Evolving Methodology in Seismic Retrofit: Stabilizing the Las Flores Adobe

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Abstract: *The Las Flores Adobe National Historic Landmark, constructed in 1868, has been seismically and structurally stabilized over a three-year period. Located in an active seismic area of Southern California, the complex of buildings represents one of a few authentic nineteenth-century, two-story adobes combining the Hacienda and Monterey styles, which are unique to Hispanic traditions of California. The buildings are constructed of adobe brick and are surfaced with a combination of earthen- and lime-based finishes.*

Since the 1970s, the unused buildings had fallen into disrepair. A phased stabilization project to save the landmark started in 2000, with participation of a multidisciplinary team. The team applied its collective expertise in architecture, engineering, and conservation to develop a design that satisfied life-safety and fabric preservation agendas.

The California Historical Building Code (CHBC) was applied to allow for alternative performance-based solutions (California Building Standards Commission 1998a). Stability-based retrofit design for this project was developed out of the Getty Seismic Adobe Project (GSAP) research program supported by the Getty Conservation Institute during the 1990s. The ranch house, or main house, and carriage house were stabilized in 2002–4 with retrofit designs that took advantage of the energy dissipation characteristics of thick adobe walls in the postelastic phase. These minimally invasive systems, using rods, steel strapping, grouted pins, and plywood sheer panels, served to improve structural continuity, prevent overturning of walls, and minimize loss of historic fabric by limiting displacement. Work on the carriage house incorporated the use of earthen grouts in the installation of center core rods. Earthen grouts are readily available, compatible with historic adobe, and reversible. A training component was integrated into the construction program.

Introduction

The Las Flores Adobe, a National Historic Landmark, is located between two major fault lines aligned with the coast of Southern California; the area is in seismic zone 4, an area in which there is a 1 in 10 chance that an earthquake with an active peak acceleration level of 0.4 g (4/10 the acceleration of gravity) will occur within the next 50 years. It is in one of the most active tectonic fault zones in the world. The building has survived hundreds of seismic events, including a major earthquake (Richter scale = 6.8) associated with the nearby San Jacinto fault zone, on April 21, 1918.

Built in 1868, the Las Flores complex includes a ranch house, or main house, consisting of a formal two-story Monterey block and a long, low Hacienda block with rooms opening onto a *portal*, or porch (figs. 1a and 1b). There is also an attached carriage house. The Las Flores site is one of a few authentic nineteenth-century adobe ranch houses combining the Hacienda and the Monterey styles, which are unique to California. The United States Marine Corps, the National Park Service (NPS), the Graduate Program in Historic Preservation at the University of Vermont, and private sector architectural and engineering professionals have partnered in the planning, design, and stabilization of the building complex.

(a)

(b)

FIGURES 1A AND 1B The Las Flores complex with a ranch house (main house) consisting of the two-story Monterey block (a) and the Hacienda block, which is the long, low section connecting the Monterey block on the left and the carriage house on the right (b).

Seismic stabilization has focused on implementing techniques advanced by the Getty Seismic Adobe Project (Tolles, Kimbro, and Ginell 2002; Tolles et al. 2000 and 1996), which impart stability to adobe walls while preserving the historic fabric and structural system. The interventions also comply with performance standards for structural design, as outlined in the California Code for Building Conservation (International Conference of Building Officials 1998), particularly with respect to the lateral design of unreinforced masonry buildings, and the California Historical Building Code.

Prior to GSAP research, retrofit technology routinely applied in similar cases involved the installation of invasive concrete post-and-beam and bond beam assemblies requiring major demolition of historic fabric. At Las Flores, the team has installed minimally invasive systems utilizing rods, steel strapping, grouted pins, and plywood sheer panels. The carriage house work required that a preexisting concrete bond beam be incorporated into the retrofit design and presented the team with an opportunity to use earthen grouts as a more compatible material substitute for the epoxies used on the main house project. This case study represents one of several in which this type of technology has recently been implemented in the field.

