BAKÁS PILIPINAS

PHILIPPINE HISTORIC PRESERVATION SOCIETY

PRELIMINARY EXISTING CONDITION SURVEY:

THE ORPHAN CHURCHES OF BOHOL

PREPARED BY: Bakás Pilipinas, Inc.

FOR: The Diocese of Tagbilaran, Bohol

OCTOBER 2015 **FINAL**

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PREPARED BY: Bakás Pilipinas, Inc.
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FOR: The Diocese of Tagbilaran
Tagbilaran City
Bohol, Philippines

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Contents

1. Executive Summary

The October 15, 2013, earthquake and aftershocks caused significant damage to the three historic reinforced concrete parish churches on the Philippine island of Bohol in the towns of Antequera, Catigbian, and Sikatuna. The damage ranged in severity from moderate to extreme. Some of the moderate damage, such as spalling concrete, does not affect the occupancy of the churches. However, in the case of loose and displaced sections of concrete, roof structure, and ceilings, the damage has led to unsafe conditions, and rendered whole buildings, or parts of the buildings, unoccupiable.

This "Preliminary Existing Condition Survey," based on a rapid visual screening of the three churches, has identified possible seismic deficiencies in the construction of some building components, such as inadequate reinforcing steel, and lack of connections between walls, that are recommended to be evaluated and remedied during repair and retrofit work to upgrade the overall seismic performance of the buildings. In addition, the earthquake brought to light some maintenance practices that should be improved to enhance the appearance of the buildings, and more importantly, to maintain a weathertight enclosure and prevent deterioration of the structural components.

Given the high seismic hazard risk of Bohol, some damage to older buildings is inevitable during strong and destructive earthquakes. However, if properly seismically evaluated and retrofitted, the risk to life safety from collapse and falling debris hazards can be greatly lowered.

In summary, the recommendations are:

- Remove dangers to life safety, including falling hazards, such as loose or displaced concrete, collapsed roof structure, and loose sheet metal ceilings.
- Install temporary protection at openings at roofs, walls, and ceilings, until permanent construction is completed.
- Perform a comprehensive seismic evaluation of the structural and non-structural components of the buildings, by a process of data collection and structural analysis, following current international standards for seismic evaluation.
- Undertake a seismic retrofit of deficient components, by a process of retrofit design, preparation of construction documents, construction following a quality assurance plan, and regular maintenance of the buildings.

These are ideal recommendations, and are presented to the Diocese of Tagbilaran with the recognition that some aspects of the recommended work may be economically unfeasible, or determined as unnecessary due to the Diocese's selected performance objectives, or must be altered to comply with requirements of applicable codes and regulations and interpretations by the local code officials. The recommendation are thus presented as a standard that the Diocese may follow for concrete churches and similar buildings of this type and age where deemed practical.

Bakás Pilipinas hopes, through its involvement in the restoration of the Orphan Churches of Bohol, that "best practices" can be established and demonstrated for the preservation of historic early 20th century (American colonial period) reinforced concrete structures, which can be found throughout the Philippines. While increasing attention is deservedly given to the preservation of Spanish colonial-era architecture in the Philippines, structures like the Orphan Churches deserve equal attention. Although the evaluation and seismic retrofit and preservation process for all heritage buildings is generally similar, early reinforced concrete buildings present challenges unlike earlier unreinforced masonry buildings. As such, the restoration of the Orphan Churches of Bohol provides the opportunity to serve as a demonstration project for the country's similarly constructed heritage structures.

2. Introduction

On the Philippine islands of Bohol and Cebu more than thirty-four churches experienced significant damage and partial or complete collapse from ground shaking during a M_w 7.2 earthquake on October 15, 2013. The churches affected by the earthquake include 18th and 19th century Spanish colonial-era churches, largely constructed of unreinforced coralstone-faced rubble walls, with timber truss roof structures, and early 20th century American colonial-era and post-World War II reinforced concrete churches.

In the aftermath of the earthquake, the National Museum (NM) and the National Historical Commission of the Philippines (NCHP), the Philippine government agencies in charge of heritage sites under the National Commission on Culture and the Arts (NCCA), took on the task of recovery and preparation of restoration plans for the older Spanish colonial-era churches.

The NCCA intervention excluded the restoration of the 20th century American colonial-era and post-colonial churches; hence, they have been nicknamed "The Orphan Churches of Bohol."

Bakás Pilipinas, Inc., is a New York-based not-for-profit (NGO) organization dedicated to the preservation of historic architecture and sites in the Philippines. At the request of the Diocese of Tagbilaran, Bohol, under whose jurisdiction the churches belong, *Bakás Pilipinas, Inc.*, prepared this Preliminary Survey on the condition of three of these "orphan" churches:

- Nuestra Señora Del Rosario Church, Antequera
- La Purisima Concepcion Church, Catigbian
- San Antonio de Padua Church, Sikatuna

The selection of the three churches that are the focus of this Survey, was made by the Most Rev. Leonardo Y. Medroso, D.D, Bishop of Tagbilaran, and Rev. Fr. Milan Ted Torralba, Chair of the Diocese of Tagbilaran's Commission for the Cultural Heritage of the Church.

This "Preliminary Existing Condition Survey" (Survey) includes observations of the post-earthquake damage conditions, a discussion of the possible causes of the damage, and recommendations for further seismic evaluation, retrofit, and maintenance of the three churches.

2.1 PROJECT UNDERSTANDING AND APPROACH

The preliminary study of the three "Orphan" churches was performed by *Bakás Pilipinas* to help establish the scope of work and proper methodology for the evaluation, retrofit, and long-term preservation of these churches. Of primary importance is prevention of collapse of the buildings, mitigation of falling hazards, and preservation of life safety features. Given that the churches often serve as essential facilities and sanctuaries for their communities during natural disasters, and are also culturally, historically, and architecturally significant, these recommendations adhere to the best international practices for seismic evaluation and retrofit. The recommendations also keep in mind the artistic and heritage value of the churches, so they follow international standards for heritage conservation.

It is the intent that the results of this survey will provide the basis for comprehensive evaluation and retrofit of the buildings, and as a basis for budgeting, and grant and funding applications.

2.2 SURVEY METHODOLOGY

Three architect-members of *Bakás Pilipinas* performed a rapid visual screening of the exterior and interior of the churches on February 2nd and 3rd, 2015. The three architects were Roz Zacarias Li, Zach Watson Rice, and Angeline Quirona.

Where close-up access was not available, the buildings were visually examined by binoculars from the ground level, the interior, and the choir loft (where accessible), for general signs of adverse conditions, such as cracks, movement, displacement of materials, staining, and similar conditions. No probes or non-destructive testing were made of the interior of columns, walls, ceilings, roofs, or other building components to determine conditions or locate reinforcing bars or voids. At the ground level the buildings were visually examined up close. Where ceilings were intact, the roof framing was not visible. Some areas where the structures were unstable were also inaccessible.

Measurement of overall dimensions of the buildings were taken to allow preparation of preliminary floor plans for orientation.

The principal authors of this Survey were Arch. Rice and Arch. Li. The drawings are by Arch. Li, and the photographs are by Arch. Rice and Arch. Quirona. Peer review was graciously provided by Engr. Kent Nash, and editing by Nancy Brooke Mandel.

2.3 AVAILABLE INFORMATION

No engineering or architectural drawings or other information on original construction or alterations, or building maintenance was available for the work of this Survey.

General research on the history and past condition surveys of the churches include the following sources:

- Jose, Regalado Trota. *Visita Iglesia Bohol: A Guide to Historic Churches.* Manila: National Commission for Culture and the Arts, 2001.
- "Commission for the Cultural Heritage of the Church Reports," prepared for the Diocese of Tagbilaran, February, 2014.

Additional sources of information that were consulted for this Survey, on subjects such as the seismology of Bohol, Philippine cement and concrete, seismic evaluation and retrofit, and concrete repair, are listed in the References section at the end of this Survey.

2.4 STIPULATION

Information on the existing construction and conditions of the buildings were developed from an examination of the readily accessible parts of the buildings. The conclusions and recommendations in this Survey may not reflect variations in conditions that could exist after the examination of inaccessible areas of the structures. Should such variations become apparent during additional data collection, structural analysis, probes, maintenance, repair, selective demolition or construction, it may be necessary to reevaluate the conclusions and recommendations based on an on-site observation of the conditions.

2.5 MONITORING OF CONDITIONS

Until work is undertaken the conditions of the buildings should be observed and monitored to determine if the existing unsafe conditions are worsening, or new ones have developed. Until the work necessary to remove the unsafe conditions, and to correct the underlying causes of damage and deterioration is completed, then measures to protect the safety of the public, occupants, and staff, should be in place and maintained in good condition.

3. Background

3.1 SEISMOLOGY

As reported by the Philippine Institute of Volcanology and Seismology (PHIVOLCS), on Bohol, Cebu, and surrounding islands, the October 15, 2013, earthquake caused 222 deaths, 976 injuries, damage to 73,002 houses, collapse of 41 bridges, and damage to 34 churches, including two that collapsed. In the following months there were over 4,000 aftershocks, including several above M_w 4.5, a few above M_w 5.0. Aftershocks have continued through 2015.

The earthquake occurred at 8:12 AM PST, during the national holiday of Eid-al-Adha, so that schools and some businesses were closed, consequently reducing casualties. The earthquake epicenter was near the municipality of Sagbayan, which is about 40 km northeast of Tagbilaran, the provincial capital.

The 2013 temblor occurred along a previously unknown "reverse fault," now named the North Bohol Fault, which runs close to, and parallel to, the north coast of the island. The Philippines has an historical record of frequent strong and damaging earthquakes for over 500 years. However, in comparison to other parts of the Philippines, Bohol has historically had relatively few damaging earthquakes. In recent history large earthquakes struck the island in 1990 (M_w 6.8) and 1996 (M_w 5.6), but with relatively minor damage, and in 2012 a strong earthquake (Mw 6.7) struck on the island of Cebu, although loss of life and damage to civil structures and buildings were not nearly as great as resulted from the 2013 Bohol earthquake.

The maximum PEIS (PHIVOLCS Earthquake Intensity Scale) for the 2013 earthquake was VII – Destructive, which can cause some well built structures to be slightly damaged and older or poorly constructed buildings to suffer considerable damage. (The PEIS intensity scale quantifies the effects of an earthquake on nature, humans, and manmade objects.) In the case of many of the oldest heritage churches in Bohol much of the severe damage appears to correspond to a PEIS intensity of VIII – Very Destructive, or above.

The Municipalities of Antequera, Catigbian, and Sikatuna are located in "Very High Seismicity" hazard areas (PEIS Intensity VIII – Very Destructive, or above) where the effects of an earthquake can be completely devastating. However it is not known what the actual PEIS Intensity was in the three towns during the 2013 earthquake.

3.2 GENERAL CHURCH HISTORY

The first churches of Bohol started to be built several decades after Spanish colonizers arrived in the Philippines. The earliest churches were built in the 1590s by the Jesuit religious order, of locally available materials, mainly of wood. As the Jesuits expanded their mission, more substantial masonry churches replaced the wooden ones, primarily constructed of unreinforced masonry walls of coralstone facing on both sides of rubble interior walls, supporting timber roof trusses. In 1768 the Jesuits were expelled from all their missions in the Philippines, in compliance with the Spanish king's order. The Jesuit territories in Bohol were immediately taken over by the Augustinian Recollects. The Recollects constructed and altered the churches built by the Jesuits, typically adding a front portico to the facades, and occasionally bell towers.

By 1898, the Recollect parishes had grown to thirty-three, but the Recollects and all the other Spanish friars left their parishes as a consequence of the Spanish-American War. Upon the departure of the Recollects, all parishes and missions were entrusted to the secular clergy, under the charge of the bishop. The secular clergy assumed the task of completing the many churches whose construction were interrupted by the Revolution.

During the Filipino-American War (1899-1902), invading American troops burned several communities and churches in Bohol, among them Immaculate Conception Church, Catigbian (September 1900), Our Lady of Mount Carmel Church, Balilihan (November 1900), Our Lady of the Holy Rosary Church, Lila (November 1901), and Our Lady of Guadalupe Church, Sevilla (November 1901). The secular clergy took on the task of rebuilding these churches as well.

The first half of the 20th century saw a resurgence in church building. Cast-in-place reinforced concrete, introduced in the Philippines in the last decades of the 19th century, perhaps partly as "anti-seismic" construction, became the material of choice. It was during this period that the churches that are the focus of this Survey were built.

3.3 STATEMENT OF SIGNIFICANCE

The Orphan Churches of Bohol are significant for both their heritage and architectural values. The churches represent the type of religious structures built during the American colonial period, using reinforced concrete, a newly-introduced material to the Philippines at the time and a departure from the unreinforced masonry construction of the previous Spanish colonial period. Typically, these churches are smaller and more modest than the older churches as befits the smaller towns where they were built, but their classical facades were carefully designed and articulated in proper proportion to their smaller size.

The churches continue the traditional site plan of earlier churches – built as the central focus of a large open town plaza in front and typically with a *convento* on one side. With the exception of the church in Antequera, the churches of Catigbian and Sikatuna exemplify the temple-type facade – with the gabled portico facade and a central tower above – typical of the smaller, vernacular, parish churches of Bohol at the time. Perhaps as influenced by the American colonial rule and culture, these churches are reminiscent of the small churches in many American New England towns.

4. General Description and Conditions

Although each of the three Orphan churches were constructed at different times, and all have different eras of additions and alterations, they do share many general characteristics that affect their seismic performance – both good and bad – and understanding these characteristics and the material properties of each building can help to clarify the causes and effects of damage from the 2013 earthquake, and to plan for their evaluation and retrofit.

The behavior and subsequent damage to each building component as the result of an earthquake and its aftershocks depends on several properties: soil and foundation conditions, construction type, material properties, geometry and configuration, roof diaphragms, and difficulty of access for maintenance.

Each of these characteristics affects the performance of the building, and the conditions found after an earthquake, in different ways.

4.1 SOIL AND FOUNDATION CONDITIONS

According to the PHIVOLCS *Bohol Liquefaction Hazard Map* the Orphan Churches are located in areas where the soil is not prone to liquefaction, which is the tendency for ground that is made of loose or saturated soils to temporarily behave like a liquid during an earthquake. Being in an area where soil is not prone to liquefaction is good, because liquefaction can cause the ground to sink, and buildings to settle, crack, or overturn. The older heritage churches along the coastal areas of Bohol are almost all located in areas where the soil is highly susceptible to liquefaction, and many of the oldest churches suffered significant liquefaction-induced damage from the 2013 earthquake.

No evidence of ground subsidence (sink holes) or building settlement was noted around the Orphan Churches during the site visit for this Survey. It is likely that the better soils under the churches contributed to their reasonably sound condition following the earthquake, and to the collapse of only poorly construction additions. However, the specific Soil Profile Type (or Site Class) for each of the churches is unknown to the survey team, and should be confirmed by a geotechnical engineer. Likewise, the design and construction of the footings under the walls, columns, bell towers, and porticos is unknown and should be determined during a comprehensive condition assessment.

4.2 CONSTRUCTION TYPE

The construction type of the three Orphan Churches is generally a cast-in-place reinforced concrete frame with concrete infill panel walls. Some of the additions, and possibly the facades, are constructed as reinforced concrete walls without frames. The bell towers are modern reinforced concrete, with diagonal corner braces at some floor levels. Unlike many of the Spanish colonial-era churches which are a mix of the unreinforced coralstone and reinforced concrete additions, the Orphan Churches appear to be constructed wholly of concrete.

In general, the concrete frames of the Orphan Churches have regularly spaced columns at the sides of the buildings, which appear to be connected together at the top by tie beams. The tall columns are expressed on the interior and exterior as slightly projecting pilasters. The concrete infill wall panels, which may or may not be fully reinforced, are perforated by window and door openings. The roof structures are light wood trusses, with wood purlins and rafters supporting corrugated sheet metal roofs and sheet metal ceilings.

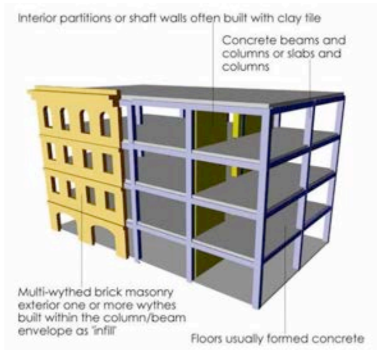
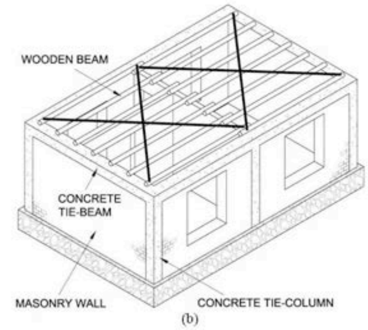


Figure 15.1-1: Building Type C3: Concrete Frames with Infill Masonry Shear Walls



Typical Components of Confined Masonry

Figure 1. FEMA Model Building Type C3 (left) from *FEMA 547* and typical confined masonry construction (right) from Brzev, *Earthquake-Resistant Confined Masonry Construction.*

Although this construction type has many construction similarities to modern concrete frame and infill panel wall types (such as *FEMA 547*'s Model Building Type C3) and to confined masonry construction (a modern low-rise seismic-resistant construction type found in the Philippines), the reinforced concrete churches of Bohol may be a construction type unique to the Philippines. See fig. 1 for similar construction types.

