An Alternative Procedure for Seismic Analysis and Design of Tall Buildings

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SUMMARY:
Building codes intend to provide for safe buildings by prescribing loads and material properties as well as structural detailing generally address all building types and construction. However, building codes may not provide for the most economical, efficient, and safe tall buildings because the codes are general and prescriptive in nature. Tall buildings are really a special class of buildings that have unique qualities and characteristics. Tall buildings are recognized to be designed with a different approach to meet safety and performance requirements, especially in regions with high seismic activity. To meet this need, an alternative procedure for seismic analysis and design of tall buildings in the Los Angeles region was developed by the Los Angeles Tall Buildings Structural Design Council (LATBSDC). The Council has been developing the alternative design procedure over eight years and recently published the third edition of the procedure.

Keywords: Tall buildings, performance-based engineering, seismic design, building codes, alternative procedure

1. INTRODUCTION

The 2011 LATBSDC procedure provides a performance-based earthquake engineering (PBEE) approach for seismic design and analysis of tall buildings with predictable and safe performance when subjected to strong earthquake ground motions. The intent of the procedure is to result in more accurate identification of the relevant demands on tall buildings thus providing for structures that effectively and reliably resist earthquake forces. The performance-based alternative procedure requires an in-depth understanding of ground shaking hazards, structural materials behavior, and nonlinear dynamic structural response. In particular, the implementation of this procedure requires proficiency in structural and earthquake engineering including knowledge of: seismic hazard analysis and the selection and scaling of ground motions; nonlinear dynamic behavior of structural and foundation systems; mathematical modeling capable of reliable prediction of nonlinear behavior; capacity design principles; and detailing of elements to resist cyclic inelastic demands, and assessment of element strength, deformation and deterioration under cyclic inelastic loading.

The aim is to provide: a more reliable seismic performance; reduced construction cost; relief from prescriptive design requirements that do not apply; accommodation of architectural features; and use of innovative structural systems and materials not currently allowed by the building code.

2. WHY IS AN ALTERNATIVE PROCEDURE NEEDED?

The basic reason why an alternative design procedure for tall buildings in seismic regions is needed is simply that our building codes are not currently adequate to address the nature and characteristics of tall buildings. The building codes are a “one size fits all” approach to the design of structures and especially to the seismic design of structures; the building codes apply to all buildings – short, medium or tall. Building codes are generally prescriptive in nature with rules about what structural systems or materials can be used and what material properties are acceptable. In general, modern building codes have produced buildings that have proven to be relatively resilient in recent earthquakes such as 2010 Offshore Maule, Chile earthquake and the 2011 Great East Japan (Tohoku) earthquake. However, each earthquake also finds the vulnerabilities of the building codes that were not previously recognized or known.

The overwhelming majority of construction worldwide consists of low-rise buildings. It is estimated that 93 percent of the buildings are less than 3 stories in height and 6 percent are between 4 and 13 stories in height; thus only 1 percent of all buildings are 14 stories and taller (Portland Cement Association, 2000). The percentage of really tall and super tall buildings (say 50 stories and taller) is much less. The performance provided by building codes has been calibrated to the past performance of the majority of structures (i.e., predominately low-rise buildings). Most building codes are based on linear analysis of buildings which is simply incapable of accurately predicting collapse and failure which are inherently nonlinear.

Tall buildings may 200 or more occupants per story or 20,000 occupants in a 100-story building. The consequence of the failure (collapse) in a tall building is much more severe than that in a low 1- to 3-story building.

