

## A comparison of analysis provisions in seismic codes

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**ABSTRACT:** The results of a comparative study between the current Chilean code and the draft of the new code are presented. The study was performed through the analysis of eight real buildings with a number of stories between one and seventeen. The code provisions analyzed in this paper are: definitions of structural irregularity and its relation with the type of seismic analysis required; alternative procedures to consider accidental torsion, minimum value of base shear in spectral modal analysis; and, economical implications of a period-dependent response modification factor  $R$ .

### 1 INTRODUCTION

In 1986 the Chilean Institute of National Standards (INN) undertook the task of preparing a revised version of Code NCh 433 "Earthquake Resistant Design of Buildings". Since the current edition (Instituto Nacional de Normalización 1972) has been in use for twenty years, a new version was overdue. The provisions of the current code, referred hereafter as NCh'72, are quite simple as they prescribe seismic actions associated to a moderate, rather frequent earthquake ground motion and include a limited consideration of the energy absorption and dissipation capacity of the structure. The revision of this code has the objective of incorporating the state-of-the-art knowledge as well as some facts related to earthquake resistant design as usually practiced by Chilean engineers that have been so important in the overall satisfactory seismic performance of Chilean buildings during the March 3, 1985 earthquake.

The draft of the revised edition (Instituto Nacional de Normalización 1989), referred hereafter as NCh'89, was issued in July 1989 and subjected to a six-month period of open discussion; the NCh 433 code committee has been evaluating the results of the discussion process since June 1990 and is expected to approve the final form of the code by the end of 1992.

NCh'89 has a broader scope than the current Chilean code. A seismic zonation of the Chilean territory is included; the effects of local soil conditions on seismic excitation are treated in more detail; explicit recognition is given to the influence of structural types and materials on structural response and design forces; new provisions concerning non-building structures and non-structural elements, and guidelines for the design of foundations, earthquake damage evaluation, and repair of structures are also part of the revision.

This paper presents a summary of the results of a comparative study between NCh'72 and NCh'89, which was performed through the analysis of eight real buildings with a number of stories between one and seventeen. Half of the buildings analyzed are one or

two stories high, which corresponds to a large percentage of constructions in Chile. The complete set of results of this study has been reported elsewhere (Hidalgo et al. 1990).

### 2 ANALYSIS OF CODE PROVISIONS

The provisions of NCh'89 are somewhat similar to those of the 1988 and 1991 editions of the Uniform Building Code (International Conference of Building Officials 1991), referred hereafter as UBC. The characteristics of the design spectra for different ground conditions, structural systems and structural materials; as well as the selection of the methods of seismic analysis have been reported already by Hidalgo and Arias (1990). Even though the code committee has introduced some modifications to the provisions included in NCh'89, the basic philosophy has remained the same. Earthquake design forces are specified as reduced values of the elastic response forces corresponding to a severe ground motion. The response modification factor  $R$  depends on the structural system type, the structural material, and the period of vibration of the structure; the latter dependence has resulted in an increase in seismic strength specified for the low-period range of structures as compared with that of NCh'72. Typical values of  $R$  are 8 for reinforced concrete, 10-story, shear-wall buildings and 4 for masonry, 4-story, shear-wall buildings. Figure 1 shows the design spectra for Building 2 used in this study; spectrum A denotes the alternative of using a different  $R$  factor for each mode and period of vibration; spectrum B is the elastic design spectrum reduced by a constant  $R$  value determined by the mode with larger equivalent mass in the direction of analysis.

The static analysis of NCh'89 considers a seismic coefficient derived from the design spectrum A discussed previously. This method of analysis offers significant advantages from the design point of view of structural elements and foundations; however, it must

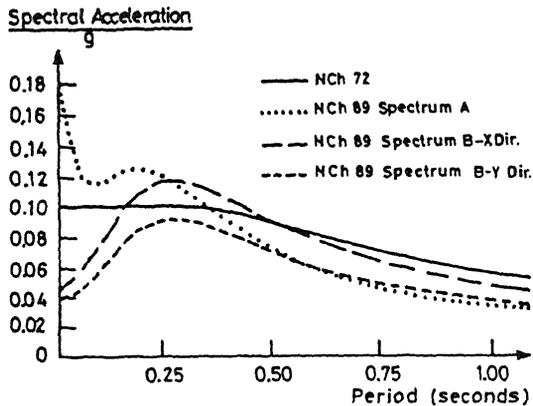


Figure 1. Design spectra used for Building 2.

