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Strengthening of an Unreinforced Masonry Building

Renforcement d'un immeuble en maçonnerie non armée

Verstärkung eines unbewehrten Mauerwerkbaus

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SUMMARY

50 Green Street is a historic brick building located in San Francisco's warehouse district. Originally built for warehouse and manufacturing use, the massive structure possessed many of the deficiencies common to unreinforced masonry construction. The strengthening scheme was sensitive to the architectural fabric of the building and included steel knee-braced frames, steel tension-rod roof diaphragm strengthening, and a pioneering effort incorporating the use of "CenterCore" reinforcement in the existing brick walls. The owner was actively involved in the process and his special concerns for cost, time, appearance, and tenant disruption were incorporated as the system evolved.

RÉSUMÉ

Erigé à l'origine pour servir de bâtiment d'entrepôt et de manufacture, cet ouvrage massif présente les nombreux défauts des constructions en maçonnerie non armée. Le concept de renforcement prenait en compte la structure architecturale de l'immeuble. Il comportait des cadres en treillis d'acier articulés, des barres de traction pour renforcer les fermes de toiture et l'incorporation d'armatures spéciales appelées "CenterCore" dans les murs en maçonnerie existants. En étroite collaboration avec le maître d'ouvrage, les travaux de rénovation furent menés à bien en tenant compte des considérations de coûts, de temps, d'aspect extérieur et de perturbation des locataires.

ZUSAMMENFASSUNG

Ursprünglich als Lager- und Fabrikgebäude errichtet, weist das massive Bauwerk viele Mängel üblicher unbewehrter Mauerwerksbauten auf. Das Verstärkungskonzept nahm Rücksicht auf die architektonische Struktur. Es beinhaltete K-Fachwerk-Stahlrahmen, Zugstangen als Verstärkung der Dachscheibe und die Verwendung von sog. "CenterCore"- Bewehrung in den bestehenden Mauerwerkswänden. In enger Zusammenarbeit mit dem Eigentümer wurden seine Anliegen betreffend Kosten, Zeit, Aussehen und Störung der Mieter in das Sanierungskonzept eingearbeitet.

1. INTRODUCTION

Whenever new construction involves work on an existing structure, special considerations will arise that require the designer to be imaginative in the application of strengthening principles, and flexible in the implementation of strengthening efforts. This is especially true in the case of unreinforced masonry buildings. Often these structures have designated historical significance or a sentimental attachment to the community in which they reside. These conditions can limit the extent to which the structure may be modified when making seismic improvements.

50 Green Street is a two-story brick structure located north of Market Street in San Francisco's warehouse district. It occupies the entire city block between Green, Commerce, Battery, and Front Streets. The exterior facade consists of an arcade of slender piers and graceful semicircular arches along all four elevations. Ornate brick relief patterns around the arches, raised detailing in the four corners, and corbelled courses of brick at the parapet give the building a distinctive appearance.

Fig. 1 Building Exterior

Construction on 50 Green Street began in early 1906, and was interrupted by the San Francisco earthquake and fire in April of that same year. Situated in an area devastated by the fire, the building was reconstructed using the original plans, and completed in 1907. Originally built as the W.P. Fuller & Co. Glass Warehouse, unique features included a railroad spur that entered the east end of the building, and enlarged arches in the center of the north and south walls for a drive through. Current use includes upscale office space for advertising and movie industry tenants.

2. DESCRIPTION

50 Green Street is a two-story unreinforced brick masonry bearing wall structure with a full basement. It is rectangular in plan, measuring 37 meters by 84 meters. The overall height is about 15 meters from basement to top of parapet, with a first story of 7 meters. Exterior walls vary in thickness from 71 cm at the first floor arched piers, to 33 cm at the parapet. Two interior 43 cm brick firewalls divide the building into three unequal areas. All walls below grade are concrete, and are founded on concrete spread footings. Including the storage areas that comprise the basement, the building has approximately 9,200 square meters of usable space.

The building was designed for heavy vertical loading associated with manufacturing and warehouse use. The floors consist of two layers of structural planking on closely spaced wood joists. The joists lap over the top of heavy timber girders spanning between massive interior knee-braced columns. Heavy timber trusses form the pitched roof structure.

3. DESIGN CONSIDERATIONS

Although unreinforced masonry buildings (UMB's) have been the target of recent legislation requiring mandatory seismic strengthening, evaluation and strengthening of 50 Green Street was commissioned by the building owners in 1991, before local UMB ordinances were finalized.

