FIGURE 4.15 (LEFT)
View of main dome over the crossing of the nave and transept, with painted pendentives, 2007.
Image: Intituto Nacional de Cultura del Perú.

FIGURE 4.16 (RIGHT)
View of umbrella dome over the side aisle.
Image: Sara Lardinois.

vaults. At each side of the nave, five perpendicular vaults or lunettes, corresponding to the location of windows in the upper nave wall, intersect with the main barrel vault (Fig. 4.14). The crossing of the nave and transept is covered with a large umbrella dome, topped with a lantern and supported by a wood frame over the pillars (Fig. 4.15). Four non-structural decorative pendentives cover the internal wood structure. The aisles flanking either side of the nave are covered with eight small umbrella domes, which have a similar configuration to the central dome and are crowned with a wood lantern that illuminates the interior aisles (Fig. 4.16). These vaults and domes are constructed in quincha, with structural wood arches or ribs that are covered with canes and plaster at both the intrados and extrados.

4.4 Geological and Environmental Description

4.4.1 Geological description and seismic history

The cathedral (lat 14°3’53” S; long 75°43’47” W) is built over compacted silty sand with 1–1.5 kg/cm^2 of permissible load.[11] Although some sectors in the city of Ica are prone to liquefaction, the area where the cathedral is located is not.

The building is located in a level 3 seismic risk zone—the highest seismic level classified by the Peruvian Building Code.[12] As the church was constructed in the eighteenth century, it has been subject to a number of seismic events throughout its history, including the 2007 Pisco earthquake (M_W 8.0), approximately 65 km to the northwest; the 1942 earthquake off the coast of central Peru (M_W 8.2); the 1868 Arica earthquake (M_W 9.0); and the previously mentioned 1813 earthquake, which destroyed the original façade of the church.[13]

4.4.2 Regional climate

Ica has a warm and dry desert-like climate. While the humidity is high along the coast, it decreases in the interior. Ica is located approximately 55 km from the Pacific coast of Peru. Average temperatures are 32°C in the summer and 17°C in winter. The cathedral is located in the moderate flood zone. According to Mitma and Alva (2005), the 100-year flood is expected to generate flows of 600 m^3/s. The most recent flood of this magnitude in Ica occurred in 1998 and resulted in damage to the city. The 5-year flood is expected to generate a flow of 250 m^3/s.

4.5 Structural Description

The following sections describe the different structural materials, elements, and systems making up the Cathedral of Ica and their current condition (Fig. 4.17). Irregularities, alterations, damages, and decay observed during the construction assessment survey are described in greater detail in section 4.6 that follows the structural description.

4.5.1 Survey sectors

For the purpose of conducting the construction assessment survey, the church was divided into six sectors (Fig. 4.18). The sectors were selected based upon differences in plan configuration, height, and construction details. The sectors are as follows:

- **Sectors A-1 and A-2**: The east end of the cathedral, including the spaces at altarpieces J and K, the sotacoro (A-1), and the choir loft above (A-2).
- **Sector B**: The south side aisle adjacent to the original Jesuit college.
- **Sector C**: The central nave between the side aisles.
- **Sector D**: The north side aisle adjacent to Jirón Cajamarca.
- **Sector E**: The transept and dome, including altarpieces C and D.
- **Sector F**: The main altar, including altarpieces A and B, at the far west end of the cathedral.

4.5.2 Foundations and base course

The Cathedral of Ica is constructed with a manmade base course and foundation. The base course is typically constructed using fired brick masonry and sometimes also rubble stone masonry. The foundations are comprised of rubble stone masonry. A sand and lime mortar is used for both the base course and foundation. The configuration and dimensions of the base course and foundations vary throughout the cathedral.

The front façade at the east side of the church is constructed of fired brick masonry with a lime mortar. Prospection IS-1, at the base of the north bell tower on the front façade, revealed that the fired brick construction extends approximately 0.30 m below the interior floor level. Below this is a 1.00 m deep foundation constructed of rubble stone masonry. This stone foundation is wider, projecting approximately 0.15 m beyond the face of the fired brick masonry wall above.

At the mud brick north lateral wall, there is a 0.90 m high fired brick masonry base course over a 0.40 m high rubble stone masonry wall (prospection IW-2). Rubble stone masonry is also used for the foundation below; however, its depth was not confirmed through any prospections along this wall. The width of the base course is the same as the mud brick wall above. Both the base course height and material composition changes at the east end of the north lateral wall, in the transitional zone between the fired brick north bell tower and the mud brick lateral wall. In this area the stone base course is interspersed with courses of fired brick and continues to a height 1.75 m above the interior floor level. Above this, fired brick construction continues up to 3 m above the interior floor level—approximately to the height of the ceiling over the side aisle. According to architect Mirna Soto, who was responsible for carrying out the prospections, this transitional technique is also extant in a church located two blocks away and dating to the same period as the cathedral (Fig. 4.19).

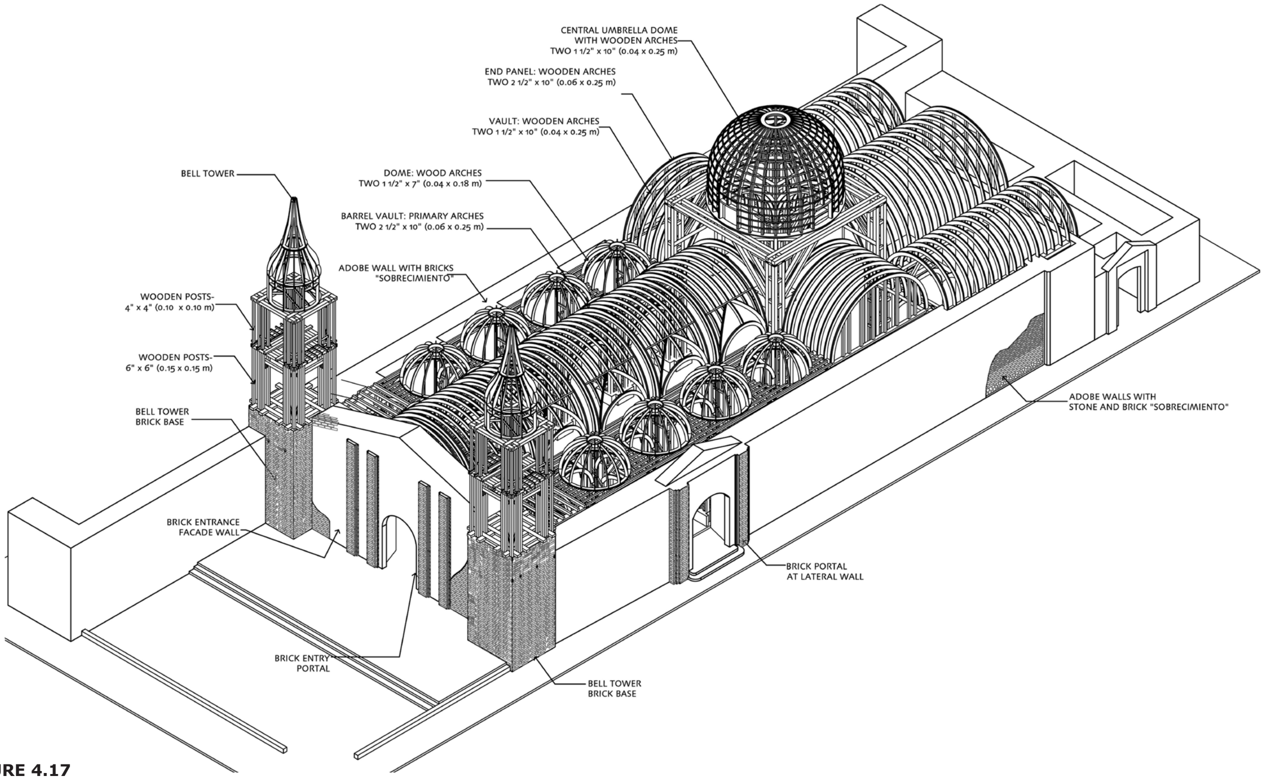


FIGURE 4.17
Overall structural scheme for the cathedral.
Drawing: Mirna Soto, for the GCI.

