

Techniques and Lessons Learned from Office to Residential Conversions in High Seismic Regions

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ABSTRACT

The modern workplace environment is changing. Digital technologies enable more hybrid or remote working arrangements, leaving many cities with large stocks of empty and aging office buildings. Simultaneously, there is a desire to revitalize denser living in city centers. Repurposing empty office buildings into new urban residential towers is one viable solution. Naturally, this solution comes with challenges, however, local jurisdictions working with developers to address housing needs has proven to be a mutually beneficial endeavour.

This paper discusses techniques used and lessons learned from over 20 successful office-to-residential conversions in Southern California, USA. These buildings represent a cross section of lateral systems (concrete shear walls, concrete and steel moment frames), building heights (5 to 32 stories) and vintages (1920s through 1990s).

Key in most of the office-to-residential conversions, as dictated by the local municipal jurisdiction, is a requirement to assess the structure to the existing building standards in ASCE 41. This often triggers structural upgrades. A variety of structural approaches are considered: 1) Utilize advanced performance-based evaluations to demonstrate the adequacy of the building thereby avoiding structural retrofit entirely; 2) Implementing fluid viscous dampers or other passive energy dissipation systems to reduce structural demands; 3) Conventional strengthening of existing lateral systems utilizing overlays (shotcrete, FRP, or steel); and 4) Adding new lateral force resisting system (LFRS) elements to supplement or replace existing deficient systems. Advantages, disadvantages and lessons learned are discussed.

Beyond structural considerations, several key architectural considerations necessary to convert an existing office building to residential units are highlighted.

1 INTRODUCTION TO ADAPTIVE REUSE

While adaptive reuse can pertain to any change of occupancy or use of a structure from its original design, this paper will focus solely on adaptive reuse cases where commercial properties (typically office space) is being converted to multi-family residential space. The concept of taking empty office buildings in urban environments and converting them into new, chic and centrally located residential is extremely appealing. Typically, it's more economical to reuse an existing building than build a new one. Plus, it's more sustainable, reducing embodied carbon and waste from the construction industry by the bones of the structure. Finally, it can be a much-needed solution to the housing crisis that affects most of the United States' major cities.

The work, however, to convert an existing office building to modern residential space is by no means simple. There is no national regulatory standard for adaptive reuse. Changing the zoning to allow residential occupancy may be a long and cumbersome process depending on the city. Some cities have restrictions on the age or size of building which can be converted, and restrictions on financing options can be a significant barrier to developers. Recognizing these policy barriers, some cities are actively worked to streamline approvals, relax regulations and create clear procedures for such conversions (IAPMO, 2024).

From a practical perspective, it should be expected that the building will be fully unoccupied to facilitate the conversion process. Oftentimes the conversion will require a complete overhaul of the MEP systems, access to structural systems for possibly extensive work and possibly new facades to modernize the aesthetics. Depending, also, on the floor plate size and configuration, there may be the need for new vertical light shafts through the core of the building.

Structural feasibility studies are a critical component in evaluating the economics of a potential project. Quite often this is one of the most challenging phases of the project depending on the availability of existing information including record structural plans with the appropriate general notes sheets with critical design criteria and material specifications as well as geotechnical reports. Decades of engineering judgment must be exploited to develop conceptual level retrofits that are simultaneously realistic and conservative in order to get pricing that is within 10-20% of the final cost otherwise you either risk putting the project budget at risk by under-estimating the scope, and/or killing the project altogether by being overly conservative.

2 STRUCTURAL REQUIREMENTS

The California Existing Building Code allows for a change of occupancy from office to residential without requiring evaluations or retrofits because these are both considered Seismic Risk Category II (IL2) structures. In the City of Los Angeles and increasingly in other jurisdictions, however, ordinances mandate that in adaptive reuse situations, buildings must be evaluated to either 75% of current code base shear forces, or to meet the Basic Performance Objectives for Existing Buildings (BPOE) criteria in ASCE 41. The rationale for this more stringent approach is because, despite occupant loads actually reducing, the occupant load combined with the time spent in a building and the hours of operation, increase the functional risk profile to life safety.

