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RETROFIT OF UNREINFORCED MASONRY CLADDING FOLLOWING THE 2001 NISQUALLY EARTHQUAKE

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SUMMARY

The 2001 Nisqually earthquake shook western Washington State and caused significant damage to unreinforced masonry (URM) structures in Seattle. Repairs to damaged URM buildings began shortly after the earthquake. Two buildings, the PacMed/Amazon and Starbucks Center suffered extensive damage to their URM exterior cladding systems.

The exterior cladding on the top three floors of the 16-story PacMed/Amazon building was removed brick by brick and reconstructed with a visually identical new cladding system called reinforced veneer. The entire exterior cladding of the nine-story Starbucks Center building was removed and replaced. Part of the building was replaced with conventional brick veneer over metal studs; the remainder was replaced with reinforced brick cladding panels.

This paper will briefly discuss the seismological aspects of the Nisqually earthquake and how the region was affected by the event. Subsequently, both the PacMed/Amazon and the Starbucks Center buildings cladding retrofits will be discussed. The discussion will include background information, sustained earthquake cladding damage, the cladding retrofit technique, and the cladding retrofit construction for each building.

INTRODUCTION

At 2:54 UTC (10:54 local time) on February 28, 2001, a strong, deep earthquake of moment magnitude Mw=6.8 shook western Washington state and caused widespread damage to buildings, bridges, and lifelines across the region. The epicenter of the quake was located in the Nisqually Delta area, approximately 58 km (36 miles) southwest of Seattle. The hypocenter lay approximately 52 km (30 miles) beneath the surface.

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Ground shaking was recorded by an array of strong-motion instruments located throughout the affected region. The intensity of the shaking was relatively moderate with peak ground accelerations between 10 and 30 percent of gravity. Ground motions varied widely in part given the large differences in geologic conditions throughout the region. Reported estimates of intensity by Creager {1} indicate most of the region experienced shaking of modified Mercalli intensity 7 or less.

Loss of life was limited to one person. Approximately 400 people were injured. Total economic loss was estimated at US$2 billion. Building damage was highly localized and particularly severe in the southern region of Seattle from Pioneer Square into the SODO district. The majority of building structural damage occurred in older unreinforced masonry (URM) buildings.

Two of the larger buildings damaged by the quake, PacMed/Amazon and Starbucks Center suffered extensive damage to their exterior URM claddings. Damage included diagonal "stair-step" wall cracking, collapsed parapet walls, fractured terracotta facades, and other out-of-plane wall damage. Collapsed and falling brick resulted in collateral damage to the surrounding exterior windows, canopies, and sidewalks.

Subsequent to the earthquake, the cladding on both buildings was retrofitted. Given the historical nature of each building, each retrofit technique was carefully considered and executed. Information regarding the sustained earthquake damage, the retrofit technique, and the retrofit construction for each building are summarized in this paper.

UNREINFORCED MASONRY CLADDING RETROFIT OPTIONS

Numerous options are available to retrofit earthquake damaged brick cladding. The choice of a repair strategy depends on a number of factors including cost, performance expectations, historic preservation limitations, scheduling of repairs, and access to damaged areas.

Each retrofit situation presents a unique set of physical and economic constraints. It is the challenge for the designer to find the best solution and not surprising that each solution is unique. Sustained earthquake damage to URM cladding from the Nisqually earthquake provided the challenge for numerous retrofit opportunities.

Two projects of many will be presented in this paper, the Packed/Amazon building and the Starbucks Center building. Both projects resulted in new and innovative solutions to retrofit and repair. A new type of brick cladding system, reinforced veneer, was conceived for the PacMed/Amazon retrofit. The solution for the Starbucks Center building included utilization of reinforced brick cladding panels.

PACMED/AMAZON BUILDING

Historical Background

The PacMed/Amazon building was built in 1932. The structure was originally a 16-story, 312-bed hospital of buff-colored brick on a nine-acre hillside site near downtown Seattle. In 1951, a three-story addition was added to the east side and in 1992 an 11-story addition was added to the north side. A photo of the original building is shown in Fig. 1. In 1981, the government transferred ownership of the hospital to PacMed, the medical-provider authority in Seattle. A stipulation of the transfer required that the building be used only for healthcare purposes. By the mid 1990's, due to a change in management strategy, PacMed attempted to find a buyer or tenant that could comply with the requirement that it remain a medical facility.