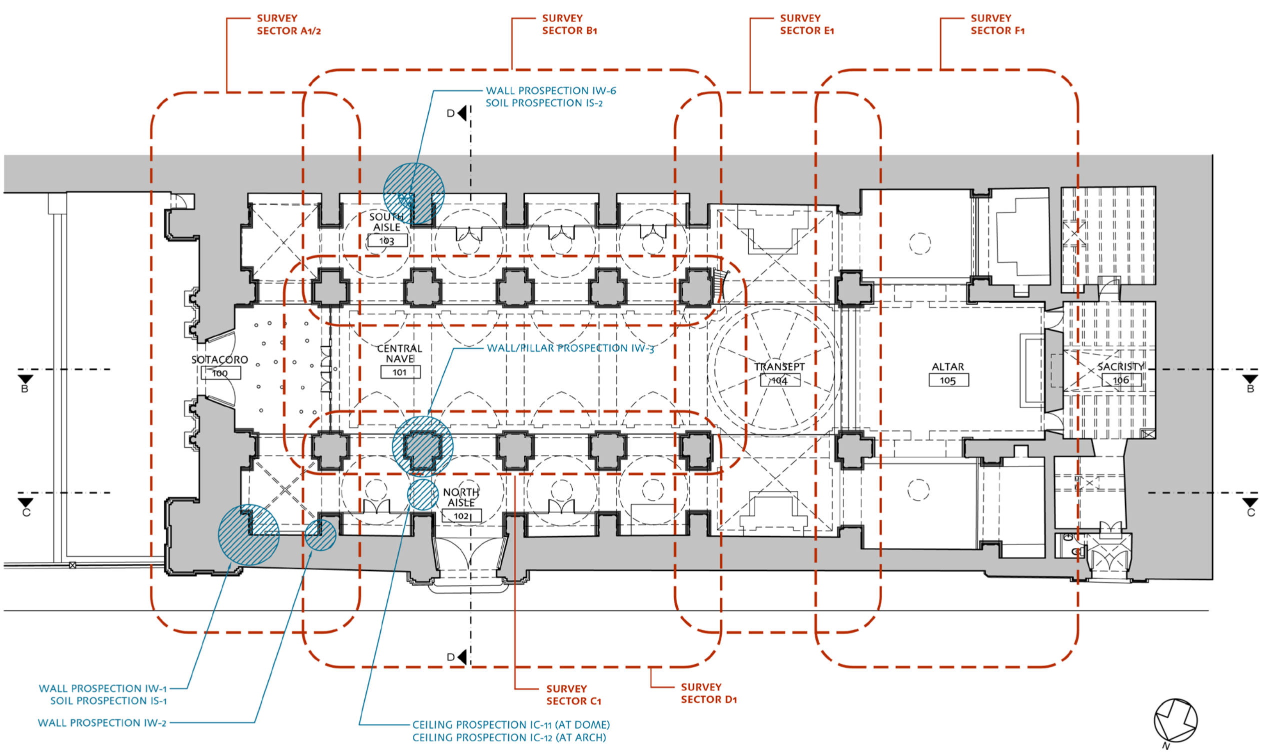
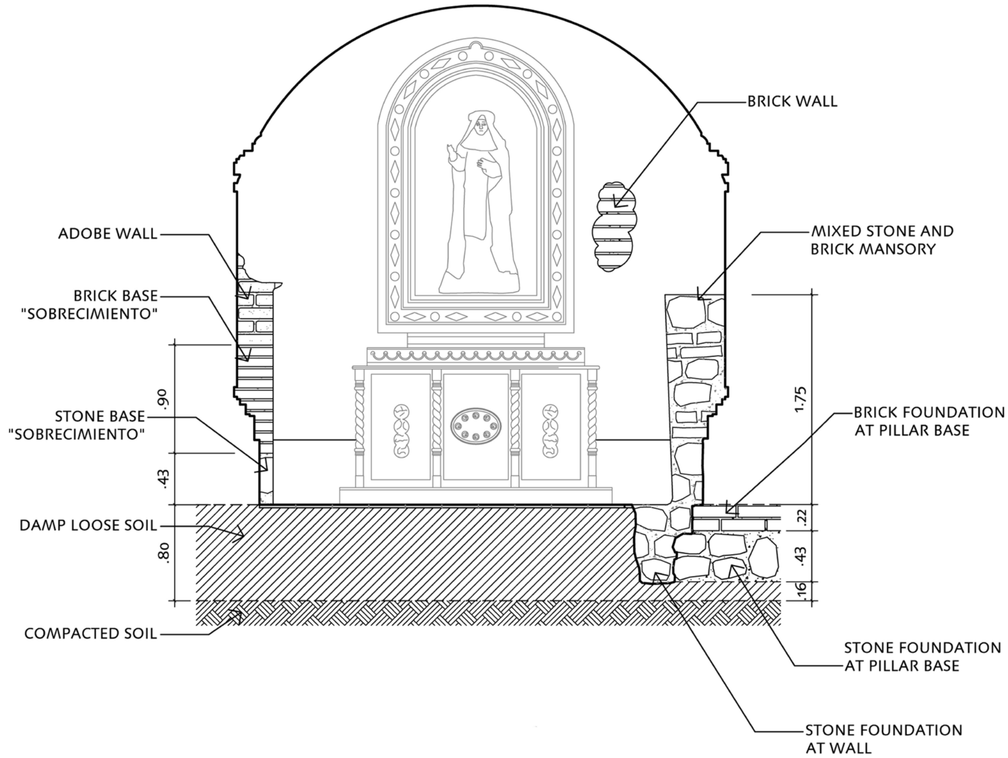


FIGURE 4.18
Floor plan, showing sector and prospection locations.
Drawing: Base drawing prepared by Mirna Soto and edited by the GCI.

FIGURE 4.19

Prospection IW-2—IS-1, elevation view showing the foundation at the north lateral wall, adjacent to the bell tower.
Drawing: Mirna Soto, for the GCI.



At the mud brick south lateral wall, the base course consists of a 0.60 m high fired brick masonry wall over a 0.48 m deep rubble stone foundation (prospection IS-2). Below this, the remains of vaulted fired brick catacombs were found. Both the base course and foundation are the same width as the mud brick wall above.

The interior wood-framed pillars have fired brick foundations that extend from 0.50 m below the floor level to 0.70 m above it to create a pillar base. The engaged pillars, or pilasters, along the lateral walls are located immediately adjacent to mud brick piers or buttresses and have fired brick base courses and stone foundations similar to those at the mud brick walls. It is important to note that the bricks at the pier bases do not interlock with the brick base course along the lateral wall.

4.5.3 Walls

The external walls are of load-bearing fired and mud brick construction, typically finished with mud plaster and painted gypsum. Cement plaster is used at the exterior base of the lateral wall along Jirón Cajamarca.

4.5.3.1 Load-bearing fired brick masonry walls

The 21 m long front façade is constructed of fired brick masonry with a lime mortar. At the lower levels, it has an approximate overall thickness of 2.25 m and a slenderness ratio of 2.4.[14] Thus the front façade is considered stable, with a low probability of lateral overturning. The top of the lower brick wall is connected to

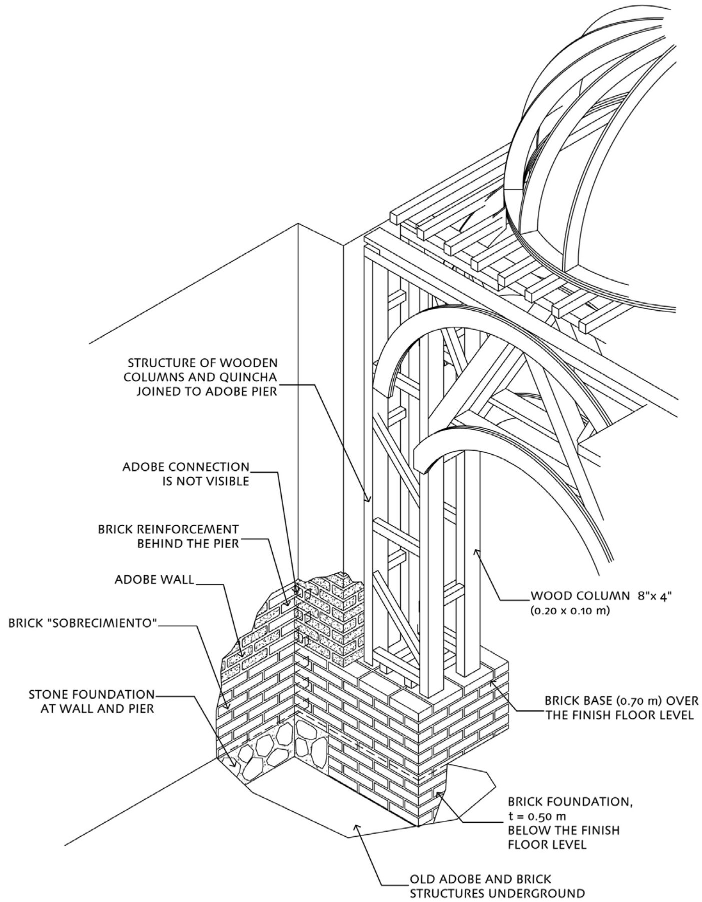


FIGURE 4.20

Propsection IS-2—IW-6, showing the fired brick reinforcing behind the mud brick piers along the south lateral wall.
Drawing: Mirna Soto, for the GCI.

the choir loft floor framing, by the 0.10 m embedment of the choir loft floor joists into the wall. In the upper portions of the façade, at the level of the pediment, the wall is significantly thinner (approximately 0.60 m thick) and thus has a higher slenderness ratio. There is not an effective joint between the pediment level and lower portions of the wall. Thus, the high slenderness ratio and lack of an effective joint make the pediment more vulnerable to lateral overturning. The brick masonry bases for the wood-framed bell towers above project from either end of the front façade wall (see section 4.5.5 for further description of the bell towers). It is assumed that there are cavities within the brick bell tower bases for stairs or storage rooms; however, the presence or dimensions of any such cavities were not verified during the construction assessment survey.

4.5.3.2 Load-bearing mud brick masonry walls

The lateral walls are constructed of mud brick masonry with a mud mortar. There are a series of mud brick piers along each of the lateral walls, behind each of the wood-framed pilasters in the side aisles. Fired brick reinforcing, within the mud brick walls, is used behind each of the piers (Fig. 4.20).

Both the north and south lateral walls have a slenderness ratio of 3.35 and thus can be classified as very thick. According to Tolles et al. (2002) adobe walls with a slenderness ratio less than five are considered to be very stable during earthquakes and have a low probability of lateral overturning.