Cracking of concrete, whether columns, beams, or walls, from seismic loading is largely due to shear forces (forces that pull the concrete in opposite directions), but can also be caused by flexure (bending), torsion (twisting), and compressive forces. The principal type of damage found in the concrete of the Orphan Churches are the formation of full-thickness shear cracks, which can be vertical, but are usually diagonal, or X-shaped, because of the way the structural system distributes earthquake forces.

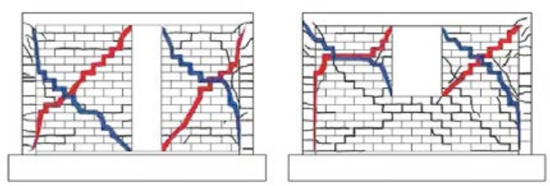


Figure 16. Failure modes in the confined masonry walls with openings[3]

Figure 2. Typical crack damage patterns at openings in confined masonry construction caused by in-plane earthquake damage in both directions. From Brzev, *Earthquake-Resistant Confined Masonry Construction.*

Concrete frames with infill walls (and the similar confined masonry type) are a structural system with components that are constructed in such a way that the infill and the concrete frame interact as a complete structural system when subjected to both vertical dead loads and multidirectional dynamic seismic forces. During an earthquake where the motion and resultant forces are parallel to the frame (known as an in-plane action) the reinforced concrete frame will deform by bending, while its infill wall panel will compress and develop diagonal shear cracks that are aligned with the compressive forces within the infill panel, generally from corner to corner of the infill panel. Perforations (doors and windows) within the infill panels are a discontinuity in the structural system which alters the compressive load paths, and leads to complex cracking patterns both through and around openings (fig. 2). Wall and door perforations within infill panels are considered by structural engineers to be the most significant factor affecting seismic behavior of infilled systems. Where the crack pattern is X-shaped this is usually the result of the building moving in both in-plane directions during an earthquake. These types of X-shaped cracks, as well as diagonal and vertical cracks, can be seen on almost all the walls at Antequera.

Although there are post-earthquake vertical, diagonal, and X-shaped cracks in many of the infill wall panels, this is to be expected in a M_w 7.2 earthquake, and indicates the infill panels performed their function of resisting frame deformation and keeping the buildings from collapsing.

Because of the age of construction, it can be safely assumed that the concrete frame construction of the churches is non-ductile, which is a term that refers to concrete structures that have limited ability to absorb and dissipate the destructive energy of a strong earthquake, and are as such prone to damage or collapse. In the years after World War II reinforced concrete construction became more robust, and more capable of resisting earthquakes, but not until the 1960s did structural engineers purposely begin to design ductile reinforced concrete frames, which were intended to better resist ground shaking. Because the bell towers of the Orphan Churches were constructed in the post-war era, they are likely to have some ductile capacity, which is evidenced by their relatively undamaged condition.

Concrete frame infill walls are typically reinforced, though often minimally. In older buildings, the infill reinforcement may be only around openings (as can be seen at damaged areas at Antequera), and possibly not provided to resist structural loads. This type of minimally or unreinforced concrete work today is classified as plain concrete, and behaves much like unreinforced masonry. In modern concrete construction, however, the concrete infill is usually reinforced with horizontal and vertical reinforcing bars throughout the panel, and acts compositely with the surrounding frame. The amount and location of reinforcement within the infill walls will vary for, and within, each church where there are additions. In some of the Orphan Churches, such as at Antequera, minimally reinforced concrete is likely to be found in the original infill walls, and full reinforcement may be present in the bell tower.

For the areas of the churches with non-ductile concrete construction some details that may be present include: inadequate column beam connections, too few transverse reinforcing bars (closely spaced rebar running perpendicular to the beams and columns), and too short rebar splices. Some partial-thickness cracking of the concrete may be due to these details, and it is recommended that these details be investigated during a comprehensive condition assessment.

During the recommended comprehensive condition assessment the construction type and details of each church should be confirmed, including the presence or absence of tie beams, whether the connections are to any degree ductile, and the locations of reinforcing steel in the infill panels.

4.3 MATERIAL PROPERTIES

Where the concrete is visible at wide cracks or spalls caused by earthquake damage, it appears that the older, pre-1941, concrete may not be comparable to current concrete construction in several aspects: there are very few reinforcing bars, and the concrete may be weaker than present-day concrete due to large and not well graded aggregate and also the possible use of non-Portland cement.

Where visible at damaged areas, the reinforcing bars appear to have twisted rectangular or perhaps hexagonal sections, which would be expected in older concrete, rather than deformed bars as are used today. Older reinforcing bars often have lower tensile strength, and lower bond and anchorage strengths, than modern concrete, so those properties can affect the performance of the building during an earthquake.

In older concrete construction the aggregate was often not as carefully selected as in modern concrete, with some large aggregate in the mix and the proportion of aggregate sizes not graded at all. This appears to be the case with some of the concrete in the Orphan Churches. Large aggregate can cause uneven concrete placement if the aggregate is caught between rebars, but this may not have an effect on the performance of the concrete in the Orphan Churches, which appear to have minimal reinforcement. Because cement is the most expensive part of the concrete mix (excluding the reinforcing steel) sometimes more aggregate is used to lower the cost of the concrete work, which can be detrimental to the strength of the concrete.

The type of cement used in the concrete can have an impact on both compressive and tensile strength of the concrete and its durability. There are some website references that the church at Antequera was constructed with “cement from Rome.” “Roman cement” was both a common name and a trade name for many brands of natural cement, which was an hydraulic lime or cement made from limestone burned at lower temperature than Portland cement. Before about 1900, when Portland cement began to overtake natural cements, Roman cement was commonly used for concrete and mortar worldwide. In general, Roman cement concrete has compressive strength comparable to Portland cement concrete of the same age; however, it can have lower tensile strength, and be more brittle. Roman cement concrete can also be very porous and permeable to water, so in a wet environment rusting of reinforcing steel can result if water is not kept from entering the concrete. The rusting rebar can lead to cracking of the concrete, initially as small partial-thickness cracks but eventually as more significant cracks which should be distinguished from seismically induced full-thickness cracks during the condition assessment.

Although the church at Antequera may have been constructed using Roman cement in the concrete, the source of the cement is not likely to have been Rome, as Italy does not appear to have been an exporter of cement to the Philippines in the early 20th century. It is more likely that the “cement from Rome” was a German or Belgian brand of Roman cement or even a locally produced natural cement: before World War I Germany and Belgium were major producers of Roman cement and exporters to the Philippines; and both the islands of Bohol and Cebu provide ample sources of limestone (coralline, argillaceous, and marl) that were capable of producing hydraulic lime and natural cements. After 1918, when the Rizal Cement Co. plant went into operation, Filipino produced Portland cement may have been used.

No matter the source, the cement types used in the Orphan Churches should be confirmed by petrographic analysis, and the structural properties determined from laboratory testing, so that the material properties can be understood during the seismic evaluation, and causes of non-seismic deterioration understood. Likewise, the strength of the reinforcing steel, and the overall properties of the concrete, should be determined, so that the actual material properties can be factored into the structural analysis.

4.4 GEOMETRY AND CONFIGURATION

Simple structures behave better than irregular structures during an earthquake. Several geometric and configuration characteristics of the Orphan Churches are considered as structural irregularities, and contributed to some of the poor seismic performance and damage. These irregularities include: the transepts, additions, and the porticos and bell towers.

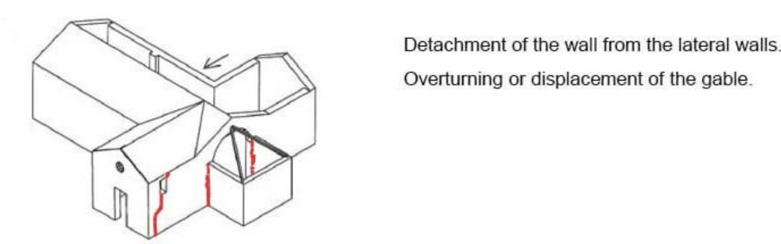


Figure 3. Typical locations of crack damage from overturning transept or facade walls and the at poorly connected additions. From *NIKER 3.1 – Damage Abacus.*

The plan of the churches is a nave with transepts, which forms a cruciform, or cross-shaped, plan. It is likely that construction of each church began as a simple nave plan, with the transepts added as the congregation grew, as was quite common world-wide. The transept additions are a common location of damage from cracking and also displacement.

Where the transepts meet the nave walls, they have what is known as reentrant corners, which are considered a structural plan irregularity. At the reentrant corners vertical or diagonal cracks in the concrete are likely to occur during earthquakes because of the formation of large shear stress concentrations and torsion (twisting). This often causes damage to be concentrated at the corners (fig. 3). Vertical and diagonal cracks at the transept corners are a common damage location at Antequera.

As the congregation of each of the churches has grown additions have been made to the buildings, often to the sides or rear, but also on the front, such as the bell towers and porticos, which were not part of the original construction of the Orphan Churches. Some of the smaller additions may have been constructed without structural engineering input, though the more recent additions, such as the bell towers, are likely to have been designed by structural engineers. A structural engineer's knowledge of building performance can greatly improve the durability of the building during both earthquakes and typhoons.

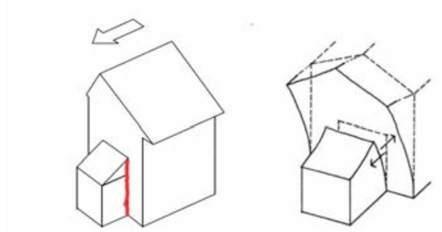


Figure 4. Movement of the main body of the church can cause of cracks at boundaries, especially from pounding or hammering of the addition by the main body of the building. From *NIKER 3.1 – Damage Abacus*.

The additions are prone to movement separate from the main church structure – due to their different size, mass, materials, and often lack of proper connection – so that damage is commonly seen at the boundary between the different eras of construction (fig. 4).

Based on an observation of construction formwork marks that can be seen in some interior and exterior parts of the churches, it is clear that the concrete work was brought up over a period of several years, perhaps as funding allowed, as is still common with church construction world-wide. Some parts of the buildings, such as the towers, were completed many years after the main part of the churches were completed, and can be considered as additions. The boundary line between the construction phases and also additions (see below), known as a "cold joint," is weaker than the adjacent concrete so the boundary line is often a place where cracks form during earthquakes. These cold joints can be both vertical and horizontal. Damage likely caused at horizontal cold joints can be seen on the transepts and sacristy at Antequera.

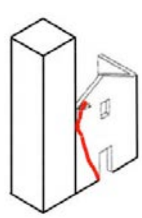


Figure 5. Typical location of cracks at intersection of bell tower with the nave from pounding during an earthquake. From *NIKER 3.1 – Damage Abacus*.

Cracks are common at the connection between bell towers and the nave or front facade of churches (fig. 5). This type of damage can be seen at Antequera.

In general, as earthquake ground motion causes a building to move, the lower parts of the building begin to move first, while the upper parts of the building, such as a bell tower, stays behind because of inertia, then begins to move, trying to catch up with the movement of the lower parts. This happens with very tall buildings, but also with bell towers, which have a tendency to rock back and forth during an earthquake, just like tall buildings. Significant stresses develop at the connection between the bell tower and the rest of the building, leading to cracks at the connection between the side elevations and front facade or portico (figs. 5 and 6). This kind of damage is prominent at Catigbian and Sikatuna.

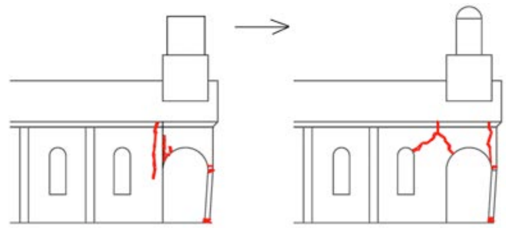


Figure 6. Typical crack damage at the corner of the side elevations and front facade or portico from rocking of the bell tower and portico during an earthquake.

The movement of the bell towers can also cause the portico columns to bend, and crack at the top and base (fig. 6). This is known as a soft story mechanism type of damage. This kind of damage can be seen at Catigbian and Sikatuna at the top and base of the portico columns.

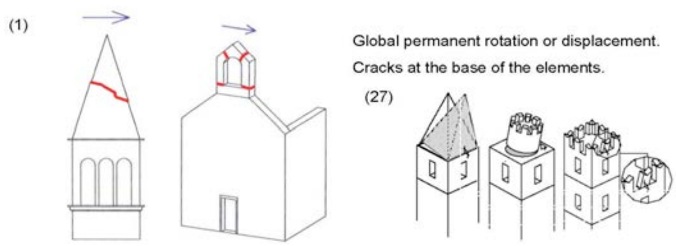


Figure 7. Vertical elements can crack and be displaced from earthquakes. From *NIKER 3.1 – Damage Abacus*.

Another common feature of the porticos and towers are non-structural architectural elements, such as projecting vertical parapets, balustrades, crosses, statues, and horizontal cornices, all of which have a tendency to crack and detach in strong earthquakes (fig. 7). Parapets and similar components and appendages that are not properly attached and braced may become disengaged and topple, and cornices, or sections of cornices that are deteriorated may detach and fall. These are among the most seismically dangerous consequences of any non-structural components. This type of damage is common to all three churches.

It is recommended that the construction history of the churches be developed to assist in better understanding how the additions and other structural and non-structural irregularities behaved during the earthquake, and what measures are best to retrofit them so that future damage is kept to a minimum. Also, each of the connections and boundaries of these structural and non-structural irregularities are recommended to be comprehensively investigated during the condition assessment and structural analysis.

4.5 LIGHTWEIGHT ROOF DIAPHRAGMS

The roofs all appear to be generally constructed of lightweight wood trusses with purlins and rafters, covered by corrugated metal roofs, with sheet metal ceilings attached to the bottom of the trusses and rafters.

In theory the roof structure, plus the roofing and ceilings, enhance the seismic performance of the buildings, by connecting the frame and walls to the roof structure, and working as a diaphragm to evenly distribute seismic forces into the frame and walls. A diaphragm also helps to tie the building together during an earthquake, which improves the building's three-dimensional box behavior, by resisting overturning of the walls, or out-of-plane movement, and twisting, or torsion. However, this is only true where the roof trusses are adequately and continuously connected to the tops of the walls, which is a detail that can only be readily confirmed at Catigbian and must be confirmed at the top of the walls of all the churches.

The sheet metal ceilings are a non-structural component that if not properly fastened are a life safety hazard, as can be seen from the sections of ceiling that have become loose and fallen at all three churches. If the roofing is also poorly attached it is prone to detachment in high winds, and can then also be a life safety hazard.

The ceilings are attached to wood, which over time can rot and split, so that over time the ceiling fasteners can become loosened and then pull out due to seismic-induced movement of the roof structure and during high winds as well. The attachment of both the ceilings and the roofing, as well as the condition of the wood trusses, purlins, and rafters, requires verification at all the churches.

4.6 DIFFICULT ACCESS FOR MAINTENANCE AND INSPECTION

Construction and material characteristics and adverse conditions such as those listed in the sections above may be further aggravated by difficult-to-maintain construction. This is an especially common problem with older concrete structures in high rainfall areas where leaking roofs and gutters can allow water infiltration into the concrete and result in deterioration of reinforcing bars, delamination of concrete, and degradation of the rebar-to-concrete bond, which then lowers the overall strength of the building.

Churches, because of their height and size, are difficult to maintain and to inspect, especially towers, roofs, gutters, attics, and ceilings, where decay can greatly aggravate the effects of an earthquake, and cause structural collapse and falling hazards. For this Survey, access was not available to these areas so it not clear if any of the structural or non-structural components that were damaged or displaced during the earthquake, such as cornice sections and ceilings, were caused by maintenance issues, nor are the conditions of components in these areas known.

Towers, cupolas, roofs, gutters, and attics are prone to the accumulation of leaves, debris, and bird droppings, which are corrosive to fasteners and other metals, including reinforcing bars, and also allow plants to grow.

Roof and gutter leaks can cause wood in the roof and ceiling structures to warp and twist and to decay because of termites, and other biological agents, such as dry rot. In roofs, deterioration of wood is often active in areas of the structure that are difficult to inspect. Decayed wood can cause a structural failure of the roof or ceiling, possibly precipitating collapse of walls, or allow sections of the ceiling or roof to come loose.

Plant growth at tops of walls and bell towers has been observed to be a significant cause of damage to heritage buildings in the Philippines. Soon after the plants become established on the building their roots begin to grow down into the walls, forcing the masonry or concrete apart, greatly weakening the structure, so that damage, and even collapse, are possible during both earthquakes and typhoons.

Due to the lack of access to the upper parts of the churches for this Survey it is not clear if any of the common conditions noted above exist (except for plant growth) or have been aggravated by difficult access for regular maintenance and inspection, so the areas should be inspected in detail during the recommended comprehensive condition assessment.

5. Nuestra Señora del Rosario Church, Antequera

5.1 BACKGROUND AND GENERAL DESCRIPTION

5.1.1 History

The town of Antequera was formed in 1876 from the barrio of Agad, a part of Maribojoc, together with some villages from Cortes. It was given its new name as a tribute to the Spanish Overseas Minister, who was born in Antequera, Spain. The town's name also coincides with that of the commander of the Spanish armada in the Philippines, Juan Antequera y Bobadilla. The parish was established in 1880, and remained under the charge of the Augustinian Recollects until the end of the Spanish regime.

