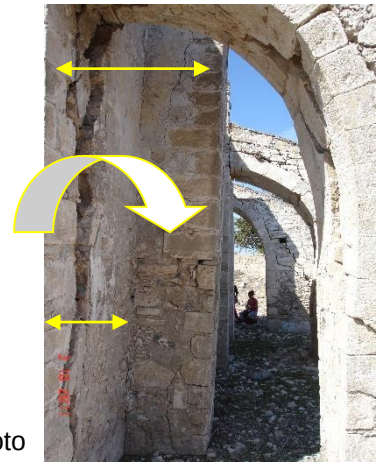
* UNDP Photo

CONDITION ASSESSMENT & PATHOLOGY

* UNDP Photos

* UNDP Photos

- Extensive severe cracks on the load bearing masonry of the Church – Large dislocations & torsional displacements on E side.



* UNDP Photo

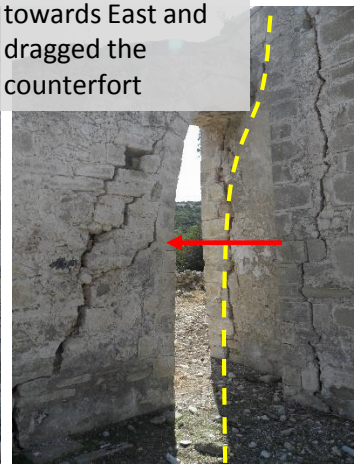
* UNDP Photo

- Extensive severe cracks on all counterforts and partial collapse of one of them.

* UNDP Photo

* UNDP Photo

This part moved towards East and dragged the counterfort



* UNDP Photo

* UNDP Photo

The dragging caused the counterfort to split [max 120mm].

CONDITION ASSESSMENT & PATHOLOGY

* UNDP Photos

- Extensive damages on all arched masonry beams & total collapse of one of them.

* UNDP Photo

* UNDP Photo

- Partial collapse of the roof & extensive cracking on the rest of it.

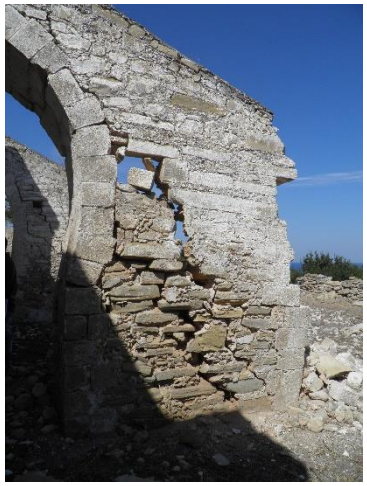
* UNDP Photo

* UNDP Photo

CONDITION ASSESSMENT & PATHOLOGY

* UNDP Photos

- Poor or no joining plaster, mortar & pointing in masonry walls.



* UNDP Photo

* UNDP Photo

- Uncontrolled plantation / vegetation inside the body of the walls, roof and counterforts.

* UNDP Photo

* UNDP Photo

* UNDP Photo

* UNDP Photos

* UNDP Photos

ENGINEERING JUDGEMENT & MODELING

- Barrel Vault behavior:
  - Figure 1:

    Integrity is ensured when internal loads [red arrows] are in equilibrium with external forces [green arrows].
  - Figure 2 & 3:
    Integrity is breached when equilibrium is disturbed either by failure of the supports or instability of the lateral elevation.
    In both cases, hinges and hence mechanisms are developing that lead the system out of balance.
- In our case, absence of monolithic action, no diaphragm & weak buttresses due to poor binding mortar led to system instability

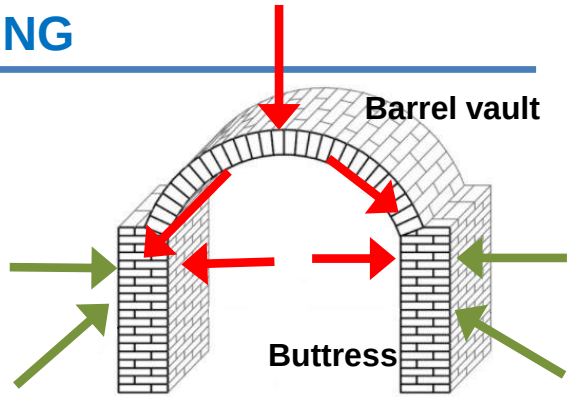


Figure 1 - Barrel Vault [1]

