Report on Mission to Evaluate the State of Conservation of THE PAOAY CHURCH (The Philippines)

22-29 July 2000

1 INTRODUCTION

1.1 Background

The Paoay church (the Church of San Agustín, see Photo 1) is one of the Baroque Churches of the Philippines included on the UNESCO World Heritage List. Although this church has been struck not only by strong earthquakes but also by heavy typhoons, it has survived for three centuries by grace of its excellent design. However, during various phases of the monument's history, deterioration of the structural materials and deformation of the structure have occurred, necessitating restoration.

Photo 1 The Paoay Church

The Philippine National Commission for Culture and the Arts (NCCA) recently facilitated the restoration of the Paoay Church towards the development of a Master Plan for conservation and preservation of the Paoay Church District. They started with its architectural documentation, geological and structural assessment, and preparation of restoration plan. Together with the documentation there was an inquiry into the structural stability of the monuments, which revealed the alarming tilting and separation of the main facade (west facade wall) from the side walls. These conditions place the monument in danger from seismic activity and material deterioration, calling for the expertise of a structure engineer with special knowledge of the problems of stone structure in a region where seismic activity is high.

An expert mission was sent to study the special conservation problems of the main building of the Paoay Church. The principal objective of this mission was to inspect the structural stability of its main facade (west facade wall).

This mission was successfully conducted in cooperation with NCCA, the responsible national agencies.

1.2 Location and Geological Condition

Paoay is a coastal town the west of Ilocos Norte Province in North Luzon (Fig. 1). This town became an Augustinian independent parish at the end of the 17th century, and the Roman Catholic church was constructed at the beginning of the 18th century. The Paoay church is located at the historic centre, about 5km from the shoreline. According to the report of the geotechnical investigation conducted by NCCA, the subsoil at the site of the church consists mainly of non-cohesive or non-plastic silty sand deposits. Within the uppermost 4m the subsoil is very loose to loose with SPT(Standard Penetration Test) N-values of 2–5 blows, while at greater depth the relative density of the soil increases from medium dense to dense with N-value of 20–50. Ground water level is at a depth of 3.0m below the surface.

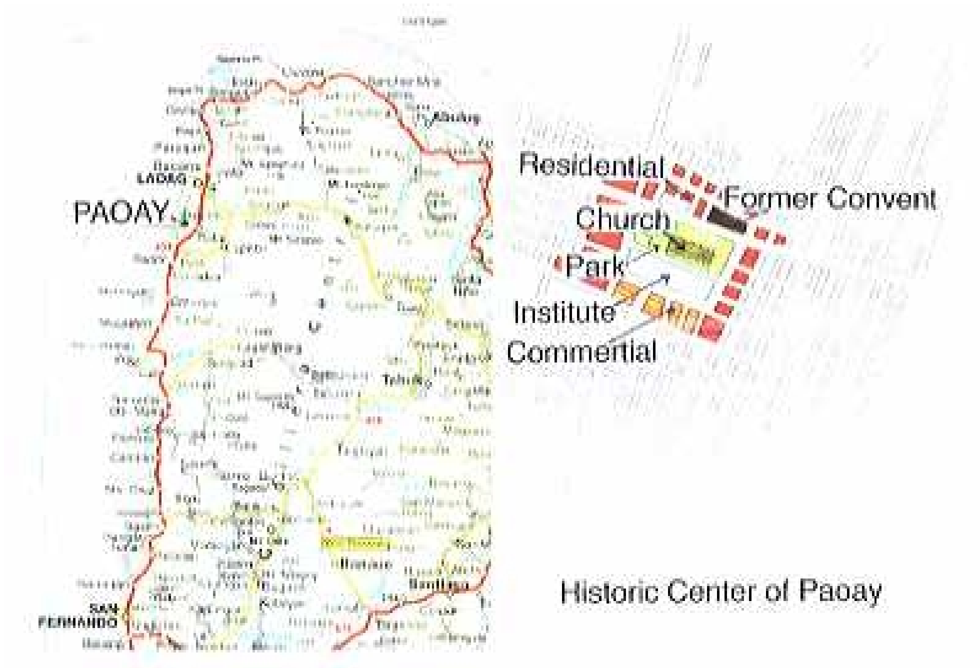


Fig. 1 Location of the Paoay Church

1.3 Architectural History and Properties

Figure 2 shows a perspective drawing of the Paoay Church. Building of the church began in 1694 and was partly completed in 1702, with final completion in 1710. The bell-tower, erected at some distance from the church for anti-earthquake reasons, was finished in the second half of the 18th century. The architecture of this church was produced in response to local natural and climatic conditions, and it was built by Philippine and Chinese craftsmen with no experience or knowledge of Western architecture. As shown in Fig. 3, the church building is of a general box-like plan that may have precedents in a traditional long-house, typical of indigenous architecture as well as similar to south-east Asian forms. This church is also the most outstanding example of "Earthquake Baroque," first described by Pal Kelman with reference to Latin America. Its phalanx of buttresses are the most massive of its kind in the Philippines. A pair of buttresses along the middle of the length of the nave are stairways used for roof access (see Fig. 2).

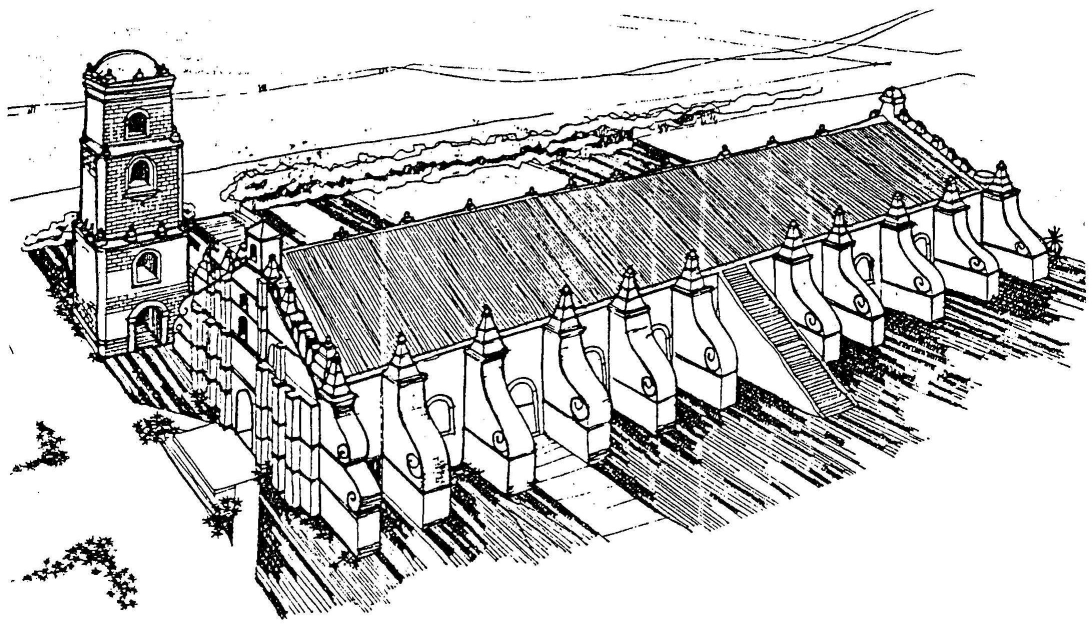


Fig. 2 Perspective of the Paoay Church

Figure 4 shows elevations of both the main facade (west wall) and the rear (east) wall. This figure also provides sections of the buildings. Elevation of the side wall is shown in Fig. 3. The facades, buttresses, and walls were constructed of traditional local concrete, consisting of lean mortar mixed with rubble (in this case the rubble was made up of chips of coral stone, limestone, and brick together with seashells), both the exterior and interior forms being of coral stones or bricks. Coral stones occupy the exterior of the upper level and the finials in the main facade (west wall). The lower half of the rear (east) wall and most of the side walls are also covered with coral stones, while the upper level of the rear wall and the lower level of the main facade are covered with bricks. Judging from the drawings of the architectural documentation, the thickness of the walls at the ground level is 4.2m for the main facade, 2.2m for the side walls, and 2.5m for the buttresses.

On the roofing system, galvanized iron sheets are used for roofing in the existing state, supported by timber trusses (roof tiles were used when the church was constructed.) Furthermore, the main trusses are supported by the reinforced concrete columns that replaced the original brick columns in the first half of the 20th century.

