NONDESTRUCTIVE EVALUATION AT MISSION SAN MIGUEL – ACHIEVEMENTS AND LIMITATIONS

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Abstract

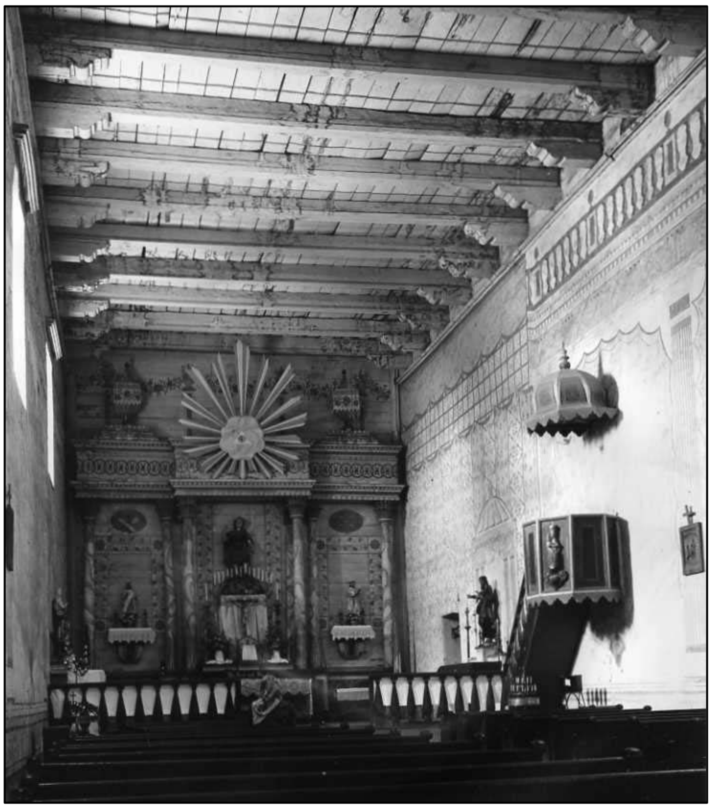
The San Simeon earthquake resulted in structural damage to the Mission San Miguel Arcangel, including the adobe church and sacristy (c.1818). The building's interior retains an extraordinary level of integrity and significance, and interior plasters and woodwork are covered in an early decorative paint scheme. Many structural elements were displaced during the earthquake, and most wooden elements are deteriorated due to termite infestation, decay, and weathering.

Visual inspection of the woodwork provided qualitative information concerning the damage distribution. To better characterize section losses, representative elements were selected for detailed examination by resistance drilling and digital radioscopy; details of the digital radioscopy are presented in a companion paper at this conference [1]. The representative survey allowed for a preliminary evaluation of member capacity and indicated the necessity of a systematic investigation.

The inspection technologies yielded a great deal of information that was useful in generating estimates of remaining sound wood, defining additional investigation needs, and designing broad treatment strategies. However, resistance drilling and digital radioscopy were only minimally useful in characterizing the condition of timber vigas embedded in the thick adobe walls and assessing termite damage in the painted ceiling decking. Quantification of section loss in embedded elements is critical in determining remaining structural capacity and for designing repairs, and will require additional investigative techniques and strategies.

1. HISTORY AND SIGNIFICANCE

Mission San Miguel Arcangel was founded on July 25, 1797, the sixteenth of 21 Spanish missions established in Alta California. Construction of the mission buildings took place over two decades, culminating in the construction of the church between 1816 and 1818. The church and sacristy make up the northeast corner of the mission quadrangle. The gable-roofed adobe church is laid out roughly on an east-west axis and is approximately 11.5 meters wide by 47.9 meters long. Nave walls are approximately 1.63 meters thick, so that the room interior is approximately 8.23 meters wide. The altar occupies the west end of the room and includes a wooden retablo against the west wall, a wooden altar railing that separates the altar from the nave space, and a wooden pulpit hung on the north wall of the nave and accessed from a wooden stair adjoining the altar railing. A wood-framed choir loft occupies the east end of the room. The sacristy is an adobe wing adjoined to the main block at the northwest corner (Figure 1).