Currently in the United States, the International Building Code (International Code Council, 2009) is the model building code. The IBC adopts by reference the ASCE 7-05 seismic provisions (ASCE, 2005). The commentary to ASCE 7-05 is found in FEMA 450 Part 2, Commentary (Building Seismic Safety Council, 2003); this commentary states that for buildings of ordinary occupancy, the intent of the provisions is to provide a low probability of collapse for buildings experiencing the Maximum Considered Earthquake (MCE) ground motions. The MCE ground motions are defined either as those ground motions having a 2 percent probability of being exceeded in 50 years (2,475-year mean recurrence interval) or, for sites near major active faults, 150 percent of the median ground motions resulting from a characteristic magnitude earthquake on that fault, whichever is less. In order to retain R coefficients and design procedures familiar to users of earlier US building codes, the IBC adopts a design-level earthquake shaking for purposes of evaluating strength and deformation that is two-thirds of the intensity of the MCE shaking. This two-thirds reduction in the design earthquake ground motions is in recognition that the R factors traditionally considered in prior US building codes incorporated an inherent margin of at least 1.5; i.e., buildings designed using these R factors should be able to resist ground shaking at least 150 percent of the design level without significant risk of collapse. However, the former codes were based on the seismic performance of the 99 percent of buildings and the record on the seismic performance of modern tall building systems is sparse. Modern tall buildings cannot be assured to perform as expected based on the performance of low- to mid-rise buildings. Tall buildings may possibly be over-designed due to this code based design process. In addition, the prescriptive restrictions of the building codes on building heights, structural systems, and materials may not allow for innovation, efficient design, enhanced safety and/or cost-effectiveness.

The 2009 edition of the IBC allows for the use of alternative materials, design and methods of construction and equipment in Section 104.11. This section states that "...an alternative material, design or method construction shall be approved where the building official finds that the proposed design is satisfactory and complies with the intent of 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 quality, strength, effectiveness, fire resistance, durability and safety." Furthermore, ASCE 7-05 (2006) and ASCE 7-10 (2010) also recognize alternative means of compliance so that "...buildings and other structures, and all parts thereof, shall be designed and constructed with adequate strength and stiffness to provide structural stability, protect non-structural components and systems from unacceptable damage and meet the serviceability requirements..."

Thus the alternative means of compliance provides a vehicle by which "Performance-Based Earthquake Engineering" may be used to provide a rational analysis based on well-established but complex principles of mechanics in lieu of prescriptive code provisions that will result in tall buildings which effectively and reliably resist earthquake forces.

3. ALTERNATIVE ANALYSIS AND DESIGN PROCEDURES FOR TALL BUILDINGS

The current approach to performance-based design in the United States relies on component-based evaluation as delineated in the FEMA 356 (2000) and ASCE 41-06 (2006) documents. In the component-based approach, each component of the building (beam, column, wall segment, etc.) is assigned a normalized force/moment - deformation/rotation relation such as the one shown in Figure 3.1 where segment AB indicates elastic behavior, point C identifies the onset of loss of capacity, segment DE identifies the residual capacity of the component, and point E identifies the ultimate inelastic deformation/rotation capacity of the component. Components are classified as primary (P) or secondary (S) and assigned with different deformation limits corresponding to various performance objectives. The vertical axis in this figure represents the ratio of actual force or moment to the yield force or moment. Primary components are those which are relied upon to provide lateral load resistance at maximum building deformation. Secondary elements are those that are relied upon to resist only gravity loads at maximum building deformation. Thus in a building with coupled shear walls, walls and coupling beams are primary components. The beam column framing system carrying gravity loading is secondary. IO, LS, and CP indicate the target building performance levels for Immediate Occupancy, Life Safety, and Collapse Prevention, respectively.

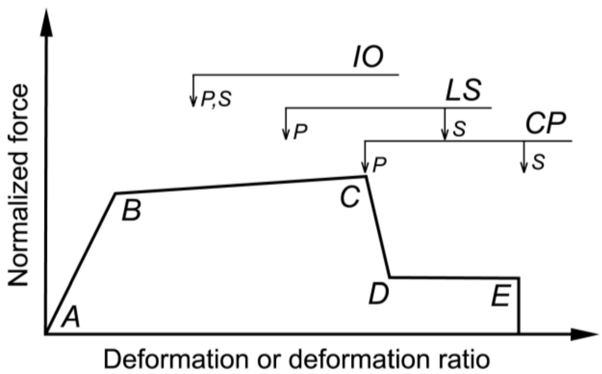


Figure 3.1. Generalized component force-deformation relations for depicting modelling and acceptance criteria in FEMA 356 (2000) and ASCE 41-06 (2006) documents

Although ASCE 41-06 is officially intended for seismic rehabilitation of existing structures, its component-based performance limits for NDP are routinely referenced by guidelines for performance based design of tall buildings. Engineers, who believe that ASCE 41-06 tabulated limits are not applicable or too conservative for their intended component, perform laboratory testing and obtain confirmation of behavior for their component subject to approval by peer reviewers and approval agencies.