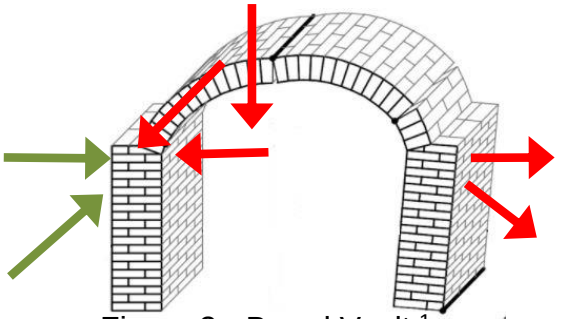


Figure 2 - Barrel Vault [1]

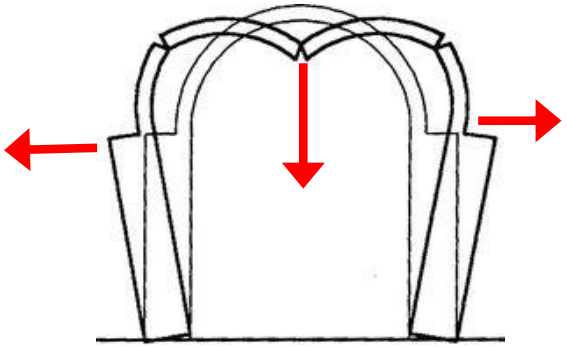


Figure 3 - Barrel Vault [2]

[1] ASCE Library Journal of Structural Engineering | Vol 143, No 6

[2] Statics of Historic Masonry Constructions pp 273-289 / Part of the Springer Series in Solid and Structural Mechanics book series

ENGINEERING JUDGEMENT & MODELING

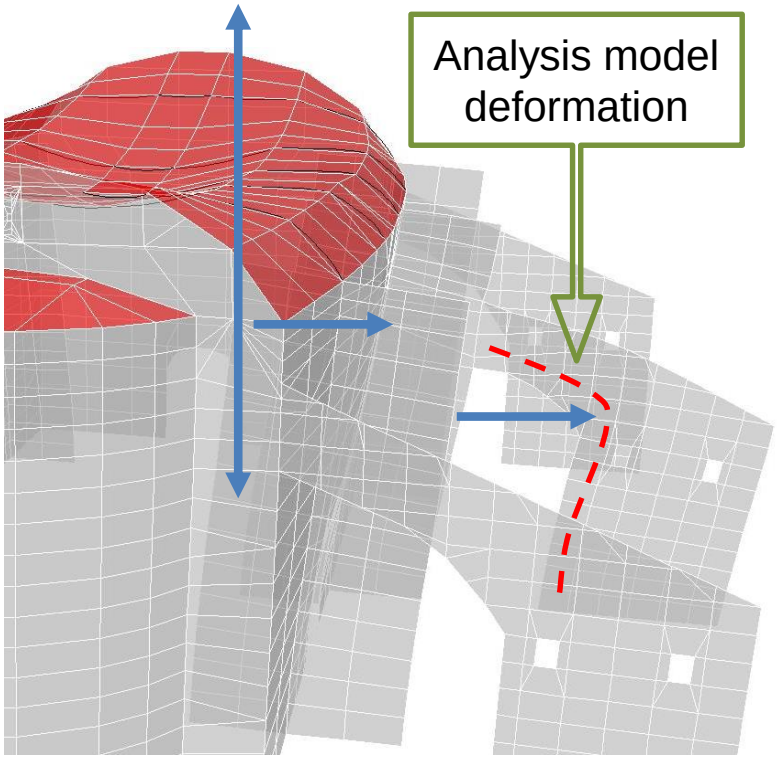
- Counterforts behavior:

– Simply attached to the body of the Church – No participation in gravity loads.

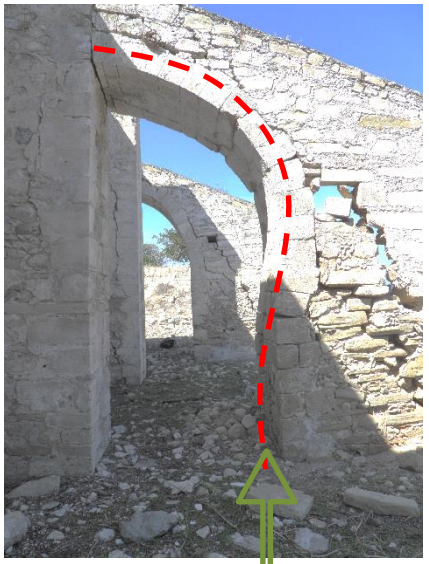
– All diagonal cracks are due to horizontal "pushing" coming from the main structure's vertical deformation.