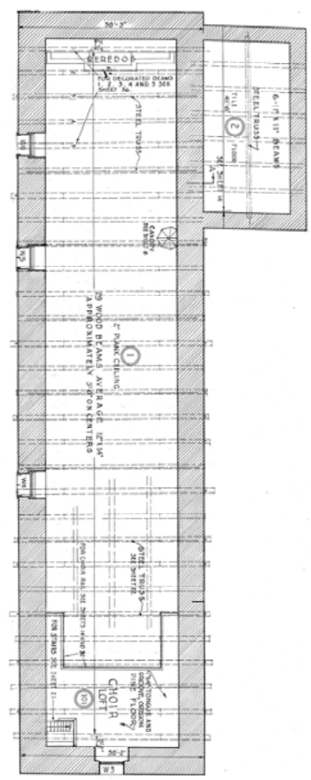


Figure 1

The church retains an exceptional level of early fabric, including a decorative paint scheme on wood and plaster completed in 1822. In this early-20th century photo, extensive deterioration of the painted ceiling is apparent.

Ceilings in the nave and sacristy consist of wooden decks supported on wooden vigas and corbels. Timber was cut from the pine forests in Cambria, 40 miles away. Corbels cantilever from the north and south walls and support vigas that span the narrow dimension of each room. Most of the nave vigas protrude from exterior walls and have mortises for vertical tusks or wedges, indicating that the vigas were intended to perform a tying function in this long building constructed without interior partitions. Nearly all of the surviving ceiling woodwork was converted by hand (methods include pit- or whipsawing and hewing), indicating an early construction date.

Nearly all of the church interior is decorated with an early polychrome paint scheme comprised of painted classical architectural elements and stenciled designs, including the earthen-plastered walls, the nave, choir, and sacristy ceilings, the retablo, and the pulpit. This paint scheme is almost universally ascribed to Esteban Munras, a Spanish immigrant, who directed a crew of native neophytes. Painting is said to have been completed sometime early in the 1820s, and in 1857 diarist Henry Miller referred to “whitewashed walls daubed with some coarse fresco painting” on the interior of the church [2]. Church and sacristy interiors retain one of the highest levels of integrity and authenticity of any of the California missions. The mission complex was listed on the National Register of Historic Places in 1971, later elevated to National Historic Landmark status. In 2006, the National Trust for Historic Preservation included the property on its 11 Most Endangered list.

2. CURRENT CONDITIONS

The church is endangered as the result of decades of neglect and damage resulting from the San Simeon earthquake of December 22, 2003. Visual inspection of the woodwork and documentary research focused on its conservation history provided qualitative information about the condition of the building and its stability, including the distribution of water-staining, and evidence of wood-boring insect activity and fungal decay. Late in the nineteenth century the roof covering on the building failed, and documentary sources indicate that the building interior was exposed to damage from weather for a period of several decades [3]. The current roof, supported on a series of steel Pratt trusses, is the product of a c.1930 intervention; there is no connection between the steel roof structure and the historic wooden ceiling structure. Damage to historic wooden elements on the building interior includes:

1. Staining and dissolution of period paints;
2. Displacement of structural wood as the result of earthquakes;
3. Section losses associated with wood-boring insect activity and fungal decay.

The levels of damage associated with water staining vary from mild to severe. Period ceiling paints appear to be well-adhered distemper paints and are water soluble. In its mildest form, water staining has resulted in the dissolution of the painted finish, resulting in pigment loss and the formation of tide lines. In its severest form, water staining has resulted in the formation of disfiguring dark crusts on the surface of the wood. Crusts appear to be the result of rainwater washing through bat and pigeon droppings in the attic spaces, resulting in redeposition of the material on painted surfaces.