3 IDENTIFYING CANDIDATE BUILDINGS

While it may seem to a casual observer that converting an office building to residential is straightforward, (after all, all you have to do is reconfigure interior partitions, right?), the process is anything but simple. One may think that all the vertical transportation, egress, and mechanical, electrical, plumbing (MEP) systems, which were designed for higher occupant loads, could be entirely reused. Reality, however, is that functionally these systems are vastly different between an office and residential usage. The habitability

requirements for residential structures are intrinsically different from an office and this plays a central role in the identification of candidate buildings. Major considerations include:

- Historic buildings – a subset of the office building inventory includes historic buildings, the nature of which likely limits or even prohibits certain measure that can be taken, including the use of exposed retrofit elements that would change the character of the building.
- Floor plan – Depending on the vintage of the building, there may be large floor plans with most of the square footage far away from windows. The floor plate is a major driver for how possible housing units can be shaped, how many units can be fit on each floor, where corridors can be located and the desirability of those finished units to command higher prices.
- Egress as it relates to fire life safety – Façade systems in offices don't need to ventilate naturally but they are required for residential uses, so existing facades are often modified to incorporate operable windows.
- Amenities – These are often needed to remain competitive in the rental market and trigger the need for more ancillary spaces often in the form of rooftop decks which then further trigger elevator and stair extensions, increased roof live loads, perimeter guard rails, etc.
- Daylighting – These are also required for residential uses that might not be for office, as such, buildings with large floor plans or those landlocked by adjacent buildings will require an internal atrium which necessitates removal of significant portions of the building diaphragm.



Figure 1. Roof Top Pool Deck and Hot Tub

4 STRUCTURAL SYSTEMS, CHALLENGES AND SOLUTIONS

Los Angeles is a large and diverse city, not only in its culture and residents, but also its buildings. They naturally span nearly a century and include every conceivable building type. So, when discussing conversions from other occupancies to residential, we're typically converting "Type I" buildings designed as offices, parking structures, malls, institutional facilities, warehouse, storage, etc. These, overwhelmingly tend to be larger and taller than standard residential construction, consisting of 2-hour fire rated structures utilizing concrete slabs supported by all manner and vintage of steel or concrete, one and two-way gravity resisting systems founded on shallow or deep foundations.

Especially for pre-1940's era buildings, the lateral force resisting systems (LFRS) may be non-existent, relying strictly on the flexural interaction of slab – column systems. More explicit LFRS can include moment

frames (with or without brick infill), unreinforced masonry, reinforced brick or masonry, concrete shear walls (perimeter or core) and a dizzying variety of steel moment and braced frame systems with a large variety of detailing practices. The three systems discussed herein represent the bulk of those encountered on adaptive reuse projects.

4.1 Concrete Shear Walls

It is extremely rare to convert a concrete shear wall building that is modern (after 1978); typically, we find that pre-1978 non-ductile concrete structures are the ones we're evaluating. Coincidentally, these have already been flagged under a separate ordinance in Los Angeles which mandates their assessment and retrofit even if they are not being converted. These buildings tend to come in three flavours: perimeter perforated shear walls, core (with or without perimeter frames), and isolated / distributed shear walls systems. The gravity systems in these types of structures are also varied, typically comprising of concrete beams and columns or concrete encased steel beams and columns. Floors tend to be either cast-in-place slabs or concrete topped metal decks.

These structures tend to be stiff enough to meet drift requirements but lack the ductility in the shear walls. Increasing the size of the shear walls or adding new shear walls is the most natural approach. Doing so, however, reduces the period of the building, increasing the seismic demand and could create a "design spiral" whereby everything just keeps getting bigger. Additionally, this approach could overload existing foundations which are inherently expensive to address. On one project, an alternative approach was taken where the existing concrete core was removed and replaced with a steel Buckling Restrained Brace Frame (BRBF) core. The gravity system of this building was already steel, making the transition of the LFRS more palatable. Changing from a concrete shear wall to BRBFs lengthened the building period and ultimately reduced the seismic demand by over 50%, countering the effects of the increased hazard and avoiding all foundation work.

4.2 Steel Moment Frames

Steel Moment Frames (SMFs) come in a wide variety of designs, fluctuating based on the era in which they were designed and constructed. Ultimately, they tend to suffer from the same deficiencies: excessive drift and deficiency in strength. In California, steel moment frames constructed prior to the 1994 Northridge Earthquake (so-called "Pre-Northridge Steel Moment Frames") are a large portion of the SMF building stock. These structures tend to have insufficient welds at the beam-column joint which are prone to brittle failure mechanisms. In evaluating or retrofitting these structures, the approaches tend to coalesce around either fixing the connections or reducing demands to keep these connections essentially elastic.

One successful approach in addressing SMF deficiencies has been the implementation of fluid viscous dampers (FVDs), distributed up the height of the structure. FVDs are velocity-dependent devices which dissipate seismic energy by forcing a viscous fluid through and around a machined piston head. Adding FVDs into a structure reduces both drift and accelerations without increasing the stiffness of the structure.