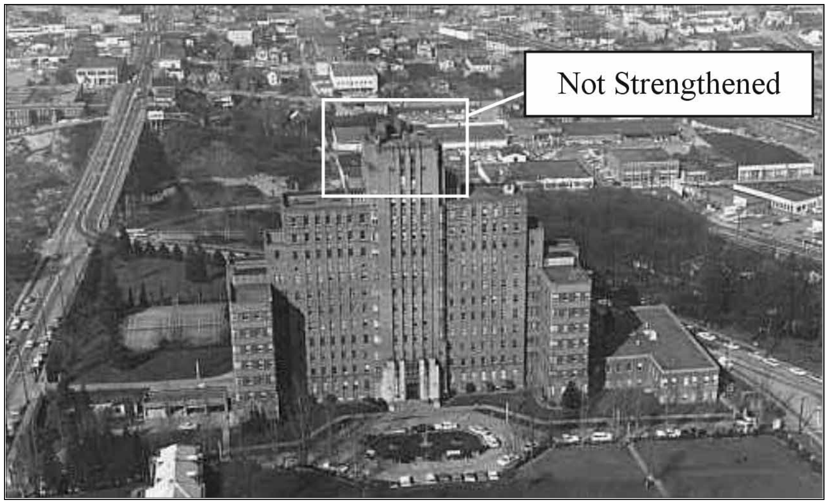

Fig. 1: Marine Hospital [ca. 1934].

The current leaseholder signed a 99-year lease with PacMed in 1998. Current uses include corporate, medical, and dental offices. Amazon.com, an e-commerce retailer, is the building's largest tenant; its corporate headquarters are in the facility. PacMed occupies space in the basement and ground level. The building was designated a landmark by the City of Seattle in 1991 and is on the National Register of Historic Places.

Building Description

The building is a cast-in-place concrete frame structure, built in several phases since 1932. Construction generally consists of reinforced concrete columns, beams, and slabs. The original concrete frames carried both gravity and lateral loading. The exterior of the building is clad with unreinforced brick, and terracotta masonry. No implicit consideration for earthquake resistance was included in the original design.

The current leaseholder completed a major upgrade of the building in 1998 and Amazon.com moved in the following year. As part of the upgrade, additional shear walls were constructed in the lower portions of the building. The upper three stories were not strengthened in the upgrade (Fig. 1), nor were most of the building's unreinforced hollow clay tile, terracotta, and brick exterior walls.

Earthquake Damage

In the Nisqually earthquake, the exterior unreinforced cladding suffered substantial damage. The hollow clay tile, terracotta, and brick perimeter walls on the upper three floors were over 80 percent damaged (Fig. 2). Both in and out-of-plane cladding failures were common in this area.

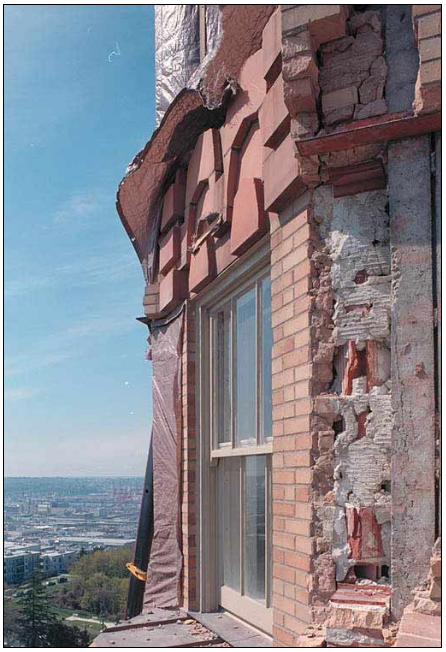

Fig. 2: Earthquake damage to exterior brick, terracotta, and hollow clay tile.

Due to the building's irregular configuration, earthquake forces created a torsional force at the top levels of the building. These forces shook the roof so significantly that one of the unanchored art deco roof pinnacles collapsed and fell through the tenth floor roof (Fig. 3). The collapse broke water lines, flooding five floors and the elevator shafts. No one was hurt.

Fig. 3: URM roof pinnacle damage shown with temporary bracing.

Cladding Retrofit Technique

Because the building is on the National Register of Historic Places, all exterior renovations required approval by the state's historic preservation office. With this in mind, the retrofit design team had to be sensitive and respectful of the building's history. Early on, the choice was made to keep the building's cladding as original as possible. This decision was the driving force behind the idea to retrofit the damaged cladding with a reinforced veneer system.