Several vigas were displaced in the last earthquake, particularly in the sacristy where paint ghosts on vigas and corbels indicate total displacement of 15 cm or more. Displacements are undoubtedly cumulative, as the result of several earthquakes, and evidence of earlier viga movement can be seen in photographs taken before 2003 [4]. The source of most of the movement seems to have been the north sacristy wall, which was recently stabilized by the installation of temporary walers against the wall exterior. Displacements in the nave are more modest, totaling no more than 2 to 5 cm. Embedment depths of vigas and cantilevered beams in the choir and sacristy are currently unknown. Sacristy vigas are of particular concern because of the amount of displacement at the south sacristy wall, and the unknown condition of the wood remaining in the wall (Figure 2).

Insect damage has been most severe in ceiling construction, with lesser levels of damage in the retablo and pulpit. Inspection of the building produced evidence of infestations by drywood and subterranean termites, and probably at least one species of wood-boring beetle. Of these, the damage caused by drywood termites is by far the most extensive, with damage from this insect appearing in virtually every ceiling element examined. In the nave, where deck boards could be examined from the attic space, damage visible on the upper surfaces of planks was extensive, affecting perhaps 30 percent of the total deck area. Heavy timber decking elements included in nave and sacristy ceiling decks are noticeably more severely damaged than much of the thinner deck material. Vigas, corbels, and the torus-molded timber installed in adobe coursing exhibit many of the same conditions. Visual inspection of the exposed ends of sacristy vigas and corbels on the exterior north wall discovered severe deterioration within several inches of the exposed surfaces.

Figure 2

Damage associated with water staining ranges from partial pigment loss to disfiguring dark crusts. Bare wood at corbel ends (left photo) indicates displacement of several cm in sacristy vigas. Nearly all of the wooden ceiling elements have been damaged by drywood termites (right photo), some severely.

3. QUANTIFICATION OF DETERIORATION USING NONDESTRUCTIVE EVALUATION TECHNIQUES

In addition to visual inspection, resistance drilling and digital radioscopy were employed to help characterize damage patterns and quantify section loss in typical elements. Resistance drilling is a quasi-nondestructive technique for determining the relative density of wood. It is best suited for determining internal problems in larger timbers that do not show obvious signs of deterioration, such as surface decay or insect bore holes. Internal voids at the location drilled can be detected by observing the relative density of the wood as it is printed on the resistograph strip.

Resistance drilling was conducted on four vigas within the nave using the IML RESI M300 Resistance Drilling System (Figure 3). The vigas were selected for testing based on their appearance to determine if it might be possible to establish a correlation between the extent of staining on the viga surface and the extent of internal damage. The drilling locations were selected to give an indication of the typical pattern of internal damage. It was discovered that, with the larger-dimension elements like vigas, corbels, and deck timbers, the distribution of water staining is not a reliable indicator of termite damage on the interior of the elements. Resistance drilling of vigas encountered section losses, occasionally in excess of 50 percent, though damage levels were typically much lower than this; section losses were encountered in water stained elements and in elements relatively free of surface damage. In general, damage was found to be concentrated along adobe walls.

Figure 3
Resistance drilling of a viga to quantify internal damage due to insect attack

Timbers supporting retablo woodwork and visible from behind the altar are termite-damaged to a height of approximately 1 m. above the floor, and above ceiling level. Loss of structural section at the lower ends is total and dimensioned-lumber sisters were installed in an earlier repair. The insects showed a preference for earlywood layers, leaving latewood lamellae, which is typical of subterranean termites. These timbers are some of the only wooden elements in the building that retain evidence of fungal decay. Structural elements in projecting sections of the retablo were not similarly available to visual inspection, and it was important to determine deterioration levels without removing casework or damaging early nineteenth century finishes. Resistance drilling provided accurate results relatively quickly and without any dismantling of the woodwork.

Examination of structural elements fixing the wooden pulpit to the adobe wall using resistance drilling confirmed insect damage in the threshold but discovered relatively little damage in the softwood elements supporting the pulpit. However, plaster around lookouts was damaged in the last earthquake, indicating some movement in the woodwork, and pulpit and canopy appear to be somewhat out of plumb. This raises obvious questions about the condition of pulpit and canopy anchorages which must be investigated in the next phase of work.