* UNDP Photos

* UNDP Photos



* UNDP Study



* UNDP Photo

Actual Deformation / Collapsing portion

ENGINEERING JUDGEMENT & MODELING

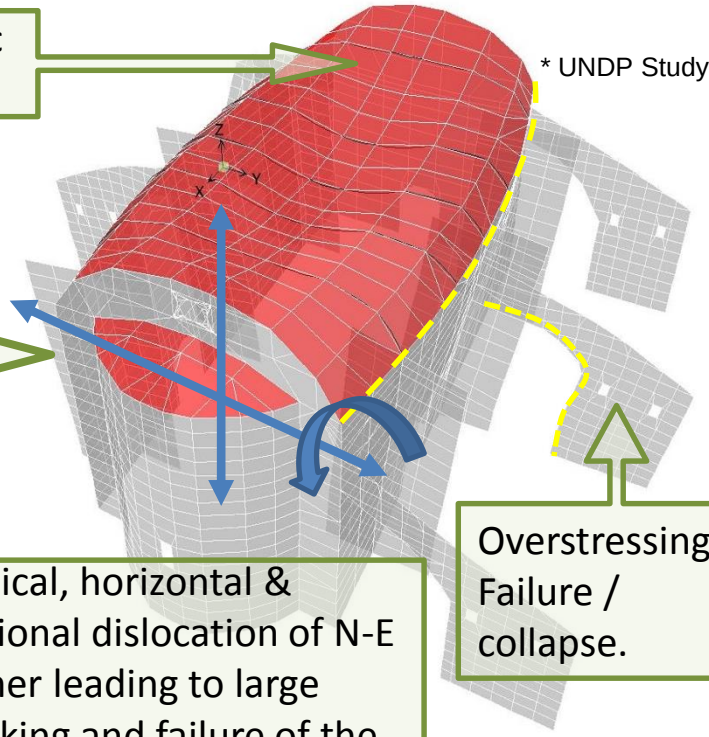
* UNDP Photos

* UNDP Photos

Etabs V.9.50 NL *Finite Element analysis*

Poor diaphragmatic behavior

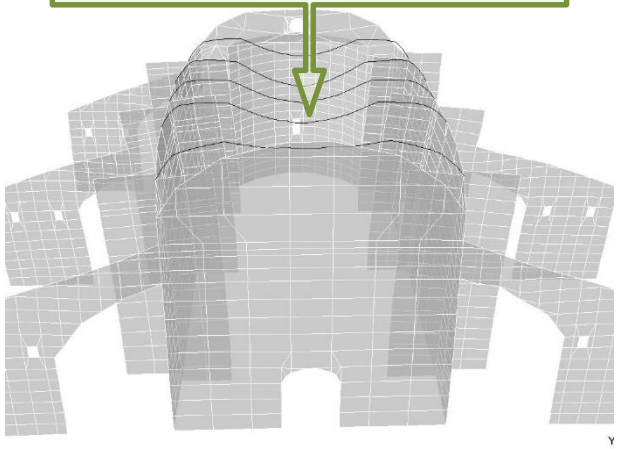
Some counterforts support / retain the buttresses while others the body of the church. That causes bad stiffness distribution making strong parts (corners) stronger and weak ones (middle body) even weaker.



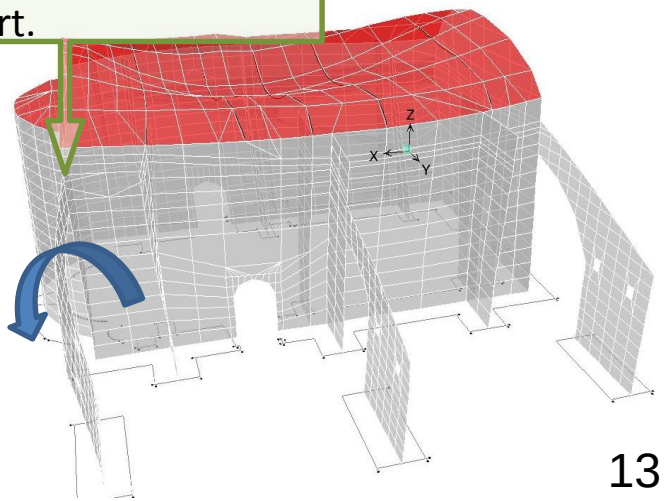
* UNDP Study

Overstressing - Failure / collapse.

Over-stretching of the arched roofing system – barrel vault action breached



Vertical, horizontal & torsional dislocation of N-E corner leading to large cracking and failure of the counterfort.



