SEAONC RECOMMENDED ADMINISTRATIVE BULLETIN FOR SAN FRANCISCO

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SUBJECT : Seismic Design and Review Procedures for New Tall Buildings

TITLE : Requirements and Guidelines for the Seismic Design and Review of New Tall Buildings using Non-Prescriptive Seismic-Design Procedures

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PURPOSE : The purpose of this Administrative Bulletin (AB) is to present requirements and guidelines for the seismic structural design, Seismic Peer Review, and building permit submittals for new tall buildings in San Francisco that use non-prescriptive seismic design procedures.

Commentary: These requirements and guidelines have been established to help Project Sponsors and Engineers of Record (EOR) understand the Department of Building Inspection's expectations with regard to Seismic Peer Review, building permit submittals, and seismic structural design for new tall buildings designed using non-prescriptive seismic design procedures.

REFERENCES :

2001 *San Francisco Building Code (SFBC)*
- Section 104.2.5 Alternate materials, alternate design and methods of construction
- Section 1605.2 Rationality
- Section 1629.10 Alternative procedures

ASCE, 2005, *Minimum Design Loads for Buildings and Other Structures* (ASCE/SEI 7-05), Prepared by the Structural Engineering Institute of the American Society of Civil Engineers, Reston, Virgina.

SEAOC, 1999a, *Recommended Lateral Force Requirements and Commentary (Blue Book),* Seismology Committee, Structural Engineers Association of California, Sacramento California.

SEAOC, 1999b, "Project Design Peer Review" (Chapter 4, October 1995) *Recommended Guidelines for the practice of Structural Engineering in California*, Structural Engineers Association of California, Sacramento, California

SEAONC, 1999, *Contractual Provisions to Address the Engineer's Liability when Using Performance-Based Seismic Design*, Structural Engineers Association of Northern California, San Francisco, California, 7 pages, June

SEAOC, 2001, "Seismology Committee Background and Position Regarding

1997 UBC Eq. 30-7 and Drift," Structural Engineers Association of California, Sacramento California, September (http://www.seaoc.org/Pages/committees/seismpdfs/UBC/30_7.pdf)

1. SCOPE

This Administrative Bulletin presents requirements and guidelines for Seismic Peer Review, building permit submittals, and seismic structural design for new tall buildings in San Francisco that use non-prescriptive seismic design procedures.

A non-prescriptive seismic design is one that takes exception to one or more of the prescriptive requirements of the SFBC related to seismic design by invoking Section 104.2.8, 1605.2, and/or 1629.10.1 of the SFBC, which permit alternative (i.e., non-prescriptive) seismic design procedures.

For the purposes of this Administrative Bulletin, tall buildings are defined as those with h_n greater than 160 feet above average adjacent ground surface.

The height, h_n is defined in the SFBC as the height of Level *n* above the Base. Level *n* is permitted to be taken as the roof of the structure, excluding mechanical penthouses and other projections above the roof whose mass is small compared with the mass of the roof. The Base is permitted to be taken at the level of the average ground surface adjacent to the structure

Procedures other than those presented herein may be acceptable pursuant to the approval of the Director.

Commentary: SFBC Sections that permit non-prescriptive or "alternative" seismic design procedures are reproduced below:

104.2.8 Alternate materials, alternate design and methods of construction. The provisions of this code are not intended to prevent the use of any material, alternate design or method of construction not specifically prescribed by this code, provided any alternate has been approved and its use authorized by the building official.

The building official may approve any such alternate, provided the building official finds that the proposed design is satisfactory and complies with the provisions of this code and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in suitability, strength, effectiveness, fire resistance, durability, safety and sanitation.

The building official shall require that sufficient evidence or proof be submitted to substantiate any claims that may be made regarding its use. The details of any action granting approval of an alternate shall be recorded and entered in the files of the code enforcement agency.

1605.2 Rationality. Any system or method of construction to be used shall be based on a rational analysis in accordance with well-established principles of mechanics. Such analysis shall result in a system that provides a complete load path capable of transferring all loads and forces from their point of origin to the load-resisting elements.