In addition to resistance drilling, digital radioscopy was used to examine selected vigas, ceiling decking and the pulpit supports to determine the presence of deterioration. The radioscopy system used at San Miguel Arcangel was the RTR-4™ portable digital x-ray imaging system manufactured by SAIC® (Science Applications International Corporation). This system is fully digital, composed of a control unit (a laptop computer), the imager, and cables which connect the imager to the controller. The source used to generate the x-rays is the XR200®, manufactured by Golden Engineering, Inc. It is a single-packaged 150 kV source that produces x-ray pulses of 60 nanoseconds duration.

This imaging system produces digital radiographs in real time, so that the images are available for viewing essentially instantly. It is easy to shift the imager if needed when the area of concern is not included in the image, or to shift the imager along an object (such as a viga) to make sequential radiographs. The images are stored to allow for post-processing to enhance features of interest within the image.

Digital radioscopy was used to characterize insect damage in two large dimension elements. In the first instance, the radioscopy equipment was positioned with the x-ray generating source on one side of a viga and the imager placed flush against the other face (Figure 4). At this location the viga was found to be in good condition with only a few termite galleries visible near the upper section of the viga; the lightest areas of the radiograph correspond to less wood in the cross section due to the presence of the termite galleries. In this radiograph, the grain structure of the element is fairly clear and distinct (Figure 4). By comparison, the radiograph of a severely deteriorated timber decking element is characterized by amorphous grain structure and the lack of any discernible galleries. This is because the three-dimensional piece of wood, riddled with termite galleries, is reduced to a two-dimensional image on the radiograph so the galleries at the "front" of the piece overlap with those in the "center" and the "back" of the piece. Although radioscopy could be used to determine the presence of, and quantify, termite damage, the technique is more cumbersome and time-consuming than resistance drilling for a more comprehensive investigation.

Figure 4

Digital radioscopy setup on viga 34 in the sacristy (left photo) and radiograph of viga 34 showing the top half of the viga, approximately 79 inches from north wall (right figure). Note the termite galleries near the upper surface of the viga.

Ceiling deck boards displayed a range of visual termite damage and were x-rayed to determine whether the loss of section due to termite damage could be quantified. Previous work for the National Center for Preservation Technology and Training by Anthony & Associates, Inc. had resulted in a methodology that provides an estimate of remaining section using radiographs of sound and damaged wood [5]. Of the decking elements surveyed, a sample from the sacristy had the most variability, with one end displaying relatively little damage from termites both visually and from the radiograph, while the other end displayed significant damage. Comparing the histogram function of the same central area in the radiographs gives an estimate of approximately 50 percent of the wood remaining. Other calculations on this decking, comparing portions of the damaged and undamaged ends, gave estimates ranging from 40 - 64 percent; damage was found to be concentrated along top and bottom surfaces.

In addition to taking x-rays of the decking through the board face, x-rays were also taken through the narrow edge (tangential to the grain) of the board. A histogram comparison of one example showed that material along the edges (where the termite galleries were concentrated, just beneath the paint) contained about 56 percent of the material in the center of the piece. Based on this image, we do not know that the center of the decking is sound but we do know that is has about twice the wood per unit volume as the edges. Using this information in conjunction with the results of the images taken through the face of the boards, we can conclude that approximately 50 percent of the wood (at least in these samples) has been lost to termite attack. Further, the most severe loss of material is just below the outer surfaces, including the painted surface.

Initially, it was thought that digital radioscopy would allow for identifying painted ceiling decking that had been attacked by termites. This information would be of use to the conservator to generate a plan for cleaning or restoring the painted boards. After examining several of the boards visually and with simple probing, it was determined that the extent of damage was wide-spread and affected virtually all of the ceiling decking. Moisture stains and residue were visible on the painted surface of as much as 30 percent of the decking. Percussive testing of representative areas of the deck determined that there is a high correspondence between termite damage in the zone adjacent to the painted surface and the presence of water stains and crustal deposits on the surface.