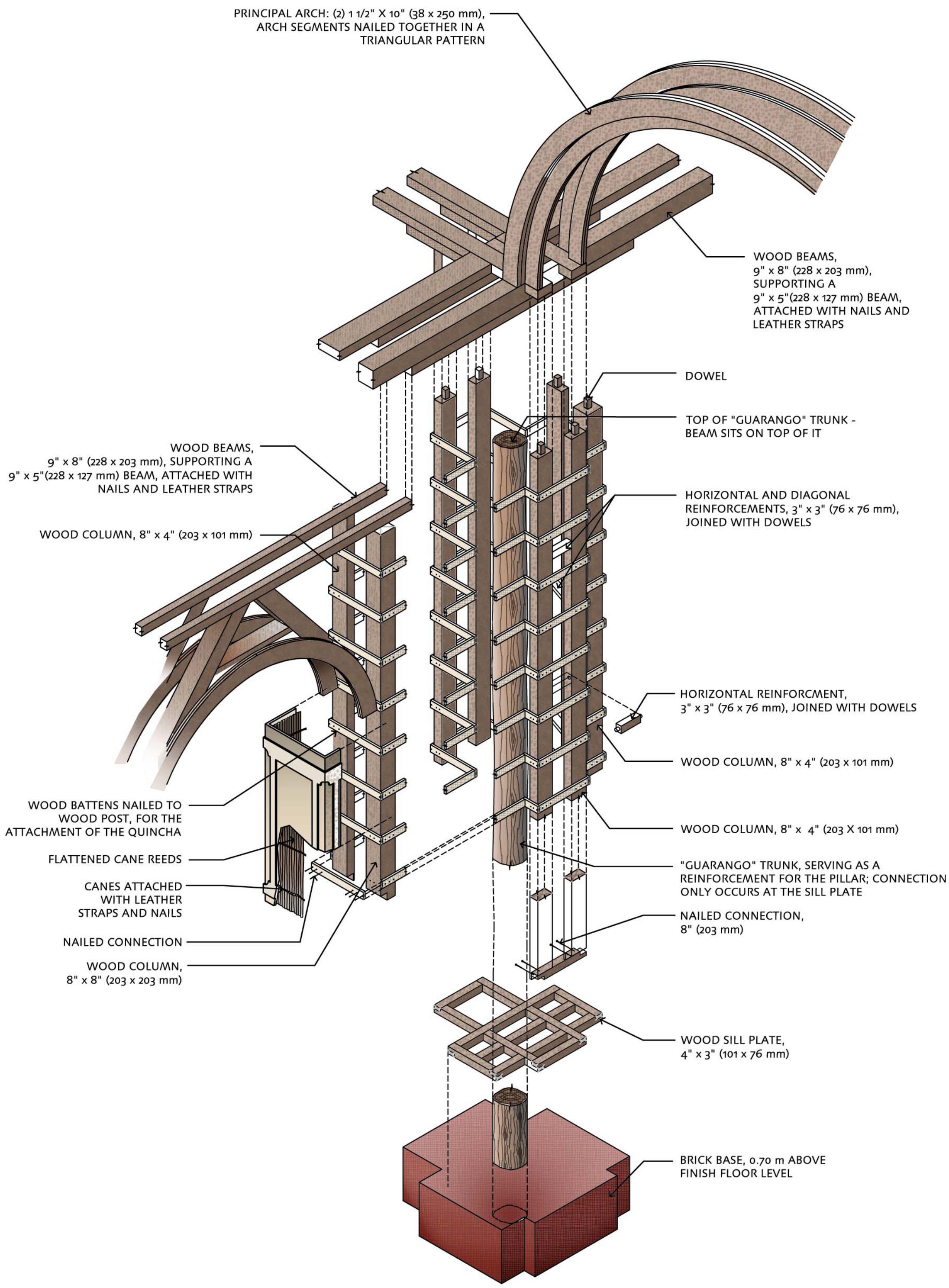


FIGURE 4.21

Prospection IW-3, exploded view showing the quincha pillar construction.
Drawing: Mirna Soto, for the GCI.

4.5.4 Pillars and pilasters

A series of wood-framed quincha pillars, spaced at approximately 5 m on center, are used to separate the central nave from the side aisle. These pillars support both the barrel vault over the nave and the joists and beams at the base of the side aisle domes. Four pillars at the crossing of the nave and transept support the main dome. The pillars are essentially hollow structures composed of eight 8” × 8” (0.20 × 0.20 m) and 8” × 4” (0.20 × 0.10 m) vertical wood posts. The tops of the pillar posts are connected with dowels to the beams, or arcade plate, above. The bottoms of the posts are nailed to a 4” × 3” (1.02 × 0.76 m) sill plate that is embedded in the fired brick base. At each side of the pillar, there are 3” × 3” (0.08 × 0.08 m) horizontal and diagonal wood reinforcements, joined to the posts with dowels. A huarango tree (*Acacia macracantha)* trunk, approximately 0.33 m in diameter, is located in the center of each pillar. The arcade plate rests on top of this tree trunk, but the two elements are not connected. The bottom of the tree trunk is connected to the sill plate below. Horizontal wood battens, nailed to the wood framing at 0.40 m on center, provide a nailing surface for the pillar finish. The pillars are wrapped in *caña chancada*, or flattened cane reeds, which are attached to the battens with nailed leather straps.[15] The reeds are then finished with plaster (Figs. 4.21, 4.23, 4.24).

In the side aisles, there are a series of pilasters adjacent to the mud-brick piers along the lateral walls (Fig. 4.22). These pilasters are similar in construction to the pillars; however, they are constructed with just four wood posts and there is not a huarango tree trunk in the center of the pilasters.

The nave pillars are joined in the east-west direction by series of wood arches, and another set of arches running in the north-south direction connect the pillars to the lateral wall pilasters. Arches are also present at the lateral walls, at the intersection of the dome pendentives and mud brick wall.

FIGURE 4.22
View of quincha pilaster along the lateral wall.
Image: Sara Lardinois.

FIGURE 4.23
View of quincha pillar.
Image: Sara Lardinois.

FIGURE 4.24
View of pillar base, above brick base.
Image: Sara Lardinois.

4.5.5 Bell towers

There are two bell towers at the front façade, each measuring approximately 3.80 × 3.80 m in plan. They are constructed with wood framing which sits on top of the fired brick masonry wall below; and the wood-framed portion of the tower, including the cupola, is approximately 14 m high. The tower walls are framed with 6” × 6” (0.15 × 0.15 m) wood posts. The post bases are connected to wood plates or beams that are embedded in the fired brick wall below, similar to the construction detail at the base of the interior pillars and pilasters. Diagonal wood framing is used to reinforce the posts. Wood joists and beams are used to create an intermediate floor level within the tower; and 10” × 8” (0.25 × 0.20 m) wood beams, joined with half-lap joints sit on top of the posts. These beams support the wood-framed cupola above. The bell towers were originally wrapped with canes and finished with gypsum plaster; however, that finish has since been replaced with cement plaster over a wire mesh lath (Fig. 4.25).

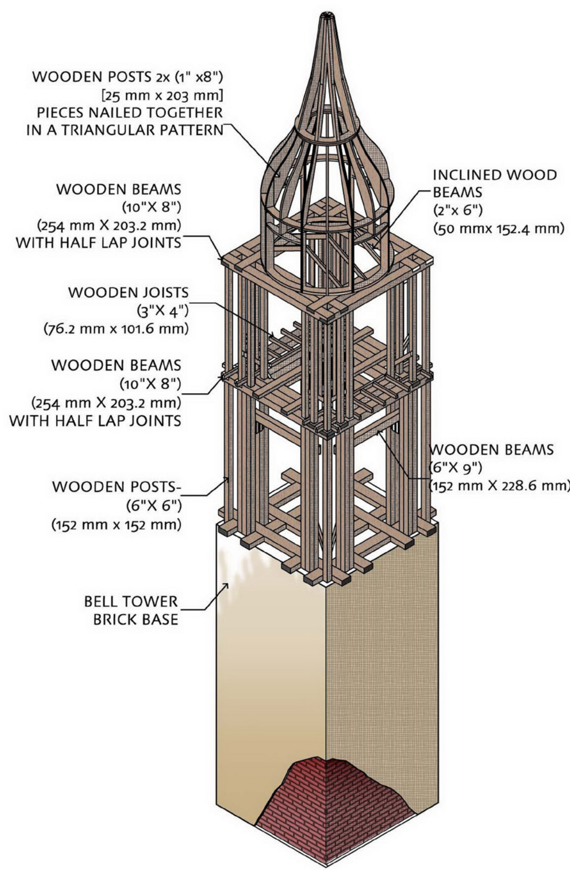
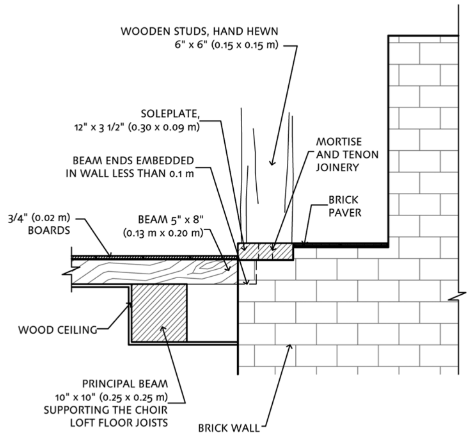


FIGURE 4.25
Isometric showing the bell tower structure.
Rendering: Jabdiel Zapata, for the GCI.



FIGURES 4.26 (NEAR RIGHT) AND 4.27 (FAR RIGHT)
Prospection IC-7, showing the embedment of choir loft floor joists in the fired brick masonry front façade.
Drawing: Mirna Soto, for the GCI.
Image: Claudia Cancino.

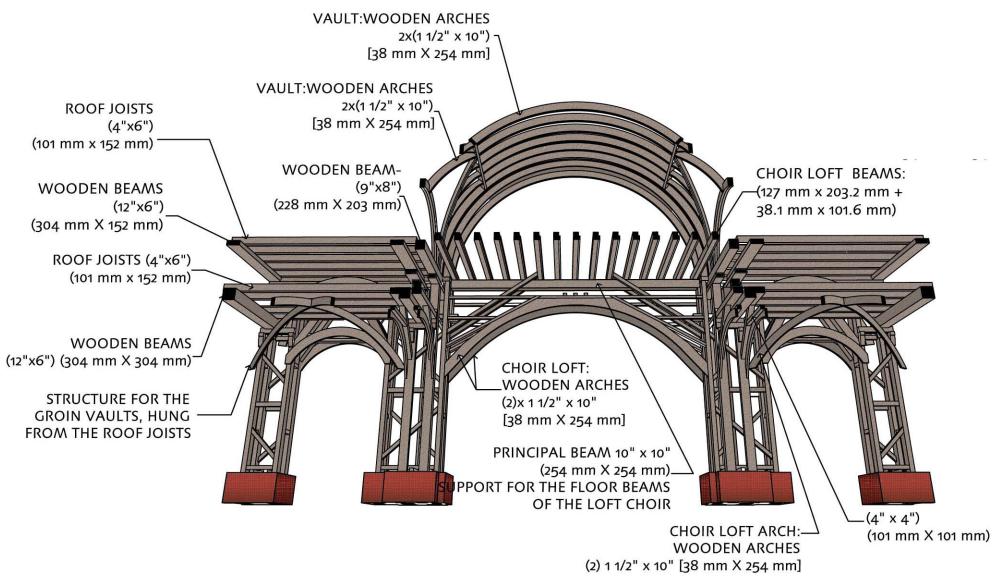


FIGURE 4.28
Section perspective illustrating the choir loft floor framing and roof structure at the adjacent side aisles.
Redering: Jabdiel Zapata, for the GCI.