The U.C.B.C. Appendix Chapter 1, "Seismic Strengthening Provisions for Unreinforced Masonry Bearing Wall Buildings" was originally selected as an appropriate strengthening criteria, with a specified base shear coefficient of 0.133g. This document was the model for the Draft S.F. UMB Ordinance which was finalized and adopted in 1993 as Chapters 14 and 15 of the San Francisco Building Code. Subsequent redesign requested by the owner to accommodate tenant concerns utilized the S.F. UMB Ordinance with a lower base shear coefficient of 0.10g.

The UMB Ordinance contains a set of minimum standards designed to reduce, but not necessarily eliminate, the potential hazards common to most unreinforced masonry buildings. Hence they are considered "hazard reduction" measures. It is important that the owner understands the potential for damage during a major earthquake still exists, even after strengthening work is completed. The ordinance prescribes allowable capacities for existing brick walls and wood diaphragm assemblies, as well as new anchors installed into existing brick. It also specifies allowable wall slenderness ratios to address out-of-plane stability. Other provisions include mandated wall anchorage for out-of-plane forces, parapet bracing, and supplemental vertical support for truss and girder elements in case the bearing walls lose integrity.

The work required some testing and research. A geotechnical investigation was performed to determine the condition of the foundation and soil design values. In-situ brick shear testing was performed to determine the quality brick masonry construction. Mortar bond strengths tested well over 690 kPa. With the owner's concerns for minimizing disruption in mind, research into alternative methods of strengthening led us to consider the patented "CenterCore" method of wall reinforcement, which involves installing reinforcing bars into grouted cores drilled vertically through the walls. Full scale testing of this system performed at California State University Long Beach in the early eighties, as reported by Breiholz in 1987, demonstrated the effectiveness of CenterCores for improving the in-plane shear strength and out-of-plane stability of brick walls. These test results were utilized at 50 Green Street.

4. OWNER AND TENANT IMPACTS

The owner was actively involved in the decision making process as his special concerns for cost, time, appearance, and tenant disruption were incorporated as the strengthening scheme evolved. A major redesign of steel concentric braced frame elements proposed for the longitudinal walls was requested when the owner learned that one major tenant was demanding significant concessions for the disruption caused by the work in their space. The concept was changed to a knee-braced configuration to avoid impacting the arched windows, and the frame elements were shifted towards one end of the building to lessen the impact on the tenant space. The new configuration had the added architectural benefit of mimicking the knee-braced framing of the existing floor construction.

Another concern was a new roof membrane that was recently installed. The owner wanted to leave it intact, so roof diaphragm strengthening was restricted to inside the building, and conventional plywood sheathing was not an option.

Finally, it was crucial to the owner that he maintain his current tenant base, so the work had to be completed while the building was fully occupied. A phased construction schedule was developed by the contractor for work performed during nights, weekends and holidays. At the end of each weeknight shift the building was returned to the tenants the next morning. This dramatically extended the duration of construction and resulted in a monumental clean up effort by a special janitorial crew each day.

5. SCOPE OF WORK

The massive nature of the construction at 50 Green Street, so strong for vertical loads, was actually contributing to the seismic deficiencies of the building. Code prescribed capacities for brick walls and wood diaphragms were not adequate for the seismic forces generated in the building. It was an interesting challenge to point out walls, 71 cm thick, and heavy timber framing to an owner who is very proud of his building, and attempt to explain just how "weak" they can be. In-plane wall strengthening was required in both directions, and diaphragm strengthening was required at all levels. The thick exterior walls satisfied UMB Ordinance slenderness requirements, but the thinner interior walls required out-of-plane stabilization.

A steel knee-braced frame was selected to supplement the longitudinal walls. A relative rigidity analysis was performed using the structural analysis program, RISA-2D, to verify that the knee-braced system would draw load from the existing brick walls. The resulting W36x150 column members are stiffness controlled. They are embedded in a concrete foundation wall that extends up to the sill of the arched windows, providing a fixed base and shortened effective story height. Centered on the arched piers, the new columns must support the existing floor girders that frame into the wall at the same location. The girders were shored, cut back from the wall to erect the columns, and then seated on a bracket welded to the column web.