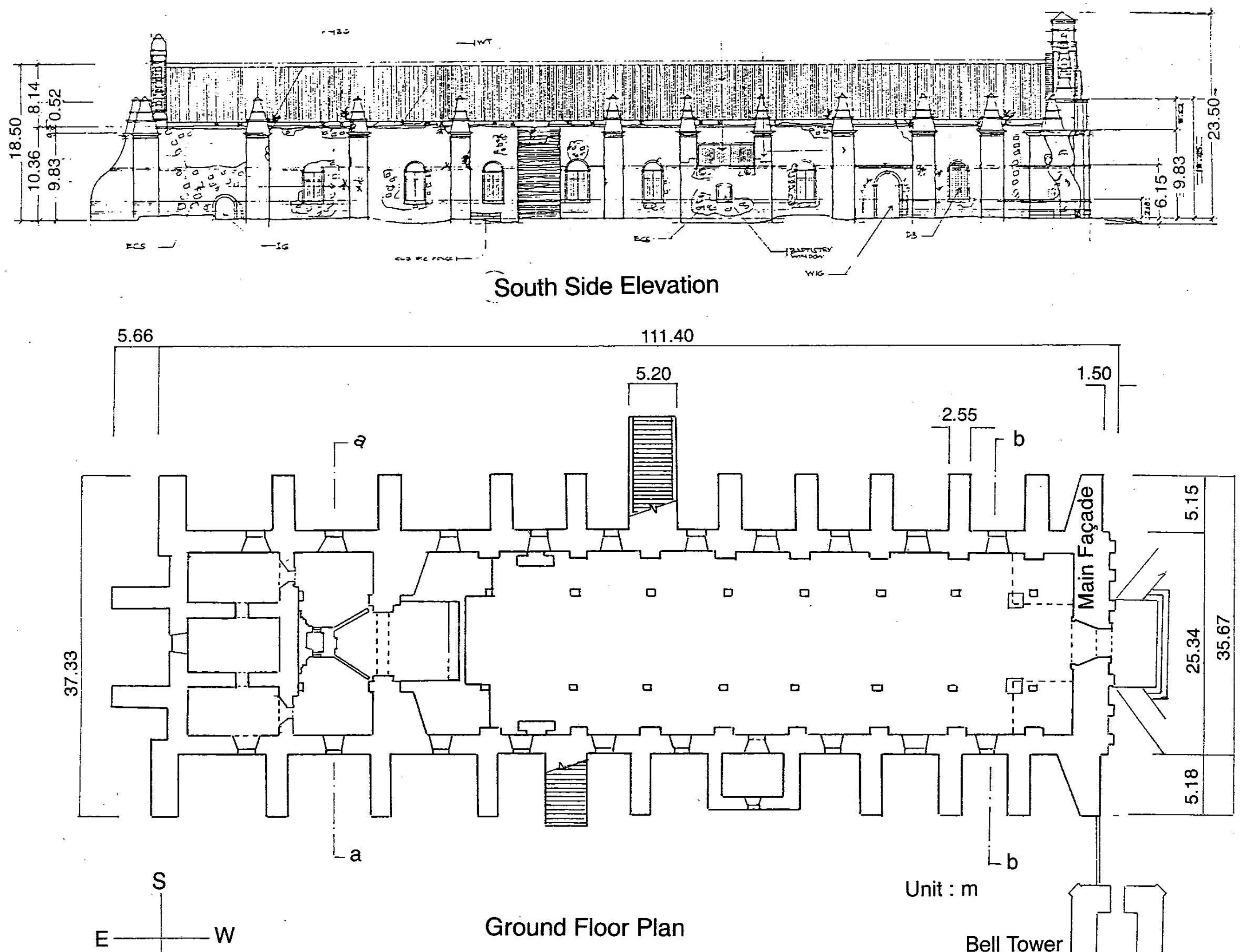


Fig.3 Ground Floor Plan and Side Elevation

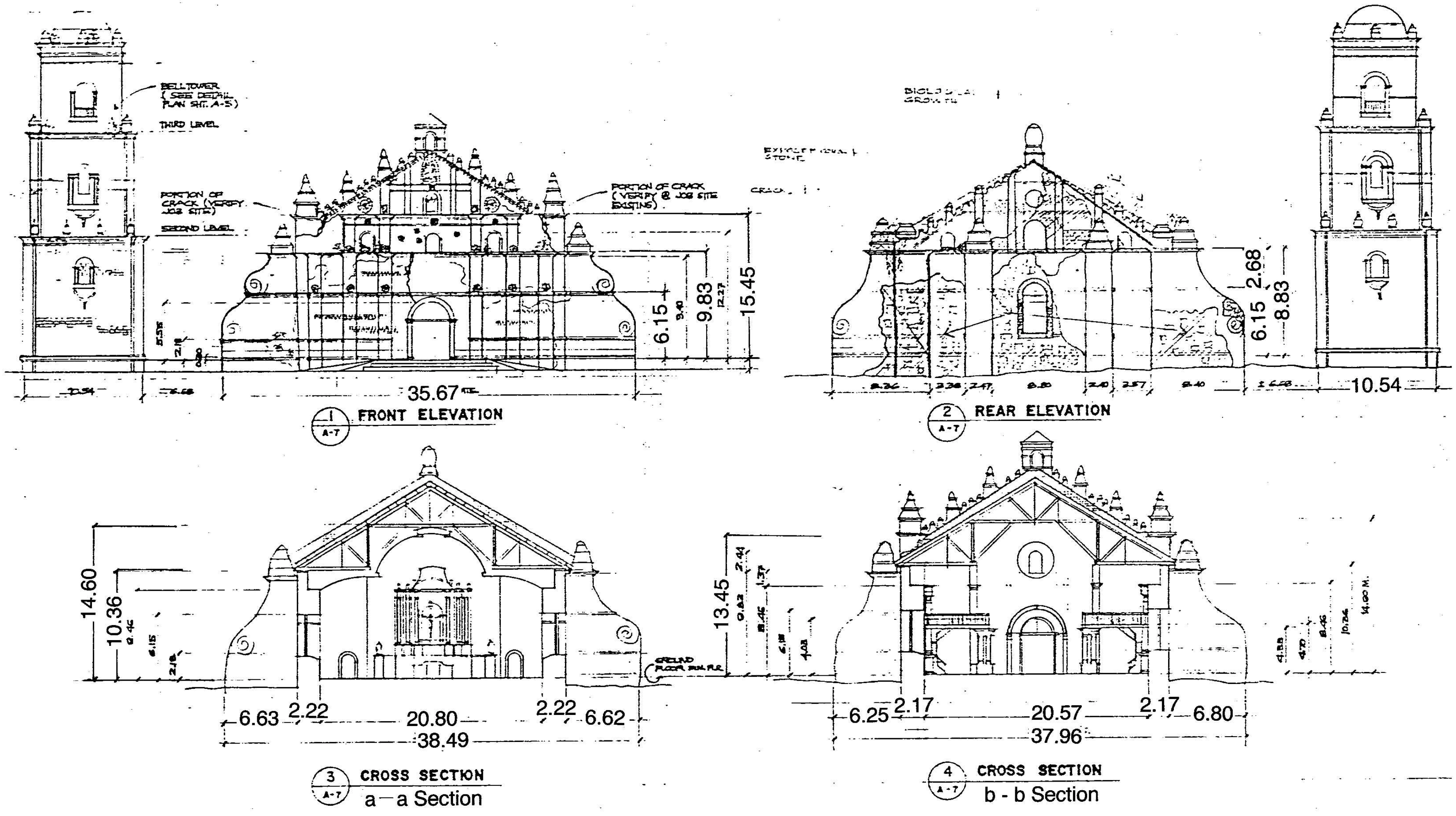


Fig.4 Front and Rear Elevations with Cross Sections

Unit : m

This monument is now used as a Roman Catholic church. Although no public acquisition is being considered, it is protected by the Philippine Government under Presidential Decrees 260 and 1505.

