DEVELOPMENT OF DESIGN CRITERIA FOR ELASTIC RESPONSE TO EARTHQUAKES

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SUMMARY

This paper develops alternate seismic design criteria for tall buildings which do not utilize the ductile frames required by current codes. Much higher elastic, or nearly elastic, design values are suggested to compensate for the reduction in proven ductility.

INTRODUCTION

Current codes utilize low seismic loads with energy absorption capacity provided by Ductile Moment Resisting Space Frames (DMRSF). The design of the lateral load resisting systems for tall buildings can be governed by wind design criteria. The resulting lateral load resisting systems are often not dependent on DMRSF and can elastically withstand a larger than code seismic event. This would indicate a reduced ductility demand. In addition, current code criteria for the design of Dual Systems may result in designs which are not capable, if not carefully detailed, of withstanding very large seismic events. Alternate seismic design criteria for tall buildings could provide more economic and possibly safer designs.

Current Codes

The 1982 Uniform Building Code (Ref. 1), the American National Standard A58.1-1982 (Ref. 2) and the Applied Technology Council ATC3-06 (Ref. 3) use artificially low minimum seismic loads. They also prescribe specialized systems to assure the inelastic energy dissipation that will be required by larger earthquakes. For "Tall Buildings", either 160' or 240' tall, only two choices of lateral load resisting systems are allowed. Either a 100% moment resisting space frame or a Dual System consisting of a bracing or wall system plus a 25% moment resisting frame is required. The required moment frames in either approach are to be designed and detailed to specific requirements so as to be ductile.

Figure 1 shows a comparison of earthquake spectra. The lower values are the spectral representation of the 1982 UBC criteria for Zone 3 with a DMRSF ($K = 0.67$). The higher values are for elastic response to a Maximum Credible Earthquake, 10% chance of exceedance in 50 years, for Seattle. The difference between these is a small factor of safety and a lot of ductility demand.

Some discussion of the concept of higher loads in exchange for lessened ductility requirements are included in code commentaries. The SEAOC commentary (Ref. 4) states:

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> "the design should comply with the ductility requirements of Section 4 unless the response of the frames due to realistic earthquake motions at the site essentially remain within the elastic capacity of the materials."

ANSI has a similar type of statement in their commentary on 9.8 Alternate Determination and Distribution of Seismic Forces which states:

> "Values of base shear . . . are applicable only if the structure is designed and detailed to be consistent with the requirements in 9.9; otherwise the structure shall be designed for a base shear consistent with its ability to dissipate energy by inelastic cyclic straining, which will generally mean a K from 2.5 to 4.0 or greater."

Reasons for Alternate Approaches

The development of alternate design criteria will be aided by a better understanding of the need for new criteria.

1. Wind Dominance

Wind strength and stiffness requirements often control major portions of the design of tall buildings. Sizing lateral systems to meet wind stiffness criteria can result in much higher strengths than that required by code minimum seismic loads. The dominance of wind requirements over seismic requirements is a function of the wind environment and drift criteria; the earthquake region and the building weight; and the building configuration.

Figure 2a shows a comparison between the 1982 UBC Seismic Loads for a Dual System and a representative wind load criteria. Wind strength controls a major portion of the structure.

Figure 2b compares the 1982 UBC seismic stiffness requirement (.005/K) to the often used wind drift index of .0025. Wind stiffness controls even more of the structure.

2. Inadequacies of Code Criteria for Dual Systems

The Dual System often used to meet both the seismic code requirements and the demands of the wind environment can result in several problems.

A) No drift limit or stiffness requirement is associated with the 25% DMRSF. Twenty-five percent (25%) of the seismic strength may result in only a very small percentage of the overall stiffness. This can be particularly true for steel frames with concrete walls. Some 25% systems appear to be marginally stable especially when P-delta effects are considered.

B) Some codes require, as one load case, that 100% of the load be applied to the bracing (or walls) independently. This discourages systems such as 50% walls and 50% DMRSF, which are potentially more ductile.

C) The codes allow the use of relatively brittle connections in seismic design requiring only that they be designed for 125% of low code load. For example, if only a nominal column splice is required by code seismic loads plus 2/3 dead load, the splice could fail in tension in a larger than code earthquake.

3. Damage Control

A structure designed to higher elastic values will suffer less non-structural seismic damage, due to smaller displacements and lessened inelastic action.

4. Architectural Constraints

The DMRSF, with their wide, closely spaced columns, are a significant restraint on the architecture of a building. A tall condominium may have an excess of concrete wall for architectural reasons and not need or want frames. Many non-building solutions of relative importance do not incorporate DMRSF, for example, nuclear reactors and bridges.

Development of an Elastic Design Criteria (R = 1)

The elastic design criteria presented here is based on a dynamic analysis in the frequency domain. A similar approach in the time domain could be used, though appropriate time histories might be difficult to develop. ATC3 (Ref. 3) develops both spectra, and a code-like approach to the frequency domain dynamic analysis. It forms the basis of the criteria presented.