4.5.6 Floors

The choir loft, located in the first structural bay to the west of the main façade, spans the width of the central nave and has a wood-framed floor that corresponds to the level of the upper structural roof at the adjacent side aisles (see section 4.5.7) (Fig. 4.28). The floor framing consists of ¾” (19 mm) thick wood boards over 5” × 8” (0.13 × 0.20 m) wood joists, with ends that are embedded up to 0.10 m into the adjacent brick wall at the main façade (Figs. 4.26, 4.27). The joists sit on 10” × 10” (0.25 × 0.25 m) wood beams that are supported by the quincha pillars and pilasters. At the west side of the floor, below the 10” × 10” (0.25 × 0.25 m) beam, there are two 1½” × 10” (0.04 × 0.25 m) wood arches with diagonal reinforcements at the spandrel. The west side of the choir loft is open to the main nave, with a decorative wood balustrade mounted to the edge of the floor framing.

4.5.7 Roof

The roof framing system consists of a series of quincha barrel vaults over the central nave, transept, and altar; quincha domes over the side aisles; and a large quincha dome at the crossing of the nave and transept. At each side of the nave, five perpendicular quincha vaults or lunettes, corresponding to the location of windows in the upper nave wall, intersect with the main barrel vault (Figs. 4.29, 4.30).

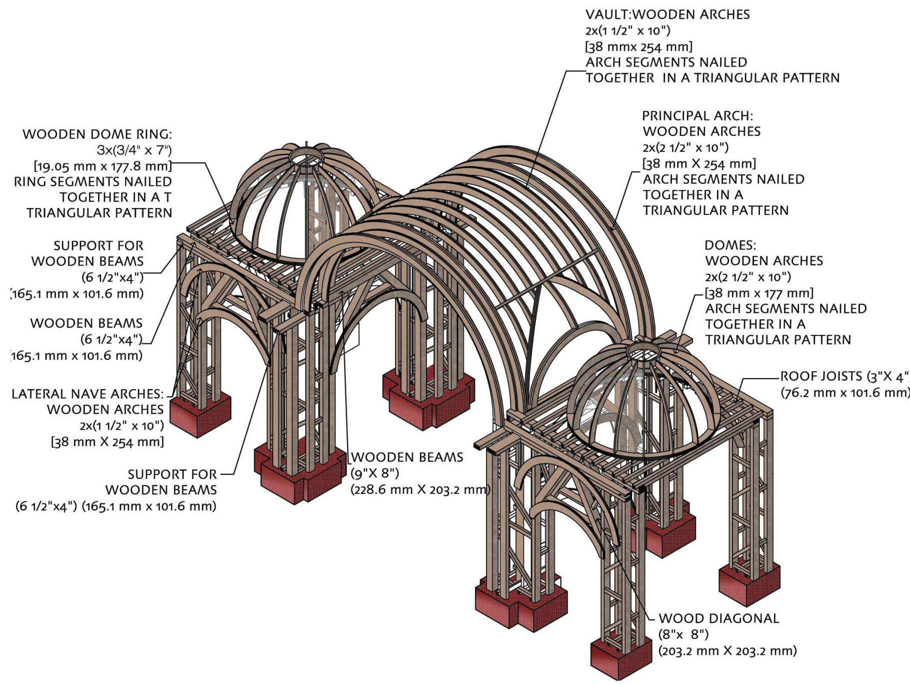


FIGURE 4.29
Isometric drawing illustrating the roof construction at the central nave and side aisles.
Rendering: Jabdiel Zapata, for the GCI.

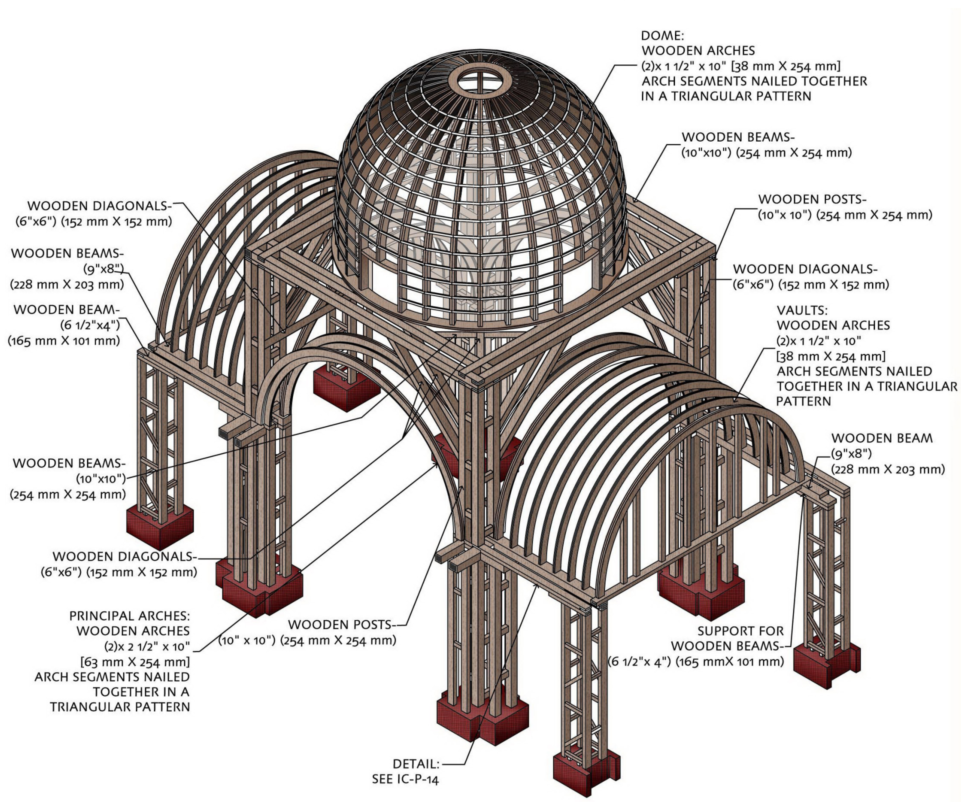


FIGURE 4.30
Isometric drawing illustrating the roof construction at the crossing and transept.
Rendering: Jabdiel Zapata, for the GCI.

At the central nave, transept, and altar, the barrel vaults are constructed with a series of principal and secondary wood arches. Two principal arches align with each of the pillars; and the ends of the arches rest on wood beams, or arcade plates, which are supported by the pillars below. Each principal arch consists of a pair of 2½” × 10” (0.06 × 0.25 m) wood arches. The supporting arcade plate consists of 9” × 8” (0.23 × 0.20 m) and 9” × 5” (0.23 × 0.13 m) beams joined with nails and leather straps. The wood pillar posts below are doweled into this plate. Between the primary arches, there are a series of secondary arches, as well as arches that form the lunettes. The ends of the secondary arches and the tops of the lunettes are supported by a 3” × 10” (0.08 × 0.25 m) wood beam spanning between the principal arches. This beam is perforated with multiple mortise holes to receive the tenons of the secondary arches and lunette framing. The secondary arches consist of pairs of 1½” × 10” (0.04 × 0.25 m) wood arches spaced approximately 0.60 m on center. The lunettes are formed by two 2” × 8” (0.05 × 0.20 m) arches. At the primary and secondary arches, as well as the lunette arches, each arch is composed of several segments which are lapped and connected with iron nails set in a triangular pattern (Fig. 4.31). At the intrados, or interior side, of the nave vault, a wide rib projects below the surface of the vault and spans between the pillars. These ribs are formed by an additional set of arches, of a smaller radius, that hang below the principal arches.

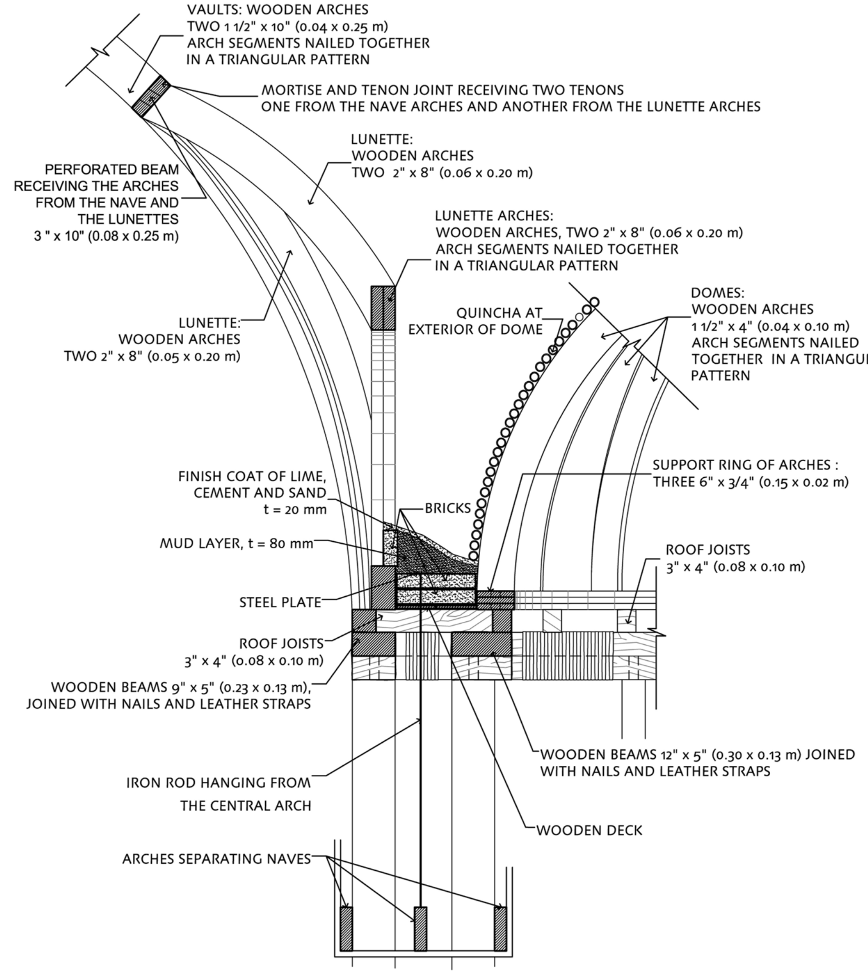


FIGURE 4.31
Prospection IC-2, section showing the construction of the nave vault and lunettes and the side aisle domes.
Drawing: Mirna Soto, for the GCI.

