ABSTRACT: In San Francisco, Los Angeles, and other urban centers in the western United States, developers are increasingly choosing concrete ductile core designs for their new high-rise projects (many are upwards of 40 stories and taller than 240 feet). Many of these new designs incorporate only a single system for resisting lateral seismic loading. This design approach has not yet been tested by a significant earthquake in the western United States. When the expected occupancy use is residential, most structural designers use Risk Category II, with an Importance Factor of 1.00. In contrast, when the structure is expected to be used as an office building, many structural designers use Risk Category III, with an Importance Factor of 1.25. This paper discusses the ramifications of using Risk Category III and an Importance Factor of 1.25 for new high-rise residential projects employing the concrete ductile core design approach. Additional costs of increasing the seismic capacity of this system when Category III is chosen are analyzed. The paper also analyzes the expected improved seismic performance in Design Basis ("DBE") seismic events and Maximum Considered ("MCE") seismic events, and the corresponding reduction of seismic risk in the legal arena for the owner of the facility. The paper demonstrates the substantial long-term benefits that can be derived from choosing Risk Category III for these projects.

Keywords: High-Rises, Risk Categories, Seismic Performance, Legal Liability

1. INTRODUCTION

Developers of high-rise towers in San Francisco, Los Angeles, and other urban centers in active seismic zones are faced with design choices that have significant ramifications for commercial risk and legal liability. Before finalizing those design choices, developers should understand that their potential legal liability profile will be shaped by the substance of the advice concerning expected earthquake performance that they receive from their structural design consultants during the design development phase of the project. Before committing to a specific structural design for construction in the field, developers should engage advisors to predict the type of sworn testimony by its design team that a facility owner can invoke to protect the owner's interests in the event the owner's facility performs poorly in a foreseeable earthquake. Put another way, before the structural design for the new high-rise is finalized, the developer should receive a description of the evidentiary record that its design team is developing concerning the seismic capacity of the proposed facility. This will enable the developer to make a better-informed decision about which structural design approach should be selected and how to allocate resources to implement it in the field.

As high-rise developers increasingly choose concrete ductile core designs for their new developments, they face the seminal choice of adhering to the structural requirements for Risk Category III specified by the American Society of Civil Engineers in its design standard entitled Minimum Design Loads for Buildings and Other Structures (ASCE/SEI 7-10 (2010)) [1] or the less stringent and less costly standards of Risk Category II. In many municipalities, the choice made by the developer is routinely endorsed by the permit-granting authority. But, as will be demonstrated below, municipal approval at the permitting stage does not automatically insulate the developer or the owner from significant commercial risk and extraordinary legal liability should the facility perform unsatisfactorily in a foreseeable earthquake.

2. COMMERCIAL CONSIDERATIONS DURING THE DESIGN DEVELOPMENT OF NEW CONCRETE DUCTILE CORE HIGH-RISES

Traditionally, developers in seismically active areas of the western United States selected structural steel designs for their high-rise projects, many of which were used for commercial purposes. Since the latter part of the twentieth century and during the first decade of this century, developers of residential high-rise towers have increasingly chosen “a substantial concrete shear-wall core [design] to provide earthquake resistance.” [2] These new residential (and sometimes mixed-use) facilities use “concrete core-wall construction without supplemental moment frames in the seismic-force-resisting system” because this design approach “can offer advantages of lower costs, faster construction, and more open and flexible architecture.” [3] Some leading proponents of this design approach refer to them as “concrete ductile core high-rises,” and that terminology will be used in this paper.

Certain commercial considerations are inherent in choosing the concrete ductile core design approach for the developer’s facility. One is that there is a “potential lack of redundancy in the structural system.” [4] Put simplistically, omitting second lines of
defense to protect the high-rise tower against lateral seismic demands (such as the “supplemental moment frames” identified above) can increase the potential for poor performance during foreseeable earthquakes. “If the shear wall fails due to unexpected loading or unanticipated structural behavior, there is no second line of defense to prevent the tower from collapsing.” [5] The consequences of loss of structural integrity or, less frequently, collapse, can be devastating for the institutional owner: diminution in the value or utility of resources invested in the high-rise; substantial additional resource expenditure for repair or demolition or replacement; loss of commercial revenues; defense against legal claims of breach of commercial obligations; defense against claims of wrongful death or personal injury; satisfying adverse legal judgments.

Another commercial concern is that these new tall concrete buildings have not been field-tested in “very long and large earthquakes” in urban centers of the western United States. Because no great earthquake has been experienced “in the mainland U.S. in modern times . . . we do not have the evidence to demonstrate the ultimate effectiveness” of the concrete ductile core structural design. [6]

A third commercial concern is that the structural engineer of record for a high-rise taller than 240 feet in a seismically active urban center (e.g., San Francisco and Los Angeles) will not be able to routinely follow the prescriptive provisions of the operative municipal building code (usually modelled after the International Building Code (“IBC”)) because most American building codes are “based around the dynamic behavior of low- and medium-rise structures, not the more complex dynamic behavior of tall buildings.” [7] As a practical matter, the developer will usually need to incur the extra expense of paying for a “peer review” panel to verify that the structural engineer of record has demonstrated that the alternate design is “at least the equivalent of that prescribed in [the local version of the IBC] in quality, strength, effectiveness, fire resistance, durability and safety.” [8] [9]

