



## **STRUCTURAL RESTORATION OF MASONRY CHURCHES IN PERU**

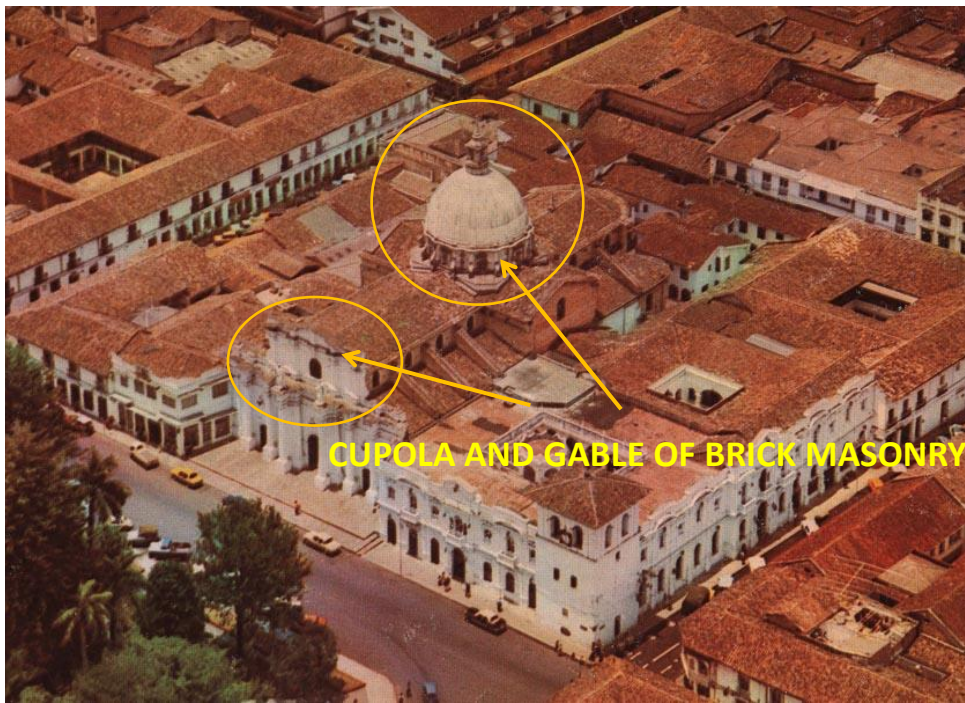
**Daniel Torrealva**  
**Pontifical Catholic University of Peru**



## **CONTENT OF PRESENTATION**

- **SEISMIC BEHAVIOR OF LATIN AMERICAN CHURCHES**
- **LOCAL SEISMIC CULTURE IN SOUTH AMERICA –  
EVOLUTION OF CONSTRUCTION SYSTEM**
- **METHODOLOGY FOR STRUCTURAL EVALUATION**
- **THE CATHEDRAL OF MOQUEGUA – A COMPATIBLE RING  
BEAM IN A THREE LEAF STONE CHURCH**
- **THE CHURCH OF SECHURA – USING POLYMER GRID TO  
ENHANCE CONTINUITY IN A BRICK MASONRY CHURCH**

# **SEISMIC BEHAVIOR OF LATIN AMERICAN CHURCHES**

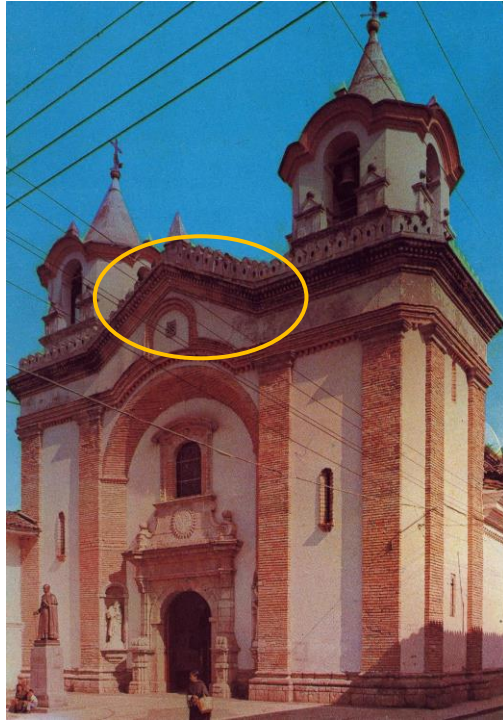




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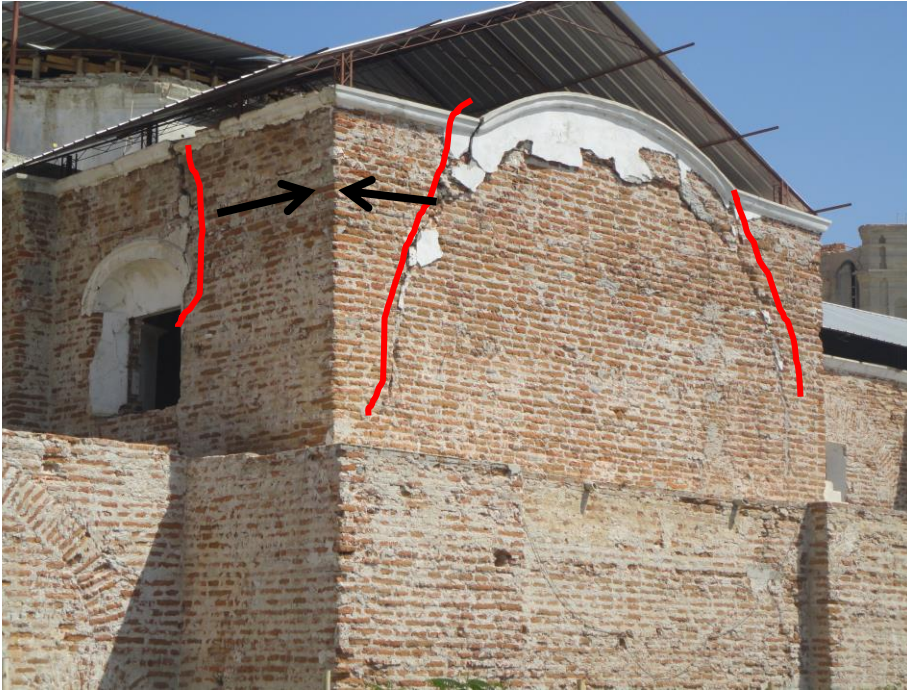


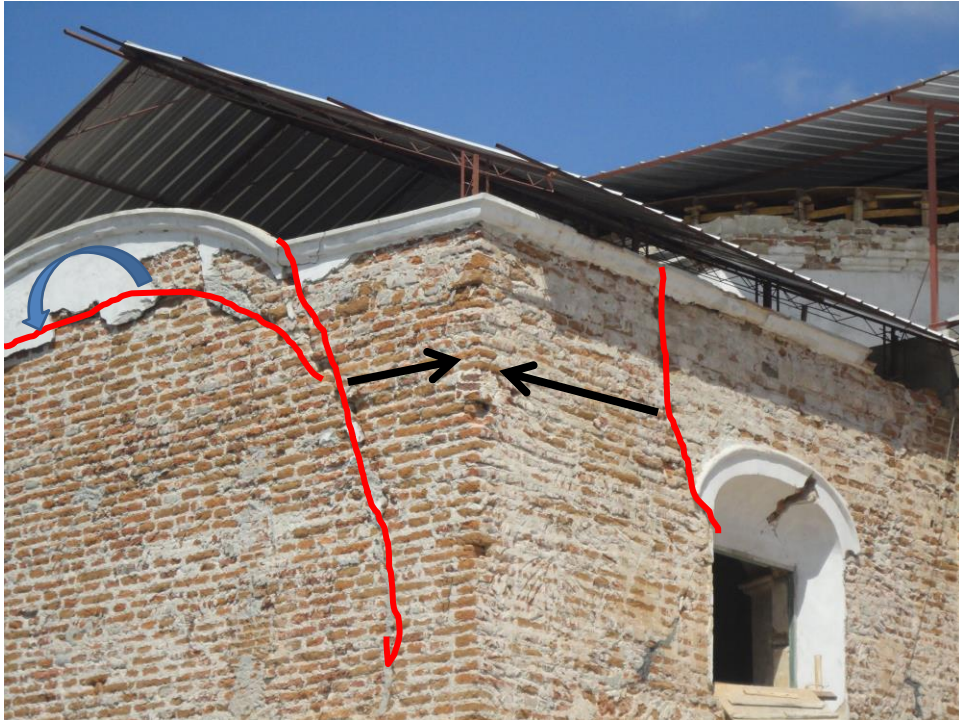
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## **LOCAL SEISMIC CULTURE – EVOLUTION OF CONSTRUCTION SYSTEM**