Photo 2 Interior of the Church

2 PROGRAMME OF THE MISSION

22 July Arrival in Manila. Meeting with Professor E Gatbonton and Ms R Jara

23 July Travel by road to Laoag (12 hours) with 7 members of the mission

24 July Visit to Laoag Church and meeting the Priest
Courtesy visit to City Hall and meeting with the Mayor
- Visit to Paoay Church
- Visual inspection of the Paoay Church and the site
- Technical inspection of the Paoay Church
  - Observation of microtremors at the ground and at the structure
  - Measurements of tilting of the facade
  - Measurement of tilting of the side wall
  - Measurements of irregular settlement of the foundation
- Mapping of the structural materials

25 July Technical inspection of the Paoay Church
Observation of microtremors on the ground
Measurements of separation between the facade and the side wall
Measurements of irregular settlement of the foundation
Mapping of cracks and joints
Sampling of the materials
Courtesy visit to meet the Governor of Ilocos Norte

26 July Technical inspection of the Paoay Church
Measurements of deformation of facade
Measurements of irregular settlement of foundation
Meeting at the convent (the priest of the church)
Visual inspection of the historic convent next to the church
Evening visit to the World Heritage Site of Vigan

27 July Visit to the Santa Monica Church in Sarrat (severely damaged by the large earthquake of 1983)
Visit to the Paoay Church
Visit to City Hall of Paoay and lunch meeting with the Mayor and local authorities in Paoay
Visit to the World Heritage Church of Santa Maria (the Church of Nuestra Senora de la Asunción)
Return by road to Manila

28 July Technical meeting at NCCA to consolidate initial findings and to discuss recommendations
Visit to the World Heritage Church of San Agustín, Intramuros, Manila

29 July Departure from Manila

3 KEY INDIVIDUALS WHO ASSISTED IN ORGANIZING THE MISSION

The mission was given ample opportunities to meet key personnel of the different heritage organizations and the executive bodies at both local and national level.

The program was organized and coordinated by:

Professor Esperanza B Gatbonton (Consultant, Heritage Sites, NCCA)
Ms Rhea Jara (Coordinator, Heritage Sites, NCCA)

The visual and technical inspection at the site was carried out with:

Professor Esperanza B. Gatbonton
Ms Rhea Jara

Ishmael C Narag (Senior Science Research Specialist, Philippine Institute of Volcanology and Seismology)
Mr Angel G Lanuza (Senior Science Research Specialist, Philippine Institute of Volcanology and Seismology)
Mr Norberto S Tolentino (National Museum)
Mr Rene Mata (Architect, NCCA Committee on Monuments and Sites, ICOMOS Philippines)
Mr Reynaldo A Inovero (Architect, Chief, Historic Preservation Division, National Historical Institute)
Mr Arnulfo F Dado (Architect, Historic Preservation Division, National Historical Institute
Mr Chito B Aquino, CE (Municipal Engineering Office, Municipal Hall)
Mr Nestor B Pacial (Architect, Dept. of Public Works and Highways, Ilocos Norte Engineering District)
Mr Emmanuel S Agustín (Draughtsman, Dept. of Public Works and Highways, Ilocos Norte Engineering District)
Mr Romillo P Ednilao (Dept. of Public Works and Highways, Ilocos Norte Engineering District

Key individuals met during the visit were:

The Hon Ferdinand R Marcos, Jr (Governor of the Province of Ilocos Norte)
The Hon Reginita Nenuca Evangelista (Mayor of Paoay)
Mgr Rodolfo R Nicolas (Diocesan Administrator, Diocese of Laoag)
Mgr Mario Garaza (Parish Priest of Paoay Church)

Those who took part in the meeting at NCCA were:

Professor Esperanza Gatbonton (introduced above)
Professor Regalado Trota José (President of Philippine ICOMOS, NCCA Committee on Monuments and Sites
Ms Emilie V Tiongco (Deputy Executive Director, NCCA)
Ms Jeannette Tuazon (Deputy Executive Director, UNESCO Philippines)
Mr Evelyn R Cajigal (Director, Legal Services, Department of Tourism)
Ms Gabriel S Casal (Director, National Museum)
Mr Orlando Abinion (Curator for Conservation, National Museum)
Mr Reynaldo Inovero
Mr Arnulfo Dado
Mr Ishmael Narag
Mr Angelito Lanuza
Ms Rhea Jara
Ms Hannah Parado (NCCA, Heritage Sites)

Key individual met during the visit to NCCA:

Mr Virgilio S Almario (Executive Director, NCCA)

4 FINDINGS OF THE MONITORING MISSION

4.1 Visual Inspection

4.1.1 Structural condition

As introduced in Section 1.3, the structure is characterized by shear walls with solid buttresses and a light roof with timber trusses. The triangle of the main facade and the rear wall show stability.

4.1.2 Non-uniform settlement of the building

Although it may be necessary to evaluate contact pressure at the base of the foundation, the settlement of the main (west) facade shows a typical pattern of settlement of a rigid structure resting on sandy soils. Settlement at both north and south ends is greater than that at the central part, caused by deformation of soils in accordance with elastic theory.

4.1.3 Problem of vegetal growth

The exterior of the building suffers from vegetal growth, though the mission was told that that the vegetation had been removed in 1997. The roots of the vegetation penetrate through the stone joints and the cracks and their growth degrades the mechanical properties of stone materials.

Photo 3 Vegetal Growth on South Wall

4.1.4 Tilting of the main facade

The main (west) facade has non-uniform tilting. While it shows inward tilting at the lower level, it shows outward tilting at the upper level.

4.1.5 Separation of the main facade and the side walls

The separation (large cracks) of the main facade from the side walls constitutes a serious structural problem, as shown in Fig .4. The separation causes large cracks at the north-west and south-west corners of the building.

Photo 4 Separation of Facade from Side Wall

4.1.6 Structural condition of the rear wall

The rear (east) wall has no structural problem because the buttresses support it and because the rear facade is a part of the apse that acts as a structural core.

4.1.7 Relationship of direction of the axes of the building and that of the active faults near the site

The longitudinal axis of the building is in the east–west direction and the main facade faces to the west. In the seismic zone of North Luzon, the active faults that might cause earthquakes run in a north–south direction. Recent studies indicate that the predominant component of earthquake ground motions (principal axis of ground motions) in an epicentric area tends to be perpendicular to the running direction of the fault lines. This means that the main (west) facade of the church has been subjected to stronger motions in an east–west direction than in a north–south direction. The separation of the main facade from the side walls may have been caused by the large earthquakes that occurred near the site in the past.

4.1.8 Historical earthquakes

There are records of the main historical earthquakes in the present mission. The church was hit by the large earthquakes in 1706, 1852, 1927, and 1983. It is understood that large earthquakes also took place in 1852 and 1983 and an inscription at the entrance describes the church as having been damaged by the earthquakes in 1706 and 1927.

4.2 Technical Inspections

4.2.1 Microtremor observations

Records of microtremors (ambient vibrations) are useful for evaluation of soil conditions from a seismic engineering point of view. They are also helpful for the simulation of anticipated earthquake ground motions at the site. Those records also reveal dynamic fundamental properties of the structure. In order to investigate dynamic properties, microtremors were measured both on the ground and on the structure.

Microtremors on the ground were measured at Borehole 1 (BH1) and Borehole 2 (BH2), both of which had been dug to investigate the soil conditions. The predominant period of the microtremors at the site was observed to be about 0.4 second, as shown in Fig. 5. This suggests that, since the subsoils are moderately stiff , amplification due to soil response is not so high. If there is PS-logging (geophysical logging) data at the site, it will be possible to simulate the amplification of earthquake ground motions at the site