To achieve meaningful performance-based earthquake engineering design of a tall building, the following are needed (Naeim, 2010):

1. A set of reasonable performance objectives.
2. A set of rational design procedures.
3. A set of earthquake ground motion records that are consistent with the hazard levels considered.
4. A set of sound performance evaluation procedures.

In 2005, the Los Angeles Tall Buildings Structural Design Council first published and distributed “An Alternative Procedure for Seismic Analysis and Design of Tall Buildings Located in the Los Angeles Region” (LATBSDC, 2005) based on performance-based earthquake engineering principles. This was a document developed by a consensus process involving many prominent academic and practicing structural engineers. The purpose of the document was to provide a rational procedure by which new tall buildings could be designed and constructed in the Los Angeles region to take advantage of more efficient and innovative structural systems and use the latest experimental testing results on structural elements, components, and connections not allowed by the existing building code at the time.

Following the LATBSDC 2005 Alternative Procedure, other documents regarding alternative procedures for tall building design were produced by other groups and institutions including the Structural Engineers Association of Northern California (2007), the Council on Tall Buildings and Urban Habitat (Willford, Whittaker and Klemencic, 2008), and the Pacific Earthquake Engineering Research Center (2010).

In the meantime, the LATBSDC has continued to update its Alternative Procedure and has produced a second edition in 2008 (LATSDC, 2008) and a third edition in 2011 (LATBSDC, 2011).

4. THE LATBSDC ALTERNATIVE ANALYSIS AND DESIGN PROCEDURE

The need for an alternative procedure grew out of the realization that a performance-based approach for seismic analysis of design of tall buildings was needed to provide predictable and safe performance when subjected to earthquake ground motions. Certain prescriptive provisions in the building codes were recognized as unnecessary for application to tall buildings and the deficiencies in the codes might inhibit proper behaviour of tall buildings. The development of an alternative procedure would be achieved by replacing a small number of code provisions with a comprehensive performance-based linear and nonlinear evaluation of system performance to provide reliable and effective performance of tall buildings. The alternative procedure not only lays out the path for analysis and design, but also addresses qualifications of the design engineers and a peer review process. This paper presents a brief summary of the procedure.

4.1. Performance Objective

The LATBSDC PBEE design procedure sets two performance objectives:

1. Serviceable behaviour when subjected to frequent earthquake ground motions defined as having a 50 percent probability of being exceeded in 30 years (43-year recurrence interval).
2. A low probability of collapse under extremely rare earthquake ground motions defined as having a 2 percent probability of being exceeded in 50 years (2,475-year recurrence interval) with a deterministic cap. [The extremely rare earthquake ground motions are the same as the Maximum Considered Earthquake (MCE) ground motions defined in ASCE 7-05.]

The evaluation is to be performed using three-dimensional dynamic response analysis. The intent of the LATBSDC serviceability performance objective is to have the building structural and nonstructural components retain their general functionality during and after frequent events. Repairs, if necessary, are expected to be minor and could be performed without substantially affecting the normal use and functionality of the building. After frequent earthquakes the building structure and nonstructural components associated with the building are expected to remain essentially elastic. Essentially elastic response may be assumed for elements when force demands generally do not exceed provided strength; a linear or nonlinear dynamic response analysis procedure may be used. When demands exceed provided strength, this exceedance shall not be so large as to affect the residual strength or stability of the structure. The intent of the LATBSDC collapse prevention objective is to validate that collapse does not occur when the building is subjected to MCE ground motions. Demands are checked against both structural members of the lateral force resisting system and other structural members. Cladding and their connections to the structure must accommodate MCE displacements without failure. For the collapse prevention analysis, the analysis should use a three-dimensional nonlinear dynamic analysis procedure.