INTERVENTIONS

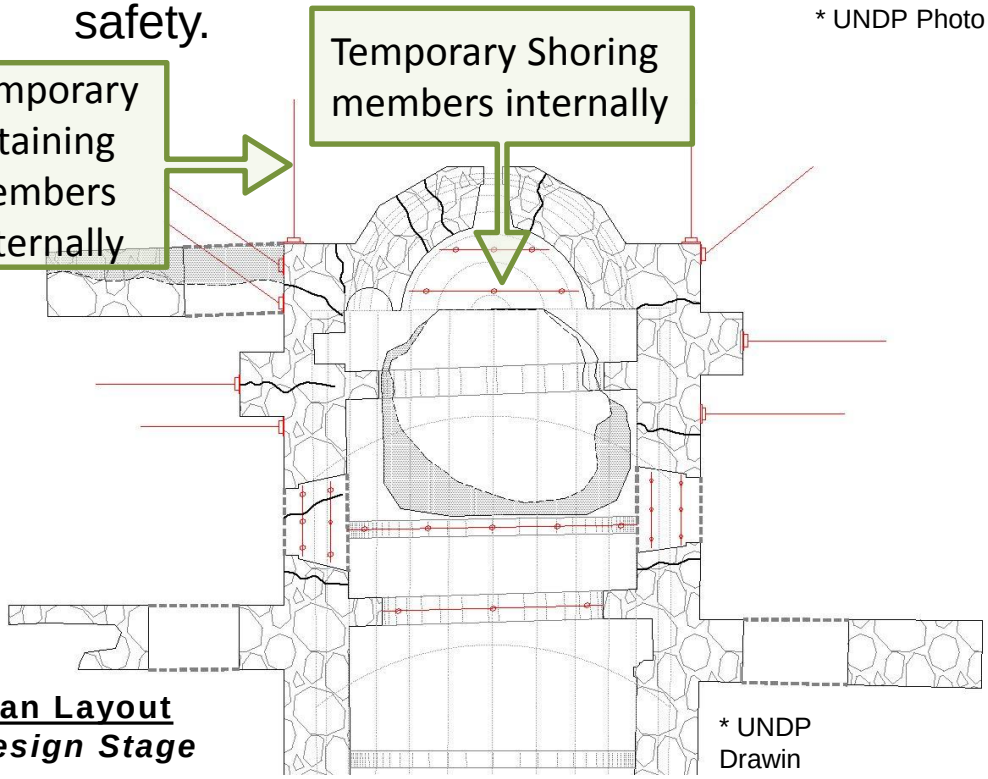
- **Temporary Retaining & Shoring system**

– Prior to the commencement of any construction work, temporary timber shoring & retaining members were installed internally and externally at the more stressed & damaged upper half of the structure towards East.

– Some of the external retaining frames remained for additional safety.

* UNDP Photos

* UNDP Photos



Plan Layout
Design Stage

* UNDP Drawing

* UNDP Photo

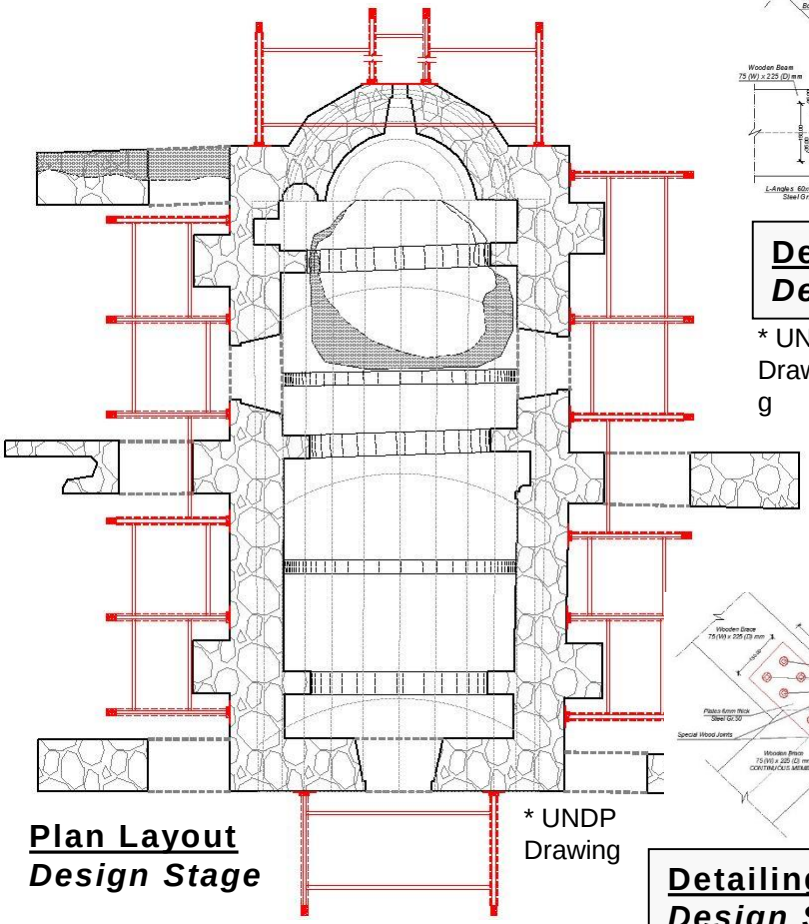
* UNDP Photo

INTERVENTIONS

- **External Timber Truss Retaining system** - To prevent the structure from further deformation, displacement and cracking, vertical timber trusses are installed at selected places all around the structure.