EARTHQUAKES IN LIMA			
Creation of Lima: 18-01-1535			
DATE (DD-MM-YY)	LOCATION	MERCALLI INTENSITY	
15-10-1555	Lima	VII	
09-07-1586	Lima	IX	
Solid brick vaults and domes	19-10-1609	Lima	VII
	14-02-1619	Trujillo	IX
	27-11-1630	Lima	VII
Phase 1	13-11-1655	Callao	IX
	17-06-1678	Lima	VII
Phase 2	20-10-1687	Cañete	IX
Phase 3	14-07-1699	Lima	VII
	10-02-1716	Pisco	IX
	06-01-1725	Barranca	VIII
	28-10-1746	Callao / Lima	X
	30-03-1746	Lima	VII
	21-11-1901	Ica	VI

Primer tercio  
S XVII

## PHASE ONE

Earthquake of 1655 en Lima caused extensive damage to several churches in Lima.

**Friar Diego Maroto** proposal was to demolish and rebuilt with better materials

Another builder, **Manuel de Escobar**, proposed a new technique using the same materials: clay bricks and lime mortar.

## PERFORMANCE OF REBUILT CHURCHES IN THE 1678 EARTHQUAKE

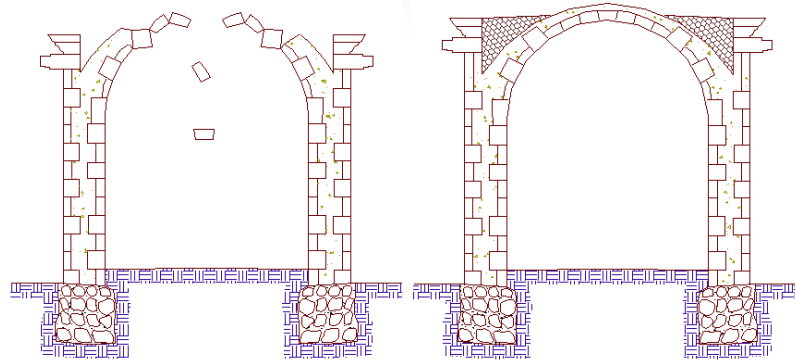


Imagen: Romer Lovón "INTERVENCIÓN ESTRUCTURAL EN UN MONUMENTO HISTÓRICO DE ADOBE"

**Friar Diego Maroto**

**Manuel de Escobar**

### PHASE TWO

Friar Diego Maroto decided to change the heavy materials of vaults and domes by timber, cane and a mud/lime mortar plaster.

## PHASE 2 OF THE PROCESS OF EVOLUTION OF CONSTRUCTION SYSTEM

Materiales ligeros (cerchas de madera y cubiertas de yeso por debajo y por encima de la bóveda)

Materiales rígidos y pesados (cal y ladrillo consolidados)

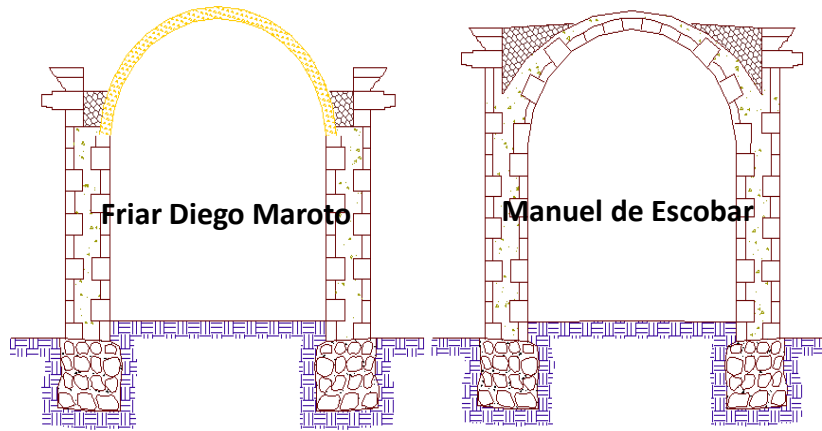


Imagen: Romer Lovón "INTERVENCIÓN ESTRUCTURAL EN UN MONUMENTO HISTÓRICO DE ADOBE"

## PHASE 3 OF THE PROCESS OF EVOLUTION OF CONSTRUCTION SYSTEM

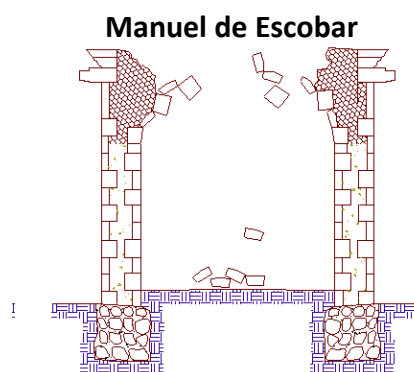
Three consecutive earthquakes in 1687, 1688 and 1690 proved that the use of lighter materials was necessary to avoid the collapse of the vaults and cupolas.

Daños muy leves y fácilmente reparables

Daño severo frente a estos sismos



Imagen: Romer Lovón "INTERVENCIÓN ESTRUCTURAL EN UN MONUMEN



MONUMENTO HISTÓRICO DE ADOBE"

## **Decree of change of construction system**



On June 7<sup>th</sup>, 1692, the Viceroy Conde de la Monclova gather all «alarifes» in the palace and decreed that the final solution for this type of structures was the use of light weight materials for cupolas and vaults.