Reinforced veneer is the name given to describe the technique of reinforcing URM cladding without altering the exterior appearance. This technique preserves the historic nature of the facade and provides seismic anchorage for previously unanchored brick and terracotta cladding. The principle behind the technique is to grout and reinforce the space usually left open in conventional veneer, anchoring brick to the reinforcement, and the reinforcement to the backup wall. For retrofit applications, the technique requires removal and reconstruction of the existing cladding.

Fig. 4 shows a detailed cross-section for the reinforced veneer system. Either reinforced concrete or conventional steel studs sheathed with cement board can provide the necessary backing for the system. Reinforcement is placed in the cavity and anchored to the concrete or sheathing with fasteners. Because of the limited width of the cavity, the reinforcement size is limited to a 10 mm (3/8-inch) diameter bar. The spacing of reinforcement is determined by allowable stress design procedures in consideration of both gravity and lateral forces.

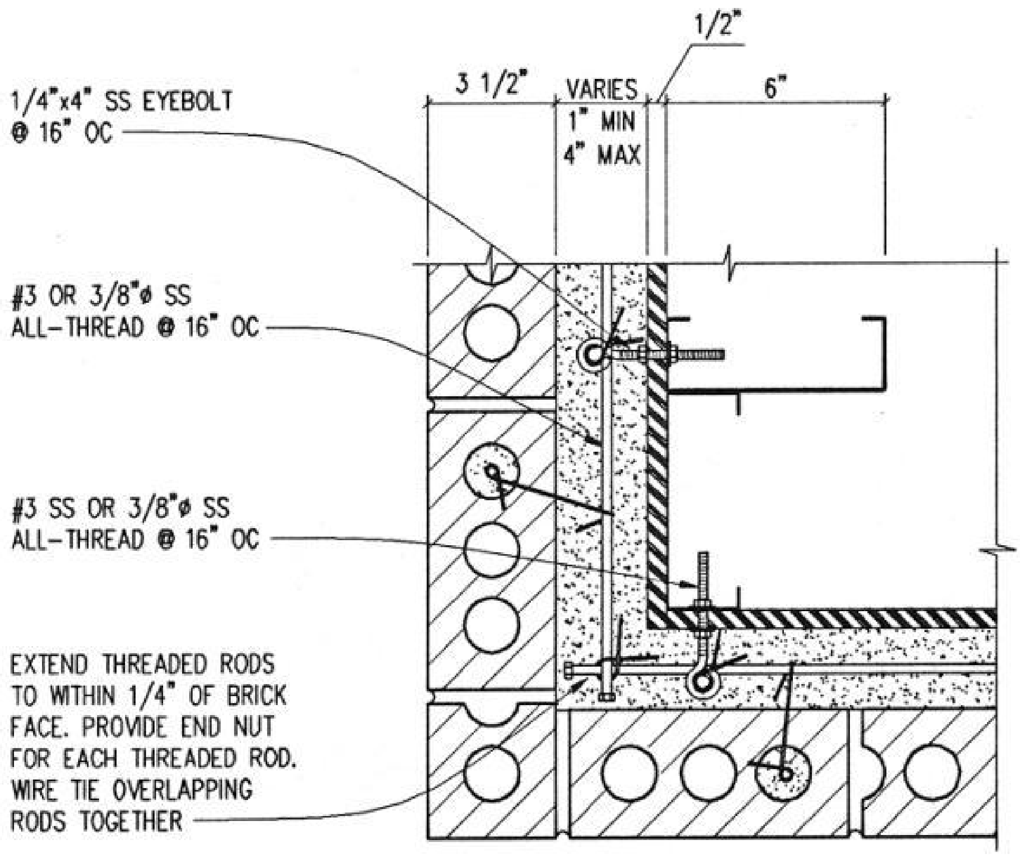

Fig. 4: Reinforced veneer typical wall section.

Contemporary architects, contractors, and engineers have had misgivings regarding the water resisting ability of a grouted cavity. Since the early 1960s, conventional wisdom has dictated that an open cavity was important for resisting water penetration. However, rain-screen and pressure equalization concepts outlined in current design guides [2] are susceptible to misinterpretation and faulty construction. The water resisting performance of buildings built with the open cavity has been poor. Prior to 1960, it was standard to fill the space behind the veneer with mortar or grout. Buildings constructed with the grouted cavity have resisted water penetration well.