ATC3 "Tentative provisions for the development of seismic regulations for buildings" does a good job in Chapter 5 of codifying the Modal Analysis Procedure. ATC3 also provides maps for the United States and other criteria necessary to develop elastic response spectra. These spectra are then reduced by dividing by "R" a measure of the structure energy dissipation capacity. This reduced spectra provides the code minimum seismic loads. Table 1 shows ATC3 R values for acceptable systems ranging from R = 5 to R = 8. This means that the base shears are reduced from that of the elastic response to the ATC3 maximum credible earthquake (approx. 10% change of exceedance in 50 years) to 1/5 or 1/8 of that value.

Elastic design, as recommended here, is generated by setting R = 1. This results in much higher loads.

There still exists some chance of yielding. The smoothed spectra is not the real event and larger quakes may happen. Even with the best geotechnical information, there is still uncertainty regarding soil structure interaction. Finally, the analysis techniques available, such as modal analysis with root-sum-square method, do not give guaranteed maximum loadings. An overstress, however, does not necessarily mean failure but a ductility demand to be met.

Intermediate Choices Between Dual Systems and Elastic Design (R/3 and R/2.5)

Two concepts are presented in this section for intermediate choices between the Dual System or DMRSF System and the elastic, R = 1 System.

The first intermediate system has a complete vertical load carrying frame, full capacity connections and redundant load paths. Such a system, when overstressed, yields its members axially. This allows significant post yielding energy dissipation. There is, however, limited seismic experience available for this type of structure. To date, the use of these systems have been limited to short building design. For these applications, ATC3 allows an R of 5-1/2 for concrete shear walls and an R = 5 for brace frames. In addition to the full ATC3 requirements, the author recommends full capacity connections be required. For tall buildings it is suggested here that an increase in the design value for these systems of 3 times value for short buildings would be conservative and appropriate. In ATC3 terminology a value of R/3 would be used. Again, see Table 1.

A second intermediate system would be a system whose strength is controlled by the use of flexural yielding of specially designed and detailed members. Two examples of these, which are not DMRSF, would be 1) eccentric bracing as developed by Popoff and Roeder (Ref. 5), and 2) shear walls with specially detailed fuse-like coupling beams. These types of systems provide a controlled limit on the base shear. Energy dissipation capacity is supported through test data. The author feels a value of R/2.5 would be justified for these systems. A comparable UBC value would be K = 2.5.

CONCLUSION

KPFF has developed and used an elastic design criteria, similar to the R = 1 concept presented here, for a 48-story UBC Zone 3 building. The system proved to be more economic and we believe the system to be a better design. It represents a class of structures that might be better served by some flexibility in the code criteria allowing much higher loads in a trade-off of strength for ductility.

References

1. "Uniform Building Code 1982 Edition," International Conference of Building Officials.
2. "American National Standard Minimum Design Loads for Buildings and Other Structures," ANSI A58.1-1982, American National Standards Institute.
3. "Tentative Provisions for the Development of Seismic Regulations for Buildings," ATC3-06, Applied Technology Council.
4. "Recommended Lateral Force Requirements and Commentary," 1980. Seismology Committee, Structural Engineers Association of California.
5. Roeder, C.W., and Popov, E.P., "Inelastic Behavior of Eccentrically Braced Steel Frames Under Cyclic Loadings," Report No. UCB/EERC 77/18 August 77, Earthquake Engineering Research Center, University of California, Berkeley.

TABLE 1

System	ANSI or UBC	ATC3		Description
	Current Code Criteria			
Ductile Moment Resisting Space Frames (DMRSF)	K=.67	R=8		Steel
		R=6		Concrete
Dual Systems with DMRSF DMRSF for 25% of Seismic	K=.8	R=8		Concrete walls + DMRSF
		R=6		Braced frame + DMRSF
Building with complete vertical system 160' to 240' max. height	K=1.0	R=5-1/2		Concrete walls
		R=5		Braced frames
	Proposed Criteria			
Building with complete vertical system, no height limit	(K 5.0+)	R=1		Elastic criteria
As above but with full capacity connections and redundant load paths	(K 3.0)	R=R/3;	R=1-5/6	Concrete wall
			R=1-2/3	Braced frames
Controlled strength systems with flexural fuses	(K 2.5)	R=R/2.5;	R=2-2/5	Coupled concrete walls
			R=2	Eccentric steel bracing

