



St. Monica's Church earthquake damage repair

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Abstract

St. Monica's Church, a reinforced concrete frame, masonry infill structure dating from 1925, was severely damaged in the 1994 Northridge earthquake. The limestone cladding cracked and displaced, and parts of some walls collapsed. We evaluated the structure and facade, and designed repairs and seismic strengthening. The repairs included adding structural elements and rebuilding the stone cladding. The church reopened approximately 15 months after the earthquake.

1 Introduction

St. Monica's parish was formally established in June, 1887 in the town of Santa Monica, near Los Angeles, California. St. Monica's Church was constructed in 1925 and is one of the oldest Catholic churches in the area. (Fig. 1) The building was designed by Albert Martin Sr. of Albert C. Martin and Associates, a prominent Los Angeles architectural firm. The church serves as a distinctive visual landmark in the city of Santa Monica as well as a home to over 5,000 parishioners.



Throughout its history, the church survived several earthquakes. It was damaged in the 1971 San Fernando earthquake. Repairs following the San Fernando earthquake included removing one story from the top of the bell tower and anchoring the front (south) gable end wall to the timber roof framing. The church was severely damaged during the January 17, 1994 Northridge earthquake. We evaluated the damage and designed repairs to restore the damaged elements and to strengthen the structure against future earthquakes.

2 Building description

The design of St. Monica's was reportedly patterned after Santa Sabina in Rome, Italy, a fine mediaeval church. Both churches follow the basilical plan with the nave separated from the aisles on either side by a row of columns.

St. Monica's is oriented with main axis of the nave and the two aisles running north-south. (Fig. 2) The main entrance is located at the south end, two secondary entrances are located on the west side, and one secondary entrance is located on the east side. A bell tower is located at the southwest corner.

The building has a high gable roof, forming a tall, narrow 18 m high nave. The side aisles have lower pitched roofs which intersect the nave wall at about mid-height. The semi-circular apse at the north end rises to a height of 12 m where it intersects the north gable end wall.

The structural system is primarily a reinforced concrete frame consisting of lines of columns located in the east wall, a line of columns between the nave and each of the aisles, and a line of columns along the west wall, connected by horizontal beams. The frame ends at the end of the nave before reaching the apse. Unreinforced masonry extends approximately three feet above the concrete frame along the east and west walls. The north and south ends of the gable are unreinforced masonry from the concrete frame up to the roof. Wall construction varies, and consists of either three or four wythes of brick, faced with one wythe of stone on the exterior. Interior surfaces are lath and plaster applied either directly

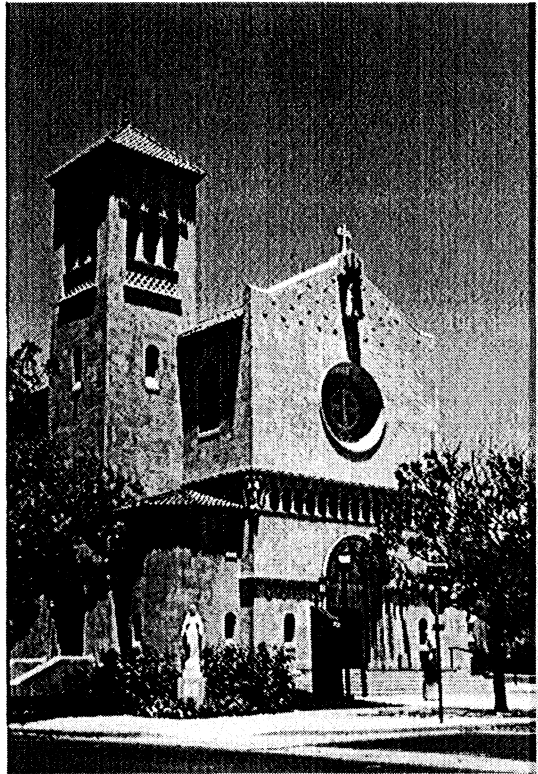


Figure 1: St. Monica's Catholic Church after restoration

to the brick, or to walls furred out with hollow clay tile. The apse is unreinforced masonry, consisting of four wythes of brick with one wythe of stone.

The exterior cladding consists of 102 mm thick variegated Indiana limestone, coursed in a random ashlar pattern. Larger limestone blocks are used for window surrounds, sills, arch voussoirs, cornices and brackets. The limestone is typically anchored to the brick infill walls with galvanized steel z-shaped straps or “header” stones extending back into the walls.