A temporary church was built in the 1880s of wood and *tabique pampango* (wattle and daub). Foundations for a larger church of stone were laid in 1896 but construction was stopped in 1898. No precise dates are available for the construction of the present reinforced concrete church (figs. 8 and 9). The Commission for the Cultural Heritage of the Church, Diocese of Tagbilaran, provides the dates of 1896-1964 as the date of construction, with the earliest date reflecting the date of the stone foundation. Citations on several websites note that construction of the reinforced concrete church began in 1908 and was completed in 1914, using "cement from Rome," and is said to be the first concrete church on Bohol. (See discussion of Roman cement above). A memorial tablet in the narthex of the church states that the facade was completed in 1964-1968. Some wooden altarpieces and furniture, especially the *retablo* (reredos) in the north transept, stylistically date from the 1950's or earlier.

The 1908-1914 construction dates are plausible, given that reinforced concrete construction was becoming common in the Philippines at that time for government buildings and public works.

5.1.2 General Description

The Church of Nuestra Señora del Rosario in Antequera is a structure with a Latin cross floor plan, with a nave approximately 14.3 x 63 meters (47 ft. x 206.6 ft) in overall dimensions (excluding transepts). There is an attached bell tower addition located at the front side. At the rear is an open-air restroom addition. At the rear and south sides are sacristy additions (fig. 8).

The main structure consists of a system of regularly spaced cast-in-place reinforced concrete frame columns, expressed in the exterior and interior as pilasters, with reinforced concrete infill wall panels between the columns. It is not clear if the structural system is a full frame – with beams connecting both the top and bottom of the columns. It is evident that the columns and wall panels were separately cast, the columns cast first before the wall panels.

At the base of the walls there appear to be two courses of earlier coralstone blocks, part of the foundation that probably dates to 1896. The building is covered by intersecting hip gable roofs with sheets of corrugated metal roofing, terminating in narrow overhangs and hung gutters.

The front facade is rendered in the Baroque revival style, featuring a complicated pediment with Rococo stylistic features. Unlike most churches in Bohol, this church does not have a true portico; however, a pair of projecting columns and entablature over the main entrance doors suggest a shallow portico. Engaged columns and pilasters divide the facade into bays. The bell tower, which is attached to the north side of the facade, creates an asymmetrical composition on an otherwise symmetrical front facade of the main structure. The bell tower consists of a square base with a hexagonal colonnaded cupola above topped by a dome and balustrade. The bell tower appears to have been constructed in the 1960s, and has a much more robust, braced, reinforced concrete structure. All facades were painted a monochromatic cream color in 2012.

Each of the infill concrete wall panels is penetrated by either windows or doors, which are articulated by classical enframements. Most of the windows and door openings are arched, while openings below the bell tower are rectangular, enframed by pediments and slim colonettes. There are oculi (circular openings) are above most of the enframed windows. Windows of the main structure are typically of glass jalousie type. The awning windows of the front facade and the oculi have colored glass panes. The doors are wood, and most windows and doors have decorative metal grilles.

In contrast to the front facade and bell tower, the side, transept, and rear facades are very simply designed, featuring simple pilasters dividing the length of the structure into bays. Each bay features a pointed arch window with an oculus above. Side doors are also arched and have gabled porch roofs. The side door on the north side has a long metal canopy. A low, one-story toilet addition is attached to the rear facade.

The interior is open, with no columns, with the simple, long nave, interrupted by transepts (a later addition), and culminating in the main altar. A choir loft supported by two intermediate columns is built over the main entrance, creating a simple narthex. The choir loft is accessible by a wood stair on one end. The ceiling consists of a shallow barrel vault finished with two layers of sheet metal panels over wood framing. A shallow domed ceiling at the intersection of the transepts and the nave is covered well with painted sheet metal panels. The interior of the bell tower is accessible at the ground level and from the choir loft, although the upper part was not entered for this Survey.

5.2 GENERAL CONDITIONS

The building is in poor condition. There are numerous falling hazards, including collapsed roof structure, loose concrete, loose eaves, and loose interior sheet metal. There are several areas, principally the transepts and rear additions, where the concrete infill panels are severely cracked and displaced and should be considered a falling hazard. The public should not be allowed to enter areas where falling hazards exist until the loose materials have been removed or stabilized.

Ssome limited areas, principally the bell tower and some sections of the nave, are in fair condition.

5.2.1 Reinforced Concrete Frame and Walls

The reinforced concrete infill wall panels fared worse from the effects of the earthquake than the columns. The columns are in fair condition, while almost all the infill wall panels between the columns exhibit diagonal, vertical, and horizontal cracks in the concrete.

Along the side walls of the nave, and at the transepts, numerous vertical and diagonal through-cracks have opened up. Most of the cracks extend through door and window openings.

On the south elevation (fig. 13) vertical cracks at the corner, and diagonal cracks that extend through the windows, appear to indicate that the facade rocked towards the east during the earthquake. These cracks extend through the wall, and can also be seen on the interior at the choir loft (fig. 28).

At almost all the infill panels there are diagonal and vertical cracks, many extending through the window and door openings (figs. 23, 25, 26, and 28).

At the nave walls, which are assumed to be the oldest part of the building, where concrete is exposed at spalls it can be seen that the reinforcing bars consist of square twisted steel bars, rather than deformed bars used today. Some of the rebar exhibit more than light corrosion. At the spalls it can also be seen that the concrete aggregate is much larger than used in contemporary concrete (fig. 24). The color of the concrete paste ranges from cream to tan, rather than grey as would be found with contemporary Portland cement concrete.

At the transepts and rear addition there are horizontal cracks at the tops of the walls where the concrete has become displaced, and is a safety hazard (figs. 16 and 17). These cracks appear to be located at cold joint boundaries between construction phases, and also appear to indicate that there is no ring beam at the top of the walls, to which the top of the walls should be connected.

The transepts, which were added, fared worse than the main structure, exhibiting continuous vertical and horizontal cracks and collapsed concrete wall sections (fig. 16).

A addition in the rear has separated from the main structure and is partly collapsed (figs. 17 and 27).

5.2.2 Bell Tower and Portico

The facade and north wall of the church has two types of cracks – diagonal and vertical on the facade (fig. 9) and vertical at the north wall (fig. 15) – that appear to have been caused by rocking of the bell tower. The front facade diagonal cracks appear to have been caused by the tower rocking to the north and pulling away from the facade. The north wall crack appears to have been caused by the same movement, and perhaps also from a southward rocking of the bell tower and subsequent pounding of the wall.

Over the front facade, part of the pediment is severely cracked and displaced from rocking. Plant growth at the pediment indicates moisture and accumulated soil or debris (figs. 11 and 12).

The hexagonal bell tower is severely cracked (fig. 14), particularly at the arched openings, which collapsed around their arched enframements. The domed structure itself appears to be stable since the collapsed parts do not support the structure. Viewed from the ground, the columns appear to be in good condition, though some of the bases are cracked, perhaps from bending.

Plant growth is visible all around the bell tower. At the interior ceiling of the bell tower (fig. 22) there are water and greenish stains, possibly algae, indicating that the roofing at the cupola is not watertight.

The base story of the bell tower appears to be in good condition, though its rocking appears to have caused damage to the facade and side wall as discussed above.

5.2.3 Roofing, Gutters and Sheet Metal

Hands-on access to the roof was not available, so its condition could not be determined. Viewed from the ground, the corrugated metal roofing appears to be in fair condition, with selective areas of sheet metal roofing showing slightly upturned seams.

What is visible of the metal flashing appear to be in fair condition. Hung metal gutters as well as the downspouts are in fair condition. Vented eave soffits are generally in fair condition except for limited areas with missing or falling boards.

The main roof structure is not accessible or visible so its design and conditions are unknown, as are the connections between the ends of the roof trusses and the exterior walls.

The sacristy roof structure behind and to the side of the altar has collapsed.

5.2.4 Interior

All exterior concrete cracks discussed above extend the full thickness of the wall to the interior (compare figs. 13 and 28).

Continuous horizontal cracks are found near the intersection of the floor and walls. This could be an indication of separation between the concrete walls and the coralstone foundation wall below.

The transept walls and the altar retablo walls exhibit severe diagonal and vertical cracks, extending from floor to ceiling through doors, and at the corners (fig. 26).

The ceilings exhibit limited areas of falling layers of sheet metal panels, exposing the wood framing above (figs. 19-21). The ceiling is a falling hazard. Typically, there are two layers of sheet metal panels - a painted finish layer covering an unpainted layer above. It appears that the sheet metal pulled out of the fastener holes. The rest of the sheet metal ceiling exhibit open seams.

The floors are finished with white, modern ceramic tiles, which appear to be in fair condition except for those at the main altar. At the time of the survey site visit, it was partially covered with dry mud, indicating flooding.

5.2.5 Windows and Doors

The windows, including the oculi windows, are in fair condition. Decorative iron grilles on windows and doors are in fair condition.

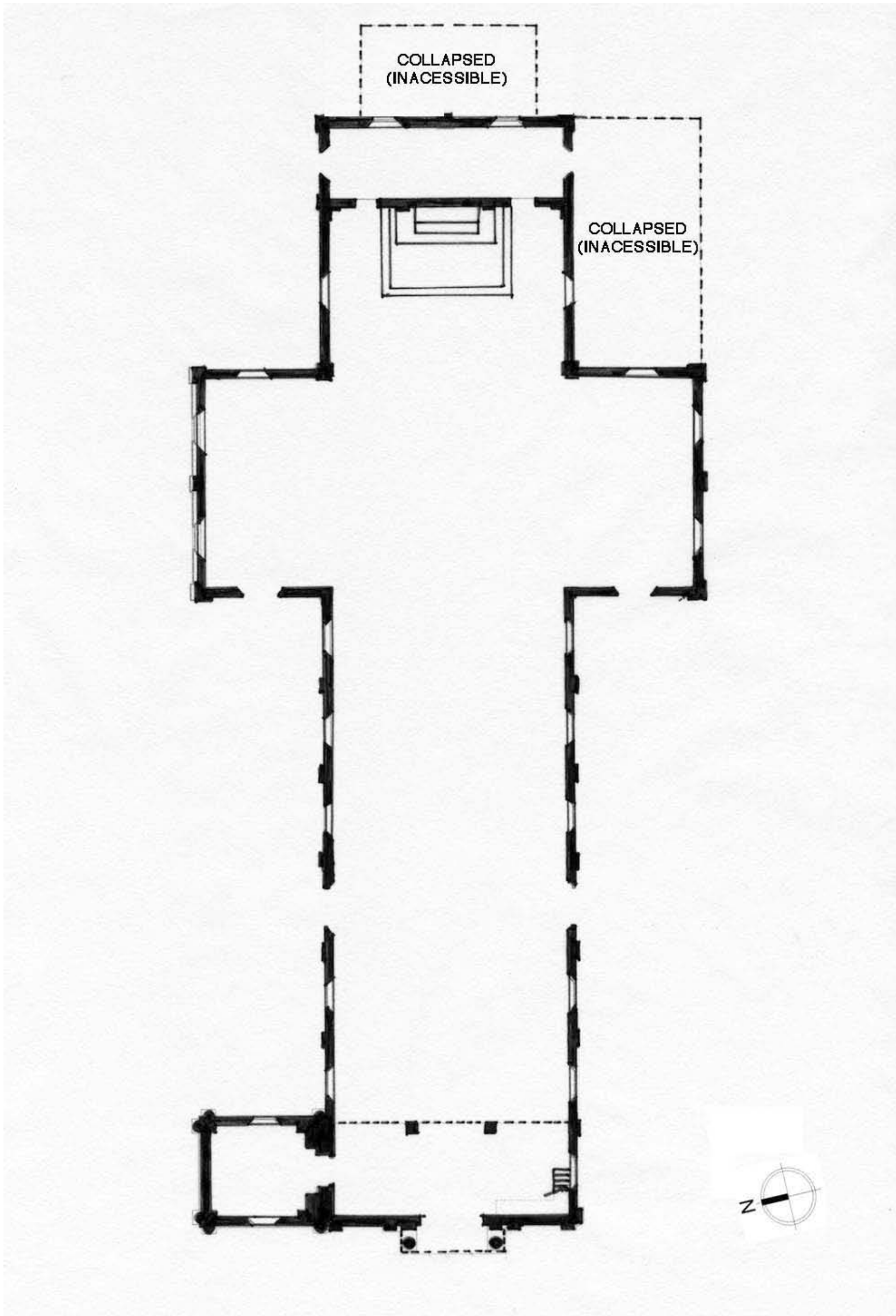


Figure 8. Ground floor plan of Nuestra Señora del Rosario Church, Antequera.

Figure 9. Front facade of Nuestra Señora del Rosario Church, Antequera, built of reinforced concrete over an older coralstone foundation. The front facade, which was constructed in the 1960s, is designed in the Baroque Revival style, with rococo features. There are cracks at the arrows, from rocking, and possibly pounding, from the bell tower. Note also plant growth at many locations above the cornice.

Figure 10. View of the northwest corner of the exterior, showing the bell tower cupola with its balustraded dome, and the north elevation and north transept.

Figure 11. View of the highly articulated pediment over the front facade, exhibiting numerous cracks in all directions, probably from rocking motion. Plant growth in the pediment is a sign of the presence of moisture and soil.

Figure 12. Another view of the pediment over the front facade showing diagonal cracks in the concrete, probably from rocking of the pediment.

Figure 13. View of the southwest corner, and nave south side elevation and south transept, showing typical diagonal cracks at the arrows. See also fig. 28 for the interior view of the same cracks. The transept wall beyond is severely cracked, with horizontal cracks at a cold joint, and vertical cracks at the reentrant corner with the nave wall. The transept walls sustained more damage from the earthquake than the nave walls.

Figure 14. View of the bell tower cupola, exhibiting severe cracks of its hexagonal walls from rocking and possible twisting. Plant growth is abundant around the cupola. See fig. 22 for underside.

Figure 15. View of the corner where the bell tower is attached to the north nave wall. The cracking in the nave wall above the openings appears to have been caused by rocking of the bell tower and subsequent pounding.

Figure 16. View of the northeast corner and north transept. The horizontal crack at "A" appears to be a cold joint boundary between two phases of construction. The vertical crack at "B" is likely due to overturning of the north transept wall.

Figure 17. View of the southeast corner, where the roof has collapsed. See interior view in fig. 27.

Figure 18. Exposed coralstone courses of the foundation wall, possibly dating from 1896.

Figure 19. View of the church interior looking towards the altar. Note the vertical and diagonal cracks on all the walls and the falling sheet metal ceiling.

Figure 20. View of interior looking west towards the choir loft. Note the vertical and diagonal cracks on all the walls and the falling sheet metal ceiling.

Figure 21. Close-up view of the ceiling area with exposed wood framing and falling sheet metal. Note that there are two layers of sheet metal ceiling and that the sheet metal has pulled through the fastener holes.

Figure 22. Underside of bell tower ceiling, showing that the construction is modern, with diagonals at the corners to resist twisting of the structure during an earthquake. Note the green stains from biological growth at leaks in the roof above.

Figure 23. View of the north nave wall, showing pervasive vertical and diagonal cracks passing through the windows, which are a discontinuity in the wall.

Figure 24. Close-up view showing steel reinforcing bars exposed by spalled concrete. These are twisted bars, which is a type common in the early 20th century. From spall locations like this it is clear that the concrete mix uses aggregate larger that recommended today, and that there are very few horizontal reinforcing bars.

Figure 25. View of the north nave wall on the east side of the transept, showing damage similar to the other section of the north wall in fig. 23.

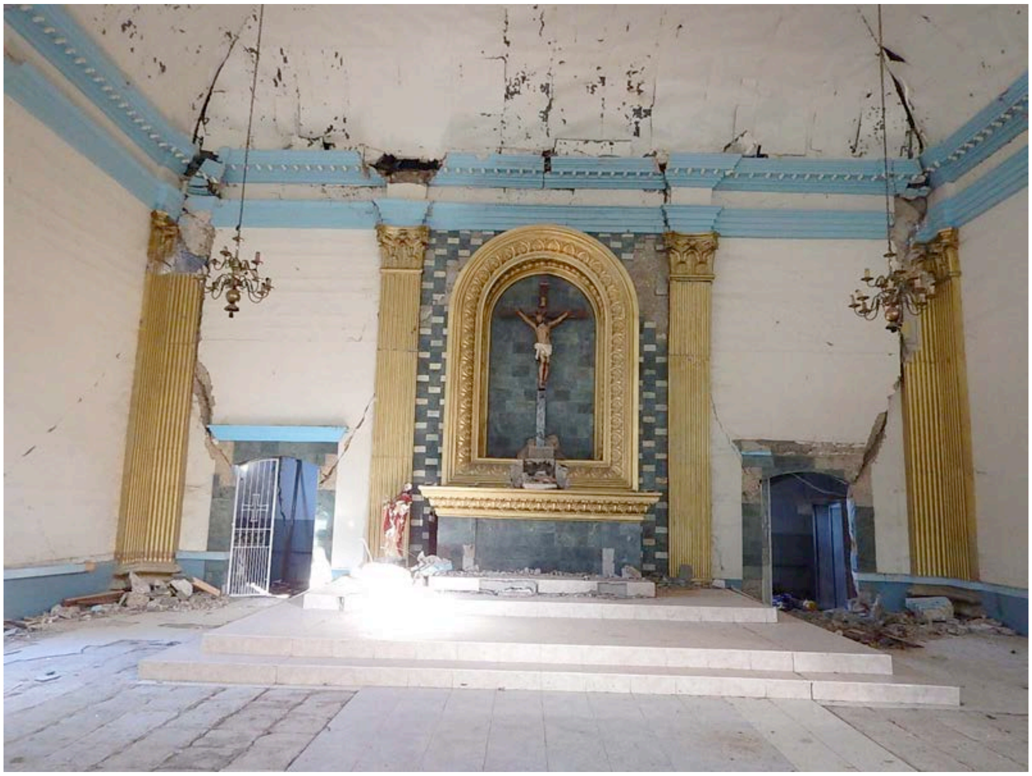


Figure 26. View of the altar wall, with diagonal cracks passing through the door openings.