be restricted to buildings exhibiting structural configurations for which the results of the static analysis reasonably predict the actual distribution of internal forces during real earthquakes. NCh'89 has limited the use of static analysis to buildings having vertical and plan regularity according to UBC. Nevertheless, UBC definition of vertical regularity is too stringent for Chilean buildings, since many buildings not satisfying those regularity conditions have been designed using static analysis and have performed very well during past severe earthquakes. The Chilean code committee has decided to modify NCh'89 and to accept static analysis when the story shear and overturning moment from this analysis do not differ in any story by more than 20% from the results of modal spectral analysis scaled to the same base shear.

Accidental torsion provisions of NCh'89 for the modal spectral analysis allow two alternative procedures: the superposition of static torsional moments to the results of a modal spectral analysis of a model with three degrees of freedom per story; or the analysis of a model with the centers of mass shifted from their natural positions. In both cases, the accidental eccentricity is 5% of the plan dimension perpendicular to the seismic action. Both procedures have been used as a supplementary requirement by Chilean design engineers to include accidental torsion effects when NCh'72 has been used.

The other code provision that is analyzed in this paper is the minimum value of the base shear when modal spectral analysis is used. Following the UBC provisions, NCh'89 defines this value in terms of the static analysis value, depending on the regularity of the structure. On the other hand, NCh'72 establishes an absolute minimum value of the base shear.

### 3 CHARACTERISTICS OF THE BUILDINGS

Most of the results presented hereafter have been obtained for the three following buildings: Building 1 has 17 stories and the structure is composed by reinforced concrete shear walls and moment resisting frames, as shown in Figure 2. The building has two major setbacks along its height (Figure 3), is almost symmetric in Y direction but shows significant X-θ

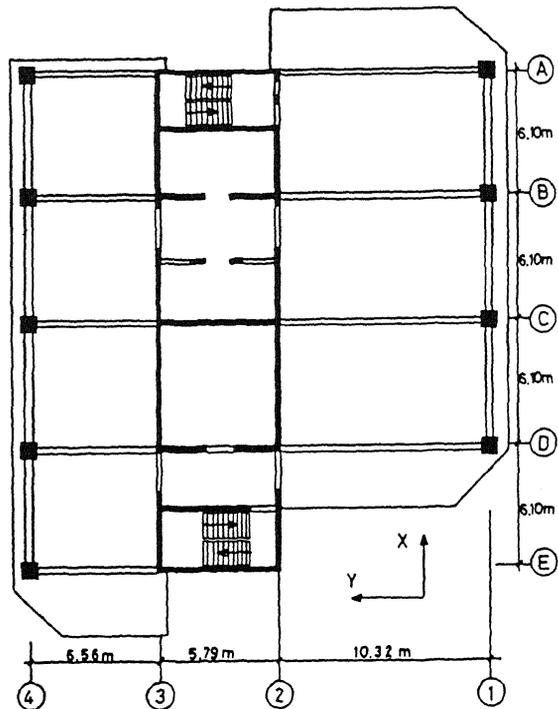


Figure 2. Floor plan at seventh level, Building 1.

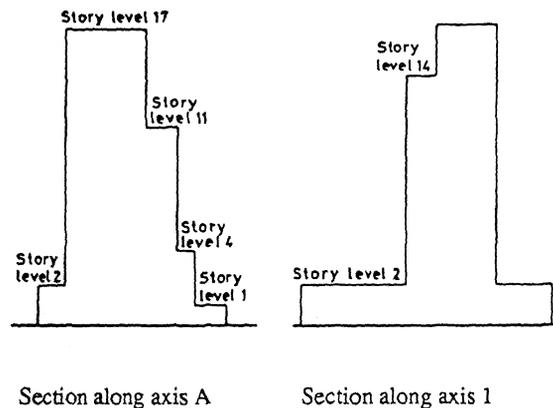


Figure 3. Schematic elevations Building 1

coupling (Table 1). UBC would indicate, for several reasons, that this building has vertical and plan irregularity.