4.2. Design Procedures

In this section, the design procedures of the LATBSDC alternative analysis and design procedure for tall buildings are described.

4.2.1. Analysis Methods

A three-dimensional mathematical model of the physical structure is used that represents the spatial distribution of the mass and stiffness of the structure to an extent that is adequate for the calculation of the significant features of the building's dynamic response. Structural models are required to incorporate realistic estimates of stiffness and damping considering the anticipated levels of excitation and damage. Generally, expected material strengths (see Table 4.1) are used throughout except when calculating the capacity of brittle elements where specified strength values are used. For serviceability analyses, realistic values of stiffness should be used such as those listed in Table 4.2. Given the current state of modelling capabilities and available software systems, there is no reason to estimate the actual three-dimensional behaviour of tall buildings by relying on approximate two-dimensional models.

Table 4.1. Suggested Expected Material Strengths

Material		Expected Strength
Structural steel	Hot-rolled structural shapes and bars	
	ASTM A36/A36M	$1.5F_y$
	ASTM A572/A572M Grade 42 (290)	$1.3F_y$
	ASTM A992/A992M	$1.1F_y$
	All other grades	$1.1F_y$
	Hollow structural sections	
	ASTM A500, A501, A618 and A847	$1.3F_y$
	Steel pipe	
	ASTM A53/A53M	$1.4F_y$
	Plates	$1.1F_y$
	All other products	$1.1F_y$
Reinforcing steel		1.17 times specified f_y
Concrete		1.3 times specified f'_c

Table 4.2. Reinforced Concrete Stiffness Properties

Element	Serviceability and Wind	MCE Level (Nonlinear Models)
Structural Walls	Flexural – 0.9 I_g	Flexural – 1.0 E_c *, **
	Shear – 1.0 A_g	Shear – 0.5 A_g
Basement Walls	Flexural – 1.0 I_g	Flexural – 0.8 I_g
	Shear – 1.0 A_g	Shear – 0.8 A_g
Coupling Beams	Flexural – 0.50 I_g	Flexural – 0.2 I_g
	Shear – 1.0 A_g	Shear – 1.0 A_g
Diaphragms (in-plane only)	Flexural – 0.50 I_g	Flexural – 0.25 I_g
	Shear – 0.8 A_g	Shear – 0.25 A_g
Moment Frame Beams	Flexural – 0.7 I_g	Flexural – 0.35 I_g
	Shear – 1.0 A_g	Shear – 1.0 A_g
Moment Frame Columns	Flexural – 0.9 I_g	Flexural – 0.72 I_g
	Shear – 1.0 A_g	Shear – 1.0 A_g

*Modulus of Elasticity is based on the following equations:

$E_c = 57000\,(f_c')^{0.5}$ for $f_c' \leq 6000$ psi

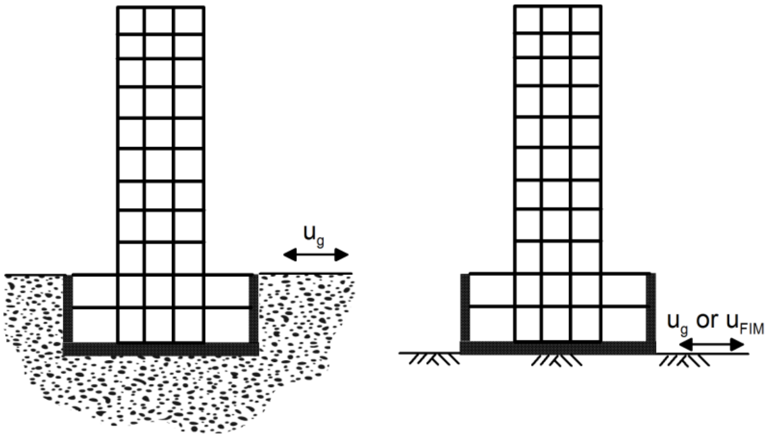
$E_c = 40000\,(f_c')^{0.5} + 1\text{x}10^6$ for $f_c' > 6000$ psi (per ACI 363R-92)

**Note that this value assumes nonlinear fiber elements are used which automatically account for cracking of concrete because the concrete fibers have zero tension stiffness.