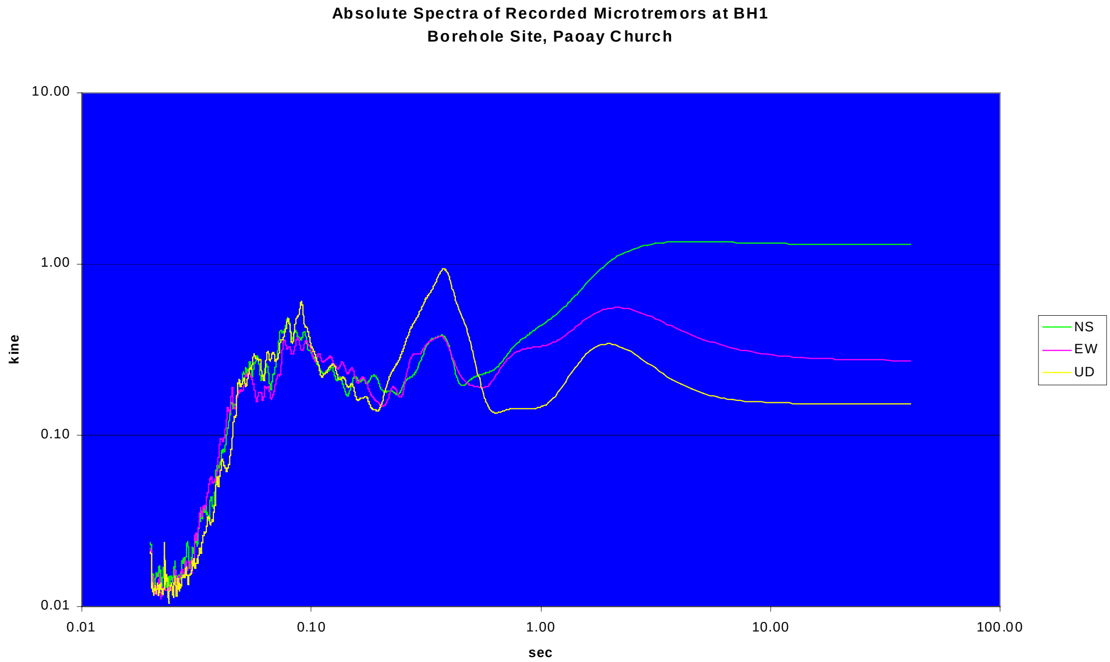


Fig. 5 Fourier Spectra of Microtremor at Borehole 1

The microtremors were also recorded at the top of the side wall and at the base. The peak period of the spectral ratio of the top to the base was observed to be about 0.1 second, as shown in Fig. 6. However, the microtremors at the main facade could not be recorded, because it was not possible to reach the top of the facade to set the transducers. Further observation of the microtremor at the main facade will be needed to investigate the fundamental dynamic behaviours.

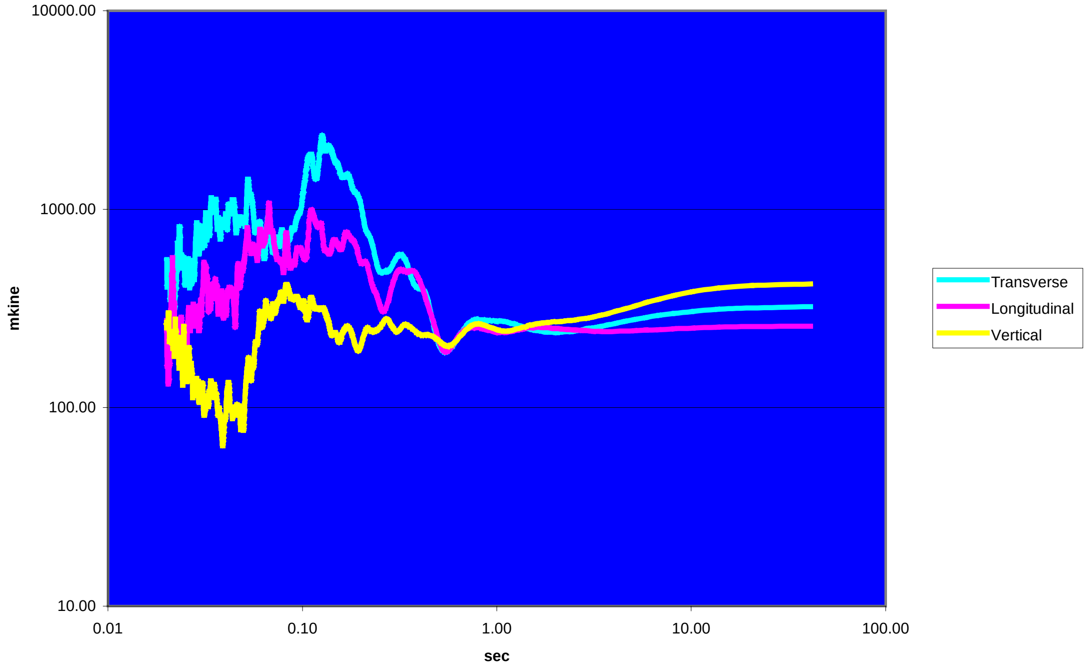


Fig. 6 Spectral Ratio of the Top of the Side Wall to the Base

4.2.2 Survey of tilting and deformation of the main facade

It should be noted that the facade (west wall) is as thick as 4.2m at the ground floor level. The facade is 23m high and the thickness is less at the upper level.. However, no data are available about the variation of thickness of the main facade along the height.

Following the inspections in this mission, the survey of tilting and deformation of the main facade can be summarized in what follows.

It was pointed out by the Philippine authorities that the tilting of the main facade threatens structural stability of the Paoay Church. However, there are no data about its alarming tilting. The deformation of the main facade was therefore surveyed, both along the elevation and in the horizontal plane. Figures 7 and 8 show the tilting of the facade and the deformation in the horizontal plane respectively. In Fig. 7 it will be seen that the facade tilts inwards at the lower level, whereas it tilts outwards at the upper level. At the apex (top of the facade), the inclination from the vertical was measured to be 1°24′ outwards. These measurements reveal that the tilting angle of the main facade is not uniform, indicating that the alarming tilting of the facade is not directly the result of irregular settlement of the foundations during the consolidation of the subsoils. On the other hand, the horizontal profile shown in Fig. 8 reveals that the facade deforms outward both at the north and the south ends where the side walls joined with the main facade

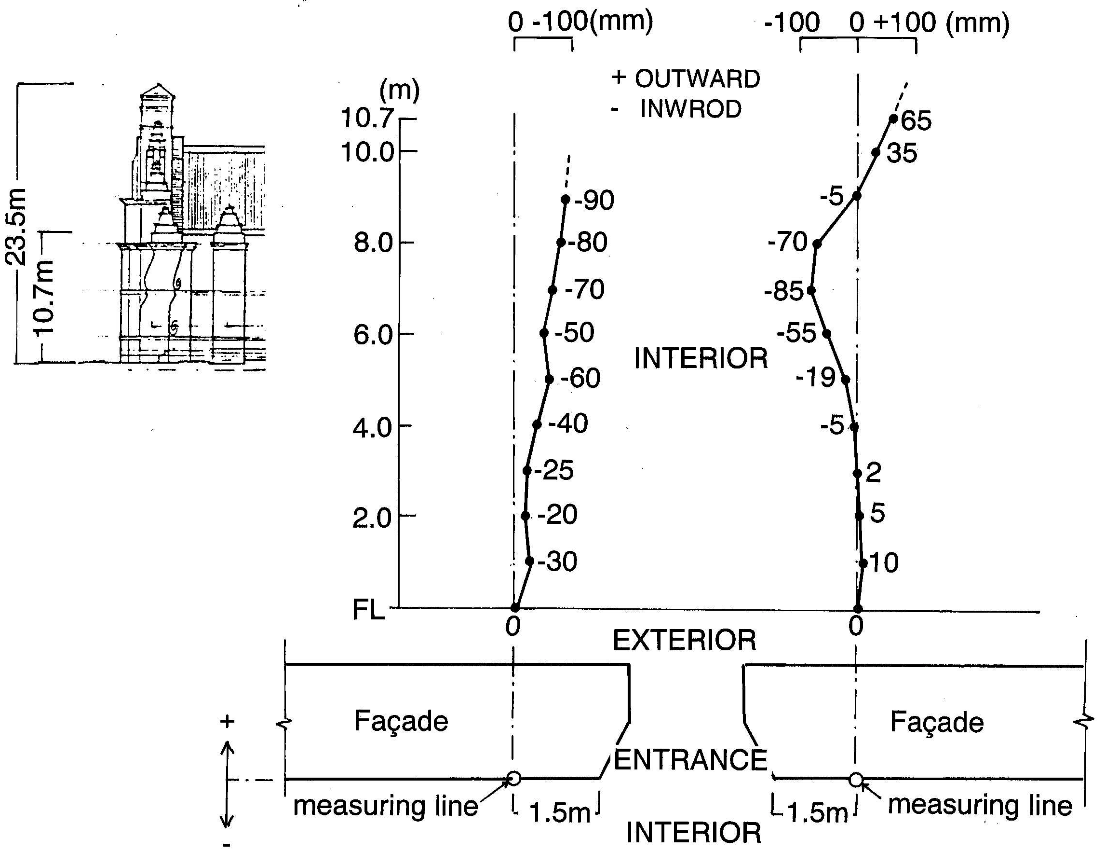


Fig. 7 Tilting of the Main Facade (FL 0.0–10.7m)