Historical Background

The Las Flores Adobe Ranch House is a 557 m^2 (5995 sq. ft.) two-story adobe building and once was part of an over 52,600 hectare (129,922 acre) ranch. It was taken over by the federal government in 1941 for use as a U.S. Marine military training base during World War II. It continues to be under the jurisdiction of the Marine Corps.

The site is representative of settlement patterns throughout most of California history, contained in one compact and largely undisturbed microenvironment. Archaeological and historical records at the Las Flores site indicate nearly two thousand years of occupation by Native Americans. In the eighteenth century, the first European colonization of California followed the spread of Franciscan missions throughout the region, and in 1798, the pueblo of Las Flores was established under the jurisdiction of nearby Mission San Luis Rey.

In 1834 the mission system was secularized after Mexico gained its independence from Spain, and Las Flores was made a free pueblo. Borders with the United States were opened under Mexican control and trade practices were liberalized, followed by the proliferation of *rancho* culture. Las Flores was purchased from the natives in 1844, and it became part of the larger Santa Margarita Ranch. California came under U.S. sovereignty in 1848. In 1868 Juan Forster, the property owner, constructed the adobe house at the Las Flores site as a wedding gift for his son. Following the collapse of the *rancho* economy in the 1860s, the Forster family fortune went into a slow decline, and Las Flores was sold in 1882 to pay family debts. A San Franciscan named James Flood bought the property and hired Richard O'Neill to manage it. O'Neill leased the Las Flores adobe and