4.2.2 Modelling Requirements

As mentioned earlier, three-dimensional mathematical models of the physical structure should be used that represent the spatial distribution of the mass and stiffness of the structure to capture the building's dynamic response. The structural model should incorporate realistic estimates of stiffness and damping consistent with the anticipated levels of ground motion excitation and damage. The percentage of critical damping used in linear models (for serviceability evaluations) should not exceed 2.5 percent. Expected material properties should be used throughout.

For modelling subterranean structural systems that are part of the tall building, the LATBSDC alternative procedure allows for a simplified model to be used for structural analysis as shown in Figure 4.1. Soil springs need not be included in the model, but floor slab strength and stiffness should be reasonably included. Since the horizontal soil restraint is ignored, inclusion of the mass of the subterranean floors may substantially exaggerate the forces induced in the structure. Either a small portion of the mass of the subterranean floors should be included or completely ignored in the analysis. Although more complicated and seemingly more realistic models may be available, the substantially greater effort required may not necessarily result in more accurate results (Naeim et al. 2010).



(a) Actual building system (b) Model to be used for analysis

Figure 4.1. Subterranean structural model

Beam-column joints in moment-resisting frames should account for the flexibility of the joint, including the panel zone. Floor diaphragms should be included in the model where necessary using realistic stiffness rigidity or flexibility of the diaphragms. Regardless of relative rigidity or flexibility, the flexibility of diaphragms with significant force transfer (such as at podium or setback levels) should be explicitly included in the model. Realistic assumptions should be used to represent the fixity of column bases.

4.2.3. Capacity Design

The LATBSDC alternative procedure requires that the building design be based on capacity design principles and analytical procedures described in the document. The capacity design criteria are to be described in the project-specific seismic design criteria. The structural system for the building is to be clearly demonstrated to have well defined inelastic behaviour where nonlinear action is limited to the clearly identified members and regions and all other members are stronger than the elements designed to experience nonlinear behaviour.

All actions (forces, moments, strains, displacements, or other deformations) are to be evaluated either as force-controlled or deformation-controlled actions. Deformation-controlled actions are those where the behavior is ductile and reliable inelastic deformations can be reached without substantial strength loss. Force-controlled actions are those where the behavior is more brittle and reliable inelastic deformations cannot be reached. Thus force controlled-actions must be strong enough to ensure that nonlinearity is limited to deformation-controlled actions. Force-controlled actions include, but may not be limited to:

- Axial forces in columns (including columns in gravity frames).
- Compressive strains due to flexure, axial, or combined flexure and axial actions in shear walls or piers that do not have adequate confinement.
- Compressive strains due to combined axial and flexural actions in shear walls or piers of shear walls where the axial demand exceeds that associated with the balanced point for the cross section.
- Shear in reinforced concrete beams (other than diagonally reinforced coupling beams), columns, shear walls, and diaphragms.
- Punching shear in slabs and mat foundations without shear reinforcing.
- Force transfer from diaphragms and collectors to vertical elements of the seismic-force-resisting system.
- Connections that are not designed explicitly for the strength of the connected components.

Nonlinear action shall be permitted only in clearly delineated zones. These zones shall be designed and detailed as ductile and protected zones so that the displacements, rotations, and strains imposed by the MCE event can be accommodated with enough reserve capacity to avoid collapse.

4.2.3.1 Serviceability Evaluation

The purpose of this evaluation is to demonstrate that the building’s structural systems and non-structural components and attachments will retain their general functionality during and after a service level event. Repairs, if necessary, are expected to be minor and could be performed without substantially affecting the normal use and functionality of the building. The intent of this evaluation is not to require that a structure remains within the idealized elastic behaviour range if subjected to a serviceability level of ground motion. Minor post-yield deformations of ductile elements are allowed provided such behaviour does not suggest appreciable permanent deformation in the elements or damage that will require more than minor repair. The service level design earthquake is given in the alternative design procedure as being an event having a 50 percent probability of being exceeded in 30 years (43-year recurrence interval). The service level design earthquake is defined in the form of a site-specific, 2.5 percent-damped, linear, uniform hazard acceleration response spectrum. Either linear response spectrum or nonlinear dynamic response analyses may be used for the evaluation. The analyses should account for the P-delta effects and the effects of inherent and accidental torsion should be considered. If a nonlinear dynamic response analysis if performed, the mathematical model for the serviceability evaluation should be the same as used for the collapse prevention evaluation under the MCE ground motions; in addition, the ground motion time series should be selected and scaled according to the provisions of Section 16.1.3 of ASCE 7-05. The acceptability criteria for either analysis method used is the story drift in any story should not exceed 0.5 percent of the story height.