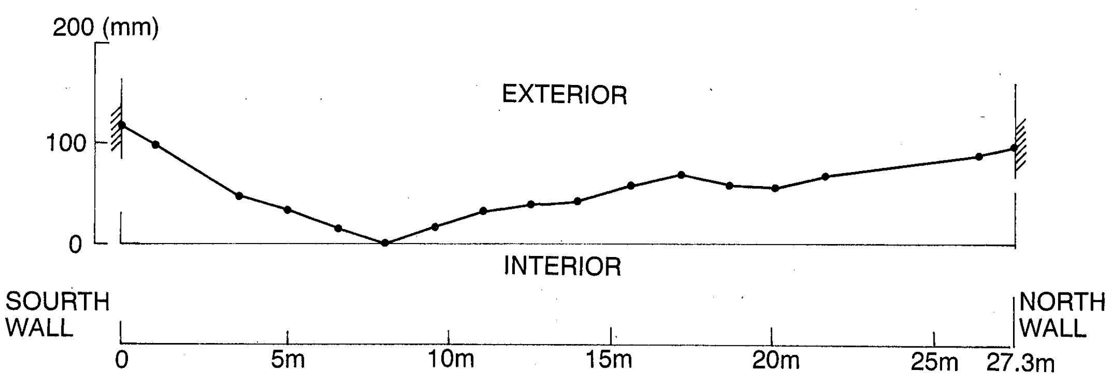


Fig. 8 Deformation of the Main Facade (Horizontal Section Profile at FL +9.0m)

4.2.3 Measurement of the width of cracks between the main facade and the side walls

Figure 9 shows the separation (large cracks) between the main facade and the side walls (see Photo 4). The separation at both north-west and south-west corners becomes larger as it rises. As shown in Fig. 9. At the top of the side walls, the width of the separation was 15cm and 9cm at the north-west and south-west corners respectively. From a structural point of view, attention must be paid to whether the separation is increasing or not. If the separation increases gradually (the cracks widen) irrespective of the variation of the climate, the structural intervention should be done as soon as possible.

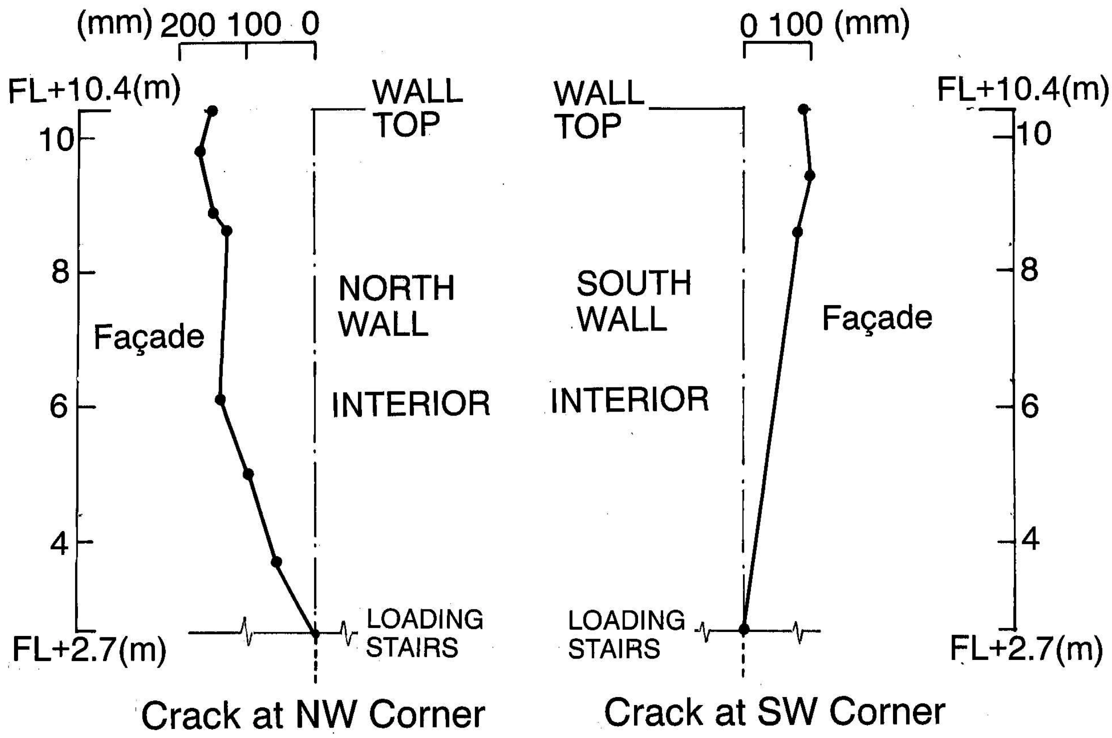


Fig. 9 Crack Width between the Main Facade and the Side Walls

4.2.4 Irregular settlement of the foundation

In the survey carried out during the mission, the level of the buttresses and the ground floor of the building was measured to investigate settlement of the foundation. Figure 10 shows the level of the skirting stones at the base of the main facade, the rear wall, the side walls, and the buttresses. Judging from both the visual inspection and the survey of the levels, the level of the north and south ends of the main facade shows a tendency to be lower than its central part, indicating the settlement of the structure due to the elastic deformation of the sandy soils, as pointed out in 4.1.1.