4. ACHIEVEMENTS AND LIMITATIONS OF RESISTANCE DRILLING AND DIGITAL RADIOSCOPY AT MISSION SAN MIGUEL

With respect to ceiling deck elements, digital radioscopy was useful in characterizing damage patterns and in quantifying section loss in some of the more severely damaged material. As a result of the limited survey work already completed, a correlation has been established between surface staining of the thinner decking elements and the condition of the wood immediately behind the painted surface. This information will be used to complete a comprehensive survey of the painted deck based on visual cues and percussive testing, and will enable conservators to adjust treatment of the painted surface to specific subsurface conditions.

In order to make some preliminary determination of the structural capacity of nave vigas (they have the largest span), it was assumed that structural elements were of No. 2 ponderosa pine. Using published values for average density and modulus of elasticity [6], and strength in bending [7], current bending stress is calculated at 1.5 MPa, with an allowable bending stress of 4.1 MPa (assuming a 23 cm x 30 cm viga). For the same viga, theoretical maximum deflection is 0.89 cm; adjusted for creep, maximum deflection of an undeteriorated viga should be approximately 1.35 cm over an 8.23 m span. Treating them as simply loaded beams and ignoring their potential behavior in seismic events, nave vigas appear on average to be adequately sized for current loads when in an undeteriorated condition. Severe slope of grain in some examples, section losses encountered in examinations of vigas using the resistance drill, and deflections in some members that exceed theoretical values all call for systematic investigation of the structural capacity of individual members.

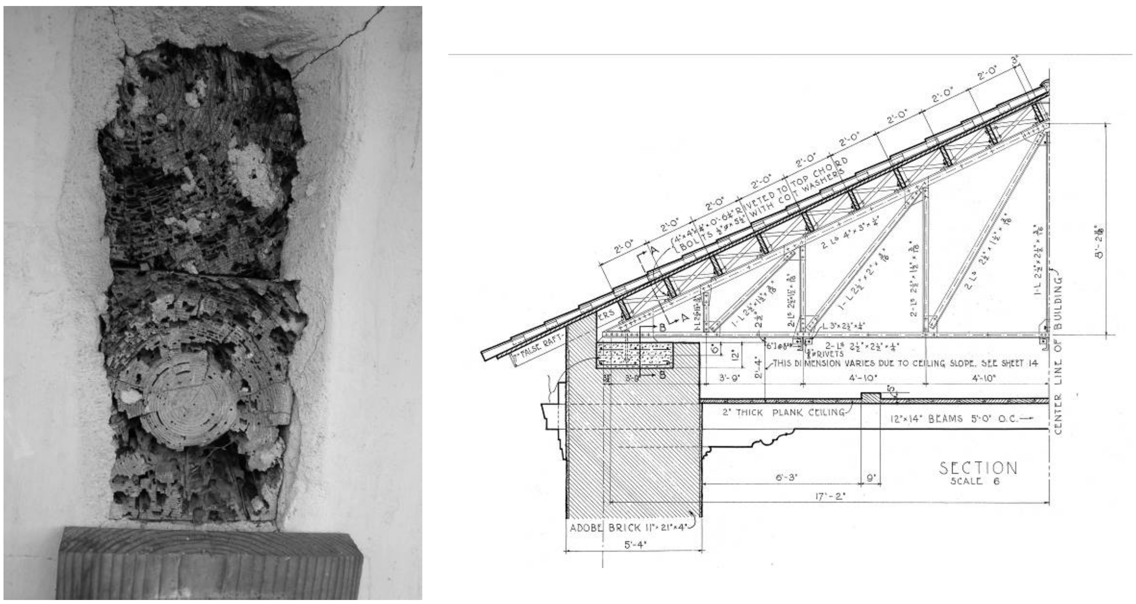


Figure 5

Many viga and corbel ends exposed on the building exterior are riddled with termite damage (left). Quantifying the surviving section of structural wood embedded in adobe walls will require a combination of resistance drilling at an angle and direct inspection with a videoscope.