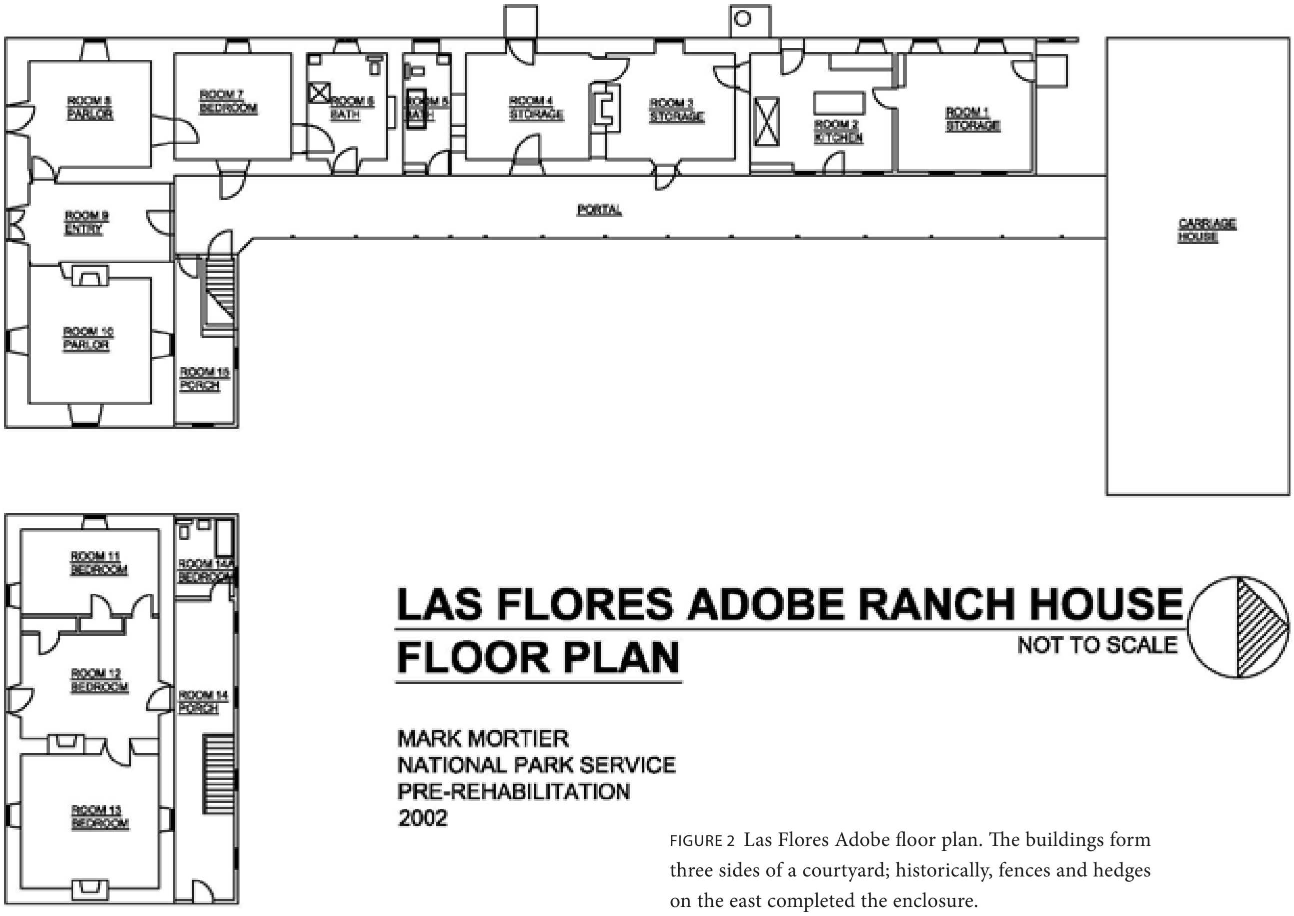


FIGURE 2 Las Flores Adobe floor plan. The buildings form three sides of a courtyard; historically, fences and hedges on the east completed the enclosure.

1500 acres (608 hectares) to the Magee family in 1888, and the site was farmed by this family for more than five decades before being acquired by the Marine Corps. The military presence has not negatively impacted the site, and in contrast to the surrounding communities, where development has obliterated all historical context of the landscape, this property is unique.

The main house embodies the joining of Hacienda and Monterey architectural styles. The house is fronted by an elegant two-story Monterey block, with a full-length two-story porch facing the Pacific Ocean (fig. 2). The ground level of the house is built of 61 cm (23.8 in.) thick adobe walls; wall thickness at the second level is reduced to 46 cm (17.9 in.). Adjoining the Monterey block on the north side of the main house, the utilitarian Hacienda section is a long, one-story wing, one room deep in plan, with doors opening onto a covered *portal* (porch). At the south end, the *portal* connects to a large hallway running through the center of the Monterey block. The Hacienda block terminates at the carriage house, which is parallel to the Monterey block, so that the complex forms a large U around a central courtyard (which is a feature of the Hacienda style). Over the years many changes have been made to the buildings to accommodate new occupants and uses. Historic images indicate that a major construction campaign was undertaken between 1917 and 1919, at about the time of a major earthquake in the region. This campaign included replacement of the roof frame and covering, construction of porches on all four sides of the Monterey block, and the introduction of new doors, windows, and woodwork.

By 1968 the main house and surrounding buildings were in an advanced state of disrepair. Public intervention saved the house and carriage house and had them placed on the National Register of Historic Places and proclaimed a National Historic Landmark, which is the highest designation for a historic property in the United States. In 1999 the Marine Corps initiated a program to stabilize the house using a multidisciplinary team.

The team included a Marine Corps archaeologist, the base museum specialist, an NPS architectural conservator, an NPS historical architect, a consulting historical architect, and an engineer specializing in seismic and adobe preservation. At certain key points in planning, the California State Historic Preservation Officer was included in the review of program and design, since ultimately the state has jurisdiction over the historic designation. In 2002 the NPS invited the Graduate Program in Historic Preservation at the University of Vermont to participate in the program.

Project Planning, Design, and Implementation

Project goals were to reverse deterioration, ensure seismic and structural stabilization, accomplish limited restoration related to stabilization, and plan for future rehabilitation. Project work began with a condition survey focused on the main house in 2000–2001, which led directly to stabilization work in 2002 and 2003. During the 2003 season, a similar survey was conducted on the carriage house, which led to stabilization in 2004. The adobe walls of the main house were found to be generally sound, although they did have some localized cracking. The two-story porch on the Monterey block had been removed in the 1980s for safety reasons, leaving exterior adobe walls exposed to the weather and resulting in losses of large sections of lime plaster. The second-story roof frame did not meet code, and shingles throughout the entire complex were at the end of their useful life.