FIGURE 4.32 (ABOVE LEFT)
View of plaster and *caña chancada* (flattened cane reeds) at the interior side of the vault.
Image: Mirna Soto, for the GCI.

FIGURE 4.33 (ABOVE RIGHT)
View of plaster and *caña brava* (cane reeds) at the exterior side of the vault.
Image: Mirna Soto, for the GCI.

The intrados of the vault is covered with plaster and *caña chancada* attached to the wood arches with nailed leather straps (Fig. 4.32). The exterior side is covered by *caña brava* attached with nails and finished with layers of mud plaster (Fig. 4.33).[16] The entire exterior surface of the vault, as well as the rest of the roof, was covered at some point with an additional layer of sand, lime, and cement mortar which adds weight to the structure.

At the east end of the vault, over the choir loft, a wood-framed semi-circular end panel beneath the final set of principal arches remains at the far east end (Fig. 4.34). This panel is constructed with eight wood posts, and the tops of these posts are connected to the arch above with mortise-and-tenon joints. The bottoms of the posts are joined with a sole plate which sits on top of the choir loft floor joists. This end panel is parallel to the façade pediment but is not connected to it—leaving a gap of 1.5 m between the vault end panel and the pediment. This gap allowed for access from the stairs in the south bell tower to the north tower. At the west end, the vault structure sits on top of the mud brick wall separating the altar from the sacristy to the west, and the ends of the transept vault sit on top of the lateral mud brick walls.

FIGURE 4.34
View of semicircular end panel that once formed the end of the barrel vault above the choir loft, which collapsed during the 2007 earthquake.
Image: Sara Lardinois.

The central dome is an umbrella dome that rises 2 m above the top of the adjacent barrel vaults and is crowned with a wood lantern. The dome is built with two 1½” × 8” (0.04 × 0.20 m) wood ribs, composed of several segments which are lapped and connected with iron nails set in a triangular pattern. The ribs are connected by horizontal wood pieces that form a series of rings parallel to the base of the dome. The ends of the ribs sit on the main collar ring which is comprised of two horizontal wood rings joined with mortise-and-tenon joints. This collar ring at the base of dome sits on a square frame made of two 10” × 10” (0.25 × 0.25 m) wood beams joined at the corners with half lap joints and leather straps and nails and reinforced with 6” × 6” (0.15 × 0.15 m) wood diagonals in the corners. This frame is supported by and connected with leather straps to the 10” × 10” (0.25 × 0.25 m) wood posts that form the pillars at the cathedral crossing (Fig. 4.35). At the interior, the frame is concealed by non-structural pendentives. Similar to the barrel vaults, the interior of the dome is covered with *caña chancada* that runs parallel to the wood rings, is attached to the wood members with nailed leather straps, and is finished with gypsum plaster. The exterior of the dome is covered with *caña brava* attached to the wood structure and is finished with mud plaster (Fig. 4.36).

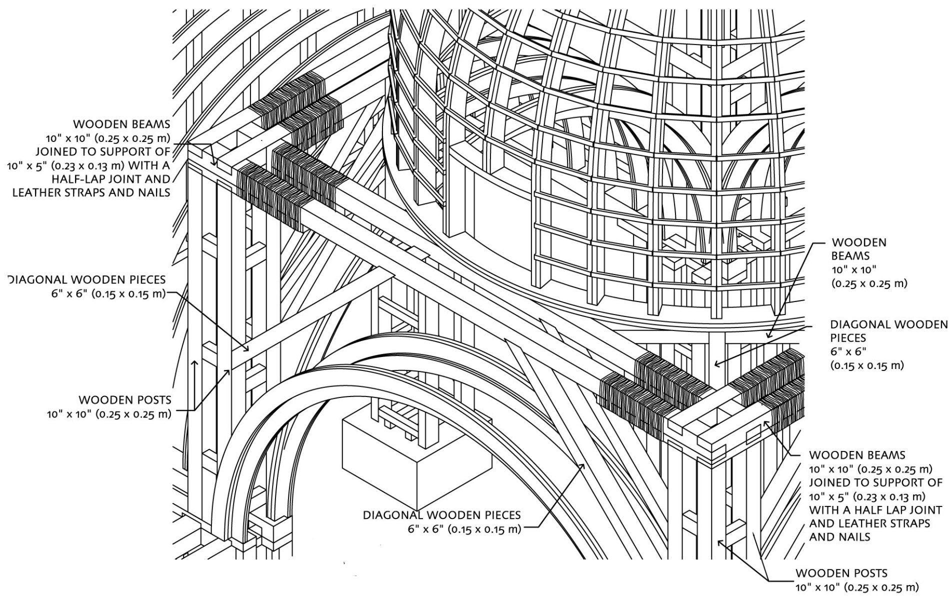
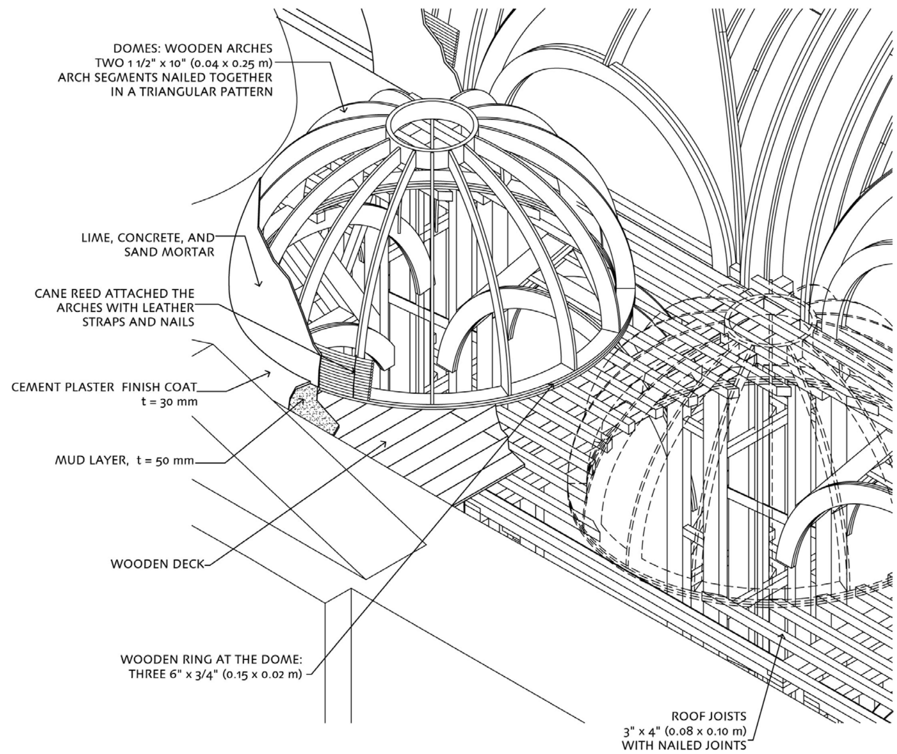


FIGURE 4.35
Prospection IC-5, showing the frame that supports the base of the central dome.
Drawing: Mirna Soto, for the GCI.

FIGURE 4.36
Exterior view of the central dome, showing the *caña brava* (cane reeds) and plaster at the exterior of the dome.
Image: Amila Ferron.

The north and south side aisles are covered with eight umbrella domes that have a similar structure to that of the central dome, but with smaller framing members. The side aisle domes are constructed with 1½" × 4" (0.04 × 0.10 m) wood ribs, joined at the base to a wood collar ring over wood joists. The extrados and intrados of the domes have the same characteristics of the central dome (Figs. 4.37, 4.38).

The east end of the side aisles, in the area of the sotacoro, have rib-vaulted ceilings which are purely architectural and do not perform any structural function. The rib vaults are composed of four intersecting diagonal wood ribs enclosed by wood arches that are wrapped with cane reeds that are attached to the ribs with nailed leather straps and are finished with painted mud and gypsum plaster. Above the wood rib vaults there is a structural flat wood roof made up of 12" × 12" (0.30 × 0.30 m) wood beams supporting 4" × 6" (0.10 × 0.15 m) wood joists. Half a meter above this roof there is a second structural flat roof made up of 12" × 6" (0.30 × 0.15 m) wood beams (Fig. 4.39). This upper roof corresponds to the level of the choir loft floor (see section 4.5.6).



FIGURES 4.37 AND 4.38
Prospection IC-9, illustrating the construction of the umbrella domes over the side aisles.
Image: Sara Lardinois.
Drawing: Mirna Soto, for the GCI.