Administrative Bulletin 83 (AB-083) of the San Francisco Building Code (adopted on March 25, 2008 and updated January 1, 2014) is the mechanism commonly used to demonstrate to a peer review panel that the developer’s proposed concrete ductile core high-rise in San Francisco will have the same seismic performance characteristics contemplated by the IBC. The structural engineer must demonstrate adequate performance of the proposed high-rise in three earthquake scenarios. First, during a “service-level” earthquake (that is, one with a 50% probability of exceedance in 30 years), the “primary structural system is required to demonstrate acceptable, essentially elastic seismic performance.” Id. at p. 83-4. Only minor damage to the primary structural system is allowed. Second, during a “code-level” earthquake (defined in the second bullet item below, as opposed to an earthquake with a 10% probability of exceedance in 50 years, traditionally referred to as a “Design Basis Event”), the primary structural system must be shown to adhere to the “story drift ratio limitations of the San Francisco Building Code,” among other things. Id at p. 83-4. Third, during a “Maximum Considered Earthquake” (“MCE” as defined in ASCE 7-10, Chapter 21, replacing the traditional definition based upon a 2% probability of exceedance in 50 years), “Calculated force and deformation demands on all elements required to resist lateral and gravity loads shall be checked to ensure they do not exceed element force and deformation capacities.” Id. at p. 83-7.

San Francisco’s AB-083 was and is based, in large part, on the design recommendations presented in the Tall Buildings Initiative: Guidelines for Performance-Based Seismic Design of Tall Buildings (“PEER TBI”). [10] The TBI design recommendations are intended to satisfy the following performance capabilities specified for Risk Category II structures in ASCE 7-10 [11]:

- withstand Maximum Considered Earthquake shaking, as defined in ASCE 7, with low probability (on the order of 10%) of either total or partial collapse;
- withstand Design Earthquake shaking, having an intensity two thirds that of Maximum Considered Earthquake shaking without generation of significant hazards to individual lives through design measures intended to assure that nonstructural components and systems remain anchored and secured to the structure and that building drifts are maintained at levels that will not create undue hazards; and
- withstand relatively frequent, more moderate-intensity earthquake shaking with limited damage.

Although the starting point for the PEER TBI guidelines is the assumption that high-rises will be required to meet the threshold performance requirements for Risk Category II structures, they also contemplate that for some structures it “may be desirable . . . [for the design] to achieve performance superior to” that required for Category II structures. [12] ASCE 7-10 Risk Category III design standards are one collection that would yield better performance in new concrete ductile core high-rises. For instance, when calculating the minimum design load for a Category II structure, the “Seismic Importance Factor” value is 1.0; for a Category III structure, a higher design load is calculated because its “Seismic Importance Factor” is 1.25. [13]

According to Table 1.5-1 of ASCE 7-10, the definition of a Category III high-rise is one “the failure of which could pose a substantial risk to human life” or one “with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure.” Table 1604.5 of the California Building Code provides non-exclusive examples of Category III facilities, but specifies (like ASCE 7-10) that structures should be classified as Category III if they “represent a substantial hazard to human life in the event of a failure.” Section 1.5.1 of ASCE 7-10 states “Each building or other structure shall be assigned to the highest applicable risk category or categories.” The Commentary to ASCE 7-10 states that risk categorization should be “based on the number of persons whose lives would be endangered or whose welfare would be affected in the event of
failure.” [14] According to Figure C1-1 in the ASCE 7-10 Commentary, if the number of persons directly at risk exceeds a few hundred, the facility should be classified as Category III.

As a practical matter, if the structural engineer is able to satisfy the structural capacity requirements associated with Risk Category III, then a reasonable expectation will follow that the probabilities favor the Category III structure to perform acceptably during foreseeable earthquakes compared to a Category II structure. This is illustrated in Table C.1.3.1b of the Commentary to ASCE 7-10 at page 316: in an MCE earthquake, the likelihood of “total or partial structural collapse” is 10% for Category II structures and 6% for Category III structures; similarly, in an MCE earthquake, the likelihood of “failure that could result in endangerment of individual lives” is 25% for Category II structures and 15% for Category III structures. It is reasonable to expect Category III structures to perform better in design earthquakes as well, with less structural damage.

Review of San Francisco Department of Building Inspection records indicates that most new office towers in San Francisco are being designed to meet Risk Category III requirements, while most new residential towers in the same San Francisco neighborhoods are being designed to meet Risk Category II requirements.

What are the expected cost consequences of using Risk Category III instead of Category II for a new concrete ductile core high-rise, say 15-40 stories tall, built on non-fill soil in San Francisco? Review of recently completed designs that have been approved by San Francisco’s Department of Building Inspection indicate that the price differential for additional steel and concrete should be on the order of three to five percent of total project costs.