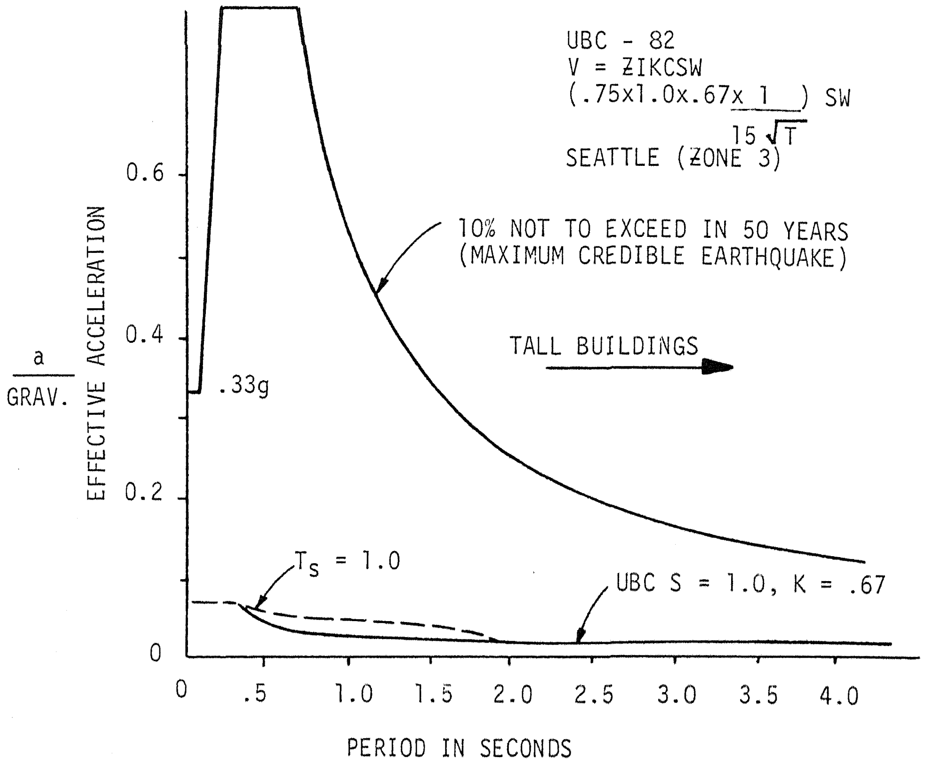


FIGURE 1. COMPARISON OF CODE AND ELASTIC SPECTRA

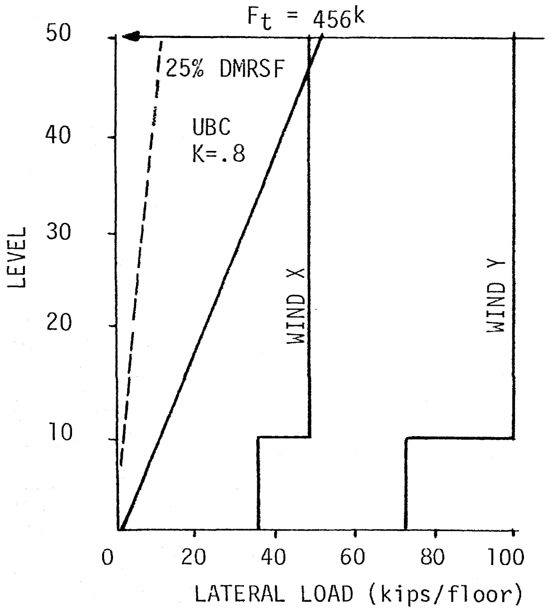
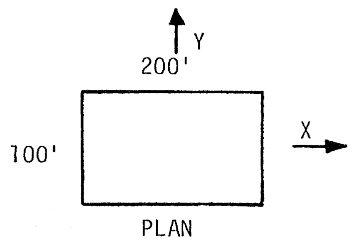
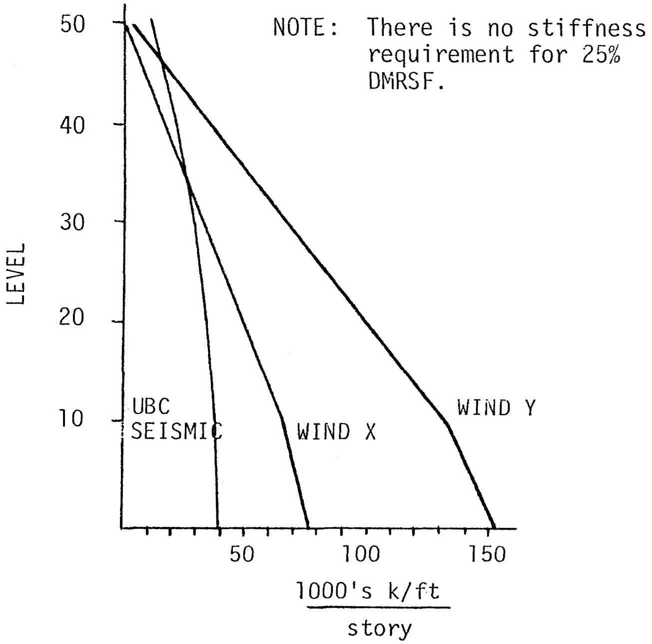


FIG 2A APPLIED LOADS





NOTE: There is no stiffness requirement for 25% DMRSF.

FIG 2B STIFFNESS REQUIREMENTS

50-STORY BUILDING 12' STORY HEIGHTS SEISMIC WEIGHT INCLUDING PARTIONS = .1k/ft^2
SIMPLIFIED WIND PRESSURE 30 lb/ft^3 to 120', 40 lb/ft^2 ABOVE. PERIOD ASSUMED TO BE 5 SEC.