Figure 27. View of the southeast corner room, with collapsed roof structure, and cracked and displaced sections of concrete wall. See exterior view in fig. 17.

Figure 28. View of the southwest corner at the balcony level. The diagonal cracks at the arrows are the same exterior cracks shown in fig. 13. Note also a vertical crack at the left of the blue pilaster. All of the cracks appear to be the result of movement of the building and front facade to the west, and a possibly overturning of the front facade.

6. La Purisima Concepcion Church, Catigbian

6.1 BACKGROUND AND GENERAL DESCRIPTIONS

6.1.1 History

Before the present La Purisima Concepcion Church was built, a predecessor church built of *tabique* walls (wattle and daub) existed on the site, constructed in the 1880s. In September 1900 American troops burned the church, along with the town of Catigbian.

The town was subsequently reorganized as "Jacinto," named after the governor, Jacinto Borja, but this reverted to "Catigbian" in 1954. In 1960, a parish was created from Catigbian.

Construction on the present church (figs. 29-30) appears to have begun prior to World War II and completed after the war, though, the Diocese of Tagbilaran says that the church was built in the early 20th century.

6.1.2 General Description

The La Purisima Concepcion Church in Catigbian is designed in a Latin cross floor plan with an arcaded front portico and bell tower above. The symmetrical, temple-front design of the facade gives the small structure a monumental appearance. The building (fig. 29), which is approximately 12 x 44 meters (40 ft. by 145 ft.) in overall dimensions (excluding transepts), is built of reinforced concrete. The concrete frame columns, spaced approximately 6.4 meters (21 ft.) apart on center, with concrete infill wall panels in between the columns. It appears that columns were cast first, then the walls after, instead of a monolithic concrete casting.

The main structure consists of a system of regularly spaced cast-in-place reinforced concrete columns, expressed in the exterior and interior as pilasters, with reinforced concrete infill wall panels between the columns. Because the ceiling is missing, the top of the wall is visible and it appears that the structural system is a full frame – with concrete tie beams connecting the top of the columns (fig. 43).

The exterior face of the reinforced concrete walls typically exhibit the impression of the wooden plank formwork used during construction. The most visible facades – the front and east facades – are painted, while the rest are not (fig. 32).

The central bay of the portico has a reinforced concrete ceiling with dropped beams and an opening for the bell, while the two side bays have no ceiling, but newly framed metal channel roofing (fig. 33). It appears that the side bay roofing was replaced after the earthquake.

The hexagonal bell tower sits on a plain square base with an oculus on each side. The arcaded area is surrounded by a railing of decorative concrete screen. The dome appears to be of sheet metal with patches. A plain cross is installed at the very top.

All window and door openings are typically arched, with semi-circular transoms. These openings are articulated by concrete enframements with moldings. Windows have multi-pane steel sash set in concrete frames and mullions. Casement windows are at the lower level and fixed sash above. Alternate white opaque and colored pattern glass are set in the window panes. Door openings have tall, pairs of wood panel doors. Oculus windows are centered above the arches of the front facade. There are also oculus openings at each side of the bell tower's base.

The building is topped by a gable roof covered with corrugated sheet metal sheet panels in imitation of clay "Mission style" roof tiles. The roof structure consists of wood trusses and purlins.

The interior consists of a long nave terminating at the main altar. Transepts, which appear to be later additions, are attached to the sides of the nave. A choir loft is built over the entrance, with wood stairs on one side providing access. The interior is articulated by the concrete frame columns, expressed as pilasters, with arched windows and doors. Modern ceramic tiles are installed on the floors.

At the time of this Survey, a two-story rear sacristy addition was being constructed behind the altar, with concrete columns and concrete block infill walls, similar to earthquake resistant confined masonry construction (fig. 36).

6.2 GENERAL CONDITIONS

The La Purisima Concepcion Church structure appears to be in fair condition with selective areas in poor condition. The front portico and front facade, as well as the altar wall exhibit the worst conditions.

6.2.1 Reinforced Concrete Frame and Walls

The most significant damage from the 2013 earthquake is to the portico and front facade (see below) and to the sacristy, which was being rebuilt at the time of this Survey.

At a few concrete columns there are minor vertical cracks, which may be earthquake damage, but may also have been caused by deterioration of vertical reinforcing bars.

The transepts are recently rebuilt, apparently with reinforced concrete columns and concrete block walls (fig. 35).

At the time of this Survey, the rear part of the building was being rebuilt. It is not clear if the rebuilding is to address earthquake damage, or a new addition. The walls on either side of the altar exhibit vertical cracks extending the full height of the wall on each side of an infilled arch opening (fig. 41).

6.2.2 Bell Tower and Portico

The building's most significant damage is found at the portico, where rocking of the bell tower during the earthquake caused vertical cracks through the architrave and pediment (fig. 30), vertical and diagonal cracks at the front facade (figs. 30 and 33), as well as cracks where the portico arches connect to the front facade and columns (figs. 31 and 32), and at portico column tops and bottoms (fig. 32).

The cracking patterns of the front facade and portico suggest that in addition to front to back rocking of the bell tower and portico there may have also been side to side rocking, or even twisting, of the two side bays of the portico. Twisting is possible given that the central bay has a concrete ceiling with diagonal braces (figs. 33 and 34) which provides a stiff diaphragm to resist twisting, and the two side bays have very flexible or possibly non-existent diaphragms, so that twisting of the side bays would have been an likely seismic reaction.

All portico cracks have been recently filled with cementitious patching mortar (fig. 33); however, the mortar was not installed properly – the cracks were not cut out and the mortar was installed with feathered edges, which will crack and fail. The patching should be monitored for durability over time.

The bell tower itself appears to be in fair condition, exhibiting no visible cracks or displacement, in spite of the fact that the walls supporting it below are seriously cracked. A more close-up view is needed to confirm the condition.

The metal dome exhibits signs of deterioration, including patches, holes and tears in the metal.

6.2.3 Roofing, Gutters and Sheet Metal

The roof structure is visible from the nave due to the loss of the finished ceiling (fig. 40). It consists of a series of wood trusses, alternating with wood rafters, with wood purlins on top. Each truss has a vertical iron rod serving as the king post. The wood roof trusses rest on the concrete columns and are tied to the top of the columns with bent metal reinforcing bars (fig. 43). Replacement purlins of metal channels were installed in limited areas of the roof adjacent to the bell tower (fig. 42). Wood framing for the presently missing shallow vaulted ceiling structure is hung from the trusses and rafters with tree saplings or branches. The roof structure needs a more close-up inspection to determine the condition of the wood, the fasteners and connections.

The corrugated metal roofing appears to be relatively new, although there are selective areas with holes and open seams.

The hung gutters appear to be painted steel or iron, with signs of corrosion (fig. 37). Metal downspouts align with each column on each of the sides of the building. Some of the ends of the downspouts are damaged and prevent water flow.

6.2.4 Interior

At the time of this Survey, the interior of the church exhibits freshly painted concrete walls with exterior cracks visible on the inside face of the front facade. Cracks are also present at both sides of the altar (fig. 41). The interior side walls of the nave do not show evidence of cracks.

The ceiling, which would typically be of painted sheet metal panels, is missing, leaving the roof and ceiling structure exposed to view (figs 39 and 40). Temporary tents have been erected over the pews inside the sanctuary to provide protection from the rain and bird droppings, which are found all over the floor.

The ceramic tile floor finish is in good condition, except for limited areas of damaged tiles on the altar floor.

Temporary light fixtures are strung up along the center of the nave.

Below the choir loft, the plywood ceiling has missing panels, exposing the choir loft's wood floor structure (fig. 42).

6.2.5 Windows and Doors

The steel windows are in fair condition, exhibiting signs of initial corrosion. Some of the concrete mullions and transom bars are cracked, possibly due to rusting reinforcing bars (fig. 38). The glass panes are in good condition.

The wood doors are in fair condition. Typically, the natural finish has degraded, leaving raw wood exposed. The bottom rails are vulnerable to rotting from moisture.

The wood semi-circular transoms above some windows and doors are open and missing their glass panes.

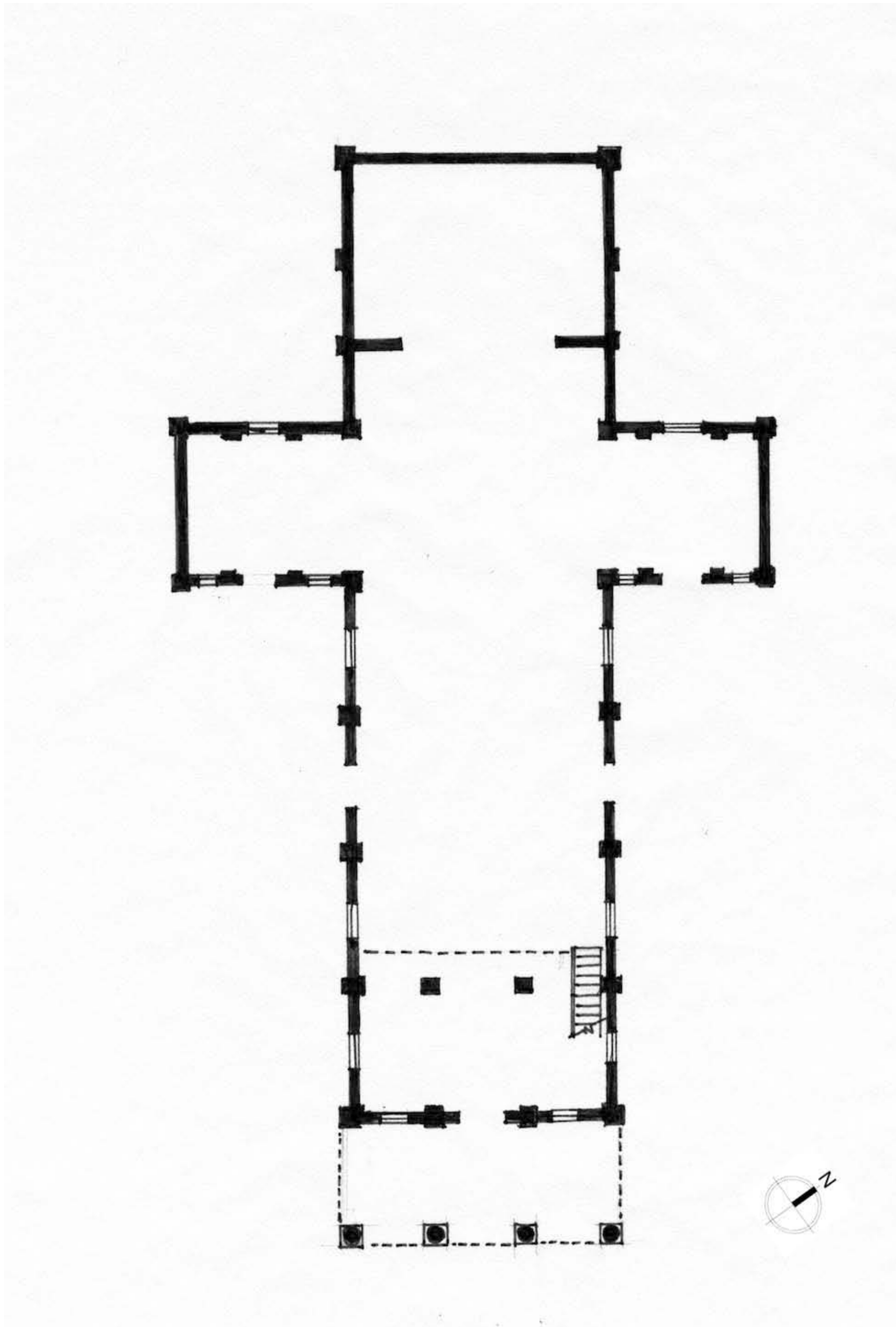


Figure 29. Ground floor plan of La Purisima Concepcion Church in Catigbian.

Figure 30. Front facade of the La Purisima Concepcion Church in Catigbian, built of reinforced concrete during the 1930s, and likely completed after WWII. The temple-front facade is typical of the churches in smaller towns of Bohol. Note recently patched vertical cracks at “A,” diagonal cracks at “B,” and cracks at the column top and base at “C.” See details and discussion in the following figures.

Figure 31. View of the north side of the portico and bell tower and north elevation. The cracks at “A” appear to be from rocking of the portico and bell tower from soft-story and mass irregularities. The cracks at “B” are from bending of the columns during the portico rocking motion.

Figure 32. View of the south side of the portico and bell tower and partial south elevation. The cracks at "A" and "B" match those in the previous figure. At "C" can be seen what appears to be a beam connecting the tops of the frame columns. See interior view of beam in fig. 43.

Figure 33. Facade and underside of portico, showing recently patched concrete, which is recommended to be monitored for durability. At the central bay at "A" can be seen the framing for the floor of the bell tower, which has haunches where the beams meet the walls, and diagonals in the corners, both modern concrete details designed to resist rocking and twisting during earthquakes. At "B" is the underside of the roof, which indicates that the two outer bays of the portico are less rigid and can twist during an earthquake.

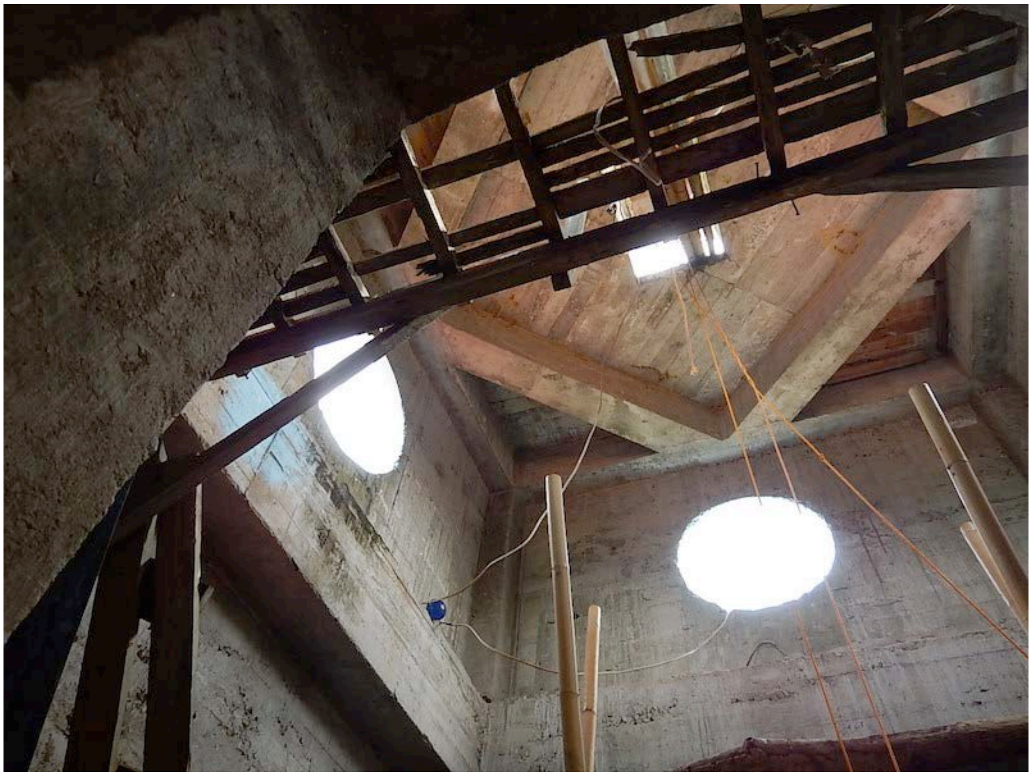


Figure 34. Interior view of the bell tower, underside of portico, showing the diagonal beams in the floor framing, which are designed to resist twisting during earthquakes.

Figure 35. South transept, which was recently reconstructed.

Figure 36. Addition to the west end of the church, using what appears to be confined masonry type of construction, which is designed to be resistant to earthquake motion, by the use of a full concrete frame, with columns connected at the top and floor levels with beams, and infilled with unreinforced concrete block.

Figure 37. Underside of the metal gutters, showing rusting, and open joints and rusting of the downspouts.

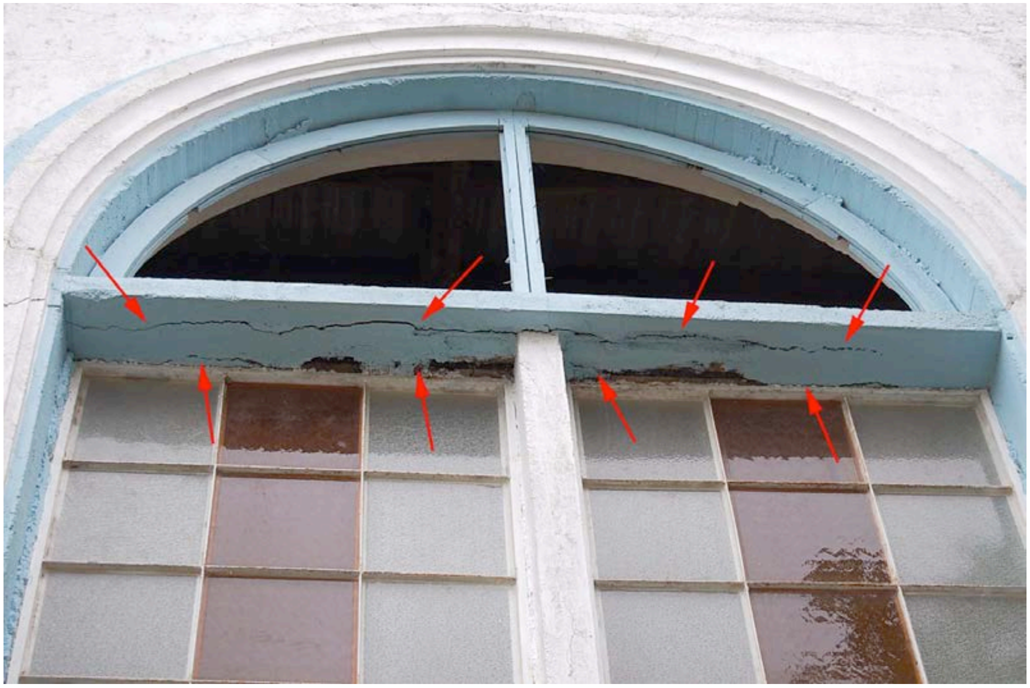


Figure 38. Typical view of steel casement windows with colored glass. The arrows point to cracks in the concrete transom bar, probably caused by rusting steel reinforcing bars, which is not seismic damage.