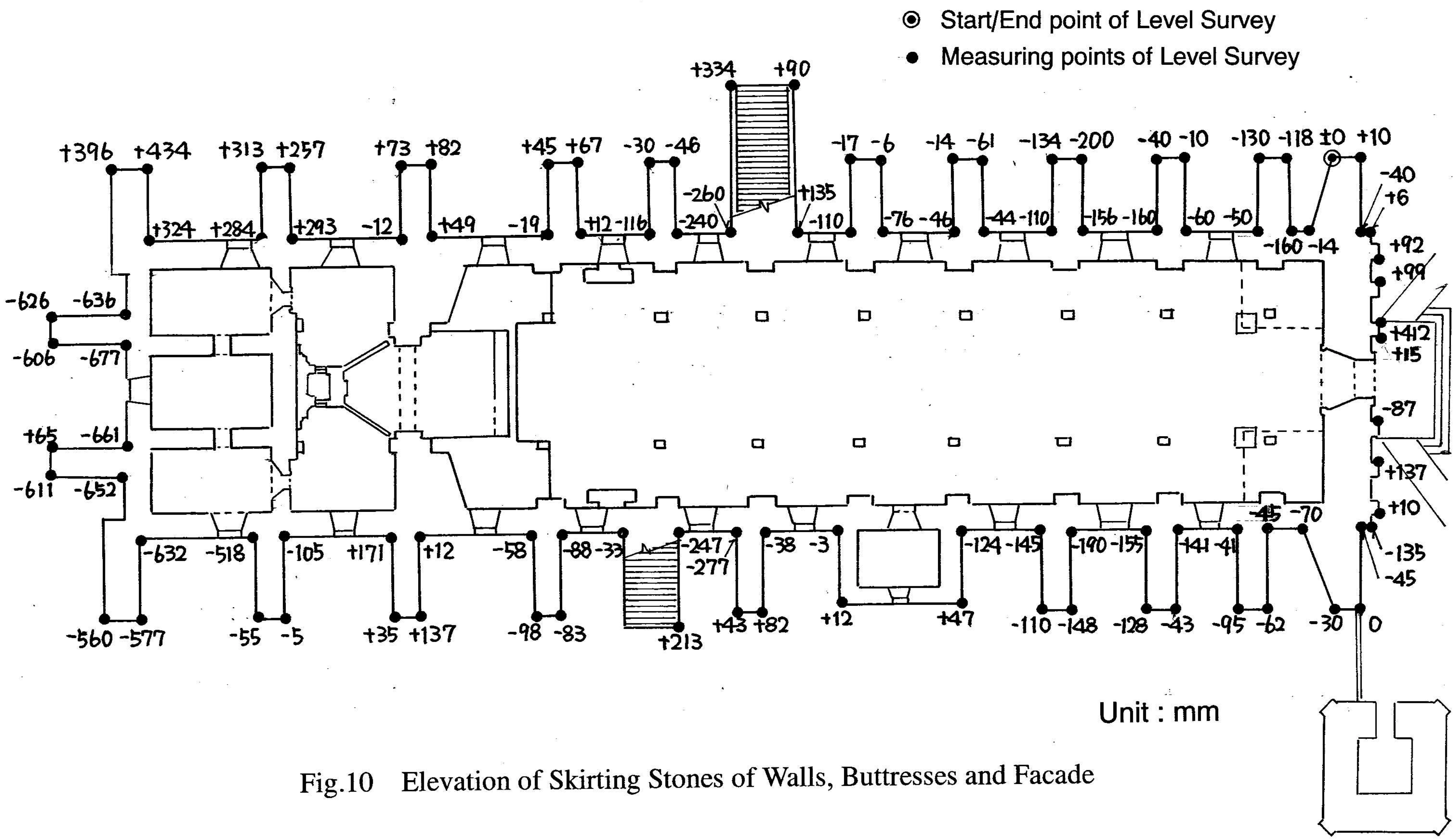


Fig.10 Elevation of Skirting Stones of Walls, Buttresses and Facade

4.2.5 Construction materials and their conditions

The maps of both the exterior and interior surface materials and the section of the structure were drawn by Paoay architects in order to understand the structural conditions. The exterior surface materials of the building were coral stones or bricks. Figures 11 and 12 illustrate typical sections of the wall on the basis of the visual inspection, also showing a typical section of the facade. As shown in these figures, the coral stones and bricks cover the traditional local concrete made up of mortars mixed with rubble. These figures indicate that this traditional local concrete is a more important material from a structural point of view. However, no information is available about the mechanical properties of the traditional local concrete.

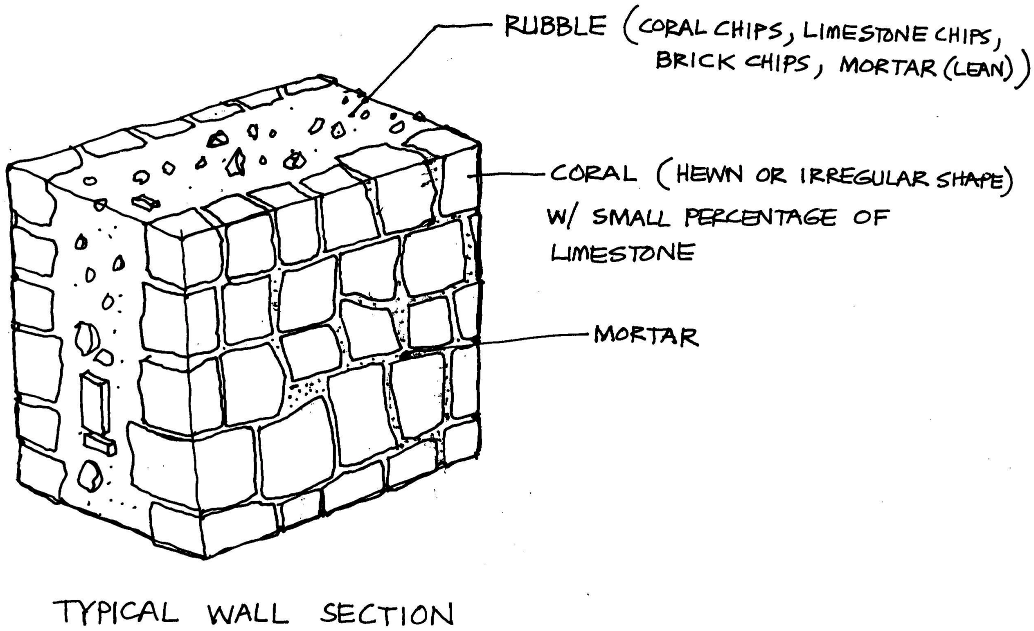


Fig. 11 Typical section of wall with coral stone

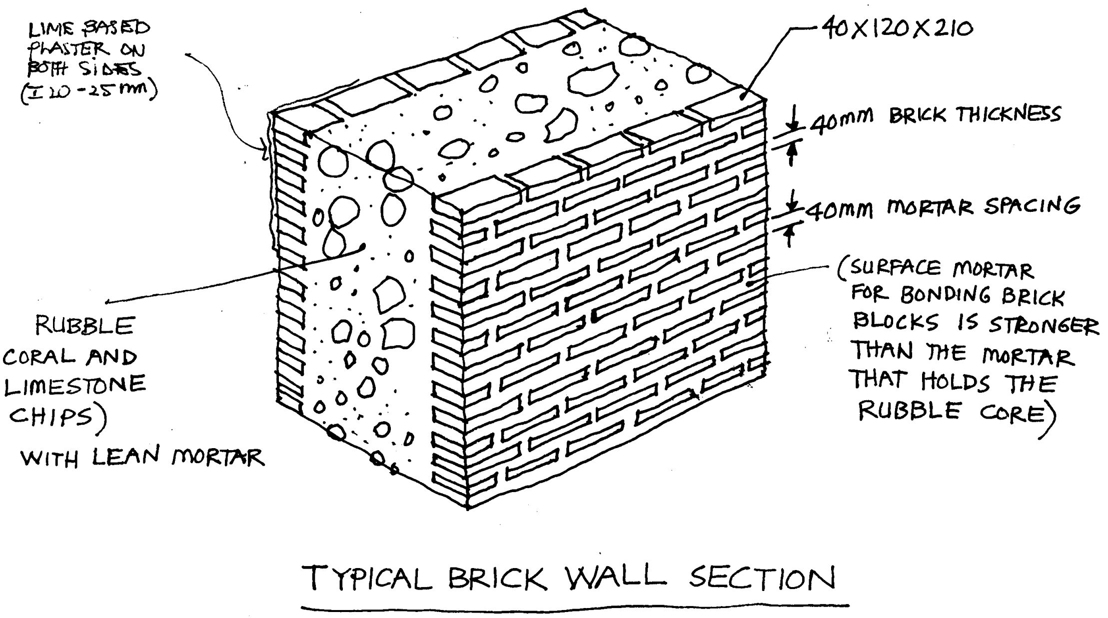


Fig. 12 Typical section of wall with brick

In this monitoring mission maps were drawn of visible cracks in the facade, the rear wall, and the side walls. At the same time, maps were drawn of cracks and joint gaps on all the buttresses; the condition of the buttresses, illustrated in Fig .13, was also recorded.

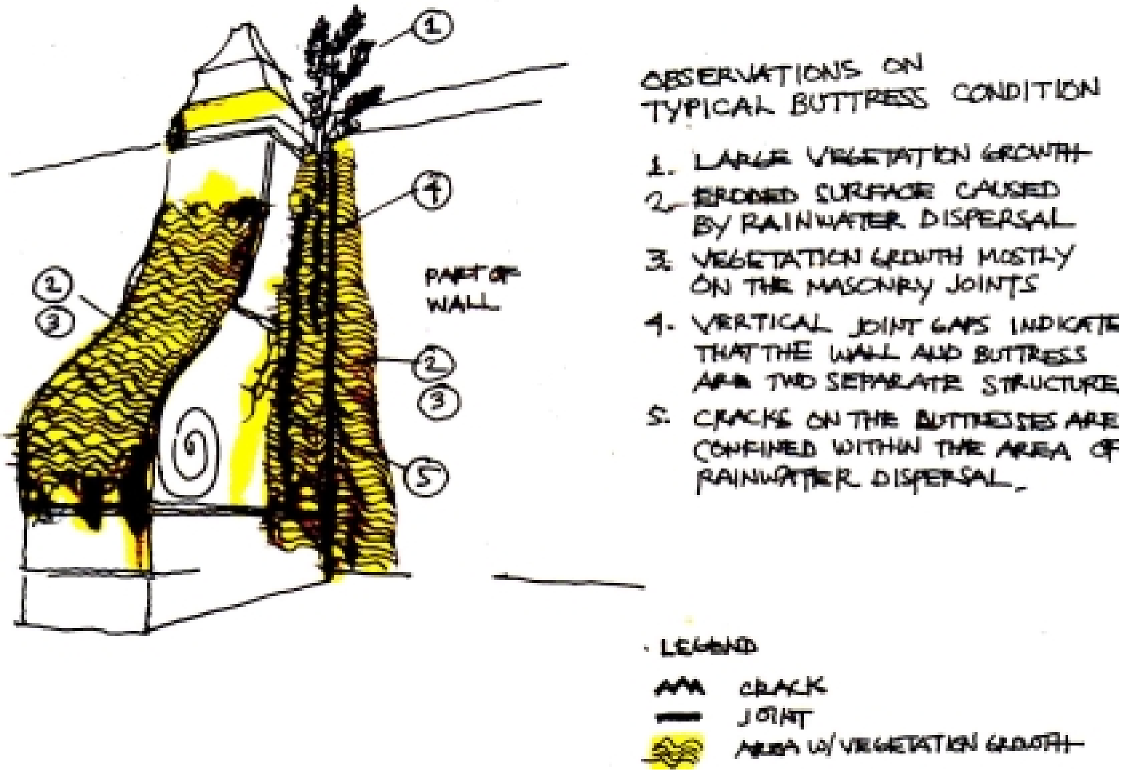


Fig. 13 Typical condition of buttresses

4.2.6 Material sampling

Sampling of the materials was carried out to obtain some pieces of the coral stones, the bricks and the traditional local concrete. The laboratory tests should be carried using these samples in order to examine the mechanical properties of the structural materials. Compression tests, tension tests, sonic (elastic wave) tests, and density tests would be expected to provide the data used for structural analyses.