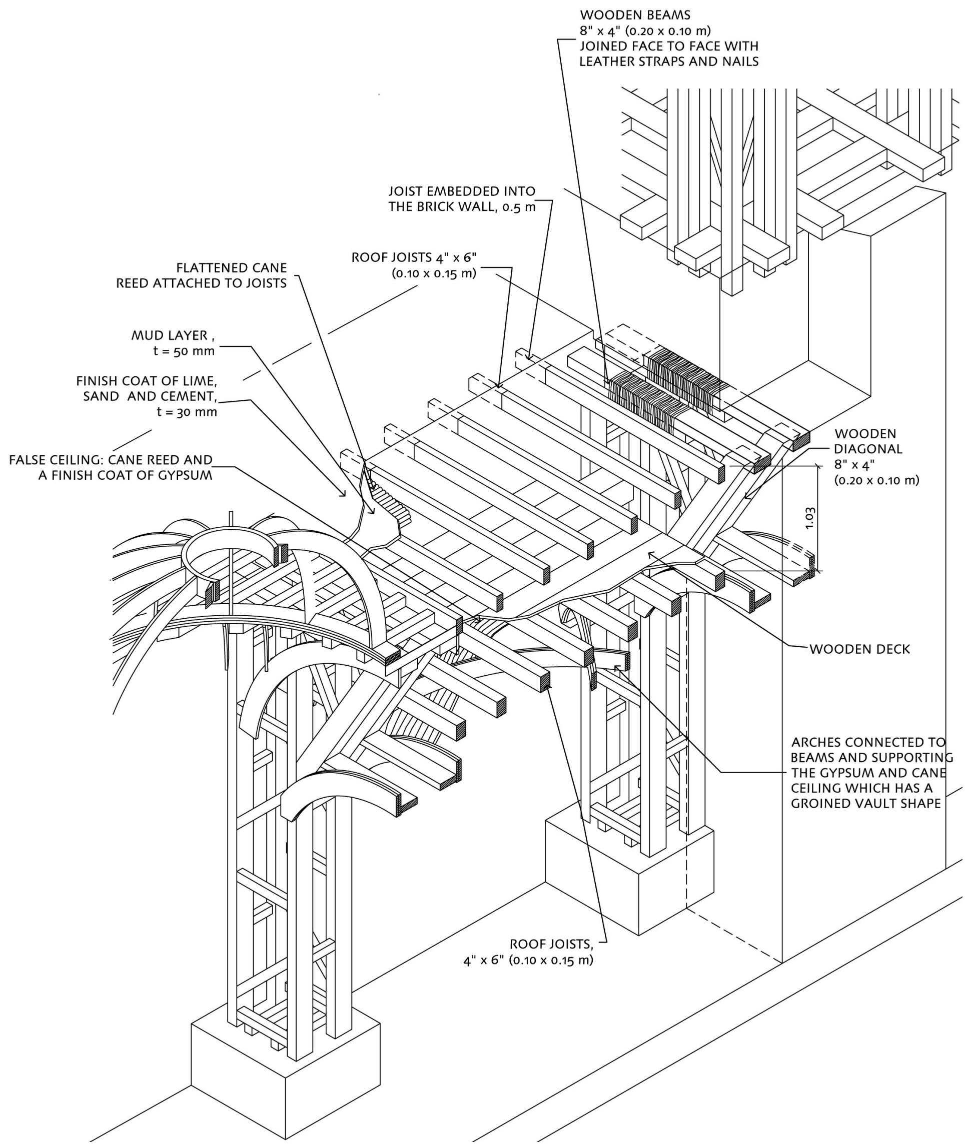


FIGURE 4.39
Prospection IC-10, illustrating the construction over the east end of the side aisles, adjacent to the bell towers.
Drawing: Mirna Soto, for the GCI.

4.6 Irregularities, Alterations, Damages, and Decay

The following sections describe the current condition of the different structural materials, elements, and systems making up the cathedral and any irregularities, alterations, damages, and decay that were visually observed during the construction assessment survey. Many of the damages related to the 2007 earthquake involve a number of different structural elements and systems and are particular to a certain sector of the building. Thus, this section of the report describes conditions, as well as damages, by sector rather than by element or system.

4.6.1 Sector A-1: Front façade and bell towers

- The principal façade is in fair to poor condition. There are horizontal cracks between the lower façade and the pediment. Diagonal cracks were observed between the upper cornice and the base of the bell towers. This diagonal cracking suggests pounding of the towers during the earthquake (Fig. 4.40).
- The wood-framed portions of the towers are in poor condition and thus present a threat to the cathedral's roof system to the west. Damages include the failure of some connections, displacement of the wood elements at the south tower from their original positions, and loss of plaster. Thus, the wood posts are exposed and show signs of severe termite damage. (Fig. 4.41).

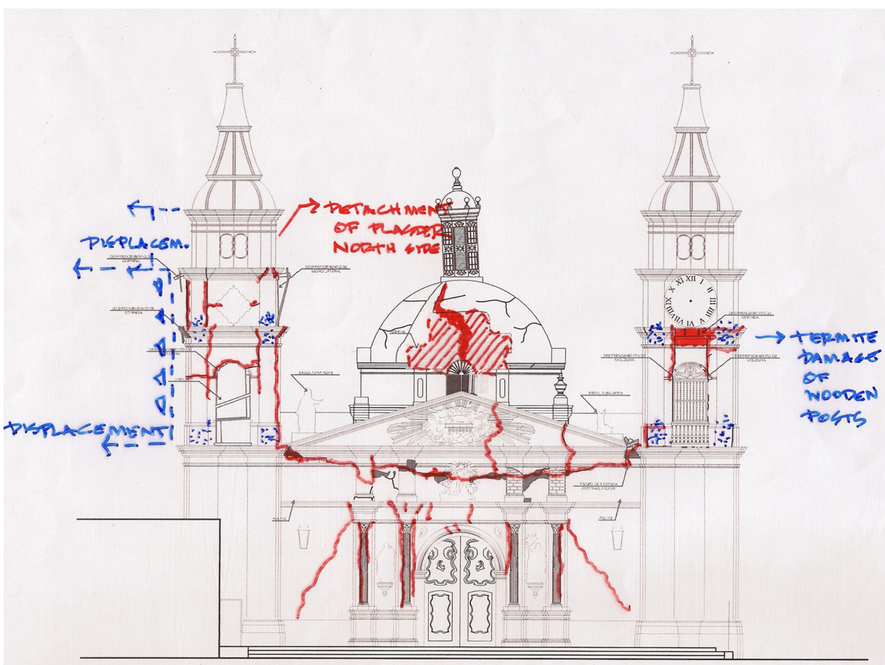


FIGURE 4.40
Front façade, graphic condition survey indicating cracks and areas of plaster loss in red and displacement and termite damage in blue.
Drawing: Claudia Cancino.

FIGURE 4.41
Loss of plaster at the south bell tower.
Image: Sara Lardinois.

4.6.2 Sectors A-1 and A-2: Sotacoro and choir loft (Fig. 4.42)

- Horizontal and vertical cracking along the perimeter of all arches and piers at the north lateral wall, in the altarpiece J (Saint Rose of Lima) space.
- Disconnection between the rib vault at the northeast corner and the north lateral wall.
- Deformation of the choir loft floor and the choir screen below.
- Vertical cracking along the pillars separating the sotacoro from the nave and structural disconnection between the pillars and adjacent choir screen.
- Total collapse of the rib-vaulted ceiling and flat roof above the altarpiece K space (southeast corner), occurring after the 2007 earthquake sometime between November 2007 and May 2009 (Figs. 4.43, 4.44).
- Collapse of the barrel vault that originally covered the choir loft.

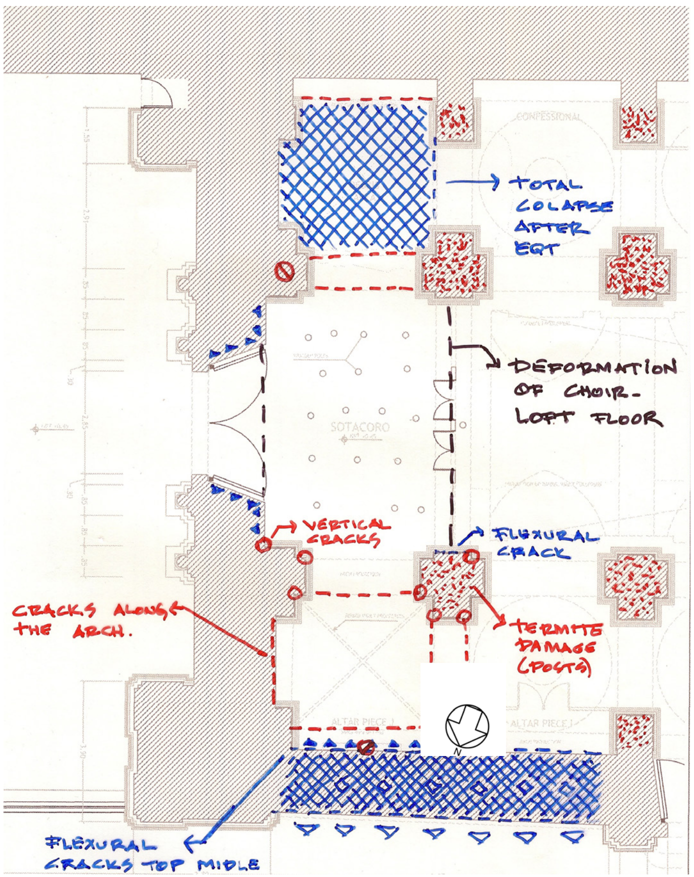


FIGURE 4.42
Sotacoro: Graphic condition survey.
Drawing: Claudia Cancino.

FIGURE 4.43 (TOP)
View of sotacoro, looking south and showing the intact rib-vaulted ceiling above altarpiece K, 2007.
Image: Instituto Nacional de Cultura del Perú.

FIGURE 4.44 (BOTTOM)
View of of roof and ceiling above altarpiece K, after collapse, 2010.
Image: Sara Lardinois.

4.6.3 Sector B: South side aisle, adjacent to the former Jesuit college (Fig. 4.45)

- Humidity in the soil and in the remains of the fired brick catacombs below the church floor (as observed in propsection IS-2). This humidity may be the result of improper site drainage in the cloister of the adjacent former Jesuit college. This moisture has led to plaster detachment and disintegration of the masonry in the wall and base course—most noticeably in lower east end of the south lateral wall. This humidity has also resulted in disaggregation of the mortar in the stone foundations, but not to the degree that stones are loose.
- Bricks at the pier bases do not interlock with the brick base course along the lateral wall. The lack of connection is thought to explain the vertical cracking that was observed between the pilasters and lateral walls.
- Out-of-plane displacement of the arches at the pillar wall between the side aisle and nave.
- Partial collapse of the arches attached to the south mud brick wall in the confessional and altarpiece H spaces (Figs. 4.46–4.48).
- Horizontal cracking along the south mud brick wall.
- Minor out-of-plane displacement of the pillar wall, towards the south side aisle.
- Structural disconnection between the pillars and their bases and between the pillars and the arches above.
- Vertical cracking at the west pillar in altarpiece D space.