1629.10.1 [Alternative Procedures] General. Alternative lateral force [i.e., seismic design] procedures using rational analyses based on well-established principles of mechanics may be used in lieu of those prescribed in these provisions.

This administrative bulletin is applicable to the 2001 SFBC. In 2008, San Francisco is scheduled to adopt a new building code based on the 2006 International Building Code. At such a time, applicability of specific requirements of this bulletin to the new code should be reviewed, in particular with respect to issues such as minimum base shear and construction quality assurance plans.

The requirements and guidelines of this bulletin are written specifically for San Francisco. Any application to other locations and jurisdictions should consider appropriate modifications, for example, to account for local seismic hazard issues (including near fault effects), different governing building codes, or different building authority practices.

This administrative bulletin is written to address only non-prescriptive seismic designs of tall buildings. Should the Director deem it appropriate to require Seismic Peer Review of a different building type or a prescriptive design, some sections of this bulletin may be applicable. Additional recommendations for Seismic Peer Review are provided by SEAOC [1999b].

2. SEISMIC PEER REVIEW PANEL

For each project, a Seismic Peer Review Panel (SPRP) shall be convened. The SPRP is to provide an independent, objective, technical review of those aspects of the structural design of the building that relate to seismic performance, according to the requirements and guidelines described in this Administrative Bulletin, and to advise the Director whether the design generally conforms to the intent of the SFBC provisions referenced in Part 1 of this Administrative Bulletin.

The SPRP participation is not intended to replace quality assurance measures ordinarily exercised by the EOR in the structural design of a building. Responsibility for the structural design remains solely with the EOR, and the burden to demonstrate conformance of the structural design to the intent of the SFBC provisions referenced in this Administrative Bulletin resides with the EOR. The responsibility for conducting Structural Plan Check Review resides with the Director and any Plan Check Review consultants.

Qualifications and selection of panel members

Except when determined otherwise by the Director, the SPRP should include a minimum of three members with recognized expertise in relevant fields, such as structural engineering, earthquake engineering research, performance-based earthquake engineering, nonlinear response history analysis, tall building design, earthquake ground motion, geotechnical engineering, geological engineering, and other such areas of knowledge and experience relevant to the issues the project poses.

The SPRP members shall be selected by the Director based on their qualifications applicable to the Seismic Peer Review of the project. The Director may request the opinion of the Project Sponsor and EOR on proposed SPRP members, with the Director making the final decision on the SPRP membership. SPRP members shall bear no conflict of interest with respect to the project and shall not be part of the design team for the project. The SPRP provides their professional opinion to and acts under the instructions of the Director.

Peer Review Scope

The general scope of services for the SPRP shall be indicated by the Director. Based on this, the SPRP, either individually or as a team, shall include a written scope of work in their contract to provide engineering services. The scope of services should include review of the following: earthquake hazard determination, ground motion characterizations, seismic design methodology, seismic performance goals, acceptance criteria, mathematical modeling and simulation, seismic design and results, drawings and specifications.

The SPRP should be convened as early in the structural design phase as practicable to afford the SPRP opportunity to evaluate fundamental design decisions that could disrupt design development if addressed later in the design phase. Early in the design phase, the EOR, DBI, and the SPRP should jointly establish the frequency and timing of SPRP review milestones, and the degree to which the EOR anticipates the design will be developed for each milestone.

The SPRP shall provide written comments to the EOR and to the Director, and the EOR shall prepare written responses thereto. The SPRP shall maintain a log that summarizes SPRP comments, EOR responses to comments, and resolution of comments. The SPRP shall make the log available to the EOR and to the director as requested. At the conclusion of the review the SPRP shall submit to the Director a written report that references the scope of the review, includes the comment log, and indicates the professional opinions of the SPRP regarding the expected seismic performance of the structure and the design's conformance to the requirements and guidelines in this Administrative Bulletin. The Director may request interim reports from the SPRP at the time of interim permit reviews.