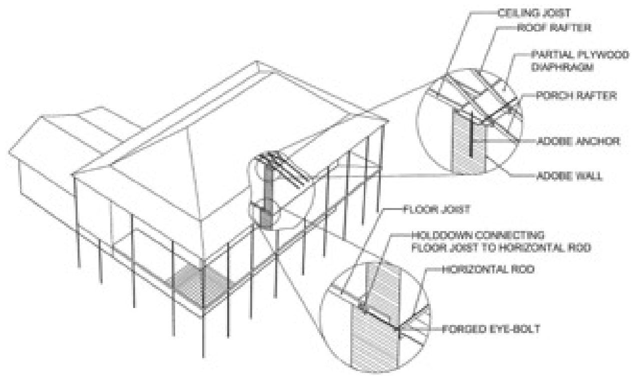
Roof frames on all of the buildings lacked substantial connections to the adobe walls. Floor frames on the ground level were set on grade and completely deteriorated. Second-floor joists were set into pockets in adobe walls without connection. Evidence of termite and fungal deterioration of wood was seen throughout the structure. Windows and doors were severely damaged or missing entirely as the result of vandalism, fungal decay, and termite infestation. Clear sheets of Plexiglas were placed over openings to secure the structure, reducing ventilation throughout the buildings. Infestations by burrowing animals and bees went unchecked, and beehives entirely filled many of the stud bays of the north porch enclosure. The electrical service, not improved after many decades of use, was a fire hazard.

The carriage house was extensively renovated in 1974. Installation of a concrete bond beam resulted in changes in the elevation and construction of the roof, and in consequent loss of the connection between the carriage house and the main house. A large section of the south wall of the carriage house, near the juncture of the two buildings, had collapsed from water damage and was repaired with a large concrete infill. The building was plastered inside and out with hard, cement-based stucco. At the same time, a concrete skirt, or partial retaining wall, was poured around the base of the exterior walls.

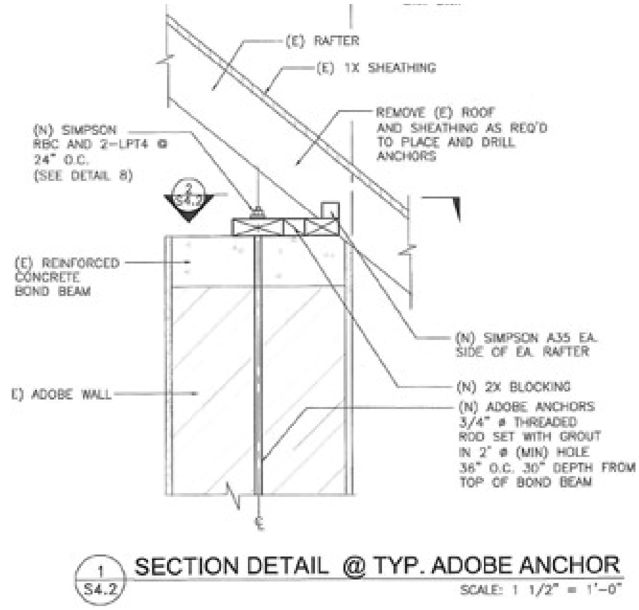
The team established design criteria and performance expectations. The main objective of the stabilization was to preserve the National Landmark values inherent in the architecture. Restoration would be limited to elements essential to meet preservation and stabilization goals. Because many construction details were hidden from view, a flexible design process was adopted, so that treatments might evolve in response to hidden conditions. The team elected to interpret a relatively long period of the buildings' history in order to preserve fabric from time periods associated with *rancho* culture and agricultural use of the property. The government's 1941 takeover of Las Flores changed the use of the property and removed maintenance incentives and proprietary interests from the occupants. These conditions resulted in very expedient and negative alterations, and so mark the end of the period of significance.

The building code applicable to this project is the CHBC. This code applies to all designated historic properties in California and serves as an amending document to the regular code, the California Building Code (CBC) (California Building Standards Commission 1998b). The CHBC is a performance-based code intended to achieve the life-safety objectives of the CBC while allowing greater flexibility in the methods for achieving those objectives. In this way, it encourages the preservation of historic materials and features of the historic property. For the Las Flores project, the CHBC was applied to egress issues, as well as to vertical and horizontal loadings of structural elements.