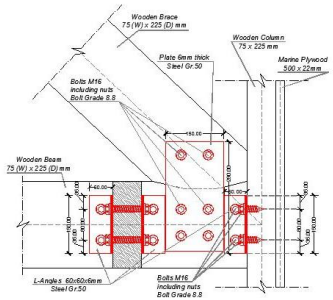
* UNDP Photos

* UNDP Photos



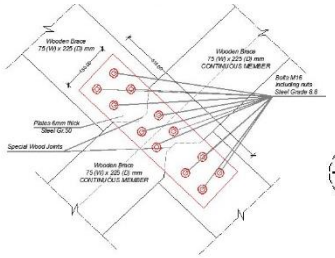
Plan Layout
Design Stage

* UNDP Drawing



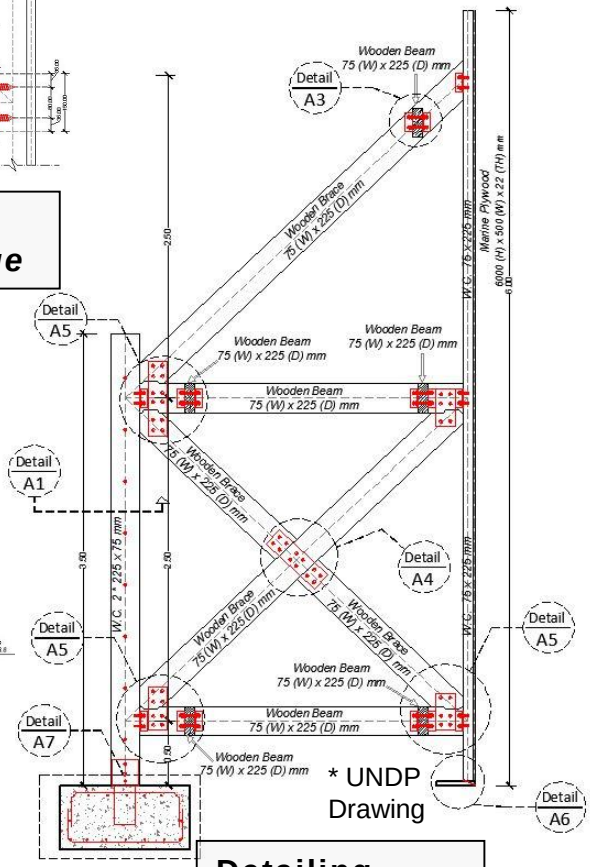
Detailing
Design Stage

* UNDP Drawing



Detailing
Design Stage

* UNDP Drawing



Detailing
Design Stage

INTERVENTIONS

- **External Timber Truss Retaining system** - Photos

* UNDP Photos

* UNDP Photos

* UNDP Photo

* UNDP Photo

* UNDP Photo

* UNDP Photo

* UNDP Photo

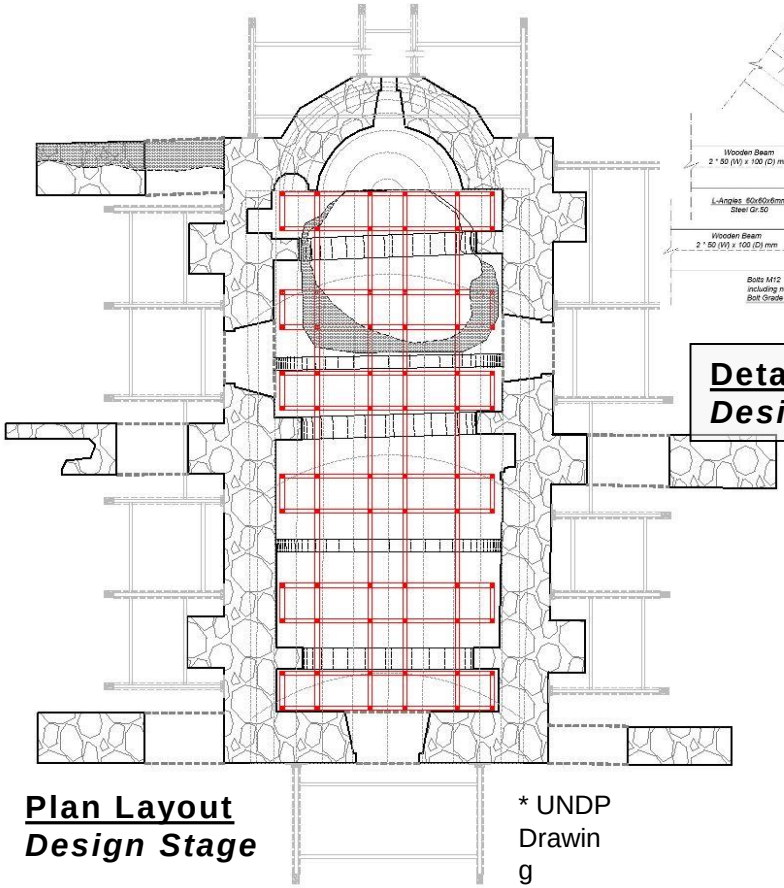
* UNDP Photo

INTERVENTIONS

- **Internal Timber Truss Shoring system** - A timber truss system is installed in the interior of the Church to support the damaged vaulted roof preventing further collapsing. This system is designed and constructed so as to not disturb any future renovation works but even more, facilitate / help their execution.

