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Bill Tremayne is a principal and technical director at Holmes Culley. With more than 13 years of experience, he leads the firm's practice of performance-based engineering, which has been successfully applied to numerous seismic evaluation, retrofit, and new building projects in the United States and New Zealand. Bill is an ongoing contributor to the development of the masonry and analysis provisions of ASCE 41.

One of the tallest seismic retrofits in North America was undertaken in the heart of San Francisco. The Pacific Telephone & Telegraph Company headquarters was an achievement of architecture of its day when completed in 1925, and it remains an emblem of the Art Deco movement. The building's current owner decided to embark on the challenging endeavor of reviving the historic structure. This meant preserving the historic fabric, creating an open, flexible workspace, and infusing state-of-the-art technology and sustainability into all its aspects, including a voluntary full seismic structural upgrade.

Introduction

Situated in the heart of downtown San Francisco, the Pacific Telephone & Telegraph (PT&T) Company headquarters opened in 1925, reaching 132.7 meters and becoming the tallest building in the city upon completion (see Figure 1). The building, now known as 140 New Montgomery (140NM), still stands as an icon of design and a reminiscence of the power of the latest technology of the time.

The building's current owner since 2008, Wilson Meany, a real estate developer, decided to embark on a challenging endeavor of reviving the historic structure. While it will continue to host offices, the building will now introduce state-of-the-art technology in all aspects, including a voluntary structural system upgrade, while maintaining the architect's original intent. In addition to preserving the building's historic features, the project team wanted to create a healthy, sustainable space for its tenants and targeted LEED Gold for the project.

This paper outlines the design goals of this upgrade: from the preservation of the historic fabric to the creation of open flexible office space, all while providing a safe and sustainable structure in San Francisco's unforgiving seismic environment. It also discusses the strengthening scheme evaluated and challenges faced during the design. It presents details on the analysis method of the seismic retrofit, which utilized a performance-based design. This method presents the engineer with the capability to look past conservative building codes and determine in a more precise way the capacity of the existing building system. Moreover, this approach allows the engineer to better understand how the new and existing systems behave together during a seismic event, and therefore provides a smart, more sustainable, and less obstructive solution while maintaining the historic fabric of the building.

Lastly, the paper discusses the environmental benefits of retrofitting versus rebuilding, and how the sustainability objectives of the project shaped the design.

The Historic Building

140NM consists of a 26-story base, with a four-story tower above Level 27 and two basement levels, designed by Timothy Pflueger and Frank Miller. When completed, 140NM became the tallest building in the city, until its height was matched by the neighboring Russ Building two years later.

The building provided space for PT&T's 2,000 employees. The PT&T building was known nationally and internationally in the business and design communities, and was visited by VIPs such as Winston Churchill, who in 1929 made one of the first Transatlantic phone calls from the building.

The building is classified by the City of San Francisco as a Category I Historic Building and is eligible to register for the National Register of Historic Places. Some of its historic features include 2.4 hectares of terracotta façade constructed by the Gladding McBean Company, and eight terracotta eagles perched atop the tower

Figure 1. 140 New Montgomery, San Francisco. © Nathaniel Lindsey

(see Figures 2 and 3). The entrance houses an ornate and dramatic lobby with detailed bronze doors, marble walls, and a hand-painted plaster ceiling by Mark Goodman (see Figure 4). The entrance also leads to a marble staircase.

Since completion, the building has remained relatively untouched, with a façade renovation in the 1980s and parapet bracing installed just prior to the 1989 Loma Prieta earthquake. Comparing the building then to now, one can quickly notice that the historic fabric of the structure has stayed intact throughout the decades.

> “Some of the building’s historic features include 2.4 hectares of terracotta façade constructed by the Gladding McBean Company, and eight terracotta eagles perched atop the tower. The entrance houses an ornate and dramatic lobby with detailed bronze doors, marble walls, and a hand- painted plaster ceiling by Mark Goodman.”

After housing one company for over 80 years, the building was sold in 2008 to a real estate developer. It was the refined character of the historic building that would set the tone for the project and the vision of its new and proud owner.