Figures 4 and 5 show the typical floor plans for Buildings 2 and 3, respectively, and Tables 2 and 3 show the modal periods and masses for the two buildings. Both buildings have a reinforced concrete shear wall structure, the floor plans are regular in height, they both have small torsional stiffness as shown by the fact that the fundamental mode is almost purely torsional, and show small coupling among the

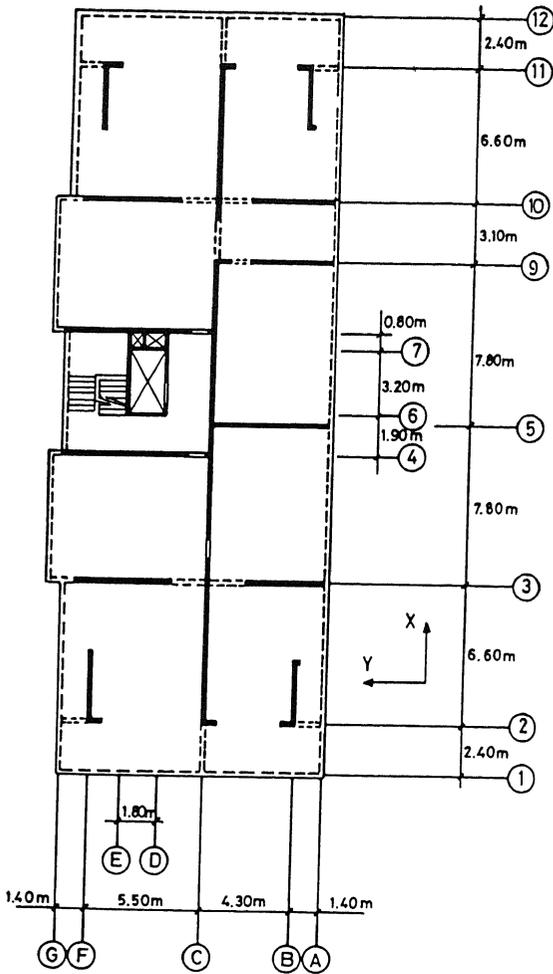


Figure 4. Typical floor plan, Building 2.

Table 1. Modal masses and periods of vibration, Building 1 (Modal mass/Total mass of building)

Mode	Period (seconds)	X-Mass Ratio	Y-Mass Ratio	$\theta$ -Mass Ratio
1	1.203	0.000	0.479	0.000
2	0.973	0.112	0.000	0.169
3	0.665	0.408	0.000	0.056
4	0.317	0.000	0.162	0.000
5	0.267	0.013	0.000	0.086
6	0.186	0.142	0.000	0.002
7	0.138	0.000	0.097	0.000
8	0.123	0.003	0.000	0.063
9	0.097	0.089	0.000	0.013
10	0.084	0.000	0.081	0.000

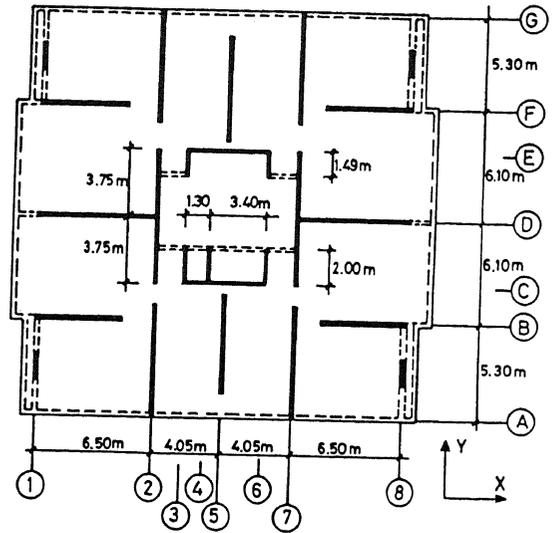


Figure 5. Typical floor plan, Building 3.