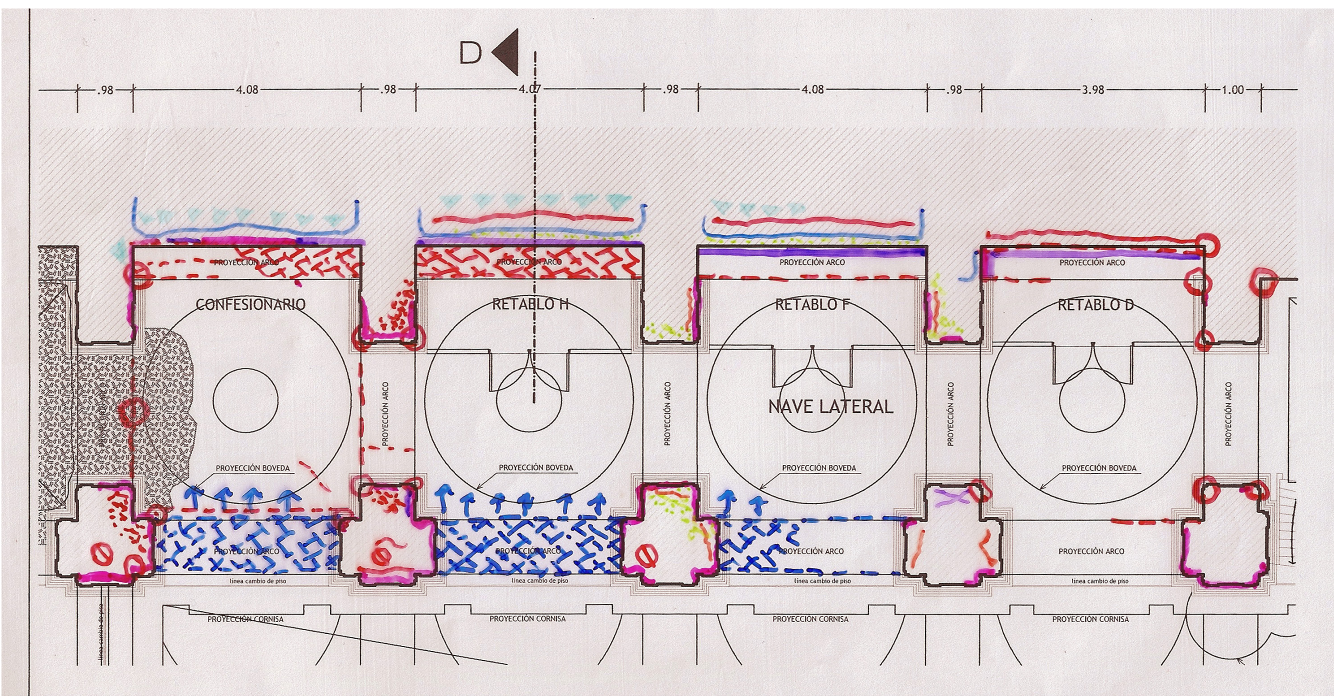


FIGURE 4.45
Sector B: South side aisle graphic condition survey. The dark blue hatch pattern and small dark blue arrows show the out-of-plane displacement at the arches between the side aisle and nave; the large, light blue arrows show areas of moisture damage; the red lines show areas of horizontal cracking; and the red circles show areas of vertical cracking.
Drawing: Claudia Cancino.

FIGURE 4.46 (LEFT)
Sector B: Cracking and partial collapse at arches at the top of the wall, confessional space, 2007. Image: Philippe Garnier.

FIGURE 4.47 (RIGHT)
Sector B: Cracking and partial collapse at arches at the top of the wall, altarpiece H space, 2007. Image: Philippe Garnier.

FIGURE 4.48
Sector B: Detail of cracking and partial collapse at arches along the south lateral wall.
Image: Sara Lardinois.

4.6.4 Sector C: Central nave (Fig. 4.49)

- Partial collapse of the central portion of the barrel vault, between the 3” × 10” (0.08 × 0.25 m) wood beams at the tops of the lunettes, in the three bays at the east end of the nave (Fig. 4.50). Based upon the GCI’s photographic records from November 2007, the central portion of eastern-most nave vault collapsed several months after the August 2007 earthquake, as photos taken in November 2007 show the vault intact but with cracking in the area that would later collapse. Heavy termite damage to the wood members and corrosion of the connecting nails is thought to have contributed to this collapse (Fig. 4.51). During the 2007 earthquake, the rocking of the pillars added tension to the already deteriorated wood vault arches, breaking them into pieces and leading to failure of the mortise-and-tenon joints. The lateral wood beam at the tops of the lunettes that runs perpendicular to the principal arches may have prevented total collapse of the barrel vault in these bays (Fig. 4.52).

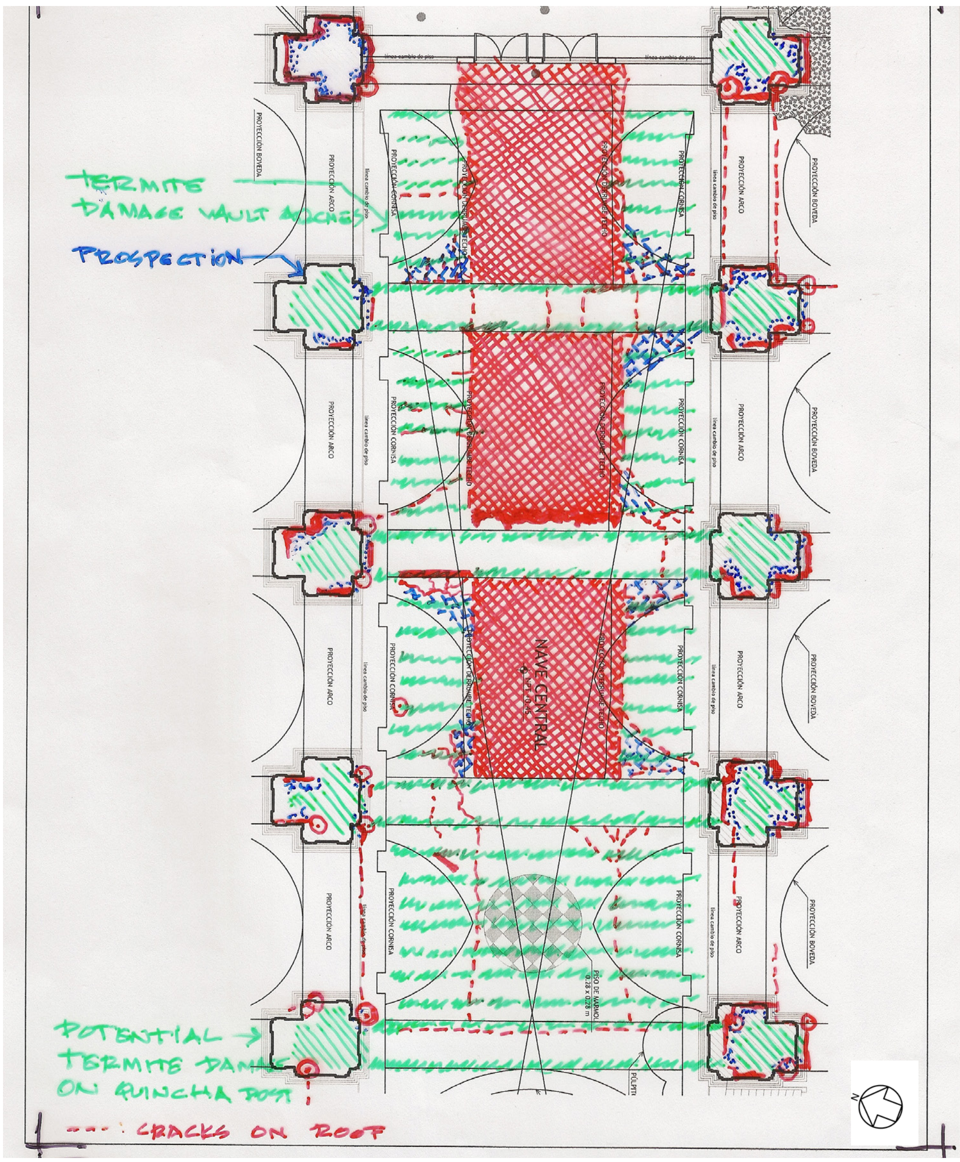


FIGURE 4.49
Sector C: Graphic condition survey. Collapsed portions of the barrel vault are shown in the red hatch pattern.
Drawing: Claudia Cancino.

- All of the pillars are in poor condition, showing signs of structural deterioration. The wood posts, diagonal reinforcements, and sill plate exhibit heavy termite damage and rot from rising damp in the brick bases below (Fig. 4.53). The connections between the posts and the wood arches in the upper part appear to be in fair condition, but some termite damage is present. Most of the plaster exhibits vertical cracking and detachment; and, in areas where the plaster has been lost, the wood elements are exposed to further deterioration. The only element of the pillars that remains in good condition is the huarango tree trunk, which probably helped to prevent collapse of the structure during the 2007 earthquake.
- Minor outward out-of-plane displacement of pillar walls.
- Vertical cracking along the lunettes in all bays.

FIGURE 4.50
Sector C: View of a collapsed bay of the nave barrel vault.
Image: Sara Lardinois.

FIGURE 4.51 (TOP)
Sector C: Damage to wood arches forming the nave barrel vault, with corrosion at the nails connecting the arch segments.
Image: Claudia Cancino.

FIGURE 4.52 (BOTTOM)
Sector C: Top of nave lunette, where the wood beam spanning between the nave arches may have prevented total collapse of the vault.
Image: Claudia Cancino.

FIGURE 4.53 (NEAR RIGHT)
Sector C: View of pillar base, showing deterioration of the wood post and sill.
Image: Sara Lardinois.