With respect to the seismic retrofit, the team selected a minimal intervention among a range of options, balancing the life-safety requirement against the preservation objective to impact the integrity of the structural components in the smallest way possible.



(a)



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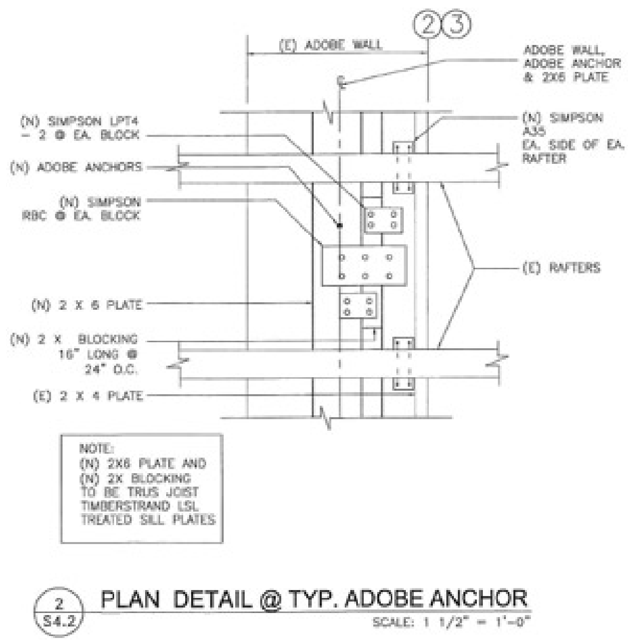

(c)

FIGURES 3A–C Las Flores Adobe retrofit design drawings. The design focused on providing lateral restraint at the tops of walls and at the level of the second-floor frame in the Monterey block (a); a section detail (b) and a plan detail (c) of the adobe anchoring system give specifics of the installation.

The seismic objective was to ensure the life safety of building occupants by preventing collapse, while recognizing that repairable damage to the building will occur. Since the adobe walls have slenderness (height-to-thickness) ratios of ≤ 5, they would require minimal lateral restraint in order to prevent overturning.

The initial design plan and second-stage carriage house design were worked out on site by the team. These on-site design meetings focused primarily on seismic retrofit concepts, coupled with architectural considerations and related stabilization issues. The GSAP guidelines were followed for development of the retrofit designs. The scope of work included replacement of the roof covering, allowing for access to the adobe walls from the top. To achieve lateral restraint of the walls, threaded rods (76 cm [29.6 in.] long x 1.90 cm [0.74 in.] diameter) would be grouted into the adobe walls at approximately 80 cm (31.2 in.) intervals on center (see figs. 3a–c). These interventions as planned could be installed without changing the visual aspects of existing walls and roof timber. Stainless steel containing molybdenum for increased corrosion resistance to chlorides and sulfides was prescribed for all rods, nuts, and straps. All nails and other fastenings would be stainless steel or galvanized.

During the 2002 and 2003 seasons, the work was focused on the main house. The seismic retrofit consisted of the addition of a wooden bond beam to the tops of the adobe walls, installation of center core pins, attachment of the roof frames to the tops of walls, and installation of a steel band around the exterior of the Monterey block at the level of the second-floor frame.

Where the tops of the adobe walls were uneven and out of level, the walls were capped with soil cement (portland cement and local soil mixed at a ratio of approximately 1 part by volume of portland to 5–7 parts

(a)

(b)

FIGURES 4A AND 4B Seismic retrofits for the main house. The tops of the walls were leveled by the addition of a pisé course. The wooden bond beam incorporated a stainless steel strap and was fastened to the walls with center core pins and to the roof frame with commercially available metal clips (a). At the level of the second-floor frame of the Monterey block, a stainless steel belt was installed below exterior plaster and tied back to floor joists with eyebolts and Simpson anchor brackets (b).