4.2.7 Active faults and historical earthquakes in North Luzon

Figure 14 is a map of the active faults and historical earthquakes in North Luzon. North Luzon is in the Philippine fault zone where the Philippine plate is subducting. Major earthquakes of the magnitude higher than 7.0 can be anticipated in this region.

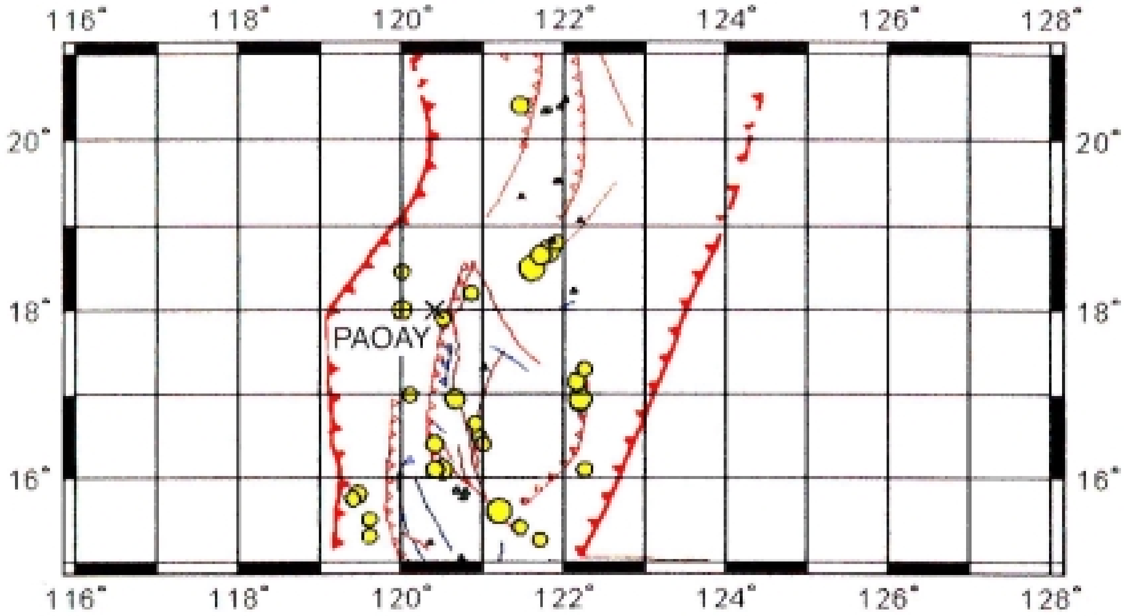


Fig. 14 Active faults and historical earthquakes of magnitude 6–9 from 1500 to 1897 (from the Philippine Institute of Volcanology and Seismology)

4.3 History of the wide separation between the main facade and the side walls

The priest of the Paoay Church said that the serious separation (large cracks) of the facade from the side walls resulted from the destructive earthquake of 1983. This earthquake caused severe damage to the masonry churches in the provinces of Ilocos Norte and Ilocos Sur. He also said that the cracks have not apparently widened since then.

Further information should be obtained from the priest who was working in the Paoay Church when the large earthquake occurred in 1983

4.4 The cause of the tilting of the main facade (Separation of the facade from the side walls)

Before carrying out the monitoring mission, the cause of the tilting of the facade was attributed to the following:

1. Irregular settlement of the foundation due to the subsidence of the soils;
2. Response to the strong movements during large earthquakes in the past;
3. Long-term deformation of structural materials which have deteriorated;
4. Deformation of the traditional local concrete of mixture of mortar and rubble during and just after the construction (similar to fresh concrete before hardening).

Visual and technical inspections were carried out during the monitoring mission.. The achievement of the monitoring mission indicated that the cause might be 2., 3., or 4. A combination of these factors may also be considered.

However, further studies will be needed to judge the cause of the tilting and deformation of the main facade. It will be necessary to conduct structural analyses, as well as investigation of the material properties and the foundation.

5 RECOMMENDATIONS

The main facade of the church is structurally stable under today's conditions, provided that the church is not subjected to destructive external loads. However, monitoring of movement of the cracks of the main facade should be started as soon as possible. Furthermore, additional surveys and analyses should be carried out to study the structural stability against large earthquakes that will occur, as well as to design the structural intervention.

5.1 General

- It is necessary to respect the inherent structural excellence of the church, which has survived for three hundred years in a seismic region.
- There is a need to understand the various phases of the monument's history and significant change concerning the structural stability and the state of the materials.
- Before making a decision on the structural intervention, it is essential to identify the causes of structural problems and the material deterioration, and then to evaluate the safety level of the structure.
- The design of remedial measures should be based on a clear understanding of the kind of actions that caused the structural damage and the material deterioration, because the philosophy of intervention may change relative to them.

5.2 Monitoring of movement of the cracks of the main facade

To check the structural stability at the present state, structural monitoring should be carried out. Movement of the cracks at the main facade (separation of the facade from the side walls) should be monitored to check whether the cracks were developing or in stable situation. At the same time, the climate conditions of temperature and humidity should be also monitored, because, in general, the width of cracks varies according to climatic conditions. It is recommended that monitoring of the main cracks should continue for at least three years in order to understand the relation between the movement of the cracks and the climatic conditions. Those data are periodically recorded by a monitoring system. The monitoring of the crack's movement should be started as soon as possible.

5.3 Further surveys needed for the structural stability

The following surveys are required for further study of the structural stability:

- Additional observation of microtremors at the main facade;
- Additional boreholes for better subsurface profiles;
- Additional sampling of structural materials and mechanical tests;

It is also desirable that earthquake observation should be carried out at the site (on movement of both the ground and the structure)

5.4 Evaluation of the cause of the cracks and the deformation of the facade

The causes of the large cracks (separation of the main facade from the side walls) and the deformation of the facade should be assessed before any structural intervention is designed. In other words, the structural intervention should be planned taking into consideration the causes of the large cracks and the deformation at the facade.

5.5 Structural safety evaluation in the present conditions

The structural safety of the church against anticipated earthquake ground motions should be examined. For this purpose, external loads and the inherent potentialities against strong motions should be evaluated. To evaluate external loads caused by the anticipated earthquakes, maps of the active faults in the region of North Luzon and the records of the historical earthquakes are available. These data can yield peak amplitude and response spectra of the anticipated ground movements. Input ground movements can be simulated by taking into account the dynamic amplification of soils at the site. (If sufficient data concerning the earthquakes are not available, the seismic building code of buildings in the Philippines will be applicable.)

The earthquake resistant capacity of the church in the existing condition should also be evaluated by structural analyses using the mechanical properties of the structural materials. It will be necessary to investigate the mechanical properties of the structural materials such as the coral stones, the bricks, and the traditional local concrete mix of mortar and rubble. In particular, the mechanical properties of the traditional local concrete are of importance for the evaluation of its earthquake resistance. Since the external facing materials have been weathering and decayed, it is essential to investigate the material properties in the interior, where the materials have not been weathering.

Furthermore, the structural condition of the foundation should be surveyed in order to obtain data about the stability against overturning of the main facade. Excavation will clarify the structural conditions of the foundation

5.6 Structural analyses for designing the seismic intervention

If the inherent resistant capacity of the building is insufficient as compared with external loads from anticipated earthquakes, seismic intervention should be applied. Since it is will be necessary to design the minimum intervention for the restoration of architectural monuments, structural analyses should be carried out.