Project Vision and Goals

An article in ***San Francisco Newsweek*** from 1925 described 140NM as “the new building generation, a monument to western progress, and foresight.” Eight decades later, a new developer was determined to continue this vision and honor its original inception as a modern communication hub and a center of innovation. 140NM was going to continue housing the technology of tomorrow by attracting creative entrepreneurs and companies in the tech sector, by providing them with state-of-the-art technology infrastructure and flexible workspace within a historic high-rise. To achieve that vision, the developer engaged a design team in 2011 that would spend the next few years following the guiding principles that would restore and reinvigorate this iconic structure.

Some of the major work undertaken in this renovation includes the historic lobby rehabilitation, elevator modernization (to support destination control), and entirely new mechanical, electrical, and plumbing systems designed with tenant controllability.

Figure 2. Terracotta façade along New Montgomery Street. © Stephen Schafer

Figure 3. Eight terracotta eagles perched atop the 140 NM. © Nathaniel Lindsey

Figure 4. Historic Lobby Entrance. © Stephen Schafer

Figure 5. Typical interior floor after soft demolition. © Blake Marvin

Figure 6. Typical existing wind brace moment-resisting connections.

The majority of the windows were replaced with high-performance glazing and will remain operable to promote natural ventilation. Some exterior restoration of the historic terracotta and historic glazed brick façade was undertaken, which included repointing of joints and patching/repainting individual units as necessary.

But one of the most important components of 140NM's refurbishment was the full seismic retrofit. This retrofit was carefully designed and implemented to improve the building's safety and performance in the harsh seismic environment of San Francisco, while preserving the building's iconic historic fabric, including the exterior façade and grand lobby (see Figure 5).

Seismic Upgrade Criteria

Existing building structural system

The existing building has an L-shaped floor plan, measuring about 46 meters along New Montgomery Street (the north-south direction) and about 43 meters along Minna Street (the east-west direction). Typical floor-to-floor height is about four meters. The structural system is made of a grid of steel beams encased in concrete for fireproofing, connected to steel columns encased in concrete at the interior floors and in brick at the perimeter. The infill beams are reinforced concrete and the floor consists of a 102- to 152-millimeter-thick reinforced concrete slab. The building steps back throughout its height at Level 19, 23, and roof. The existing foundation consists of perimeter concrete walls and concrete spread footings at each column.

The existing lateral structural system consists of steel beams and columns, classified as "partially restrained moment frames." The beams and girders, typically around the perimeter, are connected to the columns via riveted clip-angle connections (see Figure 6) and, in some instances, large gusset plates, denoted on the existing drawings as wind braces.

Performance-based engineering

The requirement to assess and enhance the seismic safety of 140NM stemmed from two main drivers: owner-desired improvement and code-required triggers per the San Francisco Building Code (SFBC). Given the building's historic classification, the following code of reference was used: 2010 California Historical Building Code (CHBC), as permitted by the 2010 San Francisco Building Code. For the evaluation of the building's seismic performance and retrofit design, ASCE 41-06, Seismic Rehabilitation of Existing Buildings (ASCE 41) was primarily used. ASCE 41 uses a performance-based engineering (PBE) approach. While traditional code-prescribed approaches are often conservative, especially for existing buildings, PBE provides the framework to capitalize on the inherent strength of the original structure.

Once seismic hazard and performance objectives were defined, a comprehensive finite element model of the building was developed. The analysis simulated how the building would perform during a large earthquake, and how a seismic strengthening scheme could be most effectively designed to reduce damage and mitigate collapse hazards. This provided the developer with a better understanding of the value and risk associated with the building. The design team was able to develop a smarter and more efficient system, taking full advantage of the inherent strength of the existing building materials and overall retrofitted system.