Detailing for resisting water penetration in the reinforced veneer system is virtually the same as that of conventional veneer. The flashing and water barrier components of the system are detailed and installed as with any other brick veneer system.

For earthquake considerations, the selected seismic design criterion was a Life-Safety performance objective. Life-Safety performance as defined by FEMA 178 [3] is the post-earthquake state in which the building has lost a significant amount of its original stiffness, but retains some lateral strength and margin against collapse.

Cladding Retrofit Construction

Once underway, the retrofit required removal and reconstruction of the cladding on the top three floors of the building. More than 800 ornate pieces of terracotta were removed, photographed, documented, and numbered. Extensively damaged elements were recast to replicate the original pieces. Bricks were removed one by one to save as much of the original masonry as possible. Where that was not possible, new brick was fired to approximate the original material. Originally, unreinforced hollow clay tile walls backed the exterior cladding. The hollow clay tile backing was removed and replaced with either reinforced concrete or a steel stud backing.

Given that the grout space was outside the water barrier, it was concluded that stainless steel reinforcement was required to meet the 50-year design life. Deformed stainless steel reinforcement was expensive and unavailable for six months. Stainless steel threaded rod, which has many industrial applications, was readily available at a reasonable price. The brick masonry was laid and tied to the reinforcement with wire anchors (Fig. 5). The anchors were specified as 1.6 mm (0.062 inch) diameter stainless steel wire. The wire anchors were spaced at regular intervals in both vertical and horizontal directions as required for the seismic requirements. The cavity was then grouted solid.

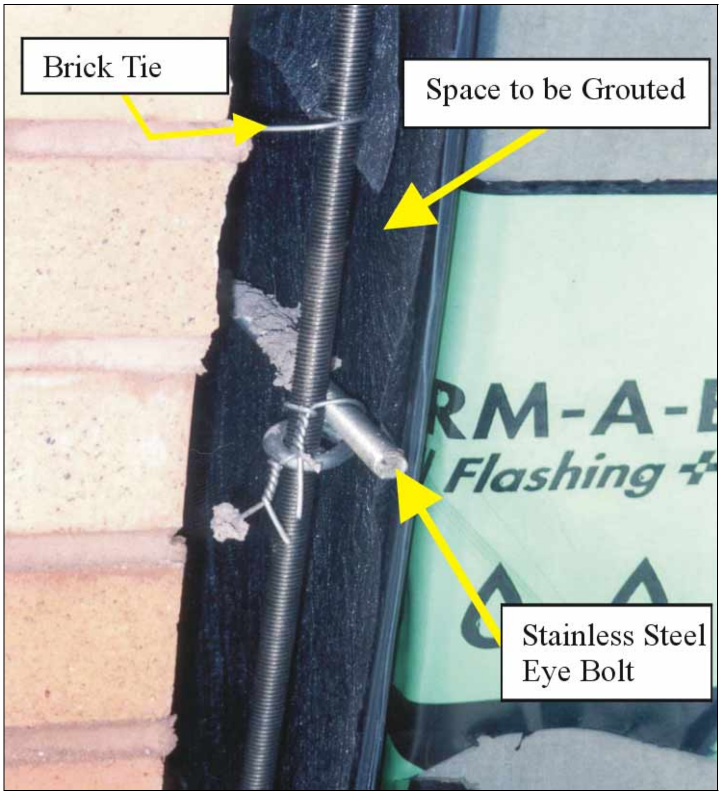

Fig. 5: Reinforced Veneer wall section prior to grouting.

To provide access for construction, the top three floors of the building were enveloped in scaffolding. Plastic coating was wrapped around the scaffolding to provide a climate-controlled working environment free of wind and rain. The entire project was completed in nine months at a cost of approximately US$9 million. The exterior elevation of the retrofitted building is shown in Fig. 6.

Fig. 6: Retrofitted PacMed/Amazon building.

The selection of reinforced veneer allowed the construction of the complex coursing and articulation of the original cladding to be accomplished far easier than standard veneer. With added ductility provided by the reinforcement, the cladding seismic performance was also improved.

STARBUCKS CENTER BUILDING

Historical Background

Starbucks Center is a nine-story building, constructed in six phases starting in 1912 and ending in 1974. The building served originally as the Sears catalog distribution center for the western United States. The building is located south of downtown Seattle in the SODO district. Upon completion of the second phase in 1915, the building was the largest structure west of the Mississippi River. A photo of the original building is shown in Fig. 7.

