181 Fremont

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There is a common misconception among the general public that buildings designed according to modern building codes will not be damaged in an earthquake. Many building owners are similarly unaware that the seismic performance objectives outlined in the code are intended only to provide life safety for occupants; they do not prevent damage or ensure post-earthquake functionality. Significant financial losses and downtime for repairs can occur after an earthquake, which likely does not meet the expectations owners have for their investments.

Jay Paul Company, the owners of 181 Fremont, envisioned a high-performance building with innovative sustainability strategies. After realizing that code-minimum earthquake performance did not align with their goals, they also chose to pursue a design strategy presented by Arup to achieve "beyond code" seismic resilience. This holistic "resilience-based" approach required identifying and attempting to mitigate all threats that could hinder re-occupancy and functionality. The building was designed to exceed the California Building Code (CBC) mandated seismic performance objectives and achieve immediate re-occupancy with limited disruption to functionality after a 475-year earthquake (the approximate recurrence interval for the CBC design basis earthquake). This is accomplished through enhanced design of both structural and non-structural components along with pre-disaster contingency planning.

181 Fremont is the third-tallest building in San Francisco, with the spire of the 56-story tower reaching a height of 802 feet. The lower 37 levels of the building are commercial office space, and the upper levels are condominiums. Arup is the Structural and Geotechnical Engineer of Record for 181 Fremont. The structure utilizes a perimeter steel mega-frame system to resist wind and seismic forces because a traditional concrete or steel core lateral force-resisting system is too slender, given the tower's small footprint. Over the lower two-thirds of the building, the structural system features mega-braces spanning between nodes near ground level and at levels 20 and 37. A secondary system of perimeter special moment frames transfers individual floor demands up or down to the mega-nodes. In the residential levels above, the perimeter braces are made of large wide flange sections and a core of buckling-restrained braces (BRBs) acts as the secondary system. An inverted chevron braced frame provides lateral continuity between the office and residential levels. Gravity loads are resisted by steel columns in the core and at the exterior as well as corner mega-columns. Transfer trusses wrapping around the building at level 3 carry all perimeter gravity loads to the mega-columns. Below ground, a 5-story basement is supported on a concrete mat with piles socketed into bedrock more than 200 feet below grade.

Arup determined that using an integrated damping system would reduce seismic forces to facilitate enhanced performance and control wind vibrations in the tower. The mega-brace system provided an excellent opportunity to incorporate damping. Each mega-brace in the office levels consists of three parallel elements – a built-up-box primary brace in the middle with solid steel secondary braces on either side. Viscous dampers are introduced at one end of each secondary brace. The mega-braces are restrained laterally at every floor to prevent buckling but slide freely along their length against polytetrafluoroethylene (PTFE) bearing pads. As the tower sways in wind or seismic events, elastic strains develop in the primary braces, causing them to lengthen or shorten between mega-nodes. Since the secondary braces are connected to the same mega-nodes, this activates the dampers and dissipates energy. BRBs were also introduced as a fuse to prevent damage to the braces, dampers, and mega-columns in the maximum considered earthquake (MCE). The system acts like a giant shock absorber to limit building drift and reduce floor accelerations.

The structural design also features innovative uplifting corner mega-columns. As the building sways, significant tension demands develop in the mega-columns. To prevent damage, the columns are designed to uplift slightly (approximately 1 inch) at their bases in the MCE, which limits demands in the columns and foundation. The mega-columns are anchored by pre-tensioned rods tuned so that uplift does not occur in wind or smaller earthquake events. A shear key transmits shear from the columns into the foundation in the event of momentary uplift.

Arup's structural design saved approximately 2,700 tons of steel compared to a baseline design by another engineering firm – roughly 25% of the building weight – while satisfying the enhanced resilience objectives. Since the damping reduced seismic forces, steel tonnage could be decreased, which reduced the building's

Arup was an Outstanding Award Winner for the 181 Fremont project in the 2019 Annual Excellence in Structural Engineering Awards Program in the Category – New Buildings over $100M. Courtesy of Jay Paul Company.

stiffness and increased its flexibility, leading to a cycle of material reduction. The increased flexibility decreased the seismic demands further, and the process was iterated until the design was tuned to meet the seismic and wind criteria. Since the tower is slender and lightweight, wind accelerations posed a challenge due to stringent criteria in the residential levels, but integrating viscous damping within the mega-frame also eliminated the need for a tuned mass damper near the top of the building. This resulted in additional material savings and freed up valuable real estate at the penthouse level.

181 Fremont was designed to avoid damage and achieve rapid recovery in the aftermath of a large earthquake, far exceeding code requirements and earning a REDi Gold rating for seismic resilience. The design strategy, including enhanced performance criteria for structural and non-structural components, was implemented with little cost premium, and will reduce the building's overall life-cycle cost and environmental footprint significantly. While a resilience-based design approach extends beyond the typical purview of the structural engineer, 181 Fremont demonstrates how informed engineers are uniquely qualified to assist owners and stakeholders who desire better performing, "beyond code" buildings.▪

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