3 Earthquake damage

3.1 The Northridge earthquake

A magnitude 6.8 earthquake struck the Los Angeles area on January 17, 1994. The epicenter was about 1 mile from Northridge, in the San Fernando Valley. Approximately 3000 structures were red-tagged (no entry allowed), including 114 in the City of Santa Monica, many of which were unreinforced masonry buildings. A survey by the Los Angeles Conservancy found that the earthquake damaged at least 171 officially designated landmarks and other significant buildings in the City of Los Angeles. (Hall¹)

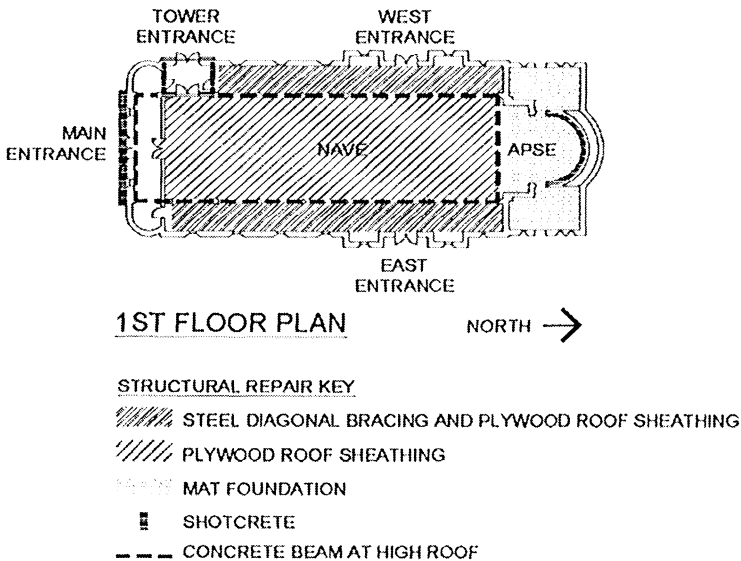


Figure 2: Plan of St. Monica's showing structural repairs



3.2 Damage to St. Monica's

We performed damage surveys on the day of the earthquake. Throughout the building, the stone veneer and backup masonry had shear cracks and extensive mortar loss, and the stone veneer had separated from the backup masonry. Large pieces of interior plaster had fallen from the ceiling and walls.

The limestone facade suffered extensive damage. In general, walls not contained within the concrete frame either suffered severe cracking and displacement or collapsed completely.

The tops of both the north and south gable end walls collapsed out-of-plane, leaving the attic space open to the exterior. (Fig. 3) At the north end, the stone had cracked and displaced away from both corner columns below the collapsed gable end wall.

The previous retrofit had anchored the top of the south wall to the roof framing with steel angles bolted to the timber framing. The bolts tore through the timber framing, along the longitudinal axis of the framing. The 3200 kg hood stone at the top of the south wall had fallen through the exterior concrete steps below, but miraculously, the statue of St. Monica, located just under the hood stone, was intact and remained attached to the facade.

The unreinforced masonry apse had diagonal shear cracking and substantial displacements of both the stone cladding and brick back-up. Several of the cornice stones, located above the concrete frame, were displaced. The voussoirs (arch stones) at the secondary west entry rotated such that the top of the arch was pulled 50 mm away from the west wall.

The tower also had extensive diagonal shear cracking and displacements. Joints between stones opened up to as much as 75 mm wide. (Fig. 4)

4 Evaluation

The damage to St. Monica's was so severe that the City of Santa Monica Building and Safety Department initially decided to condemn the church. Based on his own



Figure 3: Collapse of north gable end wall and cracking at adjacent corners.

survey, Nabih Youssef, SE, the structural engineer of record, determined the church could be repaired and met with representatives of the Building and Safety Department to stop the condemnation. Exterior facade consultants Carolyn Searls, PE, and John Lesak, RA, of Wiss, Janney, Elstner Associates Inc., evaluated the condition of the limestone facade and designed the facade repairs.

4.1 Condition assessment

We arranged for a professional photographer to photograph all elevations of the church and convert the photos into large scale rectified photo mylars. We inspected every stone, and marked our observations on the rectified photographs, which were later used to produce the construction documents. We noted stones requiring repair, including removal and reinstallation, replacement, additional anchors, patching, and/or repointing.



Figure 4: Severe cracking and displacement at tower

4.2 Testing

We made inspection openings to determine the construction of the walls and the displacement of the limestone cladding relative to the brick back-up. We used a metal detector to locate stone anchors. We performed flat jack and push tests to assess the strength of the existing masonry.

4.3 Structural analysis

We modeled the existing structure, based on plans of the existing building and material testing of existing structural elements, on the SAP90 computer program. We observed structural deficiencies at the apse and tower. We reviewed the existing structural drawings and found that improved details should be provided to strengthen the top of the masonry walls at the entire perimeter of the building.