by volume of soil) applied in pisé technique. The plywood bond beam functions as a partial diaphragm and consists of two overlapping layers of pressure-treated material glued and nailed to provide longitudinal strength. Once the bond beam was placed, holes 2.5 cm (1.0 in.) in diameter were drilled down through the plywood and adobe wall center to a design depth of 80+ cm (31.2+ in.) to receive the threaded rod. Center core pins were set into the adobe with an epoxy grout. The epoxy selected for the project was a proprietary high-viscosity epoxy that is designed for stabilizing anchors into unreinforced masonry. Stainless steel strapping was nailed at 10 cm (3.9 in.) intervals on center along the top of the plywood, and each rafter was fastened to the plywood with a nailed-on Simpson L tie. Every other bolt was torque-tested to at least 27 kg (59.4 lb.) force to ensure good binding and grab in the section. This process proceeded linearly around the building until the interconnected strapping system was complete on both the one- and two-story sections (fig. 4a).

The steel belt installed at the second-floor level attaches the floor system to the perimeter walls (fig. 4b). A 1.5 cm (0.59 in.) channel was cut though the existing lime plaster and adobe on the walls just above the level of the second-floor porch deck. Simpson HD 5A brackets were fastened to every other interior joist behind the interior surface of the wall. A threaded eyebolt was fastened into the Simpson tie with the eye set in the channel on the exterior. A 1.27 cm (0.50 in.) threaded rod was inserted into the eye, wrapped around the entire house, and fastened at the four corners to an L flange. On the east and west end walls in line with parallel running joists, stabilization required longer rod connectors drilled through two perpendicular joists, bolted with nuts and washers, and extending through the adobe wall to tie to the belting rod. This type of belted anchorage will improve the ductility of the wall construction. The anchoring capacity no longer depends on the strength of the adobe; rather, it serves to restrain the adobe wall. It is highly unlikely that the rod could be pulled through the wall, and only localized crushing of the adobe is anticipated in a seismic event.

The decision was made to reconstruct the lost two-story porch to better protect adobe walls, integrate seismic interventions, and recover the lost architecture. The porch, which completely surrounds the Monterey section, was based on photographic documentation that included detail adequate for producing construction drawings. The structural design of the porch incorporated through-wall fastening to interior floor joists, new upgraded foot-

(a)

(b)

FIGURES 5A AND 5B Grout techniques for the Las Flores Adobe retrofit. For the carriage house, techniques were developed for installing an earthen grout (a). In contrast, the crew had used a resin-based grout for installing center core pins in the main house retrofit (b). The earthen grout is more compatible with the historic wall materials and provides greater possibilities for reversibility of the treatment.

ings, custom column stands, and wind uplift retention. By installing the connecting elements in the substrate, the installation was designed to be mostly hidden.

During the 2004 construction season at Las Flores, the team implemented the seismic and structural stabilization of the carriage house; the work represented a departure from several aspects of the main house intervention. Work accomplished during the 2002 campaign was evaluated, and changes in tool use, method, and materials were adopted. The scope of work included installation of a seismic retrofit system, replacement of concrete wall infill with adobe materials, reinstatement of the connection between the main house and carriage house, conservation of earthen and lime plasters and finishes, and replacement of the roof covering.

Since a concrete bond beam had been added to the carriage house without documentation during a 1970s repair project, the retrofit needed to guarantee attachment of the bond beam to the walls, and of the roof frame to the bond beam. Removal of this bond beam was determined to be potentially damaging to historic fabric, as well as unnecessary. The large section of concrete infill was determined to be detrimental to the structure, since material and structural continuity was broken and traditional lime plasters would not adhere well to the surface. Adobe repairs were done to replace the concrete infill; new work was integrated into the wall by stepping and lacing new adobe into the old.

Since building performance during an earthquake is dependent, to a large extent, on the integrity of adobe walls at the base, a protocol was developed for evaluating adobe condition in the lowest courses. A grid was laid out on interior walls approximately 30 cm (about 12 in.) above the finished floor. Holes were drilled at each grid point; resistance of the adobe to the drill was evaluated by the drill operator, and wall materials removed from the holes were evaluated with respect to moisture content. When a void was encountered, plaster was removed, and the wall was evaluated for repair.