Fig. 7: Seattle Sears, Roebuck & Co. [ca. 1926].

At nearly 158,000 square meters (1,700,000 square feet), the structure is today the largest building in the City of Seattle. Sears continues to operate a retail store in the building, although the distribution facility ceased operations in the late 1980s.

The present owners purchased the building from Sears in 1990, saving it from demolition. Current uses include corporate office, retail, light manufacturing, and storage. Starbucks is the building's largest tenant; its corporate headquarters are in the facility. Accordingly, the building was renamed Starbucks Center.

Building Description

The building is a cast-in-place concrete structure. While the construction varies slightly from phase to phase, it generally consists of circular columns, capitals, drop panels, and flat slabs. Earlier designs anticipated subsequent construction, allowing each addition to be built integrally with the existing structure. The columns are typically spaced 6 m (20 feet) on center and the overall plan dimensions of the building are greater than 120 m (400 feet) in both directions. The structure has a partial basement and is founded on more than 10,000 timber piles. No implicit consideration for earthquake resistance was included in the original design.

Due to the substantial alteration of the building occupancy from warehouse to corporate office space, a seismic renovation was required by the City of Seattle. The renovation, completed in the mid 1990s was based on the provisions of FEMA-178 [3] with a Life-Safety seismic performance objective, Lundeen [4]. Strengthening of the URM exterior cladding was not included as part of the renovation.

Nisqually Earthquake Damage

While the building performed adequately from a Life-Safety perspective and emerged structurally intact, it sustained widespread exterior cladding damage. Remarkably, injuries were minor and there were no deaths.

Exterior cladding failures were attributed to low mortar strength, high wall height-to-thickness ratios and inability to accommodate the movement of the supporting structural frame. In-plane shear failures were common. The veneer was attempting to support the building. It was not isolated. The diagonal or X-cracking pattern (Fig. 8) is a common result of cyclic earthquake loading. In addition, parapet walls toppled out-of-plane and cascaded more than 30 m (100 feet) onto the street and sidewalk (Fig. 8).

Although the damage to the building overall was primarily cosmetic, it was also widespread. Virtually every wall section of the exterior cladding suffered some form of cracking.

Fig. 8. Starbucks Center building damaged URM parapet and exterior cladding, USGS [5].

Cladding Retrofit Technique

Due to the size and complexity of the retrofit project, numerous cladding retrofit techniques were considered. Initially, retrofit alternatives considered only replacing damaged portions of the cladding. Ultimately, the decision was made to replace the entire exterior brick cladding.

The majority of the cladding, up to the ninth floor, was replicated with an anchored brick veneer system over steel studs. This system was designed in accordance with provisions of the 1997 Uniform Building Code [6].

Above the ninth floor this system was incompatible with the architectural design features of the clock tower. The tower has a complex geometric shape inlaid with pieces of cast concrete. A conventional veneer retrofit solution was difficult to design and construct. Additionally, the west wall of the building was within 9 m (30 feet) of an electrical power corridor. Placing scaffolding to reconstruct the cladding was not possible without moving the transition lines or turning off the power. Moving the line was expensive and shutting off the power during the day was not an option.

The combination of complexity and time constraints resulted in the choice to retrofit both the clock tower and the west wall cladding with reinforced brick cladding panels. Reinforced brick is the name given to describe hollow reinforced clay brick masonry. The complex cladding shapes were fabricated off site in a controlled environment. Simultaneously, the damaged cladding was removed saving precious time. On the west wall, the power could be shut down at night and the panels erected with a crane during the low power demand periods.

In design of reinforced brick panels, the designer must consider the serviceability requirement to prevent cracking of brick units. Many of the panels were three-dimensional and resisted a full complement of strains, including torsional effects. Cracking of mortar joints is generally acceptable, but cracking the brick is esthetically unacceptable. Unlike conventionally anchored brick veneer, the typical closely spaced brick ties are replaced by less frequent rigid steel connectors. The rigid connectors are attached to the building’s primary structural system for gravity and lateral support.

The geometry and design for the tower panels were particularly challenging (fig. 9). The cladding was required to accommodate a 50 mm (2-inch) story drift without damage. In addition, the surface articulated in both directions. The solution was to support the cladding on corner cladding panels that were rigid with the floor. This isolation technique is sometimes referred to as the "moving box".