For an elastic response analysis, the structure shall be deemed to have satisfied the acceptability criteria for story drift if none of the elastic demand ratios (ratio of Elastic Response Parameters (ERP) to the applicable LRFD limits for steel members or USD limits for concrete members using $\phi = 1.0$) exceed either a value of 1.50 for deformation-controlled actions or a value of 0.70 for force-controlled actions.

For nonlinear dynamic response analysis, a minimum of three pairs of horizontal ground motion time series scaled per the provisions of ASCE 7-05 should be used; seven or more pairs are recommended in the alternative provisions. If less than seven pairs are sued, the maximum response values should be used for the evaluation; otherwise, the average of the maximum values should be used.

4.2.3.2 Collapse Prevention Evaluation

The MCE ground motions are to be represented by uniform hazard response spectra and coefficients derived from these spectra should be determined in accordance with the procedure described in Chapter 21 of ASCE 7-05. A suite of seven or more pairs of appropriate horizontal ground motion time series should be used in the analyses. The ground motion time series and their selection should comply with the requirements of ASCE 7-05 Section 16.1.3. Either amplitude-scaling procedures or spectrum-matching procedures may be used. Where applicable, an appropriate number of the ground motion time series should include near-fault and directivity effects such as velocity pulses producing relatively large spectral ordinates at relatively long periods.

The collapse prevention evaluation requires a three-dimensional nonlinear dynamic response analysis. P-delta effects are to be included and all building dead load should be explicitly included. Besides the designated elements and components of the lateral force resisting system, all other elements and components that in combination significantly contribute to or affect the total or local stiffness of the building should be included in the mathematical model. Expected material properties should be used in the mathematical model to provide realistic results (see Table 4.1); ϕ should be taken as 1.0. The stiffness properties of reinforced concrete should consider the effects of cracking on initial stiffness. All structural elements for which demands for any of the nonlinear dynamic response analyses are within a range for which significant strength degradation could occur, should be identified and the corresponding effects appropriately considered in the dynamic analysis.

Significant hysteretic energy dissipation should be captured by use of inelastic elements in the model. A small amount of equivalent or combined mass and stiffness proportional damping may also be included. The effective additional modal or viscous damping should not exceed 2.5 percent of critical damping for the primary modes of response. Damping effects of structural members that are not incorporated in the analysis model (such as gravity framing), foundation-soil interaction, and non-structural components that are not otherwise modelled in the analysis can be incorporated through equivalent viscous damping.

Components may be analyzed using the collapse prevention values for primary elements published in ASCE 41-06 with Supplement 1 (American Society of Civil Engineers, 2006 and Elwood et al., 2007) for nonlinear response procedures, or may be based on analytical models that are validated by experimental evidence. The ASCE 41-06 component force versus deformation curves may be used as modified backbone curves, with the exception that the drop in resistance following the point of peak strength should not be as rapid as indicated in the ASCE 41-06 curves as it may cause numerical instability in the analysis. Alternatively, the modelling options presented by Applied Technology Council (2010) may be used.

Response modification devices (such as seismic isolation, damping and energy dissipation devices) should be modelled based on data from laboratory tests representing the severe conditions anticipated in MCE level ground motions. Foundation components that have significant flexibility or will experience significant inelastic behaviour (such as rocking or uplift) should be modelled using the same approach as for components of the superstructure.