Improved details should also be provided to attach the roof trusses to the east and west walls.

5 Repairs

5.1 Structural repairs and strengthening design

5.1.1 Structural design criteria

Our structural analysis and repair of the church followed the guidelines of the State Historic Building Code and the Secretary of the Interior's Standards for Rehabilitation. Our goal was to repair and upgrade the existing lateral force resisting system to a performance level that would improve the life safety of the church and limit damage to the historic and architectural fabric in future seismic events. We developed repair and strengthening schemes to meet the performance criteria and minimize the impact on the historic and architectural fabric of the church.

5.1.2 Structural repairs

We designed the following structural repairs (Fig. 2):

- (1) Provide a new ductile concrete frame and mat foundation at the north (apse) end of the church.
- (2) Replumb as required, repoint and low pressure injection grout existing damaged masonry walls. Replace existing masonry as required with new masonry or reinforced shotcrete wall.
- (3) Remove the interior wythe of masonry and install new reinforced, spray-applied concrete wall over the remaining existing masonry at the apse, the tower, and selected portions of the east and west walls of the church. Strengthen the existing footings at the tower.
- (4) Inject cracks in existing concrete frame members with epoxy (primarily at the tower).
- (5) Reinforce existing low roof diaphragm with tubular steel diagonal braces and plywood sheathing over the existing roof sheathing.
- (6) Reinforce existing high roof diaphragm with plywood sheathing over the existing roof sheathing.
- (7) Provide new concrete beam and wall at the high roof level around the perimeter of the church to transfer diaphragm forces to the exterior masonry walls.

5.1.3 Structural details for interior remodeling

We developed structural details for proposed interior remodeling including:

- (1) New wall openings in the masonry wall supporting the choir loft.
- (2) Structure for new mechanical equipment support and floor penetrations in the tower.
- (3) Revisions to the altar and sacristy area including new concrete slabs and a new baptismal font.

5.2 Limestone facade repairs

The repaired structure provided a sound substrate for anchoring the limestone. An elaborate and sturdy scaffold system around the entire building, erected by the general contractor, was instrumental in allowing the stone masons to work efficiently.

5.2.1 Removal and reinstallation of stone

In severely damaged areas with large stone displacements, including the gable ends, the tower, the west entrance, and the apse, each block of limestone was removed and labeled (prior to its removal) for reinstallation in the same location. At all of these areas except the apse, the brick back-up wall was replaced with concrete. Vertical stainless steel dovetail slotted channels were placed in the concrete walls for later use in anchoring the stone. The stone was anchored using a dovetail anchor, with the dovetail end placed in the slotted channel and the straight end bent up and down into kerfs cut in the bottom and top of the stone blocks. The stone was installed quickly using this system, because the vertical location of the anchors did not have to be determined in advance, since the dovetail could fit anywhere along the height of the channel. Likewise, the kerfs in the stone were cut as the stone was placed, eliminating pre-measuring of horizontal distances to locate anchors. (Fig. 5)

At the apse, the inner wythe of brick was removed, and steel reinforcing and shotcrete were placed. The outer wythe of brick was removed and the dovetail slotted channels installed. Then shotcrete was placed on the exterior face of the brick, to level the surface even with the dovetail channels.

At areas where stone was removed and replaced, or where new stone was installed, the new anchors met the requirements of the governing building code. The code requires one anchor for every 0.19 square meters of stone surface to resist a horizontal force of two times the weight of the anchored stone.

5.2.2 Replacement stone

All serviceable stones were reinstalled, however, some stones were too damaged to reinstall or they had been removed from the site by crews performing emergency stabilization immediately following the earthquake. We obtained replacement stone from the same quarry that supplied the original stone, the Evans quarry near Bedford, Indiana.

5.2.3 Cross and hoodstone

The church's original Celtic cross had fallen off in the San Fernando earthquake, and was never replaced. We had a precast concrete replica of the cross made, based on original drawings. It was installed at the apex of the south elevation, just above the hoodstone. The hoodstone, which had fallen off in the earthquake, was repaired and reused. To make the hoodstone easier to handle, it was cut into three pieces, then anchored to a new cast in place reinforced concrete wall.



5.2.4 Anchoring of existing stone

Most of the stone located within the area of the concrete frame and masonry infill, except at the tower, was undamaged. The existing strap anchors we found were irregularly spaced and each anchor tied back between 1.3 and 2.0 square meters of stone. In addition, some of the stones were turned sideways as “headers” and tied the stone cladding to the back-up wall. While this anchor spacing did not meet current governing building code regulations, we did not deem it necessary to add anchors at most ashlar blocks. Fortunately, while the California State Historic Building Code requires reconstructed walls to meet current code, it allows minor repairs to existing walls to be done per the original construction.