Figure 39. View of the sanctuary interior looking towards the entrance and choir loft above. Note the tents to protect from rainwater and bird guano.

Figure 40. View from balcony looking towards the altar. Note the missing finished ceiling, exposing the lightly framed roof structure.

Figure 41. View of the altar, showing cracks and collapsed sections.

Figure 42. View of the choir loft. Note missing plywood panel ceilings, and steel roof purlins in one section of the roof.

Figure 43. Close-up view showing trusses bearing on the concrete columns and fastened to the concrete with bent iron bars at "A." Note the beam at "B," which can be seen on the exterior in fig. 32.

7. San Antonio de Padua Church, Sikatuna

7.1 BACKGROUND AND GENERAL DESCRIPTIONS

7.1.1 History

Construction is reported to have begun on the Church of San Antonio de Padua in Sikatuna in about 1925, according to conversations with the head of the church technical committee, who also noted that the parish was established in 1935, which is the date scratched into the concrete of the choir loft balustrade adjacent to "Constrocted [sic] by H. Maghoyop." The church and adjacent rectory, both built of reinforced concrete, are located on the north side of the Tagbilaran-Sikatuna Road on a rise in the middle of a grassy lawn that surrounds the church.

The town of Sikatuna was named after the Bohol chieftain who conducted a blood compact with Spanish Governor General Legazpi in 1565. The establishment of the parish is noted as 1931 in the first parish books, but is listed as 1935 in the *Catholic Directory of the Philippines*.

7.1.2 General Description

The San Antonio de Padua Church has a Latin cross floor plan with a temple-front portico, topped by a bell tower, a form typical of the smaller 20th century churches of Bohol (fig. 44 and 45). The transepts may have been constructed at the same time as the main nave structure, unlike transept additions to other churches of this type. A choir loft is built over the narthex entrance bay.

The building, which is approximately 13 x 53 meters (43 x 173 ft.) in overall dimensions (excluding transepts), is built of reinforced concrete (fig. 44). Concrete columns are spaced approximately 4.6 meters (15 ft.) apart on center, with the exception of the south corners where the side walls meet the front facade, where there are no columns. There are reinforced concrete infill walls between each column. The reinforced concrete infill walls, though painted, show the marks of the wood formwork used for placing the concrete.

The main structure consists of a system of regularly spaced cast-in-place reinforced concrete columns, expressed in the exterior and interior as pilasters, with reinforced concrete infill wall panels between the columns. It is not clear if the structural system is a full frame – with beams connecting both the top and bottom of the columns.

Concrete buttresses have been added to two concrete columns on each of the side facades. The buttresses adjacent to the side entrances were recently added (fig. 47).

The roof over the structure is a low gable, corrugated metal roof. At the crossing, there is a raised pyramidal roof supported by corner concrete columns. The sides of the crossing are covered with painted sheet metal panels.

Each bay of the side facades has a tall, arched window opening with an oculus above. The window openings are in-filled with decorative concrete screen blocks. The oculi are louvered.

The three-bay arcaded portico is slightly narrower than the front facade. The square columns are articulated with decorative panels and moldings. The bell tower is framed by corner columns and has a slender arched opening at each side. A statue of San Antonio de Padua stands at the very top, surrounded by a wood balustrade.

The rear of the building has a lower concrete addition with a flat roof.

The interior of the church is a straightforward expression of the structure and the exterior facades – concrete columns expressed as pilasters, concrete infill walls with arched window openings and a simple cornice all around (fig. 57). The walls are smooth and painted. Floors are finished with ceramic tiles. The ceiling is flat and finished with plain, painted sheet metal panels; the roof structure is not visible.

7.2 GENERAL CONDITIONS

The San Antonio de Padua church structure appears to be in good condition with selective areas in poor condition. The most significant damage is vertical cracking at the corner of the side walls and the front facade and portico.

7.2.1 Reinforced Concrete Frames and Walls

There are minor vertical cracks at the joint between the columns and side walls in a few locations, but, in general, the concrete frame and walls are in good condition, with the exception of the line between the side walls and front facade-portico-bell tower (see below).

There is plant growth in cracks in the concrete and other biological growth where the concrete is damp from the opening in the bottom of the gutter and the missing downspouts (fig. 48). Continued plant and biological growth will cause future deterioration of the concrete.

7.2.2 Bell Tower and Portico

The building's most significant damage is found at the portico, where rocking of the bell tower during the earthquake caused wide vertical cracks to open up at the corners where the side walls meet the front facade and portico (figs. 46 and 48), as well as cracks where the portico arches connect to the front facade and columns (fig. 51), at portico beam haunches (fig. 53), and at portico column bottoms (fig. 54).

The wide vertical crack in the concrete reveals inadequately spaced horizontal reinforcing bars (fig. 50) connecting the corner together. It is possible that the lack of rebar at this corner is due to the front facade having been constructed as an addition to the side walls, so that a weak boundary exists between them. The cracks at the column bases appear to indicate only vertical reinforcing bars, without lateral (horizontal) tie bars, which are standard in contemporary concrete construction.

Parts of the cornice mouldings at the top of the portico are spalled and there are also vertical cracks in the pediment (fig. 55).

The bell tower appears to be in fair condition, showing no visible evidence of significant cracks as viewed from the ground level. Due to lack of access, a close-up inspection of the upper parts of the tower could not be performed.

7.2.3 Roofing, Gutters, and Sheet Metal

The roof was not accessible for close-up inspection at the time of this Survey. The corrugated metal roof panels appear to be in fair condition, although some of the seams have opened up, and need to be re-fastened.

The pyramid roof over the transept crossing exhibits a slight sag at the hips and edges. This roof has no gutters and downspouts.

Reinforced concrete gutters exhibit cracks and spalls at several locations (figs. 49 and 56). Without close-up inspection, it could not be determined if the gutters have a metal liner, though cast iron outlets appear to be in place in the gutters (fig. 56), where there are vertical cracks in the concrete. Downspouts are missing. Locations of former downspouts are stained by biological growth (figs. 46 and 48). Plant growth is also visible in the gutter ends close to the front facade. Plant and other biological growth is common all over the building.

The main roof structure is not accessible or visible so its design and conditions are unknown, as are the connections between the ends of the roof trusses and the exterior walls.

7.2.4 Interior

The greatest signs of structural distress that are visible in the interior, are concentrated in walls around the front facade. Cracks observed on the exterior extend the full thickness of the walls to the interior. As seen more closely from the choir loft, the vertical corner cracks reveal very few horizontal reinforcing bars connecting the side wall to the front facade (figs. 58 and 59). There is some minor loss of concrete or plaster at the top of the pilaster capitals (fig. 60), perhaps from movement of the ceiling during the earthquake or during installation of the ceiling.

7.2.5 Windows and Doors

The decorative concrete screen blocks within the window openings are in fair condition. The arched wood panel doors of the front entrance and the glazed wood panel side doors are in fair condition.

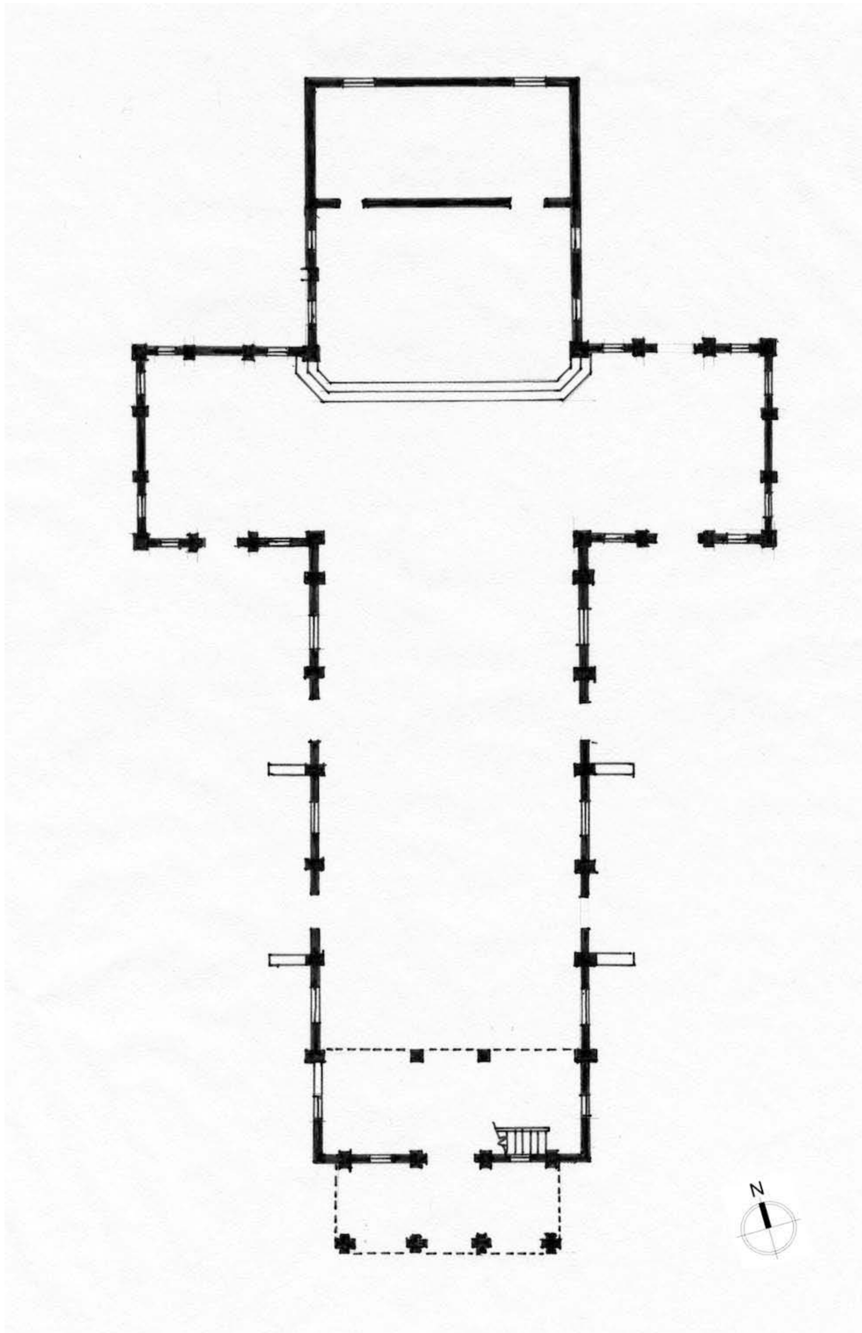


Figure 44. Ground floor plan of San Antonio de Padua Church in Sikatuna.

Figure 45. Front facade of the San Antonio de Padua Church in Sikatuna. The temple-front facade with a bell tower is typical of other churches of the period in Bohol.

Figure 46. View of east side of the portico and bell tower, with the arrows pointing to crack, which all appear to be from rocking of the bell tower and portico. See fig. 58 for interior view of the crack at "A."

Figure 47. View of west elevation. Note the concrete buttresses that have been added to the original structure. The left buttress was recently constructed. See following figures for details.

Figure 48. Detail of figure above, showing at "A" vertical crack and hinge cracks at "B," both from rocking of the portico. At "C" is a gutter outlet, which is missing its downspout, and significant plant growth from excessive water saturation of the concrete. See details in the following figures.

Figure 49. Detailed view of the crack at the southwest corner. Note the reinforcing bar at "A," which appears to be for the cornice. At "B" is a gutter outlet, which is missing its downspout, and has caused extensive plant growth on the wall and in cracks in the wall.

Figure 50. Detailed view of the crack at the southwest corner, showing exposed twisted reinforcing bars, and also exposed concrete with reveals large aggregate.

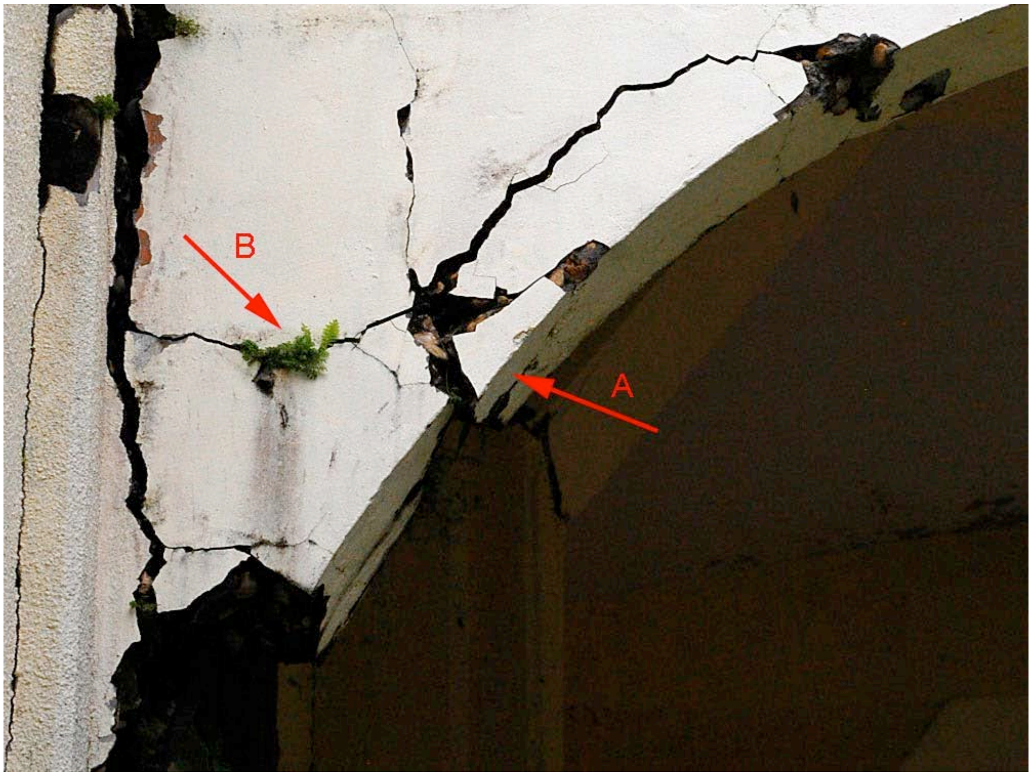


Figure 51. Detail of west portico arch at front facade, showing vertical cracks on the left, loose concrete at "A" (which is a safety hazard), and ferns growing in the crack at "B."

Figure 52. View of the front facade at the southwest corner. Note cracked concrete at haunch at "A," and fallen ceiling sections at "B." The roofing can be seen above the ceiling, indicating that the portico structure is similar to Catigbian (see fig. 33), so prone to twisting during an earthquake.

Figure 53. View beneath the portico. Note the cracks around the beam haunches from rocking of the portico and bell tower.

Figure 54. Concrete portico columns are typically cracked and spalled at the bases from bending. This is a common damage type for portico rocking caused by a soft-story and mass irregularity such as a bell tower.

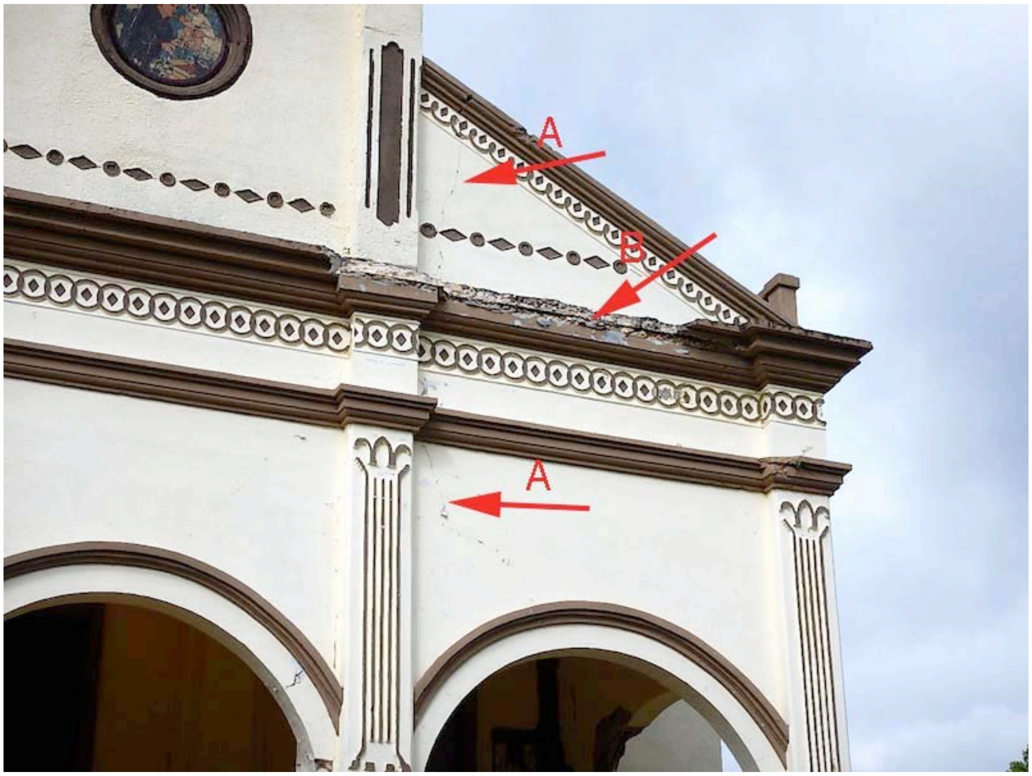


Figure 55. East side of the portico, showing vertical cracks at "A," similar in location to cracks found in the portico at Catigbian (see fig. 30). Also, part of the cornice molding at "B" has fallen, exposing the reinforcing bar.