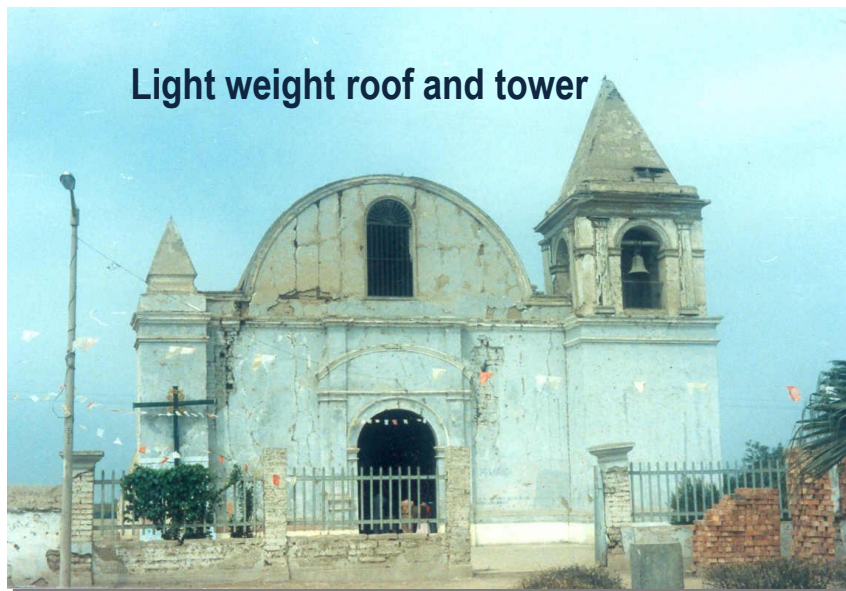
**SAN JOSE CHURCH, ICA**

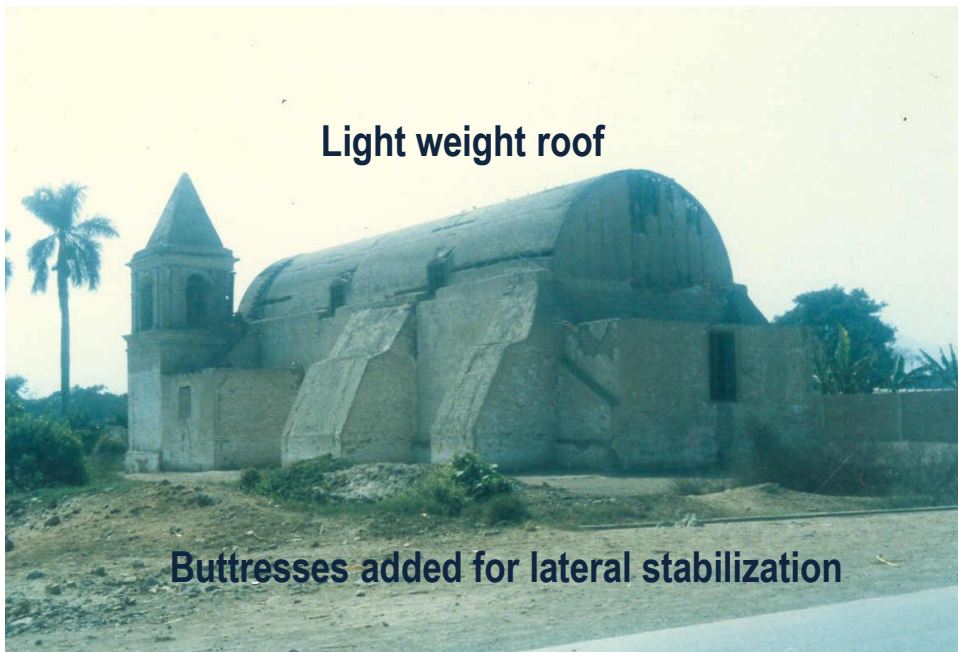
**TIMBER TOWER WITH  
CANE AND MUD-LIME  
PASTERL**





**IGLESIA SAN JOSÉ, ICA**





**CATEDRAL DE ICA**

## PLAN LAYOUT OF ICA CATHEDRAL

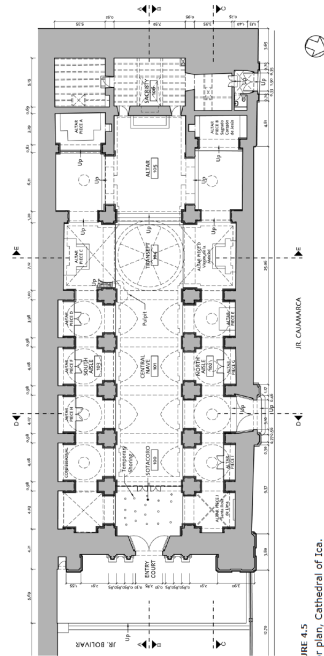


FIGURE 4.5  
Floor plan, Cathedral of Ica.  
Drawing: Base drawing prepared by Mirna Soto and edited by the GCI.

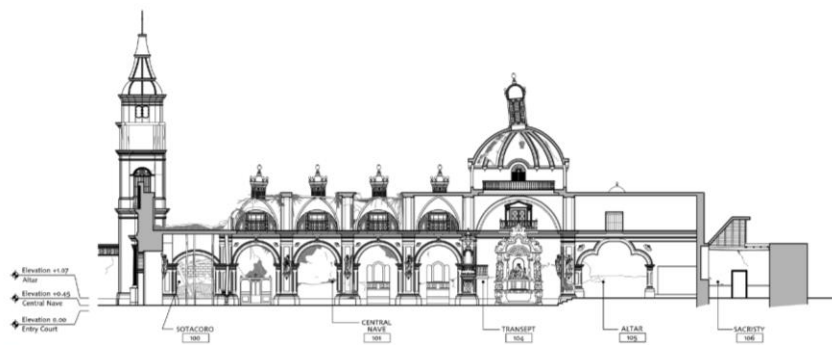
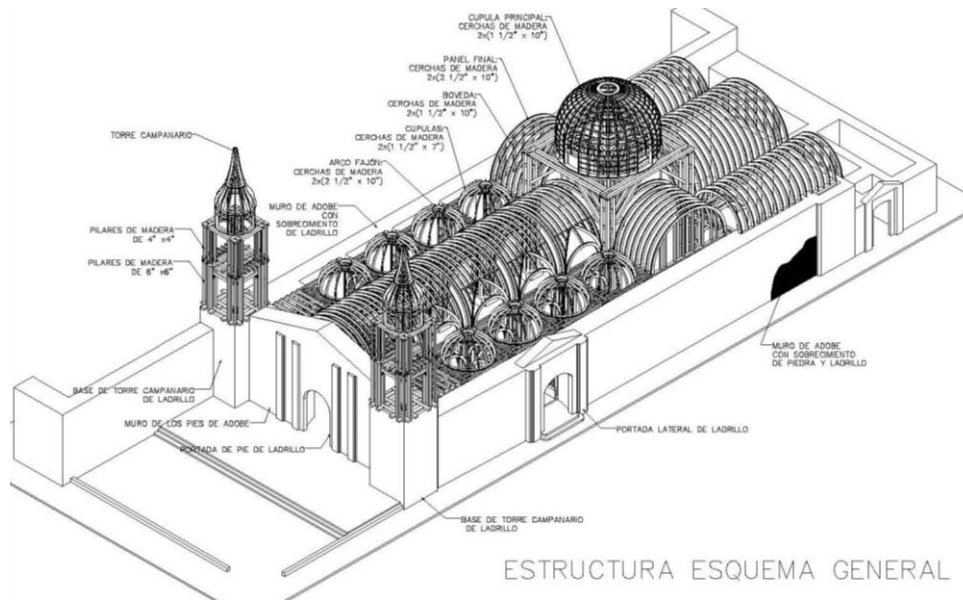
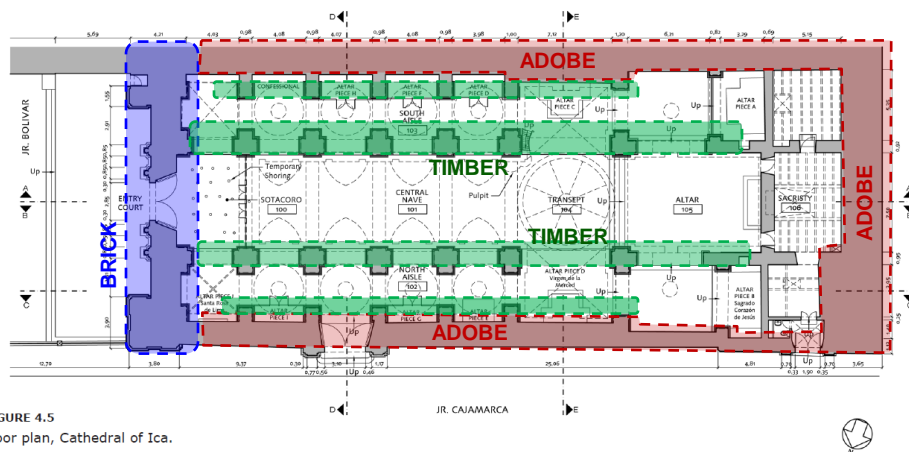


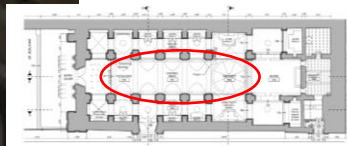
FIGURE 4.6  
Cross section A-A, Cathedral of Ica.  
Drawing: Base drawing prepared by Mirna Soto and edited by the GCI.