Rehabilitation objective and design criteria

In the case of 140NM, the global seismic rehabilitation objective for the building was to achieve the Life Safety Performance Level at 75% of the ASCE's Basic Safety Earthquake 1 (BSE-1) seismic hazard. This corresponds to a return period of 310 years with a 15% probability of exceedance in 50 years. This performance objective was consistent with the intent and requirements of the CHBC, which requires enforcing agencies to accept reasonable equivalent strategies to the regular code, and permits the seismic forces used to evaluate the structure to be limited to 75% of those prescribed for new construction.

Analysis procedure and earthquake ground motions

In the vicinity of the project site, strong shaking can be expected from a moderate-to-large earthquake. In particular, a potential moment-magnitude 7.9 rupture on the nearby San Francisco peninsula segment of the San Andreas Fault controls the seismic hazard adopted for this project. The geotechnical engineer, Treadwell & Rollo, developed the suite of earthquake time histories used for this project (see Table 1). Those earthquakes ranged from a magnitude of 6.9 to 7.9, with duration of 25 to 90 seconds. For this project, a nonlinear dynamic procedure (NDP) was adopted for the analysis of 140NM.

Finite element modeling the existing building

The analytical model was prepared using geometry obtained from a comprehensive set of existing drawings. Grades and strengths of materials used in the model were obtained from material testing, including strengths of the steel (at column, beam, plate, angles, rivets, and reinforcing) and concrete. Being able to use expected strengths versus more conservative code-prescribed strengths provided an average increase in strength of 10%.

The model included the foundation, concrete floors, built-up steel columns, and the steel beams with the contribution of their concrete encasement. The partially restrained (PR) moment frame connections were explicitly modeled to evaluate their strength and flexibility. The contribution of the relatively stiff existing infill brick façade was also accounted for. The stiffer response resulted in the exterior frames attracting a greater proportion of the lateral load that would be assumed from the bare steel PR-frame alone, which consequently resulted in more severe demands on the existing steel columns.

After running the model of the existing building (pre-retrofit), it was concluded that the existing building would perform poorly, with excessive damage to the masonry façades and column failures due to high axial demands.

The strenghtening scheme

In order to select a seismic strengthening scheme, a number of criteria were established by which to measure overall performance:

- Life Safety
- the proposed architectural layout of the renovated space
- the need to maximize leasable square footage
- the need to minimize impact on the existing historic building elements
- constructability
- LEED Gold objective
- overall project cost

The brick and terracotta cladding system is inherently brittle. Therefore, the seismic strengthening system needed to be sufficiently stiff to limit the potential for damage to this façade under the specified seismic hazard.

New Seismic Load Resisting System (SLRS)

Based on the evaluation of a number of schemes with respect to the previously discussed selection criteria, a strengthening scheme utilizing new reinforced concrete core walls with structural steel outrigger trusses was chosen. Other considered schemes included propped steel-plate shear walls, internal steel-braced frames with buckling restrained braces (BRBs), and perimeter shotcrete overlay walls. The proposed scheme had the smallest impact on the existing building, was the most efficient and innovative structurally, and was cost-effective.

Record (Earthquake, year, station)	Magnitude	Duration (second)
Loma Prieta, 1989, Los Gatos, California	6.9	25
Landers, 1992, Joshua Tree, California	7.4	44
Landers, 1992, Yermo, California	7.4	44
Kocaeli, 1999, Gebze, Turkey	7.4	28
Kocaeli, 1999, Duzce, Turkey	7.4	27
Duzce, 1999, Duzce, Turkey	7.1	26
Denali, 2002, PS10, Alaska	7.9	90

Table 1. Earthquake time history suite

The new reinforced concrete shear walls, with coupling beams, were located around the new stair and service cores extending from the basement level foundation to the underside of Level 27. The walls over the typical floors were connected to the existing adjacent steel columns to effectively provide a composite column, which strengthened the existing deficient elements. These new "core" elements provided not only a suitable location for new lateral load-resisting elements, but also a functional separation between the tenant spaces and service areas.

The core walls were stiffened with the two-story deep outrigger trusses located below Levels 8 and 19. They were located as high as practicable in the building without adversely impacting the usable floor space, as the building façade steps at Level 19. The

Figure 7. BRB at outrigger truss.