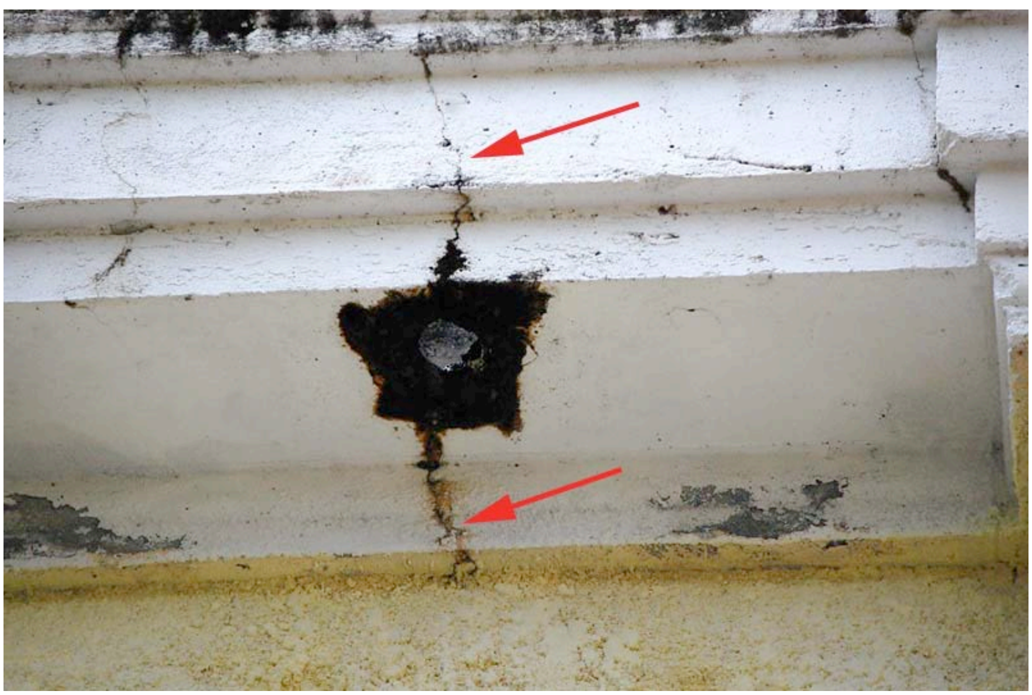


Figure 56. Crack in the gutter cornice at the gutter outlet, which appears to be from rusting iron, and not from seismic damage.

Figure 57. View of the interior from the choir loft. The ceiling appears to have been recently replaced.

Figure 58. Close-up view of the southeast corner crack from the interior. Compare with fig. 46. At this location it can be seen that the reinforcing bars are of small size and inadequately spaced. Note also plant roots from plants growing on the exterior.

Figure 59. View of the inside face of the front facade at the choir loft. The vertical cracks appear to be at the boundary between construction phases, and extend through the exterior.

Figure 60. The interior pilaster or concrete capital shows damage of its top molding, possibly from seismic movement of the ceiling, or during the ceiling reinstallation.

8. General Recommendations

The recommendations for the Orphan Churches are broken down into "General Recommendations," which apply to all three churches, and "Specific Recommendations," which apply to a particular church.

The intent and recommended performance objective of this Survey is to plan for and expect: damage in a major earthquake, but not the collapse of the building; damage that is repairable in a moderate earthquake; and no significant damage in a minor earthquake. These are only recommendations, and ultimately, the decisions on the amount of damage that is acceptable for each of the buildings must be made by the Diocese.

In all cases, the general recommendations of this Survey are:

- Avoid serious injury and loss of life due to structure collapse and failure of non-structural components, such as ceilings.
- Preserve means of egress, including doors and stairs.
- Avoid loss of use of churches that are occupied as emergency shelter during natural disasters.
- Avoid release of hazardous materials into the atmosphere.
- Reduce repair costs where practicable.
- Lessen damage during an earthquake to non-structural ecclesiastical, artistic, and heritage components.
- Restore and extend the life of the historic values of each building.

The primary general recommendation is a detailed seismic evaluation of the structural and non-structural components of the buildings, and the design of retrofit, restoration, and maintenance measures to provide for safe buildings, and to uphold the heritage values of each building.

Following the international model for preservation of heritage structures, the recommended design team for the evaluation and retrofit should include, at a minimum, a structural engineer experienced with heritage concrete structures, a geotechnical engineer, a conservation architect, a non-destructive testing consultant, a material scientist or conservator, materials testing laboratory, and often a contractor.

The evaluation and retrofit must comply with the applicable Philippine building, structural, and fire codes, especially the *National Structural Code of the Philippines* (*NSCP*) and interpretations by the local code officials. In areas where the *NSCP* may not provide sufficient direction for the evaluation and retrofit of early concrete structures, such as the Orphan Churches, it is recommended that applicable international standards regarding seismic evaluation and retrofit of concrete structures and their non-structural components be consulted, specifically:

ASCE/SEI 41-13: Seismic Evaluation and Retrofit of Existing Buildings.

ACI 369R-11: Guide for Seismic Rehabilitation of Existing Concrete Frame Buildings and Commentary.

FEMA 547: Techniques for the Seismic Rehabilitation of Existing Buildings.

FEMA E-74: Reducing the Risks of Nonstructural Earthquake Damage: A Practical Guide.

Preservation Brief 15: Preservation of Historic Concrete.

These standards, and the additional standards listed in the References section at the end of this Survey, are considered international "best practices" and provide guidance on assessment of damage, understanding material properties, analysis of structural and non-structural components, and design and implementation of seismic retrofits for existing and historic concrete structures.

8.1 OUTLINE OF GENERAL RECOMMENDATIONS

8.1.1 Seismic Evaluation

The first recommended step is a comprehensive evaluation of each building, which includes a process of data collection and analysis. The amount of data collected and the degree of analysis, whether simplified or comprehensive, should be appropriate to the performance objectives for each building. The parts of the evaluation process are:

Data Collection

- Prepare base drawings
- Develop history of construction
- Undertake comprehensive condition assessment
- Gather material properties

Structural Analysis

- Prepare Mathematical Building Model
- Analyze soils and foundations
- Analyze structural system and components
- Analyze non-structural components

8.1.2 Seismic Retrofit

The next recommended step is the retrofit process, which includes three parts:

Retrofit Design

- Structural retrofit
- Non-structural retrofit

Implementation

- Construction documents
- Construction
- Quality assurance

Maintenance

- Provisions for access
- Regular maintenance schedule

Each recommended step outlined above is described in detail in the following sections of the Survey.

8.2 DATA COLLECTION

8.2.1 Prepare Base Drawings

Because of the size of the churches and difficulty with access to the upper parts of the buildings, drawing preparation using laser scanning is recommended, rather than traditional hand measuring of the buildings. Following completion of the on-site laser scanning, the three-dimensional scanning data, or "point cloud," is converted into two-dimensional DWG format CAD drawings, and possibly into a three-dimensional model, depending on the structural engineer's requirements for the mathematical model. The drawings are printed and verified in the field during the comprehensive condition assessment, and also marked-up and annotated in the field with locations of damage and other observed conditions.

The recommended base drawings should include a foundation plan, floor plan, choir loft plan, and roof plan, and interior and exterior elevations, and show geometry, configuration, and dimensions of structural components (foundations, frames, walls, columns, towers, trusses, roofing, etc), and key non-structural components that are falling hazards (retablos, statues, ceilings, parapets, gutters, etc.) or are key life safety features (doors, stairs, etc.). Some of the drawings will require full-up site visits to verify dimensions and configurations, such as in attics, and foundations, where test pits will be required. Very detailed drawings are not required, but sufficient information must be presented that all surfaces are shown so conditions can be recorded, and so a mathematical building model can be developed for the structural analysis.

8.2.2 Develop History of Construction

In order to understand the behavior of different parts of the building it is recommended that as much information as can be found on the construction history of the building be gathered together. This information could include oral histories from retired priests, older town residents and congregation members, old photographs, original engineering drawings, newspaper clippings, and parish or diocese records. The types of significant information to be gathered include dates of original construction, dates and locations of additions, modifications, roof and ceiling replacements, and prior earthquake damage and when or how it was repaired. Involvement of the parish and town community is invaluable in gathering this type of information.

8.2.3 Comprehensive Condition Assessment

A comprehensive condition assessment is the next recommended step after preparation of the base drawings and development of the construction history. The condition assessment will require access to the upper parts of the building in order to verify materials, conditions, and connections, by ladders, lifts, and possibly scaffolding. It appears that lifts will fit through the doors of all the churches, though this must be verified, as well as the capacity of the floors to support the lift.

The condition assessment is a full hands-on survey of conditions, including crack mapping, and sounding to locate incipient spalls, voids, hollow areas, and other discontinuities, with conditions found marked up on drawings in the field. Examples of how to record damage can be found in *FEMA 306* and *FEMA 307*, and in fig. 61 below.

Crack mapping is essential to evaluate and retrofit concrete buildings because through an analysis of the cracks (location, orientation, width, depth, etc.) one can work towards an understanding of the causes of the damage (compressive, tensile or flexural stresses, construction phase boundary, inadequate reinforcing, etc.), and design proper retrofit measures to mitigate future damage. During the assessment it is important to distinguish between recent cracks caused by the earthquake and older cracks caused by rusting reinforcing bars or other causes.

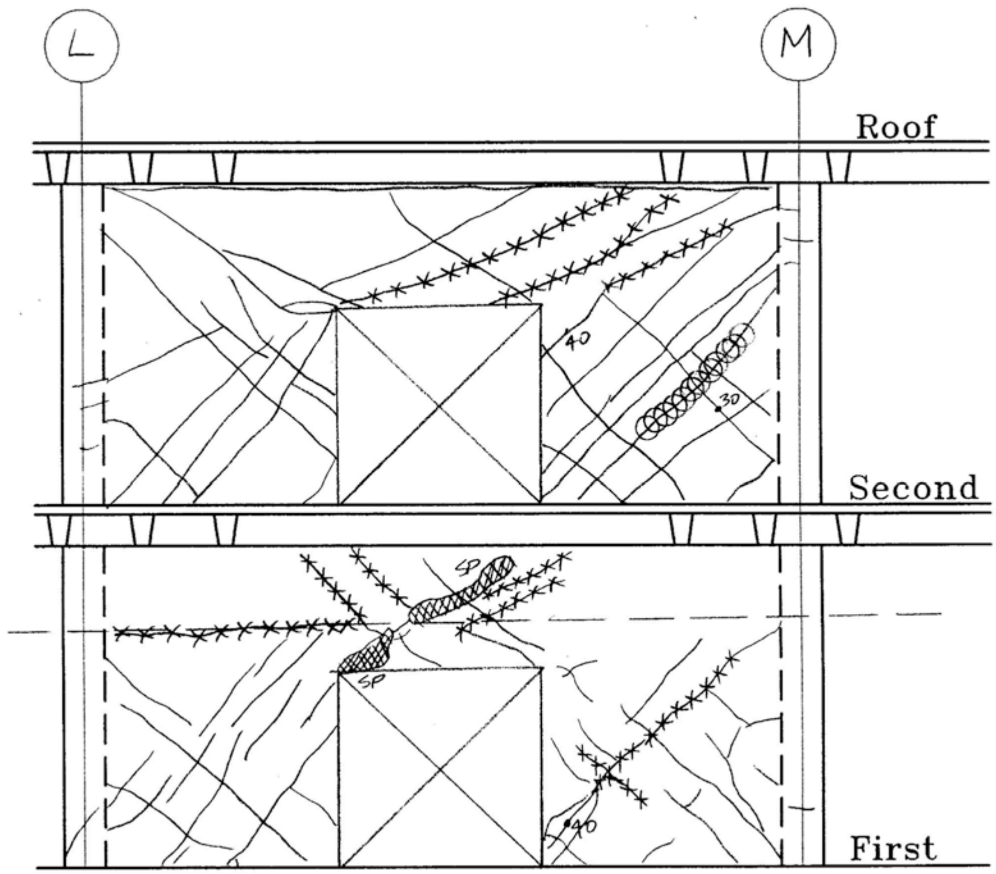
Foundation conditions may require assessment by a geotechnical engineer where geologic hazards are identified based on PHIVOLCS data or visual observations. Where such hazards are identified, an in-situ geotechnical investigation is recommended to be performed to identify the characteristics of the hazards and to determine soil stiffness and strength characteristics, so that an assessment can be made of the effect of earthquake-induced hazards at the site caused by fault rupture, liquefaction, differential settlement, compaction, landslides, etc., on the foundations and structure.

8.2.4 Gather Material Properties

Materials testing is recommended to quantify and confirm the uniformity of construction quality, the presence and degree of deterioration, as well as to provide data necessary for structural analysis.

Component Damage Record D4		
Building Name: Concrete Shear Wall Building	**Project ID:** ATC 43 Example	**Prepared by:** ATC
Location Within Building: **Floor:** 1st/2nd **Column Line:** 7 **Component Type:**		**Date:** 24-Sep-97

Sketch and Description of Damage:



Legend:

Crack
Crack Width in Mils (0.001 Inch)
Crack Previously Filled with Epoxy
Crack at Pre-existing Surface Patch
Spall
Not Accessible
Partition

Figure 61. Sample of a "Component Damage Record" form from *FEMA 307*, indicating one recommended method of how to record cracks, spalls, previous work, and similar conditions.

Guidance on best practices for concrete materials testing for seismic evaluation is detailed in *FEMA 306,* as shown in fig. 62 below, and in *ACI 228.2R.*

Materials testing should not be undertaken until the need has been established during consultation with the structural engineer, so that the type, location, and number of tests economically provides data necessary for the structural analysis. Some of the recommended material tests are common and can be undertaken by local design professionals and field and laboratory technicians, while others require specialized knowledge and field or laboratory equipment, and are thus more costly.

Table 3-1 Summary of Inspection and Test Procedures

Structural Or Material Property	Material			Test ID	Test Type
	Reinf. Conc.	Reinf. Mas.	URM	(Section 3.8)	
Crack Location and Size	✓	✓	✓	NDE 1	Visual observation
Spall Location and Size	✓	✓	✓	NDE 1	Visual observation
	✓	✓	✓	NDE 2	Sounding
Location of Interior Cracks or Delaminations	✓	✓	✓	NDE 6	Impact echo
	✓			NDE 7	Spectral Analysis of Surface Waves
	✓	✓	✓	IT 1	Selective removal
Reinforcing Bar Buckling or Fracturing	✓	✓		NDE 1	Visual observation
	✓	✓		IT 1	Selective removal
Relative Age of Cracks	✓	✓	✓	IT 2	Petrography
Relative Compressive Strength	✓	✓	✓	NDE 3	Rebound hammer
Compressive Strength	✓	✓	✓	IT 3	Material extraction and testing
Reinforcing Bar Location and Size	✓	✓		NDE 4	Rebar detector
	✓	✓		NDE 8	Radiography
	✓	✓		NDE 9	Penetrating radar
	✓	✓		IT 1	Selective removal
Strength of Reinforcing Bar	✓	✓		IT 3	Material extraction and testing
Wall Thickness	✓	✓	✓	NDE 1	Visual observation
	✓	✓	✓	NDE 6	Impact echo
	✓	✓	✓	IT 1	Selective removal
Presence of Grout in Masonry Cells		✓	✓	NDE 2	Sounding
		✓	✓	NDE 6	Impact echo
		✓	✓	NDE 7	Spectral Analysis of Surface Waves
		✓	✓	IT 1	Selective removal
Strength of Masonry		✓	✓	IT 3	Material extraction and testing
			✓	IT 4, 5	In situ testing
Mortar Properties		✓	✓	IT 2	Petrography
			✓	IT 4, 5	In situ testing

NDE: Nondestructive
IT: Intrusive

Figure 62. Sample of a Component Damage Record form from *FEMA 307*, indicating one recommended method of how to record cracks, spalls, previous work and similar conditions.

The design professional responsible for materials testing should carefully consider the need for the data that the tests would provide and the costs, and time required, for the tests.

Confirmation of the location, configuration, condition, and properties of reinforcing steel is especially critical to understand the performance of concrete structural components.

Several non-destructive examination (NDE) methods are recommended to be undertaken during the hands-on condition assessment, such as:

- Soil borings and ground penetrating radar (GPR) may be required, if sufficient soil data is not available from adjacent sites, including location of voids, the type, composition, consistency, relative density, and layering of soils to a depth at which the stress imposed by the building is impacted by the soil classification. Also, the water table height and its seasonal fluctuations beneath the building should be determined.
- Sounding of concrete with hand tools to locate voids, hollows, and loose material.