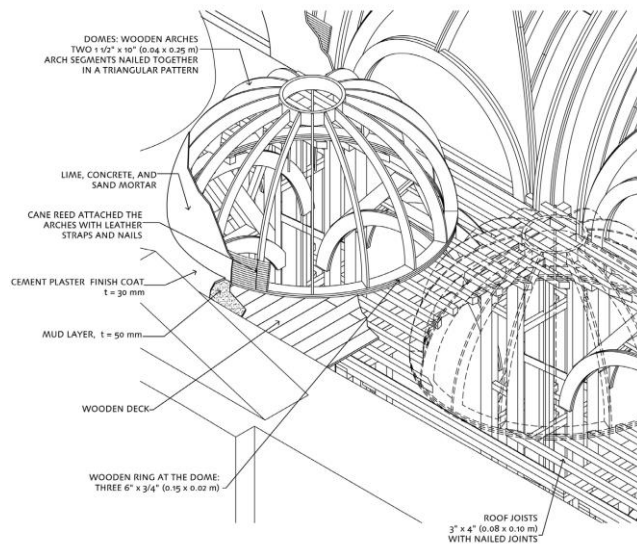
## MATERIALS – ICA CATHEDRAL



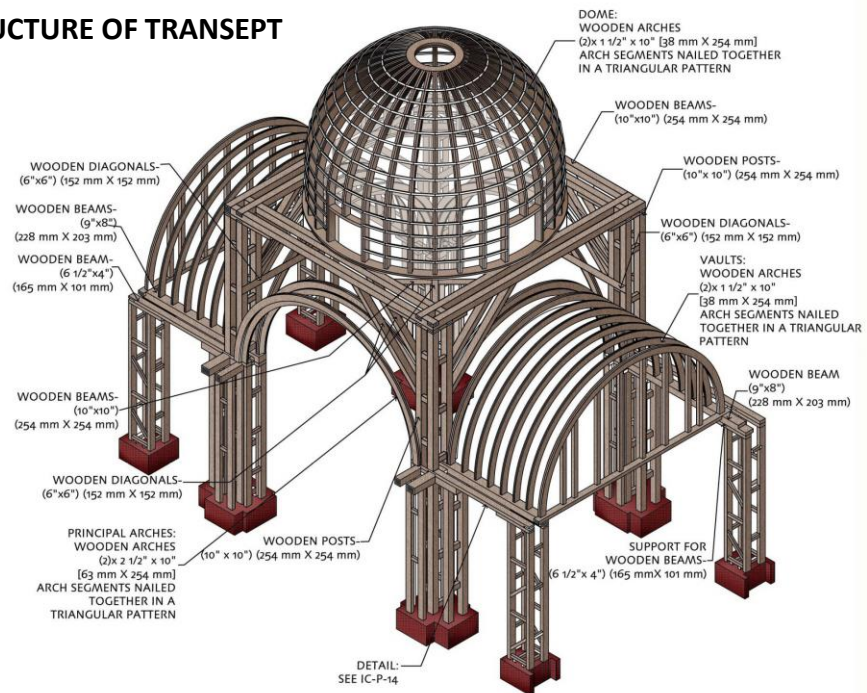
**FIGURE 4.5** Floor plan, Cathedral of Ica.  
Drawing: Base drawing prepared by Mirna Soto and edited by the GCI.







## STRUCTURE OF TRANSEPT





**BUILDING IN CUSCO CITY**

## **METHODOLOGY FOR STRUCTURAL EVALUATION**

## STEPS FOR A STRUCTURAL RETROFITTING PROJECT ON HISTORIC BUILDINGS



## STRUCTURAL EVALUATION

## Defining the Structural System

Is the first step in the structural evaluation.

Structural system for vertical loads.

Structural system for horizontal loads.

The structural system can be divided in Macro Elements, and each one them divided in Elements.

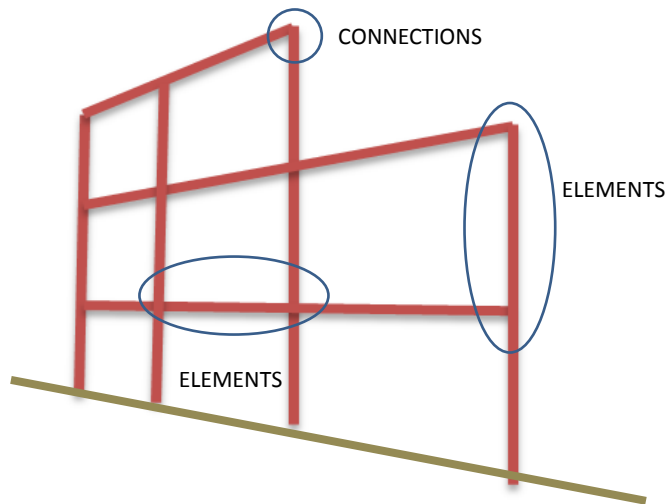
Elements can be of a single material (wood) or a combination of materials (masonry).

## WHAT IS A MACRO ELEMENT?

Macro Elements are defined as sub-structures that has a particular structural behavior . They may or mat not be of different materials and they are capable of ***interact*** between them.

Macro Elements are composed of Elements and these are joined by “***connections***”