Essentially following that of the main house intervention, the seismic retrofit system for the carriage house consisted of a series of center core anchors that pass vertically through a continuous wooden plate, through the bond beam, and 76 cm (30 in.) into the adobe wall below. A series of holes was bored with light coring bits; holes were bored through the concrete bond beam and into the adobe with nonvibratory drilling equipment.

Rods were fixed into place with a soil-cement grout (fig. 5a). This choice marked a major change in design and represents a desire for greater compatibility and reversibility of treatments. In contrast, the main house retrofit system relied on a resin-based grout with strength characteristics in excess of design criteria (fig. 5b). Earthen grouts are compatible with historic adobe materials and offer greater potential for reversibility and thus were chosen for the carriage house. The grout mix selected was similar to one developed by Nels Roselund (1990) and tested for use in the repair of the historic Pio Pico Adobe in Whittier, California; it consisted of adobe soil, sand, a small amount of portland cement, and a grout additive (Sika GroutAid) to minimize shrinking during curing.

Initial testing of the grout included qualitative evaluation of material samples with respect to shrinkage, hardness, abrasion resistance, and permeability, and injection of the grout into test panels that then could be visually evaluated to assess crack-filling properties. Subsequent testing by Krakower and Associates included tension and shear tests of anchors installed with the grout, in order to determine bond strength of the grout to anchors and to adobe wall materials. At Las Flores, sample cylinders were made for conducting compression strength tests in the lab. Tests were conducted on a Tinius Olson machine operating in the lowest range (0–272 kg, 0–600 lb.). Results, including load versus deflection and shear angle, were consistent from sample to sample.

Low-tech methods were developed for placing the grout. An adobe test wall was constructed, and placement methods were developed and practiced until placement could be effected smoothly and consistently. A placement device was made by attaching a grout bag to a length of PVC pipe (fig. 5a). The pipe allowed placement to begin at the bottom of the holes, preventing voids due to trapped air bubbles. The method for placement involved filling the device with grout and twisting off the bag to prevent loss of material when transferring the grout to the hole to be filled. Holes were minimally prewetted with a 1:1 mix of denatured alcohol and water to retard absorption of the mix water by the wall materials. Workers placed grout in a prewetted hole by squeezing the grout bag and simultaneously withdrawing the pipe from the hole. Once the hole was filled to within 5 cm (2 in.) of the top, the threaded anchor was inserted. After setting, samples were exposed and visually evaluated with respect to shrinkage and voids. Sample anchors, set in grouted center cores in the test wall, were torque-tested to 88 Nm (65 ft.-lb.) to ensure that connections could be adequately tightened without failure of the grout.

A new wooden plate was installed around the building perimeter on top of the concrete bond beam, fastened to the threaded anchors with stainless steel nuts and washers. With commercially available L clips, the existing roof structure was fastened to the new wooden plate, effectively tying the roof structure to the walls. Because the west wall of the carriage house is of wood-frame construction, a bond beam had never been installed along this wall. To tie the north and south bond beams together, the crew installed a steel tie rod in the west wall cavity; the rod is fastened to commercially available clips anchored to the ends of the bond beam at the northwest and southwest corners of the building. Interior plaster was removed, and this wall was resheathed in plywood to improve its performance in shear.

Conclusion

Key to the success of the Las Flores project—measured by limited alteration to the historic character-defining features of the house—was the multidisciplinary planning and design process, and the flexibility built into the construction phase by the use of architectural and engineering services throughout. This practice prevented the break in linkage among disciplines that often occurs in large construction campaigns. Management participation ensured that project goals and resource allocation stayed viable throughout. Bringing the University of Vermont into the process offered capacity building, training, and research opportunities. The design solutions represent a minimal and efficient treatment approach that achieved the basic goals while simultaneously accomplishing resource preservation agendas (fig. 6).

FIGURE 6 The Las Flores Adobe after completion of structural and seismic stabilization of the buildings. By the close of the 2004 construction season, porches on the Monterey block were reinstated, building envelopes were secured against weather, and interior rehabilitation was started.