In the three-dimensional nonlinear dynamic response analysis, the effect of accidental torsion should be examined if the serviceability analysis indicates that torsion is a concern. If the ground motion components represent site-specific fault-normal and fault parallel ground motions, the components should be applied to the model according to the orientation of the earthquake fault with respect to the building orientation. When the ground motions represent random orientations, the components should be applied to the model at orientation angles that are randomly selected, but individual ground motion pairs need not be applied in multiple orientations.

The acceptance criteria for the collapse level evaluation are performed at the component and global levels. At the component level, two types of actions must be considered: (1) force-controlled actions and (2) deformation-controlled actions.

For force-controlled actions, there are critical actions and non-critical actions. Force-controlled critical actions are those in which the failure mode poses severe consequences to structural stability under gravity and/or lateral loads. In the LATBSDC alternative procedure, force-controlled critical actions should satisfy Eqn. 4.1:

$$F_{uc} \leq \phi F_{n,e} \tag{4.1}$$

where F_{uc} = 1.5 times the mean value of demand, $F_{n,e}$ = nominal strength as computed from applicable codes but based on expected material properties, and $\phi = 1.0$. For non-critical force-controlled actions where failure of the component does not result in structural instability or potentially life-threatening damage, the non-critical actions should satisfy Eqn. 4.2:

$$F_u \leq \phi F_{n,e} \tag{4.2}$$

where F_u = the mean value of demand, $F_{n,e}$ = nominal strength as computed from applicable codes but based on expected material properties, and $\phi = 1.0$.

For deformation-controlled actions, the demand values (member total deformations) are allowed to be taken as the average of the values determined from analysis using seven or more pairs of time histories. The global acceptance criteria include peak transient and residual story drift and loss of story strength. For the peak transient drift in each story, the mean of the absolute value of the peak transient drift ratios from the suite of analyses should not exceed 0.03. In each story, the absolute value of the maximum story drift ratio from the suite of analyses should not exceed 0.045. For residual drift in each story, the mean of the absolute values of residual drift ratios from the suite of analyses should not exceed 0.01 and the maximum residual story drift ratio in any analysis should not exceed 0.015. The criterion for loss in story strength is that in any nonlinear dynamic response analysis, the deformation imposed at any story should not result in a loss of total story strength that exceeds 20 percent of the initial strength.

4.2.4 Specific Provisions for Reinforced Concrete Structures

The LATBSDC alternative procedure generally accepts the requirements of the American Concrete Institute in ACI 318-08 (2008). The alternative procedure has some exceptions and these are presented in the document.

4.3 Peer Review

A key element of the analysis and design procedure is that each project should have a Seismic Peer Review Panel (SPRP) convened to provide an independent, objective technical review of the structural design of the building that relate to seismic performance according the requirements and guidelines of the alternative procedure. The SPRP can also advise the Building Official whether the design generally conforms to the intent of the alternative procedure and other requirements set by regulation and the Building Official. The SPRP should consist of members with recognized expertise in relevant fields, such as structural engineering, earthquake engineering research, performance-based earthquake engineering, nonlinear dynamic response analysis, tall building design, earthquake ground motions, geotechnical engineering, engineering geology and other relevant expertise. The SPRP participation is not intended to replace quality control or quality assurance measures that are the responsibility of the Engineer of Record (EOR) in the structural design of the building. The responsibility for the structural design remains solely with the EOR to demonstrate conformance of the structural design to the intent of the Alternative Procedure and other regulatory requirements. The responsibility for the structural plan review resides with the Building Official.

4.4 Seismic Instrumentation

The LATBSDC Alternative Procedure has provisions for seismic instrumentation of the tall building. The purpose for the instrumentation is to provide valuable data that can enhance understanding tall building performance during earthquakes, improve computer modelling techniques, and enable damage detection for post-earthquake condition assessment. Guidelines for instrumentation are given in the alternative procedure.

5. CONCLUSIONS

The 2011 edition of the Los Angeles Tall Buildings Design Council alternative analysis and design procedure provides guidance for design of tall buildings in the Los Angeles region. Although specifically written for a local region, the document could be used in other seismically active regions as a rational alternative analysis and design procedure for the design of tall buildings. Copies of the Alternative Procedure are available from the LATBSDC website at www.tallbuildings.org.

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