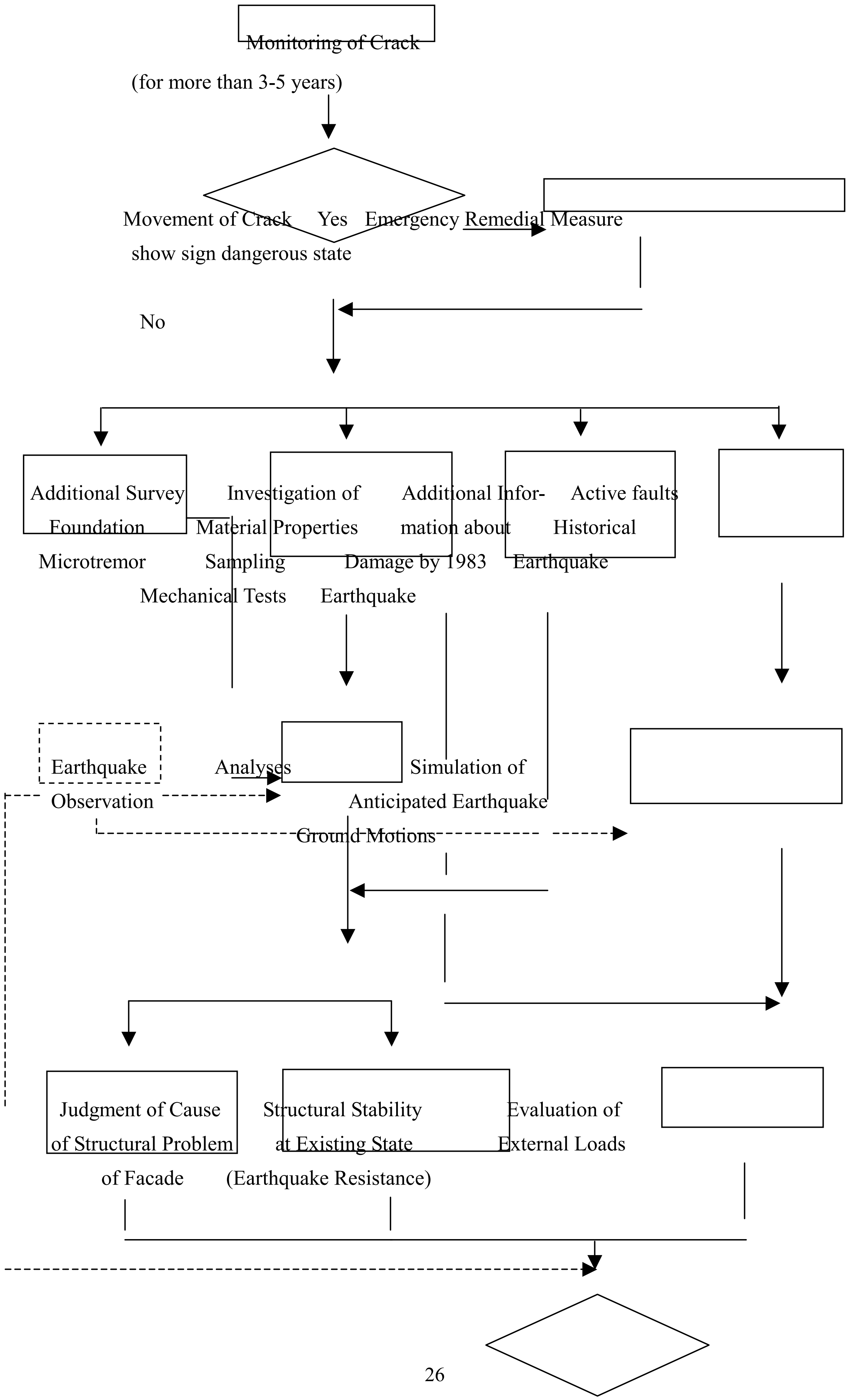
5.7 Materials for structural intervention

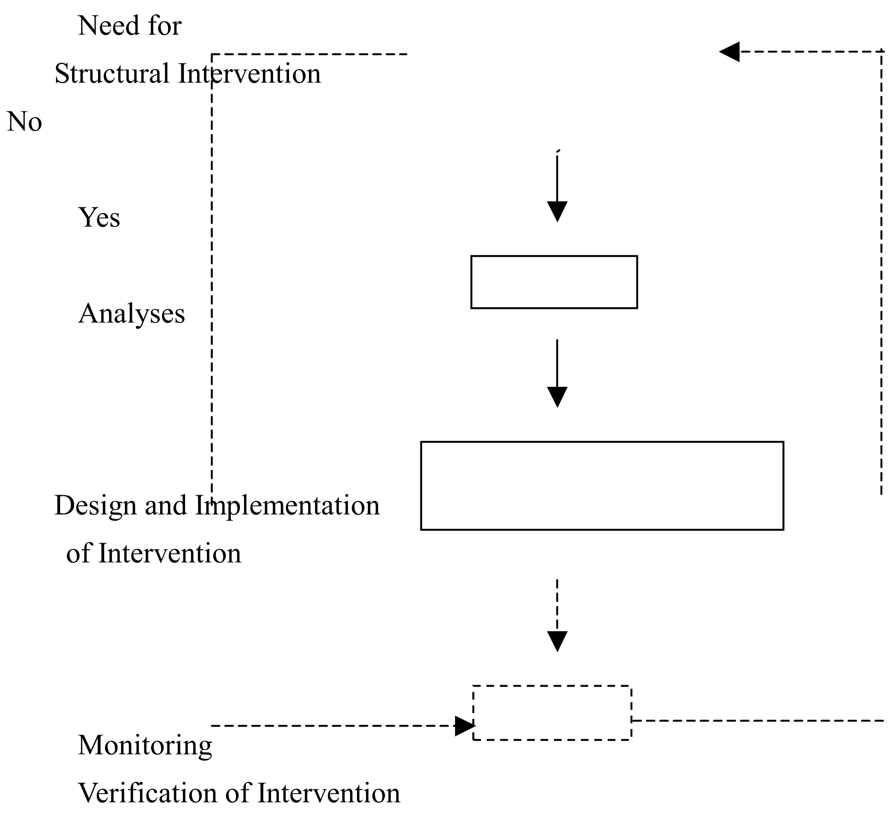
In selecting materials used for intervention, attention must be paid to their durability. If ordinary structural steel members are used, attention should be paid to the fact that they rust under such tropical climate conditions, and that the construction materials may contain salt. The traditional local concrete contains seashells, which indicates that the rubble contains salt. If the traditional local concrete in the main facade contains salt, structural steel inserted in the facade may corrode rapidly. When steel members are used for structural interventions, protective measures against rust should be applied at the same time. Other materials such as stainless steel, titanium alloy, or carbon fibre may also be used for structural interventions, although these are considerably more expensive than structural steels.

5.8 Recommendation of flow chart

A full understanding of structural behaviours and material characteristics is required in conservation practice. For this purpose, structural analyses, additional mechanical tests of materials, and investigation of earthquake records are required. Safety evaluation and understanding of the significance of the structure should be the basis for conservation measures. Furthermore, no actions should be undertaken without it having been confirmed that they are indispensable. Long-term monitoring should be carried out before, during, and after the intervention to ascertain its results and its efficiency. All these activities should be documented and the records maintained as part of the history of the structure.

On the basis of these concepts, a flowchart for the structural preservation of the Paoay Church is recommended in the following figure. In the present flowchart, broken line denote additional studies that may be expected to perform.


Monitoring of Crack
(for more than 3-5 years)
Movement of Crack
show sign dangerous state
Yes
Emergency Remedial Measure
No
Additional Survey
Foundation
Microtremor
Investigation of
Material Properties
Sampling
Mechanical Tests
Additional Infor-
mation about
Damage by 1983
Earthquake
Active faults
Historical
Earthquake
Earthquake
Observation
Analyses
Simulation of
Anticipated Earthquake
Ground Motions
Judgment of Cause
of Structural Problem
of Facade
Structural Stability
at Existing State
(Earthquake Resistance)
Evaluation of
External Loads



Recommended Flow Chart

Toshikazu HANAZATO

ICOMOS International (Paris)

ICOMOS Japan (Tokyo)

17 September 2000