3. RAMIFICATIONS OF DESIGNING NEW CONCRETE DUCTILE CORE HIGH-RISES TO MEET RISK CATEGORY III PERFORMANCE STANDARDS.

Research at the Pacific Earthquake Engineering Center indicates that over intermediate time frames (e.g., 50 years), compared to lighter structures, certain structural systems will prove far more resilient and much less costly to repair when exposed to foreseeable moderate earthquake demands; and the savings usually are far in excess of the three to five percent (or more) of additional construction costs that may be required for the better system during original construction. [15] It is reasonable to assume that the same will be true when the direct and indirect costs of earthquake repair for Risk Category III structures are compared to those of Risk Category II structures over the next 50 years and beyond. It is highly likely that Risk Category III structures will provide a better return on investment than Risk Category II structures if both are exposed to moderate, strong or severe earthquakes in San Francisco and Los Angeles during their service lives.

In the legal arena, the owner who has chosen to pursue the Risk Category III design path should be better able to reduce his or her possible exposure to legal liability for unsatisfactory seismic performance because the owner may be in a better position to demonstrate that he or she reasonably relied upon the technical advice of a competent structural consultant. In California, for instance, the basic rule of tort liability for property owners (including an owner of a new concrete ductile core high-rise) is that the owner must use ordinary care in the management of his or her property to prevent injury to another. [16] This means that the owner of a concrete ductile core high-rise must act to prevent unsatisfactory seismic performance that may result from foreseeable earthquakes. Unsatisfactory performance in a downtown San Francisco concrete ductile core high-rise could well include a hypothetical partial collapse causing serious injury and death to visitors when the facility is exposed to peak ground acceleration on the order of .27 gravity (most structural consultants would not expect to see partial collapse at that level of ground-shaking). In California’s leading legal precedent concerning owner liability for poor seismic performance, the California Court of Appeal ruled that the test for the trier of fact (often a jury) is whether the owner has acted as a reasonable person in view of the probability of injury. Myrick v. Mastagni (2d District 2010) 185 Cal App. 4th (2010).

In the Myrick case, the owners of a commercial building were found liable for the deaths of two women who were struck by a collapsing roof during moderate shaking during the 2003 San Simeon earthquake. A jury required owners to pay $2 million in compensation mainly because the owners failed to act promptly to increase the seismic capacity of their building (by retrofit) after becoming aware of its seismic vulnerability. The owners appealed on the theory that they had no duty to retrofit until 2018, the deadline established by local municipal ordinance and, as a matter of law, owners’ duty “was limited to compliance with the ordinance.” The appellate court rejected that argument, reasoning that in California the “general rule is that statutory compliance is not a complete defense in a tort action.” Among other things, “a statute, ordinance or regulation defines a minimum standard of conduct” and mere adherence to that minimum standard “does not preclude a finding that a reasonable person would have taken additional precautions under the circumstances.” Myrick, supra, 6 Cal 4th 539, 547-548.

In our hypothetical collapse scenario, the owner would likely not avoid a jury trial by arguing, as a matter of law, that he or she was insulated from liability for wrongful death or injury simply because owner chose to develop the high-rise as a Risk Category II structure in accordance with AB-083 and California’s Building Code, as adopted by San Francisco. These most likely would be treated as “minimal standards” by the trial court and the jury would be authorized to consider whether “additional precautions” should have been taken in order to satisfy the “reasonable person” standard of care. Ordinarily, owner and his consultants would be required to testify as to how owner relied upon the advice of the consultants concerning which performance standards, Risk Category II or III, were selected. Common sense dictates that if all other factors are held constant, the legal exposure of the owner who relies on his or her consultants to choose Category III standards will be more favorable to owner than if he or she chooses Category II standards. In most instances, the difference in legal exposure alone will be well worth the expected three to five percent increase in original construction costs.
4. ADDED VALUE FOR THE POST 2015 FRAMEWORK FOR DISASTER RISK REDUCTION AND CONCLUSIONS

The seismic capacity of new concrete ductile core high-rises will be increased if owners choose to have their structural consultants develop designs to meet ASCE 7-10 Risk Category III performance criteria instead of Risk Category II criteria. The extra original construction costs associated with the increased seismic capacity should yield advantageous reductions in repair costs and beneficial reduction in legal exposure for owner over the medium-term in light of the foreseeable seismic demands to which the high-rise will be exposed. In addition, risk of wrongful death and serious personal injury to visitors, inhabitants and other third parties will be reduced. As a policy matter, community resilience should be enhanced by adhering to Risk Category III. Additional technical research into the nature of cost increases associated with choosing Risk Category III over Risk Category II (mostly concrete and steel) would help owners quantify the differences in the two design approaches.

5. REFERENCES


[4] Yanev & Thompson, supra at p. 95.

[5] Yanev & Thompson, supra at p. 95.

[6] Yanev & Thompson, supra at p. 95.

[7] Yanev & Thompson, supra at p. 95.


[9] International Building Code, Section 104.11. In San Francisco, the operative provision is Section 104.2.8 of the San Francisco Building Code. See also, ASCE 7-10, section 11.1.4.


[13] ASCE 7-10, section 1.5.1 and Table 1.5-2.

[14] ASCE 7-10 Commentary, p. 321 and Figure C1-1.