Documentation and maintenance by site stewards will ensure that, in the future, a post-seismic event review occurs that will fully evaluate the levels of efficacy achieved. The true test will occur during and after a future earthquake, and results cannot be presupposed or fully anticipated until that time.

References

California Building Standards Commission. 1998a. *1998 California Historical Building Code*. Sacramento: California Building Standards Commission; Whittier, CA: International Conference of Building Officials.

_____. 1998b. *California Building Code*. Whittier, CA: International Conference of Building Officials; Sacramento: California Building Standards Commission.

International Conference of Building Officials. 1998. *California Code for Building Conservation*. Whittier, CA: International Conference of Building Officials.

Roselund, Nels. 1990. Repair of cracked walls by injection of modified mud. In *6th International Conference on the Conservation of Earthen Architecture: Adobe 90 Preprints: Las Cruces, New Mexico, U.S.A., October 14–19, 1990,* ed. Kirsten Grimstad, 336–41. Los Angeles: Getty Conservation Institute.

Tolles, E. Leroy, Edna E. Kimbro, and William S. Ginell. 2002. *Planning and Engineering Guidelines for the Seismic Retrofitting of Historic Adobe Structures*. GCI Scientific Program Reports. Los Angeles: Getty Conservation Institute. http://www.getty.edu/conservation/publications/pdf_publications/seismic_retrofitting.pdf.

Tolles, E. Leroy, Edna E. Kimbro, Frederick A. Webster, and William S. Ginell. 2000. *Seismic Stabilization of Historic Adobe Structures: Final Report of the Getty Seismic Adobe Project*. GCI Scientific Program Reports. Los Angeles: Getty Conservation Institute. http://www.getty.edu/conservation/publications/pdf_publications/seismicstabilization.pdf.

Tolles, E. Leroy, Frederick A. Webster, Anthony Crosby, and Edna E. Kimbro. 1996. *Survey of Damage to Historic Adobe Buildings after the January 1994 Northridge Earthquake*. GCI Scientific Program Reports. Los Angeles: Getty Conservation Institute. http://www.getty.edu/conservation/publications/pdf_publications/adobe_northridge.pdf.

Additional Resources

Allen, Daryl, and Gil Sánchez. 1992. Condition assessment and cost summary of the Las Flores Adobe at Camp Pendleton Marine Corps Base. Gil Sánchez Architect, Santa Cruz, CA.

Barrow, J. M. 2004. Project files—Las Flores stabilization. National Park Service, Intermountain Regional Office, Santa Fe, New Mexico.

Barrow, J. M., and D. W. Porter. 2005. Carriage house stabilization at the Las Flores Adobe site: Field school training in the conservation of historic adobe structures. In *Proceedings of Earthbuild 2005: Conference Held at the Faculty of Design, Architecture and Building, University of Technology, Sydney, on the 19th, 20th and 21st January, 2005.* Broadway, NSW: Faculty of Design, Architecture and Building, University of Technology, Sydney.

Barrow, J. M., E. L. Tolles, and S. J. Farneth. 2005. Stabilization of the landmark Las Flores Adobe: A case study of restrained seismic retrofit. In *Structural Analysis of Historical Constructions: Possibilities of Numerical and Experimental Techniques,* ed. Claudio Modena, Paulo B. Lourenço, and Pere Roca, 1197–205. Leiden: A. A. Balkema; London: Taylor and Francis Group.

Donaldson, Milford Wayne. N.d. Las Flores Adobe: Interim stabilization program. Heritage Architecture and Planning, San Diego.

Houben, Hugo, and Hubert Guillaud. 1994. *Earth Construction: A Comprehensive Guide*. London: Intermediate Technology Publications.

Mortier, Mark L. 2001. Conditions assessment and stabilization recommendations for the Las Flores Adobe National Historic Landmark. National Park Service, Intermountain Regional Office, Santa Fe, New Mexico.

University of Plymouth Centre for Earthen Architecture, English Heritage, and ICOMOS/UK Earth Structures Committee. 2002. *Terra 2000 Postprints: 8th International Conference on the Study and Conservation of Earthen Architecture, Torquay, Devon, UK, May 2000*. London: James and James.