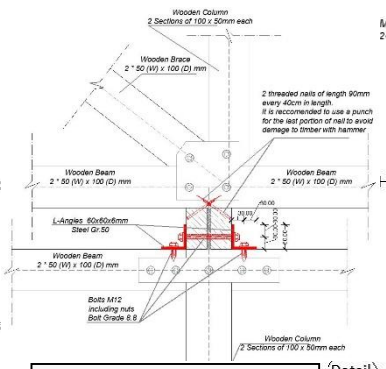
* UNDP Photos

* UNDP Photos



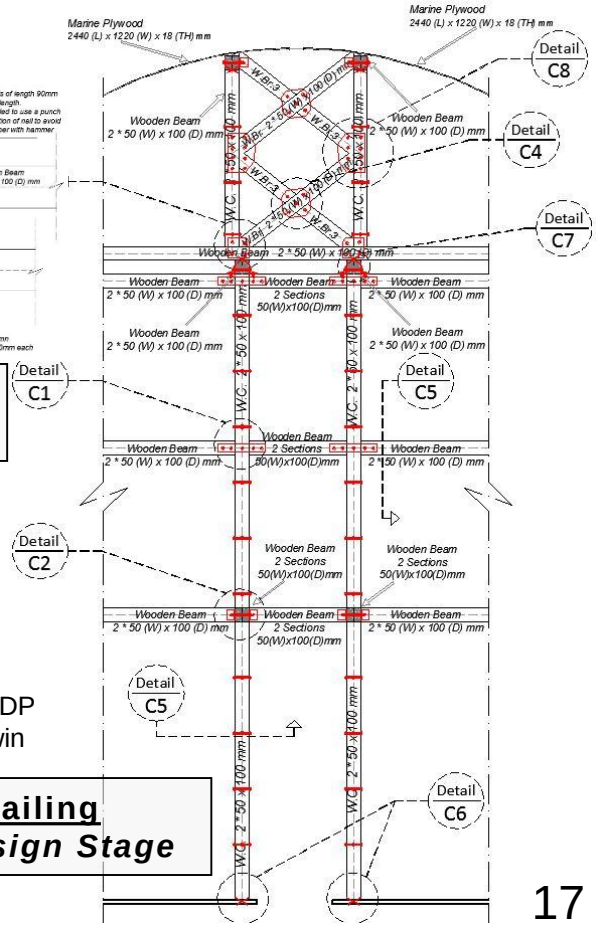
Plan Layout
Design Stage

* UNDP Drawing



Detailing
Design Stage

* UNDP Drawing



* UNDP Drawing

Detailing
Design Stage

INTERVENTIONS

- **Internal Timber Truss Shoring system** - Photos

* UNDP Photos

* UNDP Photos

* UNDP Photo

* UNDP Photo

* UNDP Photo

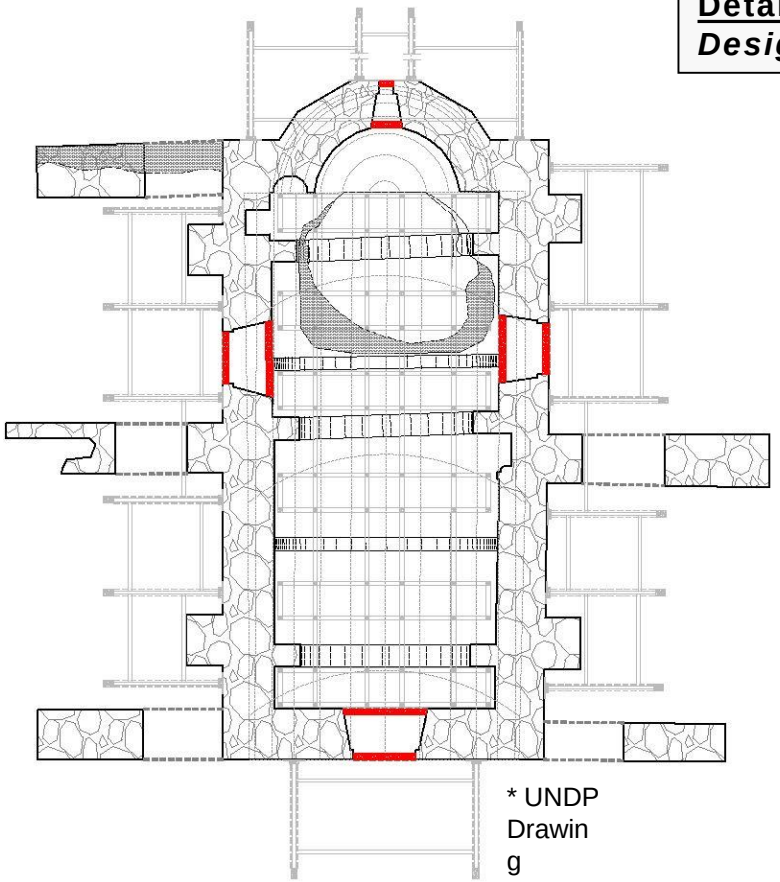
* UNDP Photo

INTERVENTIONS

- **Bracing of all openings** - Bracing of all openings is done to re-establish the wall's homogeneity.