- Rebound hammer testing of concrete to supplement the more accurate, but also more costly, laboratory compressive strength testing.
- Pachometer (metal detector) testing to verify reinforcement bar location and size.
- Impact echo and penetrating radar testing to locate internal concrete cracks and delaminations, as well as configuration and location of foundations and other site features that may impact seismic performance (see GPR above).

For some materials destructive methods are necessary. These methods are recommended to determine mechanical properties for use in the structural analysis, identify causes of deterioration, and to later develop the required properties of repair materials. Some of the recommended destructive methods include:

- Test pits to locate foundations, configuration, dimensions, material composition and details of construction.
- Core samples for standard laboratory compressive strength testing. It may also be prudent to estimate concrete tensile strength and modulus of elasticity based on the tested compressive strength where the damage and costs associated with extra coring sampling are not warranted.
- Core samples for specialized laboratory petrographic examination of binder, aggregate, bond, chemical reactions, and age of cracks, following *ASTM C856-14*, modified for examination of historic concrete.
- Selective removal of concrete cover and direct visual inspection of voids, cracks, and reinforcing bars. Generally, concrete cover can be removed and replaced to observe bar sizes, splice details, and ties, if present, and replaced with little or no impairment of structural capacity
- Selective removal of reinforcement bars for laboratory testing for yield and ultimate strength, and presence of corrosion.

In addition, pull-out tests of roofing and ceiling fasteners may be required to understand how well these components are connected to the roof and ceiling structures, and how well they would behave during earthquakes and typhoon winds so the proper fastener connections can be designed for the seismic retrofit.

8.3 STRUCTURAL ANALYSIS

8.3.1 Mathematical Building Model

Following the condition assessment, the mathematical building model is created utilizing the building's configuration and dimensions determined during the preparation of base drawings and comprehensive condition assessment. If the base drawings for the building were prepared using laser scanning then the laser scanned point cloud data can be used to create a three-dimensional mathematical model of the building's structural components for use in the structural engineer's analysis.

The mathematical model can be constructed using many three-dimensional software programs but must be compatible with the structural engineer's structural analysis and design software program.

The initial mathematical model represents the building in its pre-event state, prior to the earthquake. Where the condition assessment has found damage that diminishes the structural capacity of the building then the mathematical model must then be modified to quantify the reduced structural capacity of the degraded components. The mathematical model is then used during the structural analysis to design the retrofit measures, and the final mathematical model represents the building in its retrofitted state.

8.3.2 Analyze Soils and Foundations

The soils and foundations should be included in the mathematical building model so that the foundations can be analyzed with the above-grade structural components, and separately, as well. Actual acceleration data from recent earthquakes and aftershocks is also important for the analysis.

The foundation analysis is based on the site characterization, including soil classification and foundation data, and should follow the analysis methods outlined below for the structural systems and components. Calculations of the design foundation loads must be obtained, including separate dead and live loads, from calculations where information on the original design foundation loads are not available.

The analysis procedures should be selected by the structural engineer to evaluate the ability of foundations to withstand the imposed seismic loads without excessive deformations. Given that the foundations are likely to be shallow, the analysis should consider explicitly analyzing the load-deformation characteristics of the foundations, with consideration given to macro-element method;, however, the choice of analysis method should be based on the structural engineer's understanding of the global and specific effects of the interaction between the foundation and superstructure.

8.3.3 Analyze Structural System and Components

The analysis of the buildings will be performed using either linear static or dynamic procedures or nonlinear static or dynamic procedures, selected by the structural engineer as appropriate to the building configuration and component types. Where the *NSCP* is lacking in specificity on procedures for seismic analysis of older concrete structures then the structural engineer should follow the applicable provisions of *ASCE 41*. Under the *NSCP* and *ASCE 7*, the churches are categorized by occupancy as Essential Facilities, so the analysis should take into account the comprehensive nature of structural analysis required of buildings used as emergency shelters. The analysis selection should take into account the limitations of some procedures for analysis of the structural irregularities of the churches, including additions, reentrant corners, and soft-story and mass irregularities of the portico and towers. It is possible that a combination of procedures may be cost effective and useful for some specific components of the buildings, and should be considered where appropriate. Where nonlinear dynamic procedures are used, the structural engineer should consider review of the analysis by an independent third-party engineer with experience in seismic design and nonlinear procedures.

Also, the selected analysis method can also influence the data collection scope, so a dialogue between the design professionals responsible for data collection and the structural engineer performing the analysis is critical so that the evaluation process is economical and timely.

The buildings should be analyzed and evaluated as a three-dimensional assembly of components. The analysis should examine the building globally and each component specification for interaction with foundations, component stiffness, strength, deformation, torsion, connections between components, and performance of roof and ceiling diaphragm systems (chords, collectors, and ties). The analysis should also address concurrent seismic motion in any horizontal direction. Component stiffness should be analyzed considering shear, flexure, axial behavior, and reinforcement slip deformations. Where testing has found that the infill walls are classified as plain concrete, analysis should take that into account, and analyzed as unreinforced masonry infills following *ASCE 41*. Where material testing indicates lower strength values of the concrete than contemporary concrete, those values must be factored into the calculations.

Although the construction of each church is different, some similar damage can be found at all three buildings, so that it is recommended that the structural analysis consider these common damage mechanisms for all three churches:

- Separation of the front facade from the side elevations possibly caused by the portico and bell tower rocking due to mass irregularities and soft-story mechanism.
- Inadequate connections between walls and frames at corners of additions, transepts, and facades.
- Lack of frame or tie beams at the tops of walls.
- Continuity and connection of diaphragms and other components at the tops of walls.

Connections between additions and transepts and the main structural system of the building should be analyzed for the connections' capability of resisting, in any direction, seismic horizontal forces. Likewise. connections between roof trusses, ceilings, balconies, and similar components attached to the exterior walls should be analyzed for their ability to remain connected to the walls during earthquakes and typhoons, in order to prevent dislocation and possible collapse of the components, as well as their function within diaphragm systems. And connections between walls and frames should be analyzed to safeguard against displacement and collapse, as well as their ability to function as shear walls within the frames.

Given the lightness and detailing of the roofs, trusses, and ceilings, it is possible that they offer no resistance to out-of-plane exterior frame and wall movement, but should be analyzed for the potential for such lateral support.

And, though not within the scope of this Survey, the structural engineer should also consider an analysis of wind loads, following the procedures of the *NSCP* and *ASCE 7*, especially as wind affects the performance of the roofing and ceiling.

8.3.4 Analyze Non-structural Components

Analysis should be undertaken of non-structural components, such as roofing, ceilings, gutters, downspouts, parapets, cornices, stairs, balconies, and doors required for egress. For many of the non-structural components, analysis may follow prescriptive procedures conforming to accepted engineering practice, and as indicated in *ASCE 41* and applicable *FEMA* manuals. The analysis should ascertain the existing ability of the components to retain their positions and to present a low risk to life safety, and determine retrofit measures necessary for those performance goals.

The roofing and ceilings are sensitive to both the horizontal and vertical acceleration forces encountered during earthquakes, and are susceptible to buckling and deformation. Surface-applied or furred roofing and ceilings are primarily influenced by the performance of their supports, including the joists, rafters, purlins, and fasteners. Roofing and ceiling components that are not properly attached can become loose and fall, causing serious injuries. Structural analysis is necessary to establish the acceleration forces and deformations that may be encountered and must be accommodated by the roofing and ceilings. The analysis should consider the fastener pullout forces encountered during seismic events, taking into account the actual condition of both the wood or metal and the fasteners.

For the purposes of this Survey parapets and cornices includes exterior components that project above or away from the building. Parapets and similar vertical non-structural components, are considered acceleration sensitive in the out-of-plane direction. Statues, crosses and similar appendages can be acceleration sensitive in all directions. Concrete cornices can be sensitive to vertical acceleration, especially when poorly constructed or deteriorated prior to the earthquake. Gutters and downspouts are prone to detachment at any time that the attachment or fasteners are deteriorated.

The condition of the parapet and cornice concrete, connection to supports, type and stability of the supporting structure, and horizontal continuity, should be considered in the analysis.

Components of stairs that are attached to balcony floor framing and walls are considered deformation sensitive, and the behavior and final position is dependent on the movement and deformation of the construction to which they are attached, and the condition of the connections.

Doors used for egress can become jammed or otherwise inoperable because of building movements and racking of door openings. Egress doors should be capable of operation during and following an earthquake, and should be analyzed for this capability.

Although this Survey did not include mechanical and electrical components or furnishings, including ecclesiastical furnishings, such as retablos and organs, where the performance of any of these components in an earthquake affects life safety or significant damage, their analysis and retrofit should be explicitly considered.

8.4 RETROFIT DESIGN

Following completion of the evaluation, the retrofit work is designed by the members of the design team, which includes the structural engineer, architect, materials specialist or conservator, and often a contractor. The retrofit design is recommended to be presented to the Diocese and Parish for review and comment during its various phases, including at the end of a Schematic Design phase which is the first time when all of the proposed work is shown in a preliminary manner on drawings and in a narrative format. As each of the other design phases progresses the proposed work should be presented for review and comment, along with a cost estimate and schedule for the work.

In general, the retrofit work should be aimed at improving the overall behavior of the building, including improving structural connections between components, improving diaphragms and infill walls, removing falling hazards, and maintaining free paths of egress.

It is possible that full retrofit of some configuration irregularities, such as reentrant corners at transepts, and at the porticos and bell towers, may be economically impractical, so that damage at these locations of high stress during strong earthquakes should be expected to reoccur, though with low risk to life safety. Retrofit of other deficiencies, such as cracked infill walls, displaced wall sections, and inadequately attached ceilings are readily feasible, and damage should not reoccur at those locations if properly implemented.

The retrofit design should consider the initial and life cycle costs of the proposed design, compatibility of new materials with existing, availability of materials, and constructability with the available work force. Retrofit solutions should be selected and designed to improve the structural and non-structural safety level, but only solutions that do not detract from the artistic and heritage values of the building, and have a demonstrated record of effectiveness with the type of materials and construction technology and conditions present should be considered.

General approaches to structural and non-structural seismic retrofit include:

- Repair
- Replacement
- Strengthening
- Bracing
- Attachment

8.4.1 Foundation Retrofit

Detailed foundation retrofit design, if required, should be determined following determination of soil classification, and confirmation of the foundation type, configuration, dimensions, materials, and details, and assessment of foundation condition and structural analysis by the geotechnical and structural engineers.

8.4.2 Concrete Repairs

Concrete repairs fall into three general categories:

- Cosmetic Repairs are those repairs that improve the visual appearance of damage. These repairs may also restore non-structural properties, such as weather protection, though any structural benefit is negligible. An example is the filling of minor cracks and spalls in concrete.
- Structural Repairs address component damage directly, with the intent to restore or enhance structural properties. Examples include filling of full-thickness cracks, replacement of fractured reinforcing bars, deep spall repair, and full wall replacement.
- Structural Enhancements are repairs that comprise supplemental additions to replace structural properties of damaged components rather than to restore them. Examples include the application of fiber-reinforced cementitious matrix overlays to damaged infill walls, improvement of connections between components, and the addition of bracing to the building where these elements were not present before the earthquake.

Repair of concrete requires a balancing of the properties of the repair material for substrate compatibility, application constraints, mechanical/electrochemical/compositional performance, cost (material and installation), market and regulatory requirements, and durability during service. Guidance on concrete repairs can be found in numerous publications of the American Concrete Institute (www.aci.org) and the International Concrete Repair Institute (www.icri.org), as well as the publications cited in the References section of this Survey.

Repairs are recommended to follow *ACI 546R-04: Concrete Repair Guide*. Repairs should not be undertaken until the root cause of the damage has been determined by the condition assessment and structural analysis.

Selection of repair and replacement materials should be based on *ACI 546.3R-06: Guide for the Selection of Materials for the Repair of Concrete*. Care should be made to select repair materials – both patching compounds and replacement concrete – that are compatible with the adjacent concrete. Bond and compressive strengths are important material properties for concrete repairs, but, for older concrete many other material properties can be of equal or greater importance, including: coefficient of thermal expansion, shrinkage, permeability, modulus of elasticity, chemical properties, and color (where the concrete is to remain unpainted). The selection should be based on actual materials properties determined by testing, or where test data is unavailable, based on historic data for concrete of the same era of construction.

Most contemporary concrete patching compounds utilizing epoxy products are not compatible with older concrete.

Cosmetic concrete repairs to concrete cracks (up to about 3 inches in width) and shallow spalls (about 1 inch in depth) should follow *ACI RAP Bulletin 6: Vertical and Overhead Spall Repair by Hand Application*. Where the cracks are larger, the spalls are deep, or the structural integrity of a wall or column is to be restored, the repairs should follow *ACI RAP Bulletin 4: Surface Repair Using Form-and-Pour Techniques*.

No matter which repair, replacement, or strengthening method is required, surface preparation is critical to successful repairs, and is essentially the same: all loose, cracked, and delaminated concrete is removed to sound concrete. The shape of the prepared opening is cut out and kept as simple as possible, generally square or rectangular in shape, avoiding reentrant corners where possible, with edges saw cut perpendicular to the surface to a depth of ½ inch or more to avoid feather edging the repair material. Be wary of any repair material for which claims are made that it may be feathered. Undercut exposed reinforcement, remove corrosion by abrasive blasting with a wire wheel or needle scaler, and clean surfaces with high-pressure water or abrasive blasting. The final surface texture must be rough for proper bonding. Place and cure repair materials as recommended by the appropriate *ACI RAP Bulletin* and the material manufacturer.

Where removal of concrete has revealed that the cross sectional area of the reinforcing steel has been significantly reduced, supplement with new reinforcement as specified by the structural engineer. Where the structural engineer has specified strengthening across cracks and reconnecting damaged areas, install new reinforcement or dowels in pre-drilled holes, drilled perpendicular to cracks. Repair cracks as described above.

For wall sections that have become displaced, remove displaced sections, leaving in place as much reinforcing steel as practical for splicing to new reinforcing. Install new additional reinforcing steel at the boundary joint, spliced or set into pre-drilled holes as noted above. Install concrete formwork, and pour new concrete to replace removed sections, making sure the new concrete is connected to the old at all joints, following best practices for new concrete work. The appearance of the new wall section should match the original, but with seismic structural enhancements as determined by the analysis.

For infill wall panels with vertical and diagonal cracking the retrofit design should investigate the improvement of in-plane wall strength by the application of a fiber-reinforced cementitious matrix (FRCM) overlay. See *ACI 549.4R-13* for design and installation requirements. FRCM is a composite material consisting of a sequence of one or more layers of cement-based mortar reinforced with fiber fabric. When adhered to concrete FRCM forms an externally bonded strengthening system. FRCM is considered as a suitable strengthening material for older concrete because the cementitious matrix has the advantage over more common fiber-reinforced polymer (FRP) of compatibility with the substrate (allows vapor permeability and application on a wet surface), long-term durability, workability and installation similar to stucco, ease of cleaning of equipment and tools, absence of materials hazardous to workers and environment, and similarity in finished appearance to concrete. FRCM overlays have also been found to improve bending capacity in columns, and may be appropriate for the reducing cracking at the portico column bases.

8.4.3 Retrofit of Roof Structure

Connections of diaphragms, roof trusses, and other structural components of the roof system are recommended to be properly connected to the tops of walls, using fasteners (bolts, expansion anchors, and similar) manufactured for structural use in tropical climatic conditions. Roofing and ceiling attachment is discussed below.

8.4.4 Improvement of Access for Maintenance and Inspections

For all buildings provisions should be made for access to all areas of the roof, gutters, attics, bell towers, and porticos for maintenance by staff and outside contractors, and for regular inspections by staff, engineers, and architects as discussed below in the Maintenance section of this Survey.

Access includes, but is not limited to:

- Fixed ladders, with handrails and step platforms.
- Walkways (catwalks) with handrails.
- Fall protection systems, including harnesses, safety lines, and safety line tie-offs, for attic, roofs, gutter, and similar access at heights.
- Moveable scaffolding.
- Moveable lifts (may be leased as needed for maintenance and inspection).
- Power outlets located at distant locations for tools.

Safety of workers and inspectors is of prime importance and all access provisions should follow international worker safety standards.

8.4.5 Non-structural Retrofit

To improve life safety performance, this Survey recommends that non-structural components, such as ceilings, be retrofitted to retain their original position, without excessive movement, deformation, or displacement during an earthquake. In addition, artistic or heritage components, such as retablos, statuary, and organs, should be retrofitted to prevent significant damage.

For roofing and ceilings retrofit is recommended to take the form of removal and replacement of sheet metal, and attachment to sound material, using fasteners meeting pullout requirements prescribed by the structural engineer. Only screw and bolt fasteners manufactured for structural use in tropical climatic conditions should be used. Oversized washers should be used at fastened connections through the base sheet metal if the base is not reinforced with stiffeners. Install diagonal diaphragm bracing where indicated by structural analysis. Installation of additional purlins, furring, and new bracing of the joists and rafters may also be required to enhance lateral stability and to control buckling of the roofing or ceiling.

Gutters and downspouts should be replaced, sized to perform without leaking, overflow, or deflection in the heavy rainfalls that may be encountered. Attachment should meet accepted roofing industry practices for high-rainfall climates, utilizing only screw and bolt fasteners manufactured for structural use in tropical climatic conditions, meeting the structural engineer's specified pullout requirements.

Parapets and cornices should be braced for acceleration forces and connected to the building structure according to accepted engineering principles, using steel braces, or similar new elements.