The most critical connections occurred along the length of the drag strut which delivered load to the knee-braced frames located at one end of the building. The drag consists of a large tube section running along the wall just below the floor joists. At each pier the existing wood girders interrupted the continuity of the drag. Horizontal slots were drilled though the girders to allow splice plates to pass through and weld to the tube on either side. The drag strut also served as a horizontal strong-back, anchoring the walls to the heavy floor girders for out-of-plane loads. Diaphragm to wall connections were made using threaded epoxy anchors, installed after the drag strut was in place. The anchors were drilled to within 5 cm of the exterior surface of the wall, and were responsible for both in-plane shear transfer and out-of-plane wall anchorage.

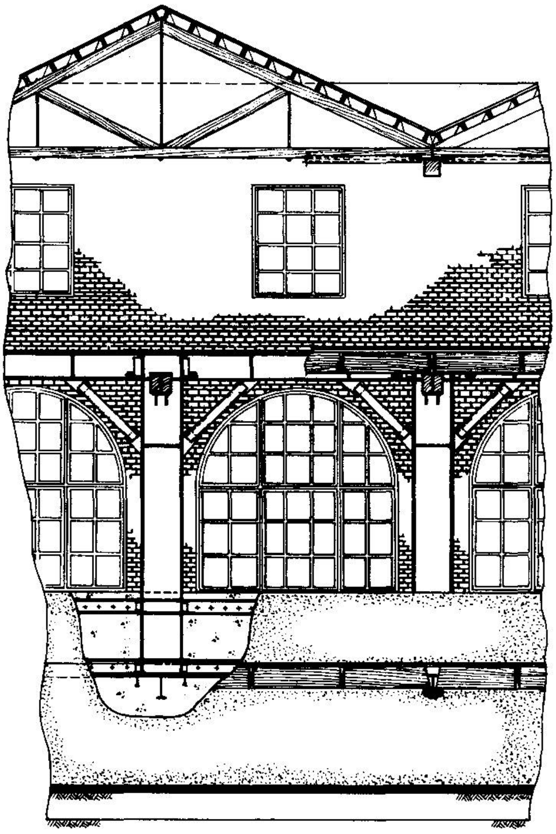

Fig. 2 Drawing of Knee-Braced Frame System

In the transverse direction, a more favorable pier configuration existed, allowing the use of the existing brick walls for transverse lateral force resistance. To strengthen the walls, deformed reinforcing bars were installed using the CenterCore technique. Cores were added at wall locations that were highly stressed for in-plane shear, and at window and door jambs to provide trim reinforcement wherever possible. CenterCores provided reinforcement to stabilize the slender interior walls for out-of-plane forces, and were designed using standard reinforced masonry principles.