Figure 8. Supercolumn installation.

"The Seismic Lateral Resisting System was capable of resisting 100% of the seismic demands associated with the specified seismic hazard. Story drifts were generally low – less than 1.2% of the total height – except at the upper levels. Drifts at the northwest corner were also slightly higher."

outrigger truss frame included one bay of diagonal BRBs which form a ductile fuse to absorb and dissipate the seismic energy in the form of heat. Figure 7 shows the BRB installed on-site. From Level 19 and below, new steel supercolumns were provided at the perimeter to transfer the load from each outrigger truss down to the foundation. Figure 8 shows the supercolumn during installation.

At the west and south wing façades, new reinforced-concrete overlay walls were added. Those perimeter overlay walls were punched to maintain the existing window openings.

Figure 9 illustrates the new seismic load-resisting system as implemented in the analytical model.

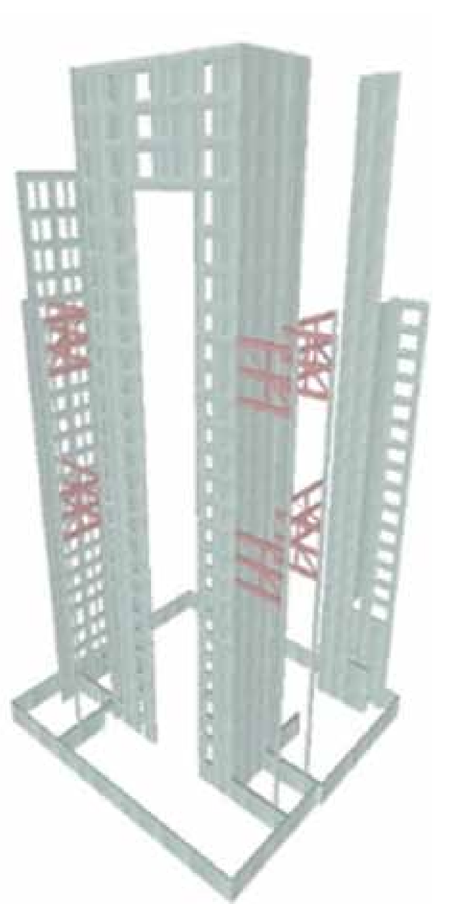

Figure 9. New seismic lateral resisting system.

Figure 10. Combined model

Combined model

The new SLRS and existing structure, each described in the preceding sections, were combined in a single analytical model (see Figure 10). This step of the analysis was crucial to verify the deformation compatibility of the two systems and ensure that they work effectively together during a large seismic event.

New Structural Lateral Resisting System

Upon running and analyzing the new structural scheme only, it was concluded that the new SLRS was capable of resisting 100% of the seismic demands associated with the specified seismic hazard. Story drifts were generally low – less than 1.2% of the total height – except at the upper levels. Drifts at the northwest corner were also slightly higher.

Combined systems

The combined model showed that the new SLRS added significant strength, stiffness, and ductility to the existing building while maintaining deformation compatibility with the existing lateral force resisting elements. This allowed the rehabilitated building to achieve Life Safety at the specified seismic hazard.

Story drifts were generally significantly less than 1%, with larger drifts at the corners and towards the top of the building (above the upper outrigger trusses) and maximum drifts less than 1.5%. Opportunities to strengthen of some existing components were identified, including reinforcement of the existing columns. The low drifts will provide added protection to the relatively brittle façade elements.

Sustainability

In the context of the built environment, sustainable design should meet the needs of the present without compromising the ability of future generations to meet their own needs. The "triple bottom line", a phrase coined in the mid-1990s by John Elkington, is the model for evaluating sustainability that includes environmental, economic, and social performance measures. While many are starting to be concerned about environmental impacts of the built environment, a creative, effective, and truly sustainable design should consider all three.