Deteriorated concrete cornice sections should be removed to sound material and repaired as described above for concrete repairs. Cornice sections should also be waterproofed on the top surfaces, to prevent future deterioration of the reinforcing bars, by installation of sheet metal or sheet membrane waterproofing.

Similar waterproofing should be installed at intersections of balustrades, pediments, and similar components roof-level components to keep water out of the building, to lengthen the life span of the components, and lessen deterioration that can lead to falling hazards during earthquakes.

Connections of stairs to framing should be retrofitted where insufficient for seismic movements.

Egress doors, door jambs, hinges, and their connections should be strengthened or altered where the doors can become inoperable due to damage or deformation of the door components, or surrounding walls.

Other non-structural components, whose seismic performance affects life safety, should also be retrofitted to improve operability following earthquakes, and to prevent falling hazards.

8.5 IMPLEMENTATION

Construction documents for the designed retrofit are recommended to show all the required work on foundation, floor, roof, and ceiling plans, interior and exterior elevations, and detail drawings, accompanied by specifications for materials, installation, and quality control. Before beginning the construction documents the designer should present to the Diocese and Parish for their review and comment a Schematic Design showing the proposed work on drawings and in narrative format.

As early as possible in the preparation of the construction documents, a cost estimate should be made to review the economic acceptability of the retrofit design. If the design proves uneconomical or otherwise not feasible, further refinement may be considered in the structural analysis, different retrofit schemes may be designed or different performance objectives may be considered.

Contractor selection should include qualification requirements for sub-contractors and craftsmen performing specialized work.

Craftsman training should also be considered as an integral part of the work, so that there will be a continuity of best practices for concrete repair and seismic retrofit from project to project.

A quality assurance plan (QAP) should be prepared by the structural engineer, along with the architect and other design professionals, to identify components of the work that are subject to quality assurance procedures and to identify special inspection, testing, and observation requirements to confirm construction quality. At a minimum the QAP should include the following: Contractor and Sub-contractor qualifications; construction quality control procedures; design professional construction services, such as review of required contractor submittals and mockupsmonitoring of required inspection reports and test results, site visits and meetings with the Contractor, and construction observation.

The design structural engineer should be responsible for modifying the retrofit design to reflect conditions discovered during construction to maintain the targeted performance objective.

For final project documentation, at the end of construction the Contractor is recommended to submit as-built drawings, specifications, reports, and photographs showing the work as it was actually installed. The documentation should be reviewed and initialed as approved by the engineer, architect, and other design professionals. At least two copies each of the final project documentation should be deposited in both the Diocese and Parish archives.

8.6 MAINTENANCE

The design professional, along with the Diocese and Parish, should establish a maintenance program to increase the design life of the retrofitted structural and non-structural components, and other building elements.

The maintenance program should be based on changes in the seasons, weather, and special event uses of the churches. The maintenance program should be written down in a manner that all maintenance staff and contractors can understand and follow the program, for instance, utilizing a calendar and checklists. The maintenance program should also allow for regular record keeping, and feedback, noting work completed, and what worked and did not work.

Provisions for safe access for maintenance should be installed during the retrofit work, including but not limited to, ladders, catwalks, handrails, positioning points for safety harnesses, and power outlets.

Training programs should be implemented for maintenance staff on special procedures for maintenance, if any, on how to report and record observed damage or deterioration, and on safety. Some maintenance work may require outside contractors, especially where access is difficult.

Regular maintenance work should include, at a minimum: reattachment of loose roofing and flashingcleaning of gutters and downspouts, removal of plant growth from bell towers, cornices, and crevices, removal of pigeon guano from attics, and reapplication of paints and coatings to avoid deterioration.

An inspection of the building should be completed by a structural engineer or architect following any significant seismic activity and storms, and changes in the structural and non-structural components documented.

9. Specific Recommendations

9.1 NUESTRA SEÑORA DEL ROSARIO CHURCH, ANTEQUERA

The following recommendations are specific to the damage and other conditions observed during the site visit for this Survey, and are in addition to the General Recommendations above.

9.1.1 Evaluation

The comprehensive condition assessment should determine the following about the structural type during the hands-on condition assessment and materials testing phase:

- Age and type of concrete.
- Extent and details of coralstone foundations.
- Presence of reinforcing bars in infill walls.
- Confirm that the pilasters express an actual structural frame.
- Confirm the presence of a tie beam at the top of the exterior walls.
- Connections to bell tower.
- Construction type and details of additions.

The structural analysis should look at the following:

- Shear resistance in side infill walls.
- Twisting and out-of-plane movement of the bell tower cupola, and need for internal diagonal or cross-bracing.
- Need for lateral bracing of the pediment and portico.
- Pounding of the bell tower against the nave walls.
- Rocking of the facade.
- Relation of in-plane cracking of infill walls to minimal reinforcement.

9.1.2 Reinforced Concrete Frames and Walls

Remove all unsafe, loose, and displaced concrete walls, and replace with new concrete walls, properly connected to the adjacent concrete and roof structure.

Perform a comprehensive condition assessment of the concrete frames and infill walls from the exterior and interior, mapping cracks, spalls, delaminations, and similar adverse conditions.

Repair all cracks. Where indicated by the structural analysis, strengthen infill walls panels with FRCM overlay.

9.1.3 Bell Tower and Portico

Brace parapets, pediments, statues, and similar projections to the building structure.

Remove plant growth, install biocide.

Add sheet metal or sheet membrane waterproofing to the bell tower and tops of pediment cornices and mouldings, to prevent water infiltration into the interior, and deterioration of the concrete.

9.1.4 Roofing, Gutters, and Sheet Metal

Remove and replace collapsed sections of rear addition roof structure with new structure, fully connected to top of walls.

Perform a comprehensive condition assessment of the roofing, looking for holes, open seams, loose fasteners, and similar adverse conditions. Where found to be damaged or deteriorated, replace deteriorated roofing panels, fasteners, sheet metal flashing, gutters, and downspouts.

Install soffit boards where missing and re-attached loose boards.

9.1.5 Interior

Remove and replace the ceiling, with fasteners attached to the purlins and rafters designed and installed to resist seismic forces. Provide bracing and other supplemental structure where indicated by structural analysis.

Patch cracks that extend from the exterior.

9.1.6 Windows and Doors

No specific work recommended.

9.2 LA PURISIMA CONCEPCION CHURCH, CATIGBIAN

The following recommendations are specific to the damage and other conditions observed during the site visit for this Survey, and are in addition to the General Recommendations above.

9.2.1 Evaluation

The comprehensive condition assessment should determine the following about the structural type during the hands-on condition assessment and materials testing phase:

- Confirm presence of reinforcing bars at corners between front facade and side elevations.

The structural analysis should look at the following:

- Confirm if side bays of the portico are prone to twisting, and explore retrofit measures, such as diaphragm or cross-bracing.
- Rocking of the bell tower and portico and their contribution to crack damage at the corner.
- Bending in portico columns.

9.2.2 Reinforced Concrete Frames and Walls

Where cracks have been recently filled, they should be carefully monitored for durability over the coming years, and replaced where they fail, following the general recommendations for concrete repairs above.

9.2.3 Bell Tower and Portico

See above for recent repairs.

Pending structural analysis, provide a stiff diaphragm or braces at the ceiling of the two outer bays of the portico to prevent twisting. This can possibly be achieved with diagonal steel strapping at the underside of the roof structure, and proper connections between the roof structure and the walls of the portico.

9.2.4 Roofing, Gutters, and Sheet Metal

Perform a comprehensive condition assessment of the roofing, looking for holes, open seams, loose fasteners, and similar adverse conditions. Where found to be damaged or deteriorated, replace deteriorated roofing panels, fasteners, sheet metal flashing.

Replace gutter liners and downspouts. Repair concrete cracks in gutters.

9.2.5 Interior

Install a new sheet metal ceiling, with fasteners attached to the purlins and rafters designed and installed to resist seismic forces. Provide bracing and other supplemental structure where indicated by structural analysis.

9.2.6 Windows and Doors

Repair cracks in concrete window transom bars and mullions.

9.3 SAN ANTONIO DE PADUA CHURCH, SIKATUNA

The following recommendations are specific to the damage and other conditions observed during the site visit for this Survey, and are in addition to the General Recommendations above.

9.3.1 Evaluation

The comprehensive condition assessment should determine the following about the structural type during the hands-on condition assessment and materials testing phase:

- Confirm presence of reinforcing bars at corners between front facade and side elevations.

The structural analysis should look at the following:

- Confirm if side bays of the portico are prone to twisting, and explore retrofit measures, such as diaphragm or cross-bracing.
- Confirm rocking of the bell tower and portico.
- Analyze bending in portico arches, beam haunches, and columns.
- Examine need for proposed buttresses at portico.

Install new gutters and downspouts.

9.3.2 Reinforced Concrete Frames and Walls

See below for Bell Tower and Portico

9.3.3 Bell Tower and Portico

Perform a comprehensive condition assessment of the bell tower and portico from the exterior and interior, mapping cracks, spalls, delaminations, and similar adverse conditions.

Reconnect the corner of the sidewall and the portico to the front facade as indicated by the structural analysis.

Repair all cracks, and where indicated by structural analysis, strengthen with rebar stitched across the cracks.

Remove all loose and deteriorated cornices and replace with new molded concrete to match the original. Install weatherproofing membrane on top of cornice to prevent water infiltration.

Remove plant growth, install biocide.

9.3.4 Roofing, Gutters, and Sheet Metal

Remove iron and deteriorated concrete from gutters. Replace with new gutter liner and patch concrete.

Install downspouts.

9.3.5 Interior

Patch cracks that extend from the exterior.

Perform a comprehensive assessment of the main ceiling, and replace or strengthen as indicated by conditions.

Replace missing sections of the ceiling under the balcony.

9.3.6 Windows and Doors

No specific work recommended.

10. References

The following references were consulted in the preparation of this Survey, and should be consulted during the next steps of comprehensive seismic evaluation and retrofit. *Bakás Pilipinas* can make copies of some of these available to the Diocese or local design professionals, if requested. All FEMA documents are available from www.fema.gov.

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11. Glossary

Apog: Lime.

Apse: Space at the 'head' of the church, where the main altar is located, and where mass is celebrated.

Baldaquin: An ornamental canopy over an altar, usually supported on columns.

Building Frame System: A structural system with an essentially complete space frame providing support for gravity loads. Resistance to lateral load is provided by shear walls or braced frames.

Calado: Openwork, such as patterns cut out from panels

Clerestory: The upper area of a nave or wall, pierced by windows.

Coffered: Used to describe a surface, such as ceiling, with deeply recessed panels.

Cold Joint: A boundary between later-applied and previously applied concrete, mortar, plaster, or coatings, which represents a plane of weakness between the materials.

Column (or Beam) Jacketing: A retrofit method in which a concrete column or beam is encased in a steel or concrete "jacket" to strengthen or repair the member by confining the concrete.

Component: A part of an architectural, mechanical, electrical, or structural system of a building.

Concrete: Mixture of Portland cement or any other hydraulic cement, fine aggregate, coarse aggregate, and water, with or without admixtures.

Connection: A link that transmits forces from one component to another component.

Conservation: Management of a natural resource, structure, or artifact to prevent misuse, destruction, or neglect. It may include detailed characterization and recording (technical or inventory) or provenance and history and application of measures.

Convent: In the Philippine context, a parish house or rectory.

Crossing: The space in the middle of the transept, at the junction of the nave and apse.

Cruciform: Plan shaped like a Latin cross, with nave, transept and apse.

Cupola: Small dome.

Diaphragm: A horizontal (or nearly horizontal) structural component that is structurally loaded in its plane, such as roof sheathing, roof structure, or floor, used to transfer seismic or wind lateral forces to vertical elements (walls or frames) of the seismic-force-resisting system. The term "diaphragm" includes horizontal bracing systems.

Ductile: The ability of a structure or element to dissipate energy inelastically when displaced beyond its elastic limit without a significant loss in load-carrying capacity.

Epistle side: Right side of the church, as one faces the altar.

Essential Facilities: Structures that are necessary for emergency operations subsequent to a natural disaster, such as designated evacuation centers,, shelter, and emergency preparedness centers.

Evaluation: An approved process or methodology of evaluating a building for a selected seismic Performance Objective.

Flexural Stresses: Stresses in a component that result from bending.

Flexure: Bending.

Fluted: Used to describe a surface with parallel vertical grooves or channels, seen on columns or pilasters.

Harigue (also haligue): A housepost or pillar, usually of hardwood.

Hydraulic Cement: Cement that sets and hardens by chemical reaction with water and is capable of doing so under water.

In-plane: Deflections or forces that are in the plane of a wall or diaphragm.

Liquefaction: A process in which saturated, loose, granular soils lose shear strength and shear stiffness as a result of an increase in pore water pressure during earthquake shaking or other rapid loading.

Load Path: A path through which seismic forces are delivered from the point at which inertial forces are generated in the structure to the foundation and, ultimately, the supporting soil.

Narthex: Vestibule at the entrance of the church, corresponding to the lobby of a building.

Natural Cement: Hydraulic cement produced by calcining a naturally occurring argillaceous limestone at a temperature below the sintering point and then grinding to a fine powder.

Non-structural component: Architectural, mechanical, or electrical components of a building that are permanently installed in, or are an integral part of, a building system.

Non-structural Performance Level: A limiting damage state for non-structural building components used to define Performance Objectives.

Out-of-plane: Deflections or forces that are perpendicular to the plane of a wall.

Overturning: Collapse of a component, such as a tower or wall, caused by rotation (rocking) about its base.

Pediment: The upper part of a façade, usually triangular in shape.

Perforated wall or infill panel: A wall or panel not meeting the requirements for a solid wall or infill panel.

Performance Level: A limiting damage state for a building, considering structural and non-structural components, used in the definition of Performance Objectives.

Performance Objective: One or more pairings of a selected Seismic Hazard Level with both an acceptable or desired Structural Performance Level and an acceptable or desired Non-structural Performance Level.

Pilaster: A 'flattened' column (as opposed to a full square or round column) attached to a wall.

Plain Concrete: Structural concrete with no reinforcement or with less reinforcement than the minimum amount specified for reinforced concrete.

Portico: A porch or covered space consisting of a roof resting on columns or on a series of arches.

Portland Cement: Hydraulic cement produced by pulverizing clinker, consisting essentially of crystalline hydraulic calcium silicates, and usually containing one or more of the following: water, calcium sulfate, up to 5 % limestone, and processing additions.

Preservation: The act or process of applying measures to sustain the existing form, integrity, and materials of a building, structure or artifact. Work, including preliminary measures to protect and stabilize the property, generally focuses upon the ongoing maintenance and repair of historic materials and features rather than extensive replacement and new construction.

Rebar: Concrete reinforcing bars made of steel.

Reentrant Corner: Plan irregularity, such as an extending wing, plan inset, or E, T-, X-, or L-shaped plan configuration, where large tensile and compressive forces can develop.

Rehabilitation: The process of returning a building or buildings to a state of utility, through repair or alteration, which makes possible an efficient use while preserving those portions and features of the building and its site and environment which convey its historical, cultural, or architectural values.

Reinforced Concrete: Structural concrete reinforced with no less than the minimum amount of steel or other reinforcement as specified in the applicable building code. The reinforcing is positioned so that the two materials act together for increased strength.

Repair: To replace or correct deteriorated, damaged, or faulty materials, components, or elements of a structure.

Restoration: The act or process of accurately depicting the form, features, and character of a structure or artifact as it appeared at a particular period of time by means of the removal of features from other periods in its history and reconstruction of missing features from the restoration period.

Retablo: A monumental structure, generally planar, at the back of the altar but facing the congregation; it features any number of niches where images of saints are displayed for veneration.

Retrofit: Improving the seismic performance of structural or non-structural components of a building.

Rubblework: Masonry composed of gravel and rough stones, held together by mortar.

Seismic-Force-Resisting System: Those elements of the structure that provide its basic strength and stiffness to resist seismic forces.

Seismic Hazard Level: Ground-shaking demands of specified severity, developed on either a probabilistic or deterministic basis.

Shear Forces: Forces that can develop both in plane and out of plane and are caused by an opposite but parallel sliding motion of a body's planes. In walls, such forces typically occur in the plane of the wall and cause diagonal, vertical, or X-shaped cracking.

Shear Wall: A wall that resists lateral forces applied within its plane by compression.

Site Class: A classification assigned to a site based on the types of soils present and their engineering properties.

Soft Story: A soft story is one in which the lateral stiffness is less than 70 percent of that in the story above or less than 80 percent of the average stiffness of the three stories above.

Soft Story: An irregularity in stiffness and mass of a building, resulting in lower seismic resistance, and a common source of earthquake damage.

Soil Classification Type: Same as Site Class.

Strengthening: The process of increasing the load-resistance capacity of a structure or portion thereof.

Structural Performance Level: A limiting structural damage state; used in the definition of Performance Objectives.

Tabique Pampango: A thin wall of woven bamboo strips or pieces of wood placed one on top of the other, covered with lime plaster; in architectural parlance, wattle and daub.

Transept: The transverse portion or "arms" of a cruciform church.

Transom: A crosspiece separating a door from the window above it.

Vertical Irregularity: A discontinuity of strength, stiffness, geometry, or mass in one story with respect to adjacent stories.

Weak Story: A weak story exists when one story has less strength (fewer walls or columns) than the story above or below it. A soft story exists if the stiffness of one story is dramatically less than that of most of the others.

Weight (Mass) Irregularity: Mass irregularity shall be considered to exist where the effective mass of any story is more than 150 percent of the effective mass of an adjacent story.