Where the elements are exposed on the interior of the building, the resistance drill will work very well for quantifying remaining section. However, it was determined in the initial survey that termite damage is concentrated along the walls, with very significant damage visible on viga and corbel ends exposed on the exterior of the building (Figure 5). Furthermore, the 2003 earthquake resulted in displacement of many of the structural wood components; in some cases, the measured lateral displacement of the vigas was in excess of 13 cm. Without knowing either the embedment depth or the condition of the viga within the wall, the effect of this level of displacement (withdrawal from the wall) on the structural integrity of the church cannot be fully assessed. Because of the thickness of the walls and the necessity of working at oblique angles to the embedded portions of the vigas, digital radioscopy has no application in this instance, and the resistance drill will have limited utility in examining embedded wood. The drill has a maximum depth of 30 cm, and so is not long enough to survey wood located near the center of walls 1.63 m in thickness. In addition, when drilling in an axial direction, the drill's needle tends to follow discontinuities in the wood, yielding undependable results.

5. PROPOSED ADDITIONAL INVESTIGATION

As a result of the limitations discussed above, systematic survey of structural wood will require collating information derived from several sources, including:

- **Engineering evaluation to determine capacities of various structural elements and loads imposed on them:** Determination of the as-built capacity of vigas and other structural elements, based on Historic American Building Survey drawings and field survey data, will allow investigators to establish repair thresholds for damaged material and alert them to marginal conditions discovered in subsequent survey work. The values derived from this analysis, when compared with findings of a systematic survey of structural wood, will allow designers to identify marginal members and design repairs that conservatively address specific deterioration conditions.
- **Grading of structural timbers:** Grading of the nave, sacristy, and choir vigas based on wood species, knot location and size, and slope of grain in order to determine impacts on structural capacity.
- **Resistance drill survey of exposed structural wood components:** Resistance drilling of vigas, corbels, cantilevered beams and lookouts, window and door lintels, and retablo column bases, with graphical and tabular organization of results.
- **Examination of embedded wood components using visual inspection, resistance drilling at an angle, and examination with a videoscope:** Examination of embedded wood will include an evaluation of damage to exposed viga and corbel ends. The resistance drill will be useful for drilling into vigas embedded into the adobe walls at approximately a 45° angle to the wall surface (resulting in effective examination depths of 20 cm). Where deterioration is found, it may be necessary to collect additional data using a videoscope or fiber-optic camera. This will require boring holes in wooden elements to create a path for the scope. Repair thresholds determined as part of the engineering evaluation will help to limit the extent of this destructive investigation; once sufficient sound wood has been discovered in a particular location, additional investigation becomes unnecessary.

6. SUMMARY

Resistance drilling and digital radioscopy were used to investigate the condition of wood components at Mission San Miguel. These nondestructive evaluation techniques were successful in achieving the following:

- The extent of deterioration and remaining cross section of the vigas and other structural wood components could be quantified where they were not embedded more than 10-20 cm in the adobe walls.

- The pattern of deterioration in the vigas due to insect attack could be determined through either resistance drilling or digital radioscopy.
- Resistance drilling was able to provide a more rapid assessment of damage in the timbers than digital radioscopy because of set-up and data analysis time required.
- The representative pattern of deterioration in the decorative ceiling boards due to insect attack could be determined through digital radioscopy.
- The representative pattern of deterioration in the decorative ceiling boards due to insect attack could not be determined through resistance drilling due to a combination of thin section and low density of the boards.
- Given the size of the building and the extent of the problem, it was not practical to use either resistance drilling or digital radioscopy for rapid assessment of ceiling deck deterioration.
- For determining the condition of timber vigas and other structural wood components embedded in the 1.5m-thick adobe walls, resistance drilling is only minimally useful and digital radioscopy has no application at all.

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