Commentary: None of the reports or documents from the SPRP are Construction Documents. Under no circumstances should letters or other documents from the SPRP be put into the EOR's drawings or reproduced in any other way that makes SPRP documents appear to be part of the Construction Contract Documents. The EOR is solely responsible for the Construction Contract Documents.

The Director will address differences of opinion between the EOR and the SPRP.

The EOR shall inform the Director of significant changes to the structural design, detailing, or materials made subsequent to the Peer Review, including during construction. At the discretion of the Director, such changes shall be reviewed by the SPRP and approved by the Director.

Compensation of the SPRP members shall be borne by the project sponsor. In the case that SPRP members contract with the project sponsor, the scope of services in the contract shall be approved by the Director. Any changes to the scope of services shall be approved by the Director.

Commentary: A number of jurisdictions contract directly with Seismic Peer Reviewers and pass the cost through to the Project Sponsor, an approach recommended by the Structural Engineers Association of Northern California. Currently the City of San Francisco procedures for procurement of professional services are not suited to this approach, so Seismic Peer Reviewers instead contract directly with the project sponsor. Even so, the SPRP provides their professional opinion to and acts under the instructions of the Director. .

3. SUBMITTAL REQUIREMENTS

Project submittals shall be in accordance with the SFBC and SFDBI interpretations, bulletins, and policies. In addition, documents relevant to the Seismic Peer Review shall be submitted to the Director and to the SPRP.

As early as practicable, the EOR shall submit to the Director an initial Seismic Design Criteria along with a description and initial drawings of the structure. The Seismic Design Criteria shall be consistent with the requirements of this bulletin, and shall be updated to reflect issues resolved in the Seismic Peer Review.

The Seismic Design Criteria shall describe the proposed building and structural system, proposed analysis methodology, and acceptance criteria. In addition, the Seismic Design Criteria shall include any proposed exceptions to the prescriptive provisions of the SFBC, modeling parameters, material properties, drift limits, component force capacities and deformation capacities. The Seismic Design Criteria shall be reviewed by the SPRP and approved by the Director. A summary of the EOR's final Seismic Design Criteria shall be included in the general notes of the structural drawings.

Commentary: A project sponsor intending to construct a tall building that uses non-prescriptive seismic-design procedures should inform the Director as early as possible so that the SPRP can be selected and the Peer Review begin in a timely fashion. Currently, for major projects, the Director requires a construction Quality Assurance Plan in accordance with Section 11.A.1.2 of ASCE/SEI 7-05. The QAP identifies components of the construction pursuant to the requirements of the SFBC that are subject to quality assurance procedures, and identifies special inspection, testing, and observation requirements to confirm construction quality.

4. SEISMIC DESIGN REQUIREMENTS

The EOR shall evaluate the structure at three levels of earthquake ground motion as indicated in the subsections below.

Commentary

The purpose of each level of seismic evaluation is as follows:

The Code-Level evaluation is used to identify the exceptions being taken to the prescriptive requirements of the SFBC and to define the minimum required strength and stiffness for earthquake resistance. Minimum strength is defined according to code minimum base shear equations, with a seismic design coefficient *R*, that may have a value different from that specified in the SFBC, within limits. Minimum stiffness is defined by requiring the design to meet code-specified drift limits, using traditional assumptions for effective stiffness. Providing a non-prescriptive seismic design with minimum strength and stiffness comparable to code-prescriptive designs helps produce seismic performance at least equivalent to the code. Minimizing the number of exceptions to prescriptive requirements also helps achieve this aim.

The Serviceability evaluation is intended to demonstrate that performance of the building for more frequent earthquakes is at-least equivalent to that for a code-prescriptive design. This evaluation is intended as a nominal check on performance related to continued occupancy or functionality, including such parameters as anticipated damage and required repair, but no performance guarantee for any earthquake is intended. It is not intended to set the minimum required strength of the structure.

The MCE-Level evaluation is intended to verify that the structure has an acceptably low probability of collapse under severe earthquake ground motions. The evaluation uses nonlinear response-history analysis to demonstrate an acceptable mechanism of nonlinear lateral deformation and to determine the maximum forces to be considered for structural elements and actions designed to remain elastic.