Benefits of a retrofitted building

It is often said that the most sustainable building is the one already built. As the annual replacement rate of buildings has historically been around 2%, reusing and greening the existing building stock offers one of the greatest opportunities for reducing the environmental impacts of buildings. Reusing existing buildings requires creative problem solving, evaluation of the best use of the existing structure, and integrated design practices. It has dramatically lower impacts on the environment by requiring not only less new material and use of nonrenewable resources, but reducing the amount of waste produced and energy required for demolition and rebuilding.

The retrofit scheme used for 140NM allowed for the reuse of 95% of the existing structure. This has a great impact on the sustainability of the project, and was achieved because of the owner's objectives and through utilizing PBE. Preserving the building had more than just environmental benefits. 140NM is a historic building and preserving it is essential to maintaining the city's heritage. Historic buildings are typically structurally robust and can be upgraded to meet current standards with typically minimal impacts to the environment. The significant reuse of the existing structure, paired with the minimal addition of new materials to bring the existing building to Life Safety level, provided not only a sustainable solution, but a smart and necessary one. With inevitable seismic events in the coming years, this retrofit is expected to have increased the building's service life by another 50 to 100 years, and has brought back to life a historic building unoccupied for years as a revitalized, restored, sustainable, and safer prominent structure of San Francisco.

Life Cycle Assessment Analysis

Life-Cycle Assessment (LCA) is a technique used to account for all of the environmental impacts associated with a product or process over its life cycle with the goal of evaluating and reducing those impacts. LCA offers a powerful tool for evaluating the environmental impacts of buildings and strategically reducing them, considering all the building systems and all stages of a building's life cycle. It enables comparison between different building components and system selections, and offers a comprehensive way to evaluate and reduce the overall environmental impacts.

The impacts from the retrofit versus construction of a new building were compared from an LCA standpoint. Rough material quantities were estimated for a new building with equivalent floor area. Athena's Impact Estimator was used for the LCA analysis. From the LCA, it can be seen that the retrofit has a little over a quarter of the environmental impact of constructing an equivalent new building, per Figure 11. The most common metric of an LCA is Global Warming Potential. This is a measure of the potential to increase the temperature of the Earth's atmosphere and oceans.

140NM achieved LEED Gold certification. The building received the maximum amount of credits available for building reuse, including an Innovation in Design and Regional Priority credit.

Conclusion

Reviving 140NM entailed designing building system upgrades and insertions as elegant and contemporary elements that would complement the building's historic features. It required delivering a robust, smart, integrated, and nimble infrastructure, and required a flexible architectural layout that could adapt over time. All those goals were achieved when the building reopened at the end of 2013. It now houses more than 1,000 people. Moreover, the seismic upgrades allow many more to experience the historic structure in future generations..

These future generations must acknowledge the significance of keeping landmark buildings close to their original design, while lending them a strong, efficient, and sustainable scheme for maintaining their future viability. It must also be recognized that, with advancing structural analysis, historic buildings no longer need to be viewed as archaic, but rather as successful marriages of preservation and innovation. ■

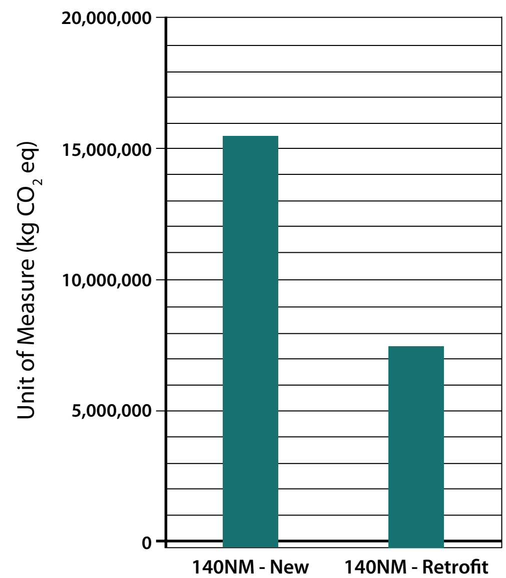

Figure 11. Comparison of global warming potential by assembly groups.

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