FIGURE 4.54 (FAR RIGHT)
Sector D: Cracking in west pillar at the north side aisle.
Image: Claudia Cancino

4.6.5 Sector D: North side aisle, adjacent to Jirón Cajamarca

- Partial collapse of the arch adjacent to the north lateral wall in the altarpiece I space.
- Horizontal cracking at the upper and lower levels of the north lateral wall in all altarpiece spaces.
- Minor inward out-of-plane displacement of the pillar wall.
- Vertical cracks at the west piers of altarpiece E space (Fig. 4.54).

4.6.6 Sector E: Crossing and transept (Fig. 4.55)

- Partial collapse of the southeast section of the umbrella dome over the crossing (Figs. 4.56, 4.57). Termite damage to the wood elements is thought to have contributed to this collapse; however, the circular rings running parallel to the base of the dome and interwoven with the wood ribs, as well as the strong connection between the collar ring and wood frame at the base of the dome, provided strength for the dome structure which ultimately kept it in place.
- Cracking parallel to the dome ribs in the remaining portions of the dome.
- Vertical cracking at the dome pendentives (Fig. 4.58).
- Cracking and disconnection between the transept and the two altarpiece spaces.
- Horizontal cracking at the lower portions of the north and south end walls in the transept.

FIGURE 4.55
Sector E: Graphic condition survey. The combination of the dark blue hatch pattern and small dark blue arrows show out-of-plane displacement; the smaller dark blue hatch pattern alone shows areas of collapse at the main dome; the red lines show areas of horizontal cracking; and the red circles show areas of vertical cracking.
Drawing: Claudia Cancino.

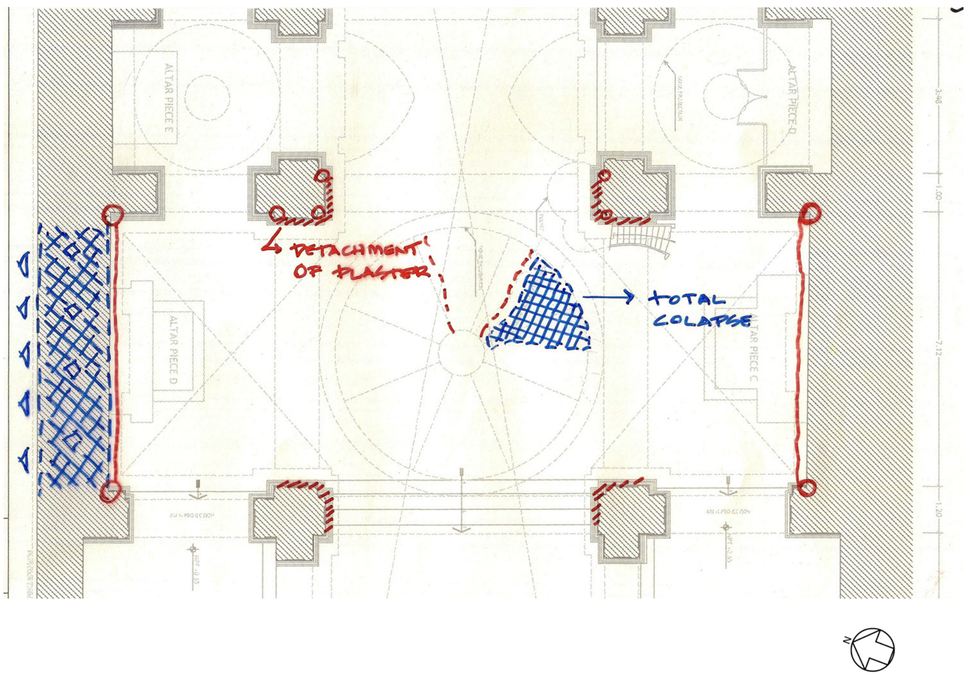


FIGURE 4.56
Sector E: View of partial collapse of quincha dome.
Image: Mirna Soto, for the GCI.

FIGURE 4.57
Sector E: Interior view, looking east, showing the partial collapse of the dome and barrel vault.
Image: Sara Lardinois.

FIGURE 4.58
Sector E: View of the vertical cracks in a pendentive at the main dome.
Image: Claudia Cancino.

FIGURE 4.59
Sector F: The upper west wall behind the altar exhibits out-of-plane displacement and cracking.
Image: Sara Lardinois.

FIGURE 4.60
Sector F: View of vertical cracking in either corner at west wall of the north side chapel, behind altarpiece B.
Image: Sara Lardinois.

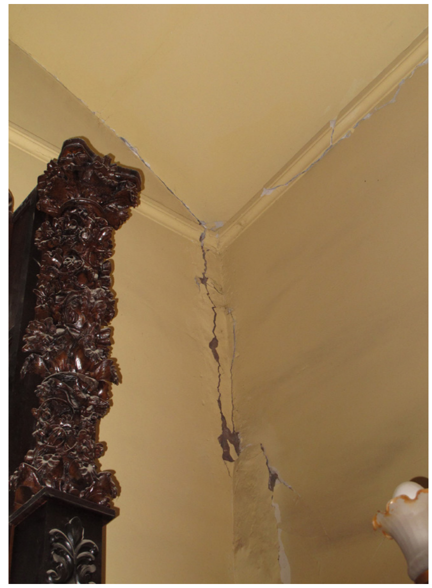


FIGURE 4.61
Sector F: Detail of vertical crack at north-west corner of the cathedral.
Image: Sara Lardinois.

4.6.7 Sector F: Altar

- Outward out-of-plane displacement, disconnection, and cracking at the upper levels of the west end of the altar and the south side chapel, altarpiece A space (Fig. 4.59).
- Cracking parallel to the direction of the vaults in the vaults covering the altar and the side chapel spaces.
- Vertical cracking at the corners of both side chapels (altarpiece A and B spaces) and at the west wall of the altar (Figs. 4.60, 4.61).
- Horizontal cracking at the upper levels of the north and south walls of the altar, as well as at the south and west walls of the altarpiece A space.

4.7 Preliminary Findings

The following preliminary findings on the structural behavior of the church are based upon qualitative methods, including historical research and direct observations made by the investigative team during surveys carried out in 2010. The investigative team utilized their past experience with historic earthen construction to interpret that data collected through research and observation and develop preliminary ideas on the possible structural behavior of the church. These preliminary findings will be explored further in the next phases of the project through quantitative methods, including static and dynamic testing and numerical modeling analyses. Following the quantitative testing and analyses, the preliminary findings will be revised as necessary and expanded upon to provide a complete diagnosis and safety evaluation.

The preliminary findings are:

- The structural performance of the church during the 2007 earthquake can be considered acceptable. The thick longitudinal walls are stable and not prone to lateral overturning. Because these walls maintain their vertical stability during strong earthquake motions, the wood structure at the interior also maintains its lateral stability.
- During the earthquake, elements of the structural system were deformed by the rocking motion and interaction between different elements. When the motion stopped, the elements did not return to their original positions because the timber connections are not rigid and did not behave elastically.
- The roof structure is a 3D linear element system covered in the intrados and extrados with plaster. Therefore, the cracking observed at the internal surface is superficial—only occurring in the plaster layer—and does not necessarily compromise the structural elements. The cracking was generated by rocking and the interaction between the roof and the walls.
- The main cause of collapse of the roof structure appears to be the heavy deterioration of the timber elements, especially at the connections.
- Horizontal cracks in the mud brick walls were caused by lateral vibrations during the earthquake, but they do not reduce the walls' stability and resistance.
- The slender pediment at brick façade is vulnerable to outwards overturning.

Notes

1 The information in the following section is summarized from a 2010 report on the history of the Cathedral of Ica, prepared by Deolinda Mercedes Villa Esteves, historian at the former Instituto Nacional de Cultura in Lima, Peru.

2 Vargas Ugarte 1963, 103–105. According to Father Rubén Vargas Ugarte, a Jesuit historian, the former Jesuit church in Ica was one of the last buildings constructed by the Jesuits in the region before their expulsion from Peru in 1767.

3 Mendicant orders, such as San Juan de Dios, San Camilo de Lelis, and a religious order created in Guatemala—Los Betlemitas—arrived later to establish hospitals.

4 For the young nobility of the indigenous population in Peru, the most important colleges were the Colegio Máximo de San Pablo and Colegio Real de San Martín, both in Lima, and Colegio San Francisco de Borja o Colegio de Nobles in Cusco.

5 Negro 2001. In the eighteenth century, Jesuits built houses and churches at their rural farms.

6 Lecca and Piaget 1974.

7 The first Jesuit presence in the region was in Pisco. Between 1704 and 1725, they built a church in Pisco, which later collapsed during the 2007 Pisco earthquake and was subsequently demolished.

8 Harth-Terré 2003, 453.

9 Vargas Ugarte 1963, 9–13.

10 Despite the fact that Jesuits did not require a choir loft for prayer, choir lofts are present over the main entrances in some rural Jesuit churches, reflecting the importance of music in the evangelization in the Peruvian countryside. Choir lofts can be seen in rural Jesuit churches in Lima (San Juan Grande in Surco, San Juan Bautista in Villa) and in Nazca (San José and San Javier). In some cases, choir lofts were added by the religious orders that took over the churches after the expulsion of the Jesuits in 1767. For example, the choir loft at the main Jesuit church in Lima was added by the Oratorians of Saint Philip Neri (Villacorta Santamato 1987).

11 Mitma and Alva 2005.

12 Seismic zones are defined in Capítulo II, Parámetros de Sitio of the *Norma Técnica de Edificación E.030: Diseño Sismorresistente*, which is available online at http://www.igp.gob.pe/web_page/images/documents/ltorres/norma_tecnica_edificaciones.pdf.

13 Information on earthquake dates, epicenter locations, and moment magnitudes (Mw) is summarized from United States Geological Survey (USGS), Historic World Earthquakes, Peru, http://earthquake.usgs.gov/earthquakes/world/historical_country.php#peru.

14 Criteria for determining slenderness ratios are based upon those provided in Tolles, Kimbro, Webster, and Ginell 2000.

15 *Caña chancada* is the term typically used in the region to describe flattened cane reeds coming from Guayaquil bamboo. The bamboo reeds are 4” (0.102 m) in diameter, with hollow centers.

16 *Caña brava* is the term typically used in the region to describe 1” (25 mm) diameter cane reeds with filled centers.