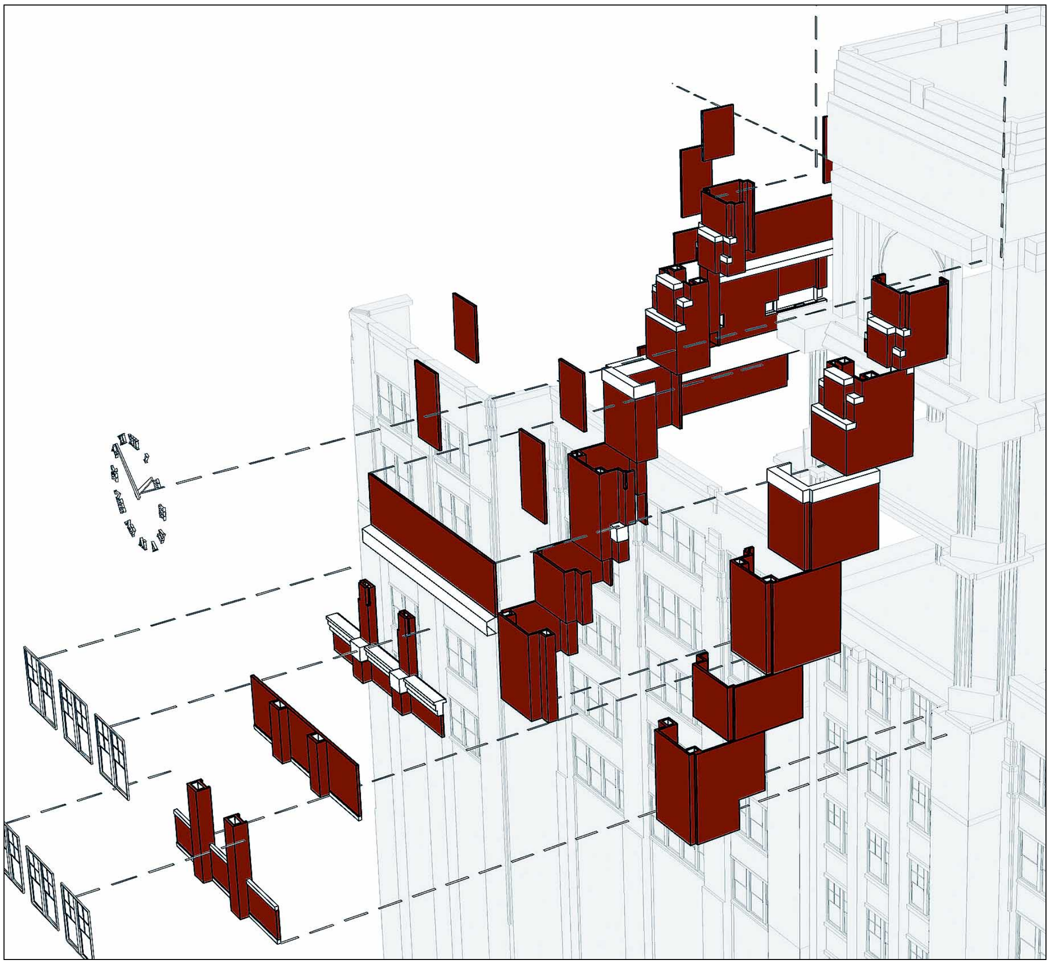

Fig. 9: Isometric of the clock tower reinforced brick panel arrangement.

Cladding Retrofit Construction

The cladding panels for the building were fabricated 48 km (30 miles) south of the project, loaded onto trucks, transported to the project site and lifted into place with a crane (fig. 10). In-place loading was not necessarily the critical design condition. In many cases, panels were designed specifically for transportation and erection forces. Erection was challenged by the panel configuration. Pick and set points required compensation for the offset in the panel center of gravity.

Fig. 10: Reinforced brick corner panel in transit.

The entire retrofit and restoration cost reportedly exceeded US$50 million. Interior restoration proceeded quickly to allow tenants to reoccupy offices. Exterior restoration was completed in the summer of 2002, nearly 18 months following the earthquake. The exterior elevation of the retrofitted building is shown in Fig. 11.

Fig. 11: Retrofitted Starbucks Center building.

The selection of reinforced brick panels provided a number of advantages over conventional brick veneer including improved design flexibility, enhanced design life, lower construction costs (speed of construction is often driving cost), and superior durability. These advantages allowed the flexibility to retrofit the building and preserve its historic heritage.

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