We did specify additional anchors for large stones such as window sills, voussoirs (arch stones), and window surrounds. The stones were anchored through the exterior face using stainless steel threaded rods set in epoxy filled holes in the brick back-up. The exterior face of the hole was plugged with limestone plugs made from otherwise unsalvageable rubble. The coping and bracket stones at the top of the walls, above the original concrete frame, were anchored from the interior through the new reinforced concrete bond beam.

5.2.5 Other stone repairs

Cracks were filled with a cement-lime mortar. Spalls were patched with dutchmen, cut from otherwise unsalvageable rubble. Cracked and deteriorated mortar joints were repointed. Following the rebuilding, anchoring and repointing, the entire

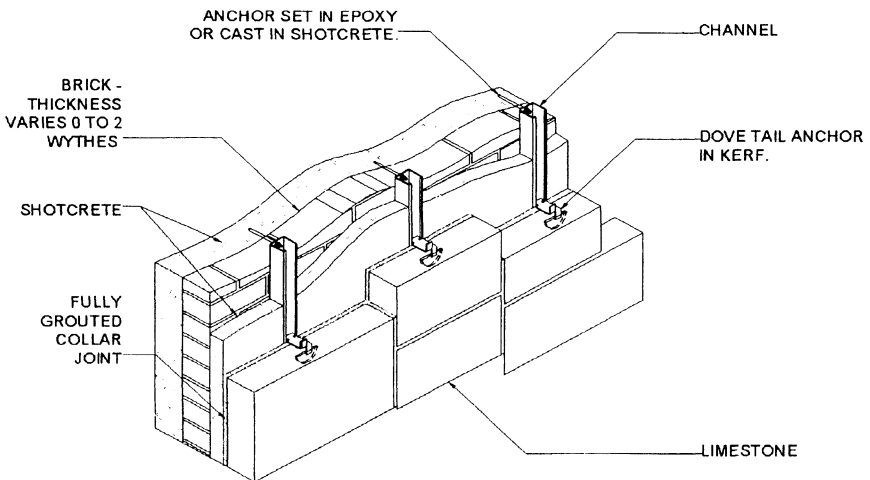


Figure 5: Removal and reinstallation of stone



facade was cleaned using a mild acidic cleaner and water rinse. The contractor had some difficulty adequately rinsing the cleaner off the stone, and we would now consider other cleaning methods.

5.3 Interior repairs

While the exterior work was underway, the interior was repaired and refurbished. The sanctuary was reconfigured. The damaged plaster ceiling and walls were repaired. The stained glass windows were protected with plywood and remained in place throughout the construction.

5.4 Access and staging

The repair and restoration was complicated by the fact that there was limited room for construction storage and staging at the site. The church is adjacent to the parish school, and is bounded on two sides by city streets. Removal and installation of large elements that required cranes were scheduled around school vacations. Extensive interior and exterior scaffolding was installed to provide a work platform and storage and staging areas.

6 Conclusion

The care, effort and hard work of the parish, the design team, the general contractor and the subcontractors allowed the church to reopen for Easter services on April 16, 1995. The bishop of Los Angeles was present, and the parishioners filled the church to overflowing. The church can now continue its many programs for the community of Santa Monica and the city of Santa Monica has a landmark that will last for many years to come.

Monsignor Torgerson of St. Monica's wrote, "My greatest remembrance of the day was the first view of the church at 4:45 in the morning. With the tower very damaged, gaping holes in the roof and an incredible amount of damage inside the church, the person who came into the church with me said, 'We have lost the church forever!' We spent that day attempting to assess the damage and to remove the precious artifacts from the building. Finally toward evening, I tried to find Nabih because many in the city felt we should take the tower down. He arrived at 7:30 that evening, with the only words of hope that I had heard all day long, 'We can save this church, rebuild the tower and the building and make it even stronger for generations to come.' The next few weeks, with the help of seismic experts, contractors and engineers, we evaluated the damage and made a decision to retrofit and restore. Fifteen months later, we were back inside that church with the celebration of Easter. While there was an incredible amount of work to be done, we were able with the help of Peck/Jones, Nabih Youssef and Construction Management, to keep the ancient integrity and beauty of that building as well as restoring and retrofitting its structure. What looked like the greatest disaster to hit this parish community became, in fact, a blessing!"



References

1. Hall, J.F., *Northridge Earthquake, January 17, 1997 Preliminary Reconnaissance Report*, Earthquake Engineering Research Institute, Oakland, California, March, 1994.