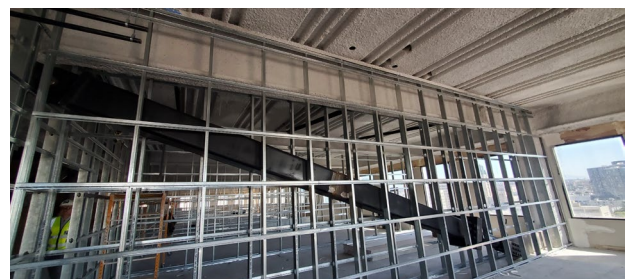


Figure 2. Retrofit of Steel Moment Frame with Fluid Viscous Dampers (placed in demising wall)

4.3 Concrete Moment Frames

This is the smallest subset of the buildings in California but tend to be desirable for adaptive reuse because of their open floor plans. Similar to shear wall system, Concrete Moment Frames built prior to 1978 suffer from

inadequate detailing and therefore exhibit non-ductile behaviour, making them expensive and invasive to retrofit.

For these systems, the first option is again to try passive energy dissipation using viscous dampers. This is because these systems tend to be flexible and heavy, so the energy absorption is critical to bringing the LFRS within compliance. Often, however, the frames themselves lack the strength to accommodate the internal forces generated by the dampers, and unlike in steel systems, strengthening the concrete elements is difficult and expensive. Ultimately, these systems may require a more brute force approach by either adding new moment frames (often to the exterior of the structure where architectural review must be considered) or utilizing new concrete shear walls. To achieve the continuity of shear wall vertical reinforcing especially in the boundaries, the walls may be offset from the frames but span between frame columns so that frame columns may be utilized, even if they must be strengthened with concrete or FRP, as boundary elements. The connection between the new walls and existing frames is critical for overall stability and to limit foundation uplift displacements. New walls must be strategically placed either in corridors or coordinated architecturally to serve also as residential unit demising walls. Where door penetrations in corridors or to the units significantly impact the stiffness of the walls, a sufficiently tall above-roof coupling beam may compensate for the reduced stiffness.

4.4 Foundations

Irrespective of the lateral system above, addressing potential foundation deficiencies is a critical aspect of the seismic retrofits for these conversions. Typically, clients will defer spending money on investigating as-built conditions below grade and with near certainty, this is where the most unforeseen conditions are encountered in the field after the plans have been permitted thereby requiring time-sensitive modifications to the designs. Overpoured, oversized, undersized, shallower or deeper than expected footing sizes and elevations, undocumented pits/walls/beams, poor soils, large boulders, existing utilities (live and abandoned) are just a few of the situations you can encounter at the outset of construction.

As a consequence, heavy attention is expended during the concept and design phases to limit or eliminate foundation retrofit. Conventionally, these elements are considered force-controlled (not ductile or limited by the ductility of the elements they are supporting) and so one strategy is to better assess the design forces in the first place. For conventional foundations a method that can be employed in both linear and nonlinear studies is to combine the LFRS models with the foundation models (as opposed to fixed-base assumptions for the former then transferring to spring models separately for the latter as conventionally done). This is because fixing the base of the LFRS will result in inflated foundation forces; but we need that fixed base assumption to conservatively design the superstructure. So one approach is to use fixed-base assumptions for the LFRS design, then separately utilize a combined model with forces from the LFRS models. This results in more realistic behaviour and force distribution to the foundation model due to permitting uplift.



Figure 3. Progress Photo of New Shear Wall – Existing Wall Interaction at Foundation Level Construction

5 OTHER CONSIDERATIONS

The cases that we've discussed always start by evaluating the building in its "as-is" condition, not only because the building, in rare cases, may already comply but also to assess what the critical vulnerabilities are to be able to address those surgically where possible.

5.1 Analytical Procedures

For the majority of buildings evaluated and upgraded, conventional linear static and linear dynamic procedures of ASCE 41 are sufficient to achieve a cost-effective retrofit solution. Evaluating the "as-is" condition highlights the critical deficiencies and allows for a more surgical approach to the retrofit, limiting scope and expense.

That said, Performance-Based approaches (non-linear static push-over and nonlinear response history analysis) can sometimes be the most effective retrofit measure, by avoiding a retrofit all together. Performance-based approaches do extend approval timelines and up-front costs but can easily be offset by the savings in retrofit costs (especially to foundations). During the initial phases where the structure is evaluated "as-is," we are regularly able to determine based on the component demand-to-capacity ratios, whether a more advanced analysis may result in a highly optimized or eliminated retrofit scheme. These approaches require significant experience and engineering judgment to implement responsibly and therefore require equally rigorous peer review which has non-trivial cost and schedule implications, as well as risk, to the project. While these issues tend to be off-putting to risk-averse clients, they present an opportunity for engineers to educate clients on their options and potential rewards. Nonlinear response history analysis is also required where energy dissipation devices, like fluid viscous dampers, are used in the retrofit approach.