## STRUCTURAL SYSTEM

MACRO  
ELEMENT 1

MACRO  
ELEMENT 2

ELEMENT  
1

ELEMENT  
2

ELEMENT  
1

ELEMENT  
2

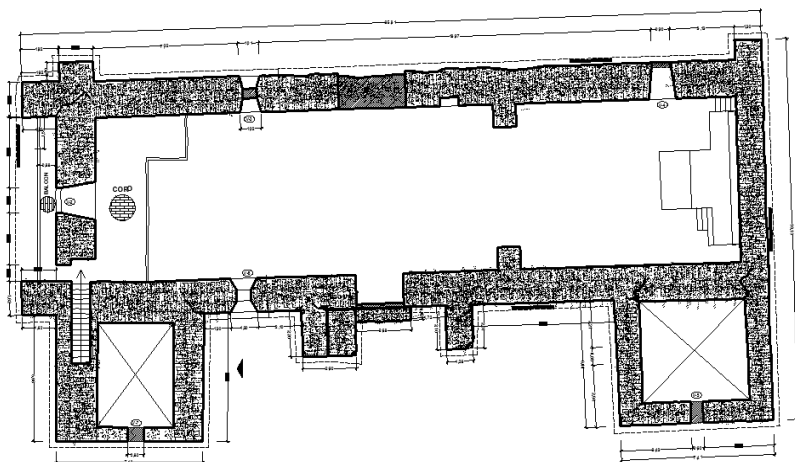


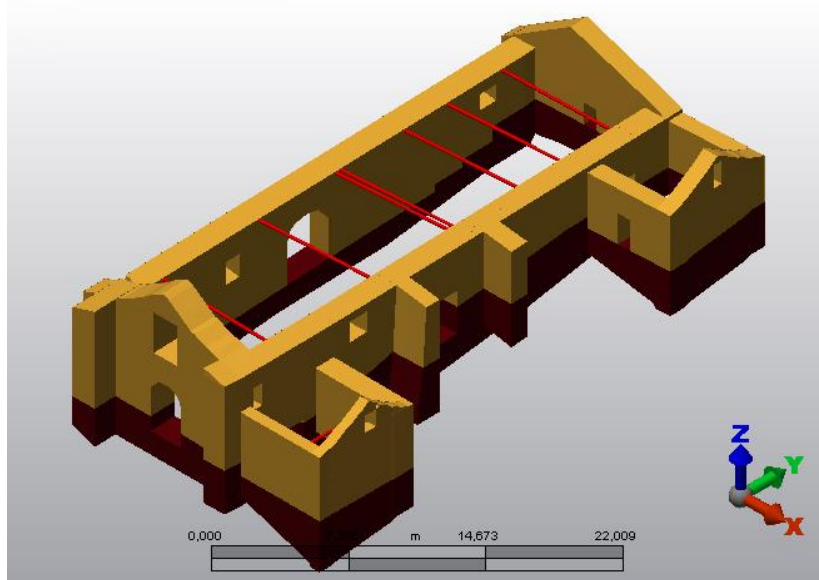
**Constitutive Materials**

## CASE STUDY KUÑO TAMBO CHURCH



## PLAN LAYOUT OF KUÑO TAMBO CHURCH (CURRENT STATE)





## MACRO ELEMENTS OF A CHURCH

**Walls: Longitudinal, Rear and Facade.**

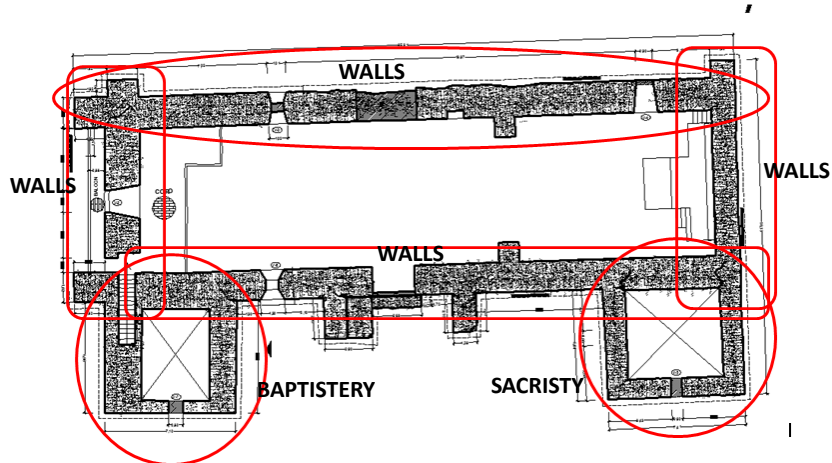
**Sacristy**

**Baptistery.**

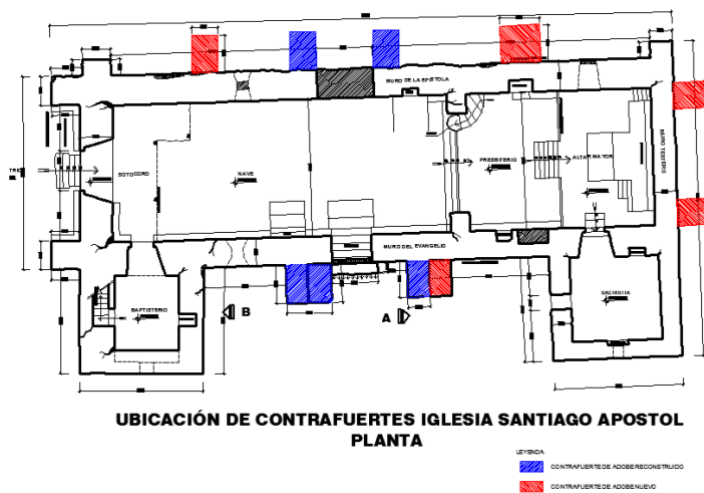
**Buttresses.**

**Roof**

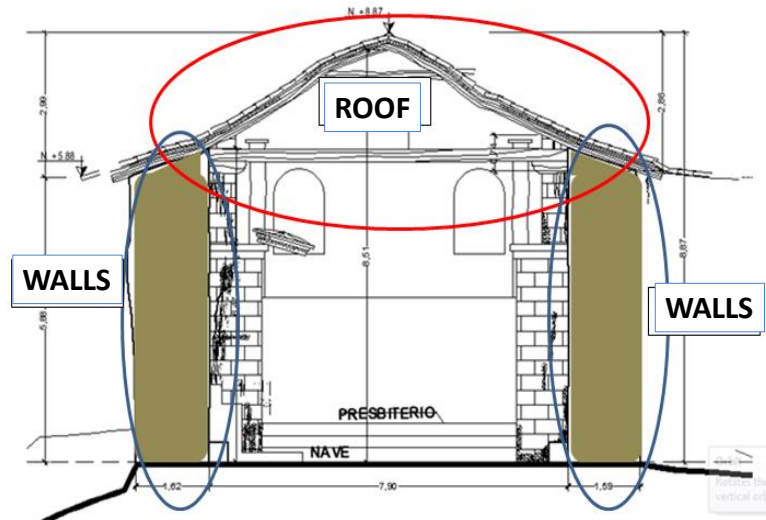
## MACRO ELEMENTS WALLS – SACRISTY - BAPTISTRY

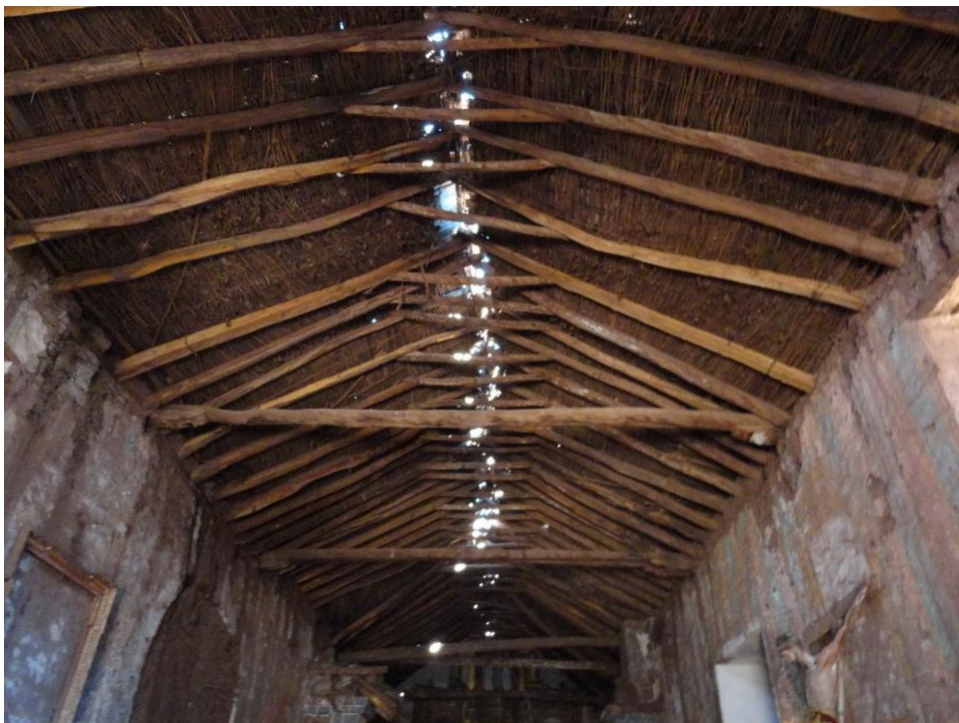


## MACRO ELEMENT: EXISTING AND PROPOSED BUTTRESSES

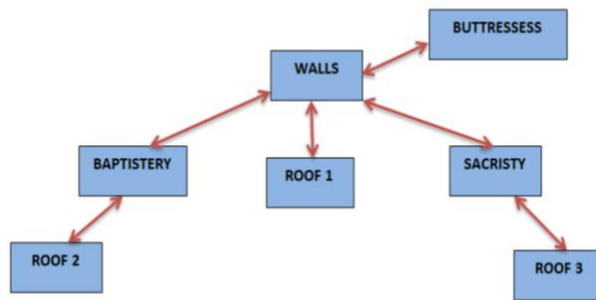


## MACRO ELEMENTS WALLS – ROOF





## STRUCTURAL SYSTEM OF KUÑO TAMBO CHURCH AND ITS INTERACTION



### VARIABLES OF EVALUATION

Five aspects are considered

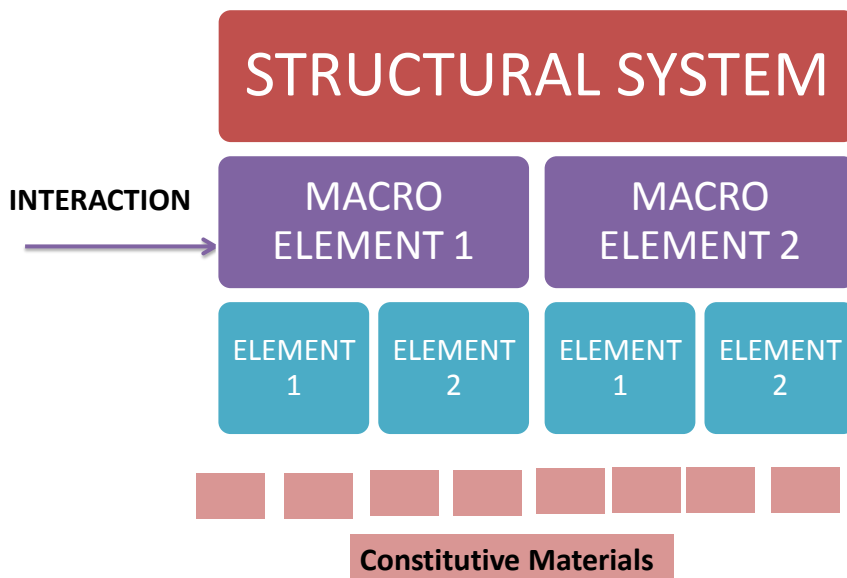
1. Conception of structural system
2. Interaction between Macro Elements
3. Connections between Elements
4. Quality of Fabric
5. Level of Deterioration