4.1 Code-Level Evaluation

The seismic structural design shall be performed in accordance with the prescriptive provisions of the SFBC, except for those provisions specifically identified by the EOR in the DCD as Code Exceptions.

The lower limits of SFBC Equations 30-6 and 30-7 in the calculation of the Elastic Response Base Shear apply to the scaling process of SFBC Section 1631.5.4. The value of *R* used shall be indicated in the DCD, and shall not be greater than 8.5.

If nonlinear response is anticipated under any of the MCE ground motions specified in Step 3, the EOR shall apply capacity design principles and design the structure to have a suitable ductile yielding mechanism under nonlinear lateral deformation. The Code-Level analysis shall be used to determine the required strength of the yielding elements. The EOR shall include in the DCD all assumptions and factors used in the application of capacity design principles.

The EOR shall demonstrate that the structure meets the story drift ratio limitations of the SFBC using a Code Level response-spectrum analysis and the following requirements:

- The design lateral forces used to determine the calculated drift need not include the minimum base shear limitation of SFBC Formulas 30-6 and 30-7
- Stiffness properties of non-prestressed concrete elements shall not exceed 0.5 times gross-section properties.
- Foundation flexibility shall be considered, using recommendations provided by the Geotechnical Engineer of Record that are defined in the DCD.
- The analysis shall account for P-delta effects.

Commentary

Code exceptions that have typically been taken for alternative designs of tall buildings in high-seismic zones include:

- Exceeding the height limitations of SFBC Table 16-N
- The reliability/redundancy factor, ρ , set to unity ($\rho = 1.0$).
- *R* factor used in Equation 30-7, different from that of the closest comparable system of SFBC Table 16-N.

The position statement by SEAOC [2001] gives background on the application of Formula 30-7 to the check of story drift ratio. The position statement recommends, and parallel code sections in ASCE/SEI 7-05 require, including the minimum forces of SFBC Formula 30-7 in the check of drift limits. However, the consensus of SEAONC's AB-083 Task Group for this Administrative Bulletin, approved by the SEAONC Board, is that Formula 30-7 need not be applied to the check of drift limits for tall buildings designed according to this bulletin, because the MCE-Level Evaluation of Section 4.3 includes a check of drift for site-specific ground motions. Such ground motions are required to take account of near-fault effects. The consensus of the task group is that this is an appropriate and more explicit way of addressing the intended purpose of applying Formula 30-7 to the check of drift limits.

Actual concrete stiffness properties may vary significantly from the value of 0.5 times gross-section properties referenced for the Code-Level check of story drift limits. This assumption is specified to provide a consistent requirement for minimum building stiffness. This requirement is intended to lead to earthquake serviceability performance related to story drift that is at least comparable to that expected of prescriptively-designed tall buildings designed to the SFBC.

4.2 Serviceability Evaluation

The EOR shall submit an evaluation demonstrating that ground motions having a 43-year return period are expected to result in serviceable behavior. Structural models used in such evaluation shall incorporate realistic estimates of stiffness and damping considering the anticipated levels of excitation and damage.

Commentary: Damage inferred from the serviceability analysis should typically not impair the occupancy or function of the building in a significant way. The damage inferred from the analysis may include minor and repairable cracking of concrete, masonry, and drywall elements. Analysis results indicating minor yielding of steel also may be permissible provided such results do not indicate appreciable permanent deformation or other damage requiring more than cosmetic repair. See Appendix G of SEAOC, 1999a for additional discussion of acceptable damage indications for Operational Performance.

It is the intent that, in usual cases, design of nonstructural components according to requirements of the building code will result in nonstructural component/system performance meeting the requirements of this section. In designs involving unusually large drifts or accelerations for the serviceability level of ground motion, additional verification may be warranted.