* UNDP Photos

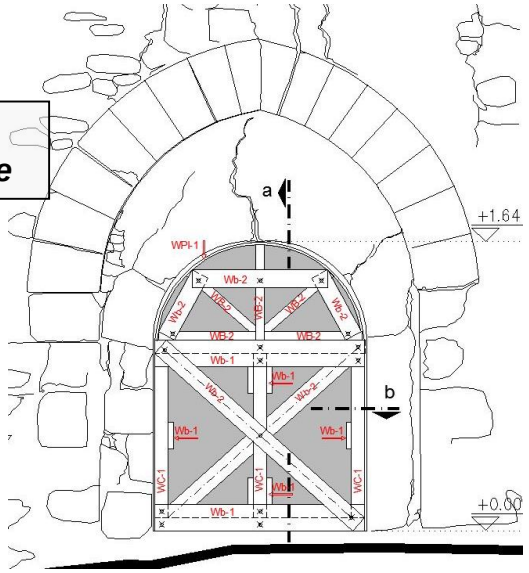
* UNDP Photos



* UNDP Drawing

Plan Layout
Design Stage

Detailing
Design Stage



* UNDP Drawing

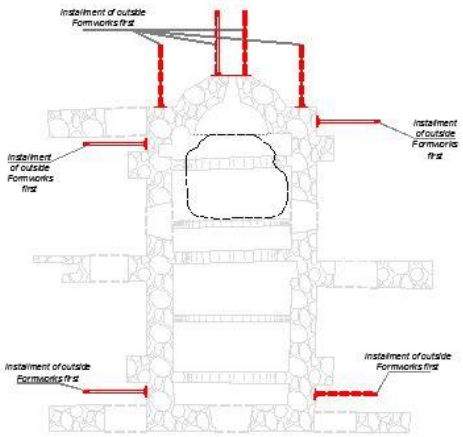
* UNDP Photo

INTERVENTIONS

- **Construction Sequence**

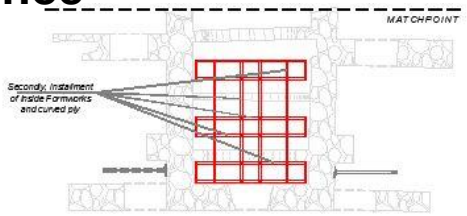
* UNDP Photos

* UNDP Photos

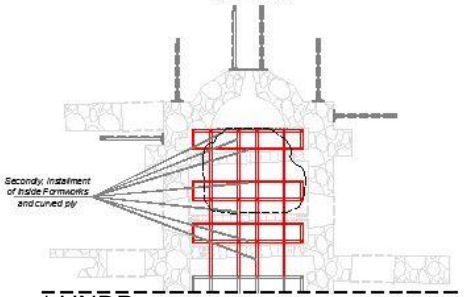


* UNDP Drawing

Step 1

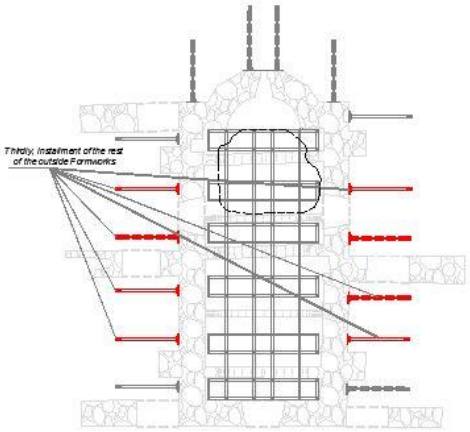


Step 2



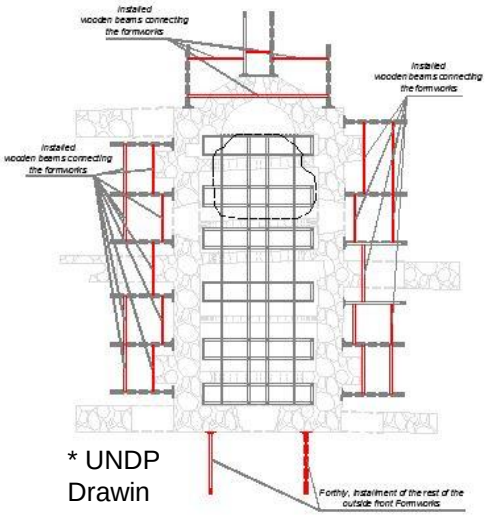
* UNDP Drawing

Step 2a



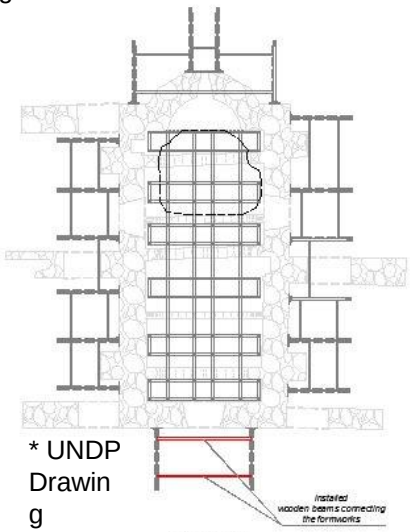
* UNDP Drawing

Step 3



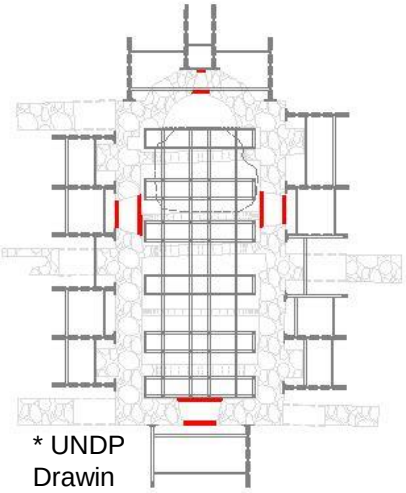
* UNDP Drawing

Step 4



* UNDP Drawing

Step 5



* UNDP Drawing

Step 6: Bracing of openings

INTERVENTIONS

* UNDP Photos

* UNDP Photos

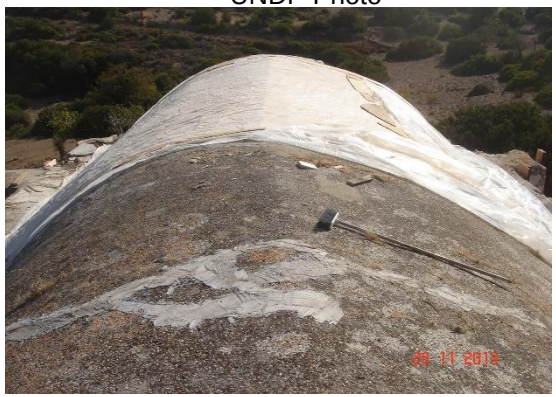
- **Grouting of all large cracking** - Grouting injections with lime-based mortar inside the masonry wall in all large cracks in order to re-establish the wall's homogeneity.

* UNDP Photo

* UNDP Photo

* UNDP Photo

- **Covering & protection of the roof** – Curved Marine Plywood panels & heavy duty carbonate type are installed to cover & protect interior from rain, water, birds or other possible enemies causing further damage.



* UNDP Photo

- **Removing plantation / vegetation with pesticide** - Growing plantation causes further damage in the body of the walls. Plantation should be removed before and after the completion of emergency measures

* UNDP Photos

* UNDP Photos

CONCLUSION

The measures taken are only to support and "relief" the structure in some extent and protect it from further damages until a full restoration scheme takes place. Regular maintenance works will help the structure withstand ageing and environmental impact.

Some next steps that would provide additional information and help future designs would be:

- Measuring and monitoring of the cracks
- Measuring and monitoring of the relevant movements and verticality of the structure
- Full topographical survey of both the site and the monument
- Further historical analysis and data recording of the church
- Complete geological / geotechnical investigation.