## Conception of Structural System

Refers to the ORIGINAL/ACTUAL SYSTEM and how it has performed over the years. Evaluation is qualitative and quantitative.

Qualitative evaluation includes the study of the history of the building.

The quantitative evaluation includes numerical models of the actual structure with actual and future loads.

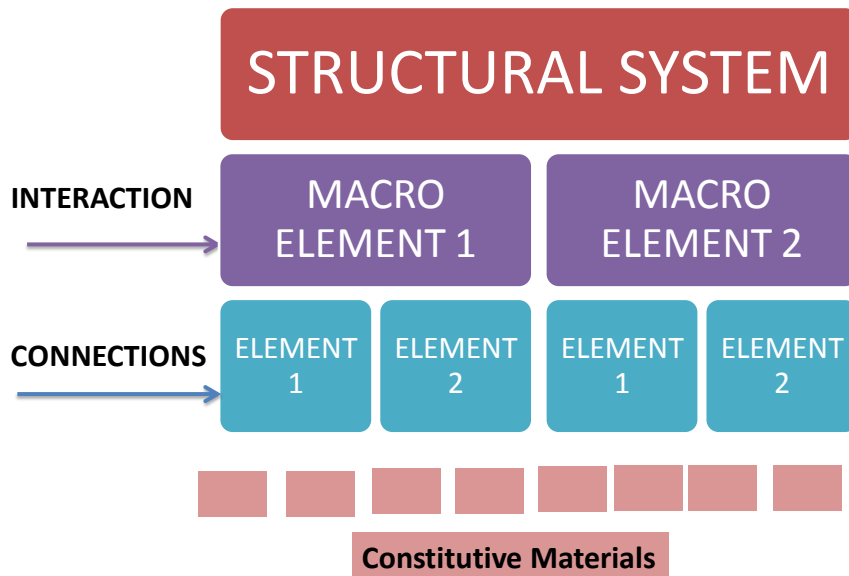


## Interaction between Macro Elements

May be positive or negative

Quantitative evaluation is by means of numerical models.

Qualitative evaluation is by inspection and by studying past performance.



### **Connections.**

How the joints perform their structural function inside a Macro Element.

Evaluation is qualitative by inspection. If needs quantitative evaluation is by experimental testing.

### **Quality of Fabric.**

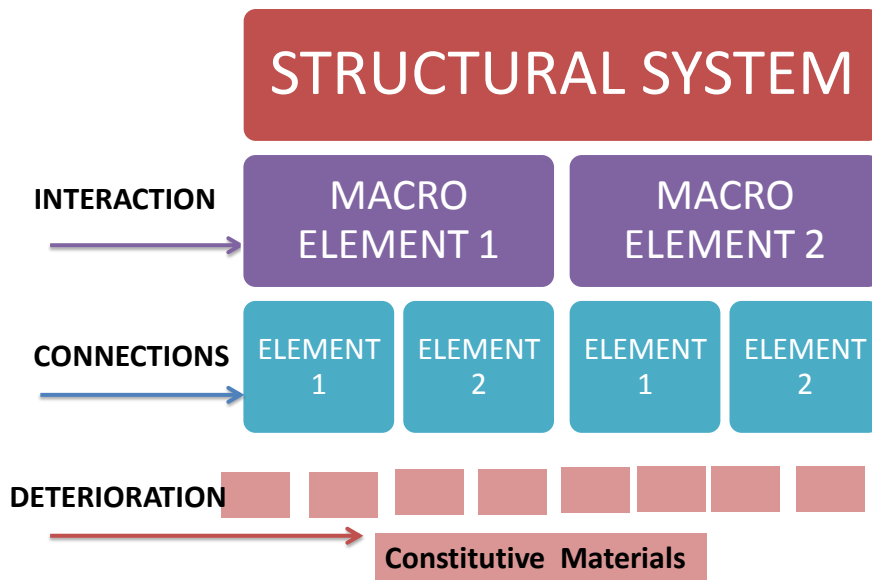
Is directly related with the quality of original materials and how were they built.

Is evaluated qualitatively by inspection

For masonry: Regularity of joints, etc

In timber: the joints and wood carpentry are evaluated.

Quantitative evaluation include in situ testing.



### Level of Deterioration.

Qualitative evaluation is by visual inspection.

Quantitative evaluation is by in situ testing.