Where numerical analysis is used to demonstrate serviceability, the analysis model should represent behavior that is reasonably consistent with the expected performance. In typical cases it may be suitable to use a linear response spectrum analysis, with appropriate stiffness and damping, and with the earthquake demands represented by a linear response spectrum corresponding to the n-year return period hazard level. Where response history analysis is used, the selection and scaling of ground motion time series should comply with the requirements of SFBC 1631.6.1 with the serviceability level response spectrum used instead of the design basis earthquake response spectrum, and with the design demand represented by the mean of calculated responses for not less than seven appropriately selected and scaled time series.

As expressed by SEAONC [1999], it should be understood "that the current state of knowledge and available technology is such that the design profession's ability to accurately predict the earthquake performance of a specific building is limited and subject to a number of uncertainties." The occurrence of damage requiring repair or imparing function following any particular earthquake should not be interpreted as sole cause for questioning the proper implementation of this design provision.

4.3 MCE-Level Evaluation

Ground Motion: The ground motion representation for this step shall be the Maximum Considered Earthquake (MCE) as defined in SFBC Section 1655.

A suite of not less than seven pairs of appropriate horizontal ground motion time series shall be used in the analyses. The selection and scaling of these ground motion time series shall comply with the requirements of SFBC 1631.6.1 with the following modifications:

a) The MCE response spectrum shall be the basis for ground motion time series scaling instead of the Design Basis Earthquake (DBE) response spectrum.

b) Either amplitude-scaling procedures or spectrum-matching procedures may be used.

c) Where applicable, an appropriate number of the ground motion time series shall include near–fault effects such as velocity pulses producing relatively large spectral ordinates at relatively long periods.

Commentary: The procedures for selecting and scaling ground motion records, as presented here, represent the current state of practice. The procedures are written to retain some flexibility so that engineering judgment can be used to identify the best approach considering the unique characteristics of the site and the building.

Selection and scaling of earthquake ground motion records for design purposes is a subject of much current research. The EOR may wish to consider alternative approaches recently proposed; however, some of the proposed approaches have not been adequately tested on tall buildings so their adoption should only be considered with caution. Aspects of particular concern include the long vibration period of many tall buildings and the contributions of multiple vibration "modes" to key response quantities.

At near-fault sites, the average fault-normal response spectrum usually is larger than the average fault-parallel response spectrum due to the presence of the rupture directivity pulse in the fault-normal component of the ground motion. It is important to include in the suite of ground motions an appropriate number of motions that include near-fault effects so that design drift demands are appropriately determined, especially considering that Section 4.1 permits the design to be exempt from applying Equation 30-7 to drift calculations.

Mathematical Model: The three-dimensional mathematical analysis model of the structure shall conform to SFBC Section 1631.3.

The analyses shall consider the interaction of all structural and nonstructural components that materially affect the linear and nonlinear response of the structure to earthquake motions, including members not designated as part of the lateral-force-resisting system in the code-level analysis (Step 1 in this AB).

Commentary: This requires explicit modeling of those parts of the structural and non-structural systems that affect the dynamic response of the building. In addition, the effect of building response on all materially affected parts of the building shall be evaluated.

The stiffness properties of reinforced concrete shall consider the effects of cracking and other phenomena on initial stiffness.

Commentary: In addition to cracking, effective stiffness can be affected by other phenomena. These include bond slip, yield penetration, tension-shift effect, panel zone deformations, and other effects.

The effective initial stiffness of steel elements embedded in concrete shall include the effect of the embedded zone. For steel moment frame systems, the contribution of panel zone (beam-column joint) deformations shall be included.

The EOR shall identify any structural components for which demands for any of the response-history runs are within a range for which significant strength degradation could occur, and shall demonstrate that these effects are appropriately considered in the dynamic analysis.

Commentary: For typical situations, component strength degradation of more than 20% of peak strength should be considered significant.

P-Δ effects that include all the building dead load shall be included explicitly in the nonlinear response history analyses.

Documentation submitted for SPRP review shall clearly identify which components are modeled linearly and which components are modeled nonlinearly. For components that are modeled as nonlinear components, submitted documentation shall include suitable laboratory test results or analyses that justify the hysteretic properties represented in the model.