5.2 Building Separations (Seismic Joints)

Because many adaptive reuse projects seem drawn to historic buildings, seismic separations between the adapted building and adjacent structures also seems to follow these types of projects. This can present significant performance risks especially to taller buildings adjacent to shorter ones; compounded by the fact that the floors do not always line up. This is addressed explicitly in ASCE 41 where some approaches are presented to address these issues, however, they can be complex to analyse and address in many cases.

In some instances, a performance-based approach can be used to more accurately account for the relative movement of the two structures. Of course, this means that you have to model both structures (Figure 2). In these models, impacts of the shorter buildings on the taller (or vice versa) may be assessed utilizing a bounding study that takes into account the size of the gap and the relative stiffness of the two structures to quantitatively compute best and worst-case scenarios to guide the proper solution.

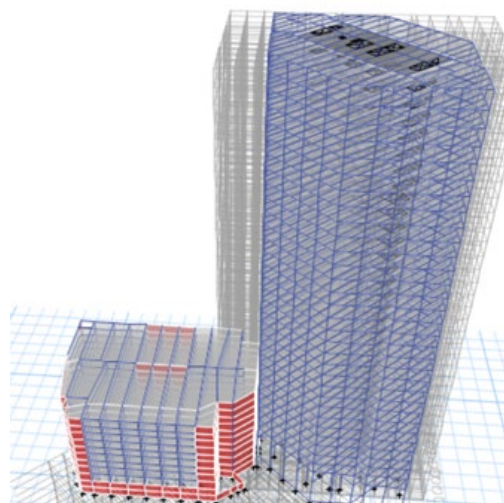


Figure 4. ETABS model of the structure being considered for adaptive reuse (the tall one) and an adjacent building to assess seismic gaps

5.3 Non-structural Elements

There are no explicit requirements to evaluate non-structural systems. Furthermore, these buildings are typically gutted, and most non-structural elements are replaced with modern code-compliant components as part of the adaptive reuse conversion. The existing egress stairs and facades, however, do tend to remain and could disproportionately pose a life-safety risk. It's important to consider how drift and floor accelerations impact these key systems and to address any deficiencies in the retrofit scheme.

5.4 Other Bits and Pieces

The list of elements to check when converting an office structure into residential units can feel infinite. The following list highlights a few of the long list that are worth noting.

- **Diaphragms:** Not an insignificant factor in any retrofit, but also not a factor unique to adaptive reuse cases. It's critical to evaluate diaphragms and oftentimes forces at transfer floors can exceed the capacity of the existing structure, especially if seismic forces have increased or the structure was stiffened as part of the retrofit.
- **Material Testing:** When existing drawings are incomplete or non-existent, material testing may be the best way forward, but can be expensive, time consuming and difficult to coordinate with existing tenants.
- **Additions:** Limited additions to a structure (e.g. adding roof decks) can be easily incorporated into a conversion retrofit while other more elaborate efforts (e.g. adding entire floors) may trigger more significant work or even requiring a full upgrade of the structure to current code forces as opposed to the limited forces or performance objectives of existing buildings.
- **Peer Review Costs and Schedules:** Peer review can increase the review schedule by a wide range from as little as 3-4 months up to a year and cost anywhere from \$20,000 to \$100,000 US dollars when considering the fees by both the peer reviewer and the structural engineer of record.

6 CONCLUSIONS

The adaptive reuse of buildings really is an economically and socially responsible way of providing much needed housing in Southern California and throughout the country. In Southern California, where high seismicity is prevalent, significant investment in the structure and its ability to achieve life safety is required. Thankfully, the inventory is large owing to the significant decrease in demand for office space. And yet, the barrier to entry is high as the plethora of design issues related, not only to structure, but every discipline tends to dissuade most investors due to the perceived uncertainties and associated risk. Experienced developers with equally experienced design teams are a pre-requisite for success.

From a structural standpoint, every single project or building presents a unique set of challenges. Finding the right approach for each requires significant upfront investment on the owners' part to properly assess whether or not structural solutions will be economically viable and usually in a very short amount of time during property acquisition windows. That said, for passionate structural engineers particularly interested in seismic design, the evaluation and retrofit of existing buildings presents a unique opportunity for us to practice and implement all the available knowledge base that academia and real-world earthquakes have informed our understanding of building behaviour in seismic events.

7 REFERENCES

The International Association of Plumbing and Mechanical Officials (IAPMO) (2024), “*Adaptive Reuse: Converting Offices to Multi-Residential Family*”. IAPMO White Paper 3-2024, IAPMO, Ontario, CA.