## CLASIFICATION SCALE OF VARIABLES OF EVALUATION (except for interaction)

A. High or Very good.



B. Medium high.



C. Medium low.



D. Low or very bad.



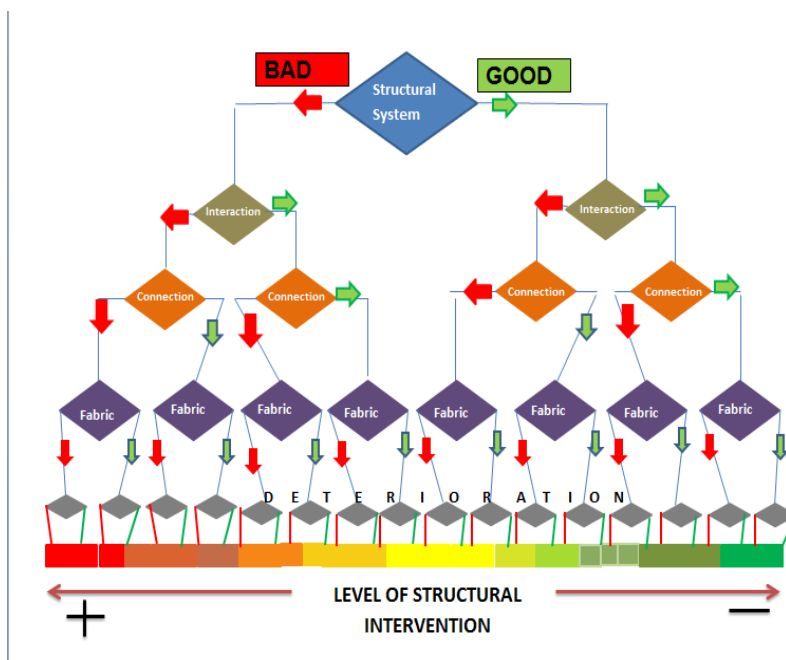
## SUMMARY OF EVALUATION FOR KUÑO TAMBO

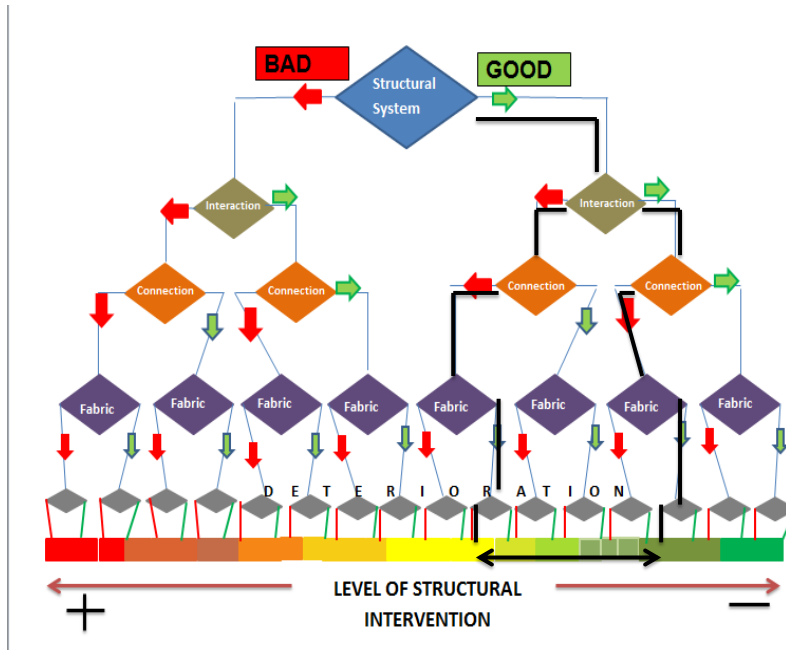
MACRO ELEMENT	STRUCTURAL CONCEPTION	CONNECTIONS	FABRIC	DETERIORATION
Facade and Rear Walls	B	B	B	C
Longitudinal Walls	B	B	B	D
Buttresses	B	N/A	B	D
Sacristy	B	B	B	C
Baptistry	A	B	B	C
Timber Roof	C	D	C	D

## RELATIVE IMPORTANCE OF VARIABLES FOR STRUCTURAL EVALUATION

By order of importance:

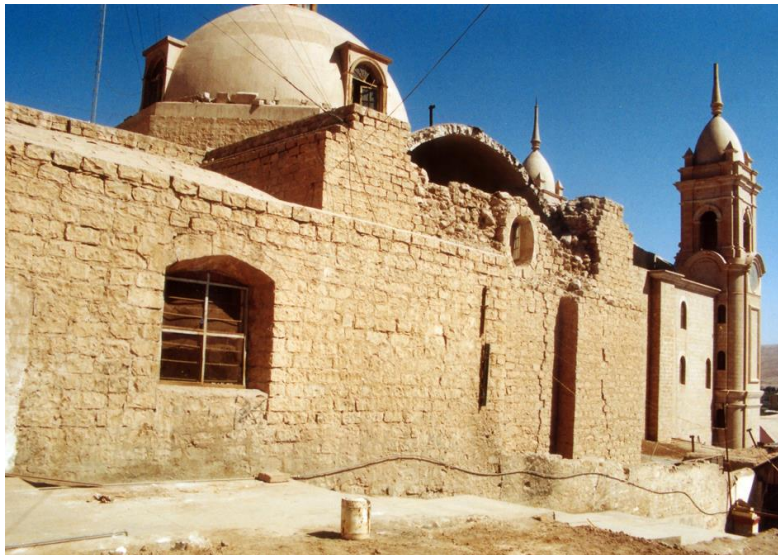
1. **Structural System**
2. **Interaction between Macro Elements**
3. **Connections between Elements**
4. **Quality of Fabric**
5. **Level of Deterioration**

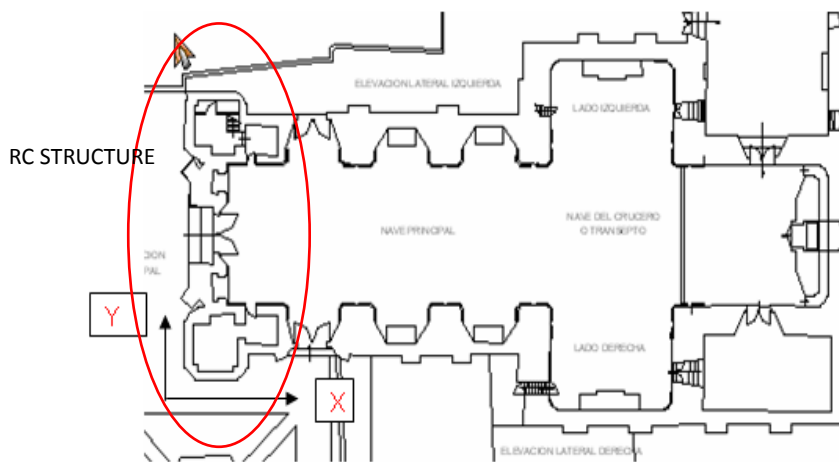




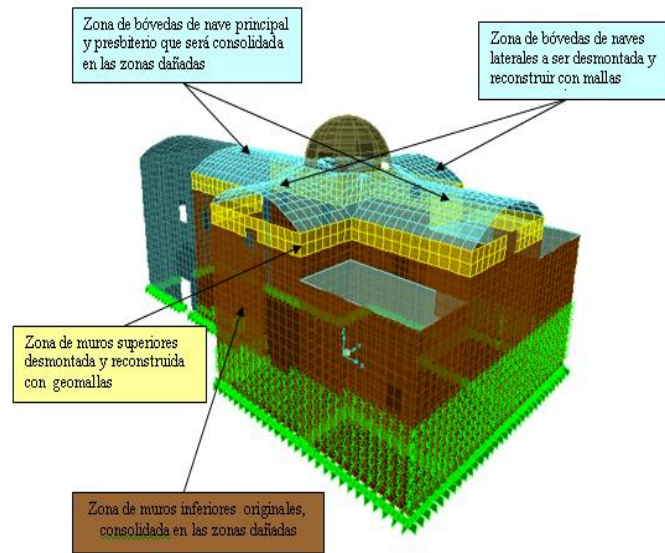
**THE CATHEDRAL OF MOQUEGUA -  
A COMPATIBLE RING BEAM FOR A THREE  
LEAF STONE MASONRY CHURCH**