The properties of components in the analysis model shall be determined considering earthquake plus expected gravity loads. In the absence of alternative information, gravity load shall be based on the load combination $1.0D + L_{exp}$, where D is the service dead load and L_{exp} is the expected service live load.

Commentary: In typical cases it will be sufficient to take $L_{exp} = 0.1L$, where L is the code-prescribed live load without live load reduction.

The foundation strength and stiffness contribution to the building seismic response shall be represented in the model. The foundation strength and stiffness characterization shall be consistent with the strength and stiffness properties of the soils at the site, considering both strain rate effects and soil deformation magnitude.

Analysis Procedure: Three-dimensional nonlinear response history (NLRH) analyses of the structure shall be performed. Inclusion of accidental torsion is not required. When the ground motion components represent site-specific Fault Normal (FN) ground motions and Fault Parallel (FP) ground motions, the components shall be applied to the three-dimensional mathematical analysis model according to the orientation of the fault with respect to the building. When the ground motion components represent random orientations, the components shall be applied to the model at orientation angles that are randomly selected; individual ground motion pairs need not be applied in multiple orientations.

Commentary: Three-dimensional analyses are required to represent the inherent torsional response of the building to earthquake ground shaking. This is done by including in the NLRH model the actual locations and distribution of the building mass, stiffness, and strength. Accidental torsion is not required to be included in the NLRH analyses (accidental torsion is required for the code level analysis (step 1).

The EOR shall report how damping effects are included in the NLRH analyses. The equivalent viscous damping level shall not exceed 5%, unless adequately substantiated by the EOR.

Commentary: The effects of damping in an analysis depend on the type of damping model implemented. Some models may over-damp higher modes or have other undesirable effects.

For each horizontal ground motion pair, the structure shall be evaluated for the following load combination:

$$1.0D + L_{exp} + 1.0E$$

Alternative load combinations, if used, shall be adequately substantiated by the EOR.

Demands for ductile actions shall be taken not less than the mean value obtained from the NLRH. Demands for low-ductility actions (e.g., axial and shear response of columns and shear response of walls) shall consider the dispersion of the values obtained from the NLRH.

Commentary: In typical cases the demand for low-ductility actions can be defined as the mean plus one standard deviation of the values obtained from the NLRH. Procedures for selecting and scaling ground motions, and for defining the demands for low-ductility actions, should be defined and agreed to early in the review process.

Acceptance Criteria:

Calculated force and deformation demands on all components required to resist lateral and gravity loads shall be checked to ensure they do not exceed component force and deformation capacities. This requirement applies to those components designated as part of the lateral-force-resisting system in the code-level analysis (Step 1 in this AB), as well as those components not designated as part of the lateral-force-resisting system in the code-level analysis but deemed to be materially affected.

Commentary – Components not designated as part of the lateral-force-resisting system in the code-level analysis (gravity systems) may be subjected to substantial deformations and forces as they interact with the primary lateral-force-resisting system. Nonstructural elements such as cladding are evaluated according to code requirements. This AB does not require checking nonstructural components at the MCE level.

The EOR shall identify the structural components or actions that are designed for nonlinear seismic response. All other components and actions shall be demonstrated by analysis to remain essentially elastic.

Commentary: Essentially elastic response may be assumed for components when force demands are less than design strengths. Design strengths are defined as nominal strengths multiplied by strength reduction factors, where nominal strengths are calculated based on expected material properties, and strength reduction factors shall be as prescribed in the governing building code for non-ductile actions and shall be permitted to be taken as $\phi = 1.0$ for ductile actions. Alternative approaches to demonstrating essentially elastic response may be acceptable where appropriately demonstrated by the EOR.

For structural components or actions that are designed for nonlinear seismic response, the EOR shall evaluate the adequacy of individual components and their connections to withstand the deformation demands. Deformation capacities shall be based on applicable documents or representative test results, or shall be substantiated by analyses using expected material properties.

The average result, over the NLRH analyses, of peak story drift ratio shall not exceed 0.03 for any story.

All procedures and values shall be included in the DCD and are subject to review by the SPRP and approval by the Director.