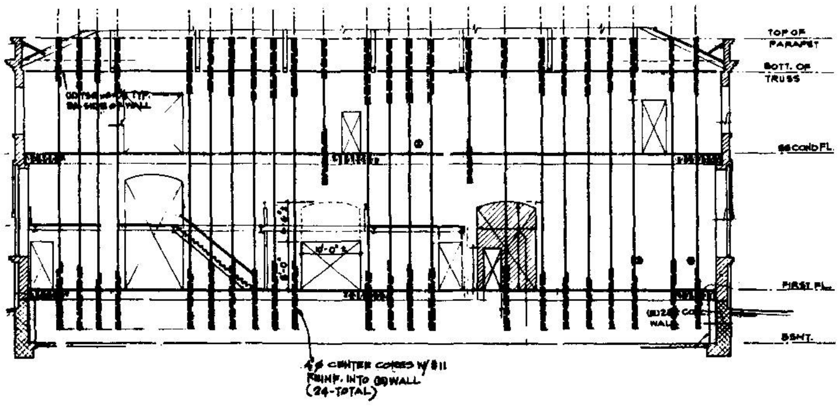

Fig. 3 **Interior Elevation of CenterCore Locations**

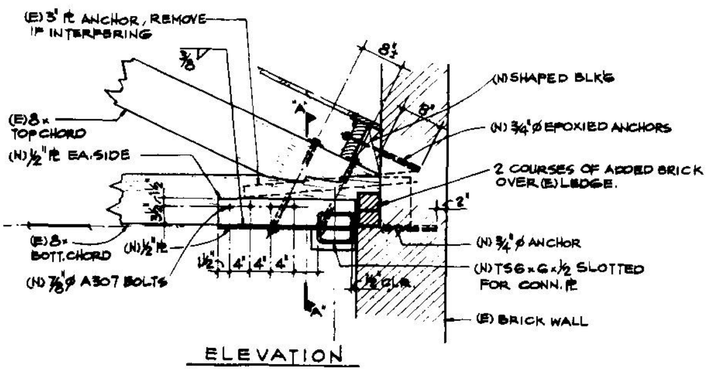

Fig. 4 **Roof Diaphragm Connection at Truss**

The CenterCore technique involves core drilling vertically through the wall from parapet to foundation, and installing grouted reinforcing bars. Coring specifications allowed a tolerance of two inches out of plumb at the base of the wall, 15 meters below the top of the parapet. Occasional repairs to wall surfaces were required when the bit broke through the side of the wall after being forced off line by unexpected iron embedded in the wall. A dry coring method was selected to avoid the disruption of water associated with wet coring operations. This resulted in dust migrating through micro-cracks in the walls during coring operations. Dust became so severe that the entire length of each wall within the building was wrapped in plastic and ventilated with negative air machines to prevent infiltration throughout the tenant spaces. Based on lower unit cost and superior performance noted in the Breiholz report, polyester based resins were specified for grouting the cores. The resin emanated such a strong styrene odor, however, that tenant complaints forced a change to a more expensive epoxy based resin, that had comparably little lingering odor.

To avoid the new roof membrane, a steel tension rod diaphragm was installed at the bottom chord of the roof trusses. Slotted tube connections, clevises, and turnbuckles allowed fit up tolerance and angular adjustments during erection. In anticipation of inevitable variations in field conditions, a liberal safety factor was incorporated into the design. This came in handy when existing conditions were not "square" and eccentricities had to be built into the system. Particularly challenging, were connections between the new steel elements and the integral wood trusses. Connection brackets were prefabricated, and consisted of vertical tabs for bolting into the side of the truss, welded to horizontal gusset plates. Extra bolt holes were provided in the tabs in case non-typical truss connections interfered with a prefabricated bolt location.

As a diaphragm, the sturdy floor system was also overstressed by seismic forces generated by the massive walls. Plywood diaphragm strengthening was provided over the most highly stressed regions around the perimeter. Since the tenant spaces were to be returned by the start of each work day, plywood was installed in small sections. Offices were cleared out on Friday afternoon, sheathed in plywood, inspected, carpeted, and moved in by Monday morning.

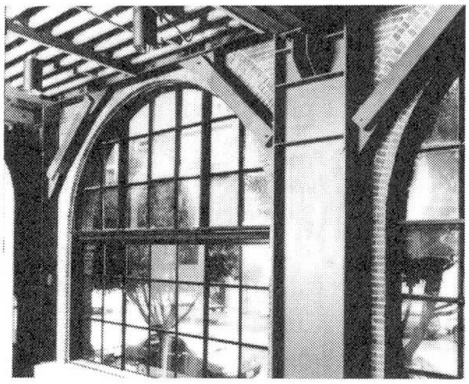

Fig. 5 Completed Knee-Braced Frame

The result of this work was a strengthening system that provided a complete load path for seismic forces which was sensitive to the architectural fabric of the building. The completed work was recognized by the Foundation for San Francisco's Architectural Heritage, and received their Award for Excellence in Architectural Preservation.

6. TIMELINE AND COST IMPACTS

The original construction documents were completed in 1992, and estimates for construction costs totaled about $2,800,000. Subsequent redesign to address tenant concerns was completed in 1993, with a bid for construction costs of roughly the same amount. Phased construction began in September of 1993 with substantial completion in May of 1994, eight months later. It is estimated that phased construction during off hours in the fully occupied building increased the cost of this work by 25% over that in an unoccupied building. Special janitorial services totaled $50,000. Final costs, after field change orders, totaled about $2,900,000, within 3% of the original bid. Close cooperation with the contractor, and sensitivity to cost and constructablity of changes, kept this difference to a minimum. The cost of CenterCoring operations was estimated to be $150 per foot of core, including drilling and grouting. Because of out-of-plane problems associated with the interior transverse walls, CenterCore strengthening was estimated to be roughly the same cost as conventional strengthening for these walls, but had the added benefit of less disruption and no architectural impact.

7. ACKNOWLEDGMENTS

Contributions from Don Davella of Plant Construction Company regarding detailed cost information and the specifics of tenant impacts on construction are gratefully acknowledged.

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