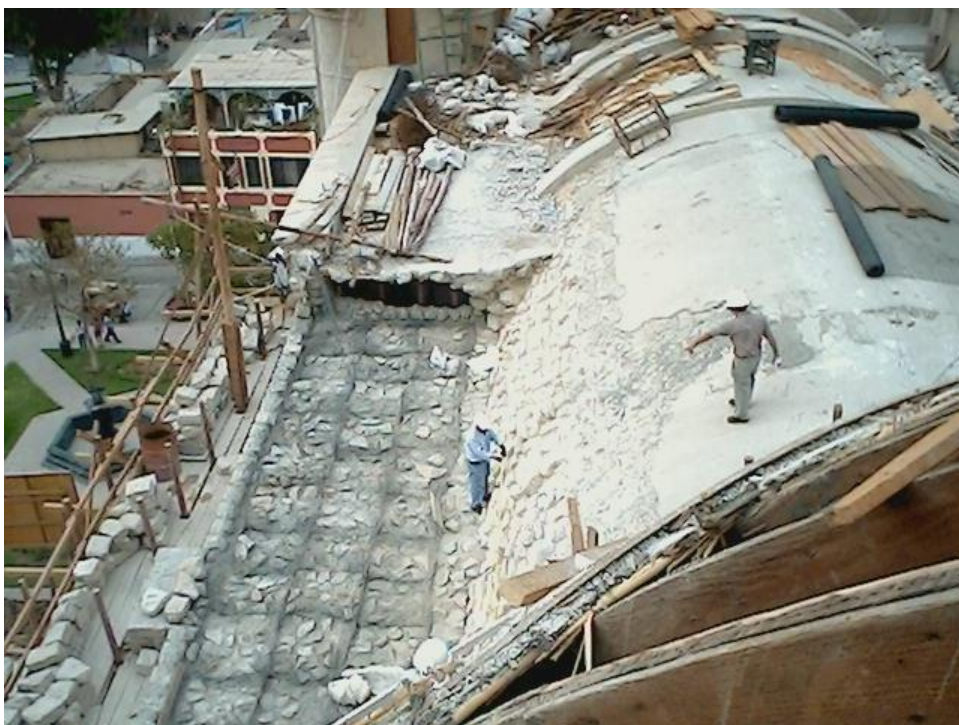


PLAN LAYOUT OF MOQUEGUA CATHEDRAL.











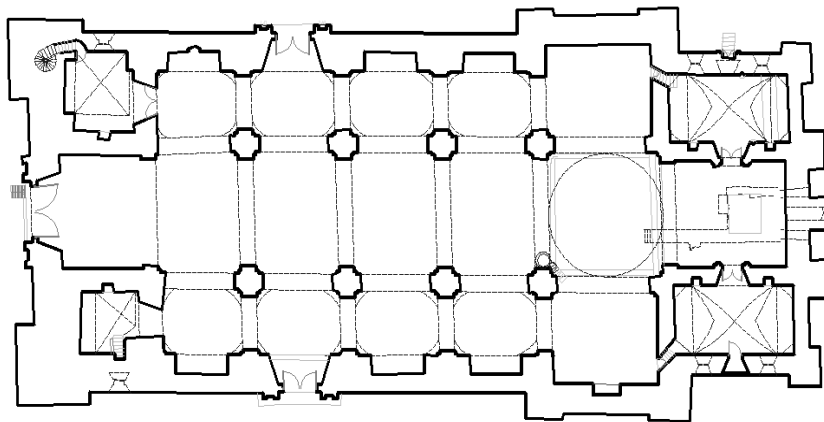




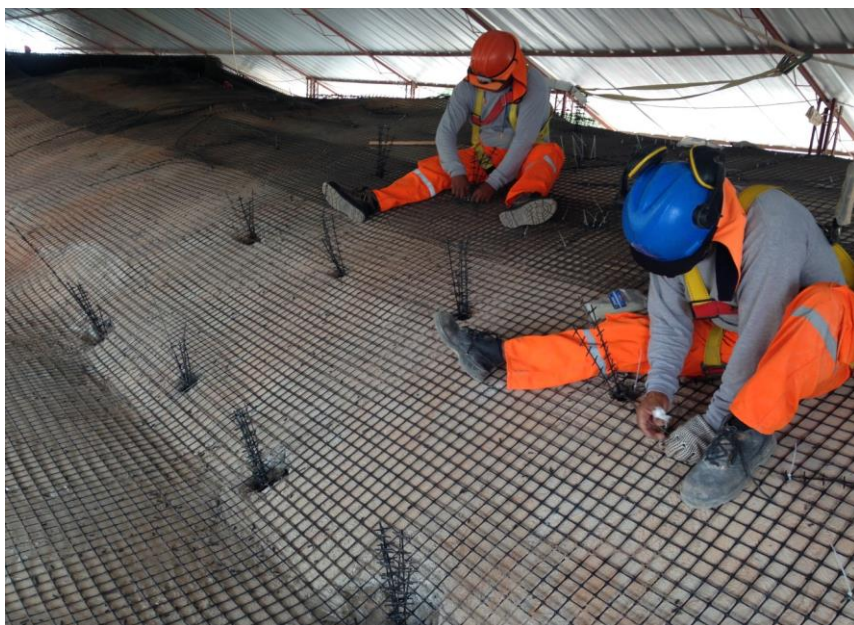


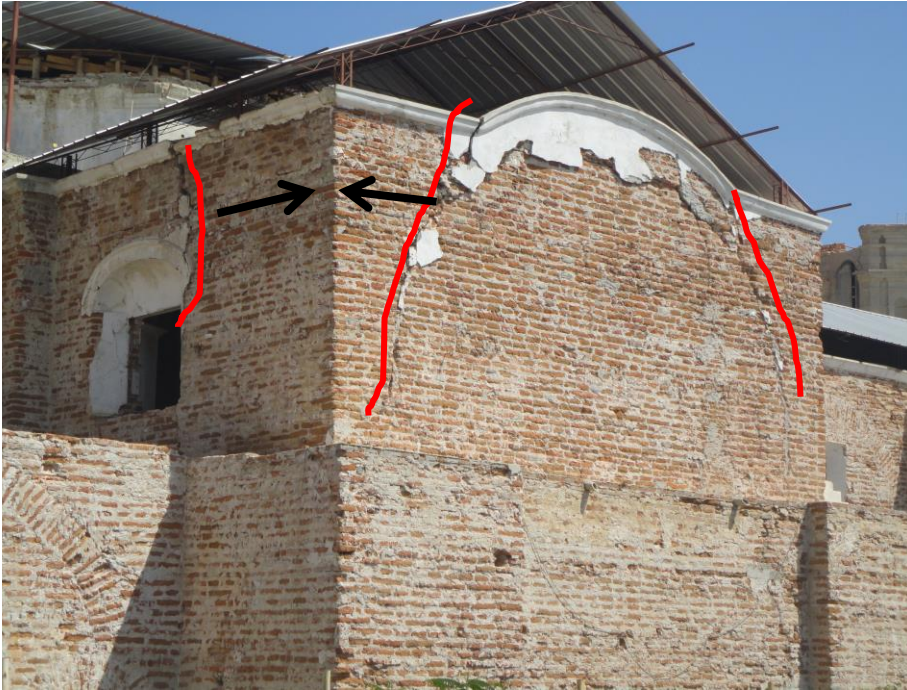


**THE CHURCH OF SECHURA – USING  
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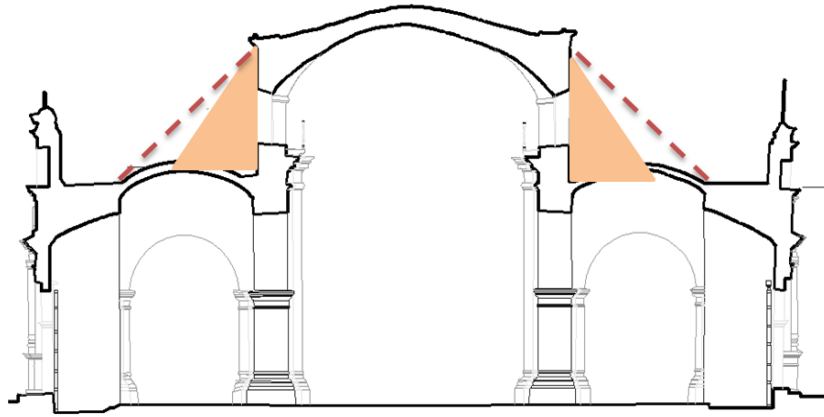
















**THANK YOU VERY MUCH FOR YOUR  
ATTENTION**