Table 2. Modal masses and periods of vibration, Building 2 (Modal mass/Total mass of building)

Mode	Period (seconds)	X-Mass Ratio	Y-Mass Ratio	$\theta$ -Mass Ratio
1	0.920	0.002	0.000	0.708
2	0.532	0.000	0.705	0.000
3	0.267	0.738	0.000	0.004
4	0.174	0.002	0.000	0.186
5	0.111	0.000	0.194	0.000
6	0.076	0.149	0.000	0.007
7	0.073	0.017	0.000	0.054
8	0.052	0.000	0.050	0.000
9	0.045	0.002	0.000	0.025
10	0.041	0.037	0.000	0.001

Table 3. Modal masses and periods of vibration, Building 3 (Modal mass/Total mass of building)

Mode	Period (seconds)	X-Mass Ratio	Y-Mass Ratio	$\theta$ -Mass Ratio
1	0.868	0.002	0.000	0.682
2	0.568	0.000	0.675	0.000
3	0.550	0.672	0.000	0.000
4	0.181	0.000	0.000	0.202
5	0.113	0.217	0.000	0.000
6	0.111	0.000	0.212	0.000
7	0.080	0.000	0.000	0.064
8	0.051	0.062	0.000	0.000
9	0.050	0.000	0.000	0.027
10	0.048	0.000	0.065	0.000

modes of vibration. Building 2 has 9 stories with a small decrease in the lateral stiffness of the first story. UBC classifies this building as having stiffness vertical irregularity and torsional irregularity. Building 3 is a 10-story quite symmetric building, with no vertical irregularities but having torsional irregularity according to UBC.

## 4 ANALYSIS OF RESULTS

### 4.1 Vertical irregularity and methods of analysis

Story shears and overturning moments were computed using different methods of seismic analysis and the spectra of NCh'89, in each of the X and Y directions of the floor plans of the buildings. Figure 6 shows the most critical results for the story shears using the static method and the modal spectral analysis with spectra A and B. Results were normalized to have the same base shear obtained from the static analysis. Superposition of modal contributions was performed using CQC for all the results reported in this paper. Results obtained for the story overturning moments show significantly less discrepancy between the static and modal spectral analysis than for the story shears. As expected, modal spectral analysis shows the influence of higher modes in the overall response of Building 1, while the response of Buildings 2 and 3 is dominated by the fundamental mode of vibration. The distribution of story shears obtained from the static analysis is not very different from the distribution obtained from the modal spectral analysis; the maximum difference exceeds 20% of the modal spectral analysis value only at midheight of Building 1, which is a rather clear case of vertical irregularity. These results indicate that UBC definitions of vertical regularity are not the proper way to select the required method of analysis; instead, it is suggested to use a comparison between the overall responses given by the static and the modal spectral analyses, and to allow the use of the static method when the differences are less than a given percentage of the modal spectral analysis results.

### 4.2 Consideration of accidental torsion in modal spectral analysis

Both alternatives discussed above to include accidental torsion were studied using the NCh'72 spectrum, to obtain the angle of twist per story shown in Figure 7. When the static torsional moments were used, the total angle of twist was obtained by adding the absolute value from the torsional moments action to the absolute value given by the modal spectral analysis of the model with the centers of mass in their natural positions. Results of Figure 7 indicate that the static torsional moments produced less torsion than the analysis of the model with the masses shifted, when the structure has plan symmetry in the direction of seismic analysis. Therefore, static torsional moments are not able to reproduce in a symmetric structure the dynamic effect of an eccentricity between seismic action and structural reaction, but the results show that this effect tends to disappear with increasing lack of symmetry in the structural plan. Note that the results for Building 2 showing very small angles of twist induced by the

seismic action, correspond to the case when centers of mass were shifted to the right of their natural position, thus obtaining a model where centers of mass and of stiffness are almost coincident.

### 4.3 Minimum value of base shear in the modal spectral analysis

The spectral modal analysis may use alternative procedures that yield different distribution of internal forces. In this study, different design spectra as shown in Figure 1 or different rules to perform the modal superposition have been used, which imply different degrees of conservativeness or rigorousness.

The results obtained for the eight buildings included in this study indicate that the UBC provision, to adjust the base shear obtained from the modal spectral analysis to the static analysis base shear when this last value is larger, generally requires to amplify the results obtained from the modal spectral analysis. As this amplification increases with increasing differences among both analyses, the final result of this amplification is a change in the relative ranking of element internal forces due to procedures with different degrees of conservativeness or sophistication (Hidalgo et al. 1990). This fact is relevant from the design point of view since it usually implies a penalization of the more rigorous procedure. Therefore, it seems preferable, as required in NCh'72, to use an absolute minimum value for the total base shear resulting from of the modal spectral analysis; this provision only affects long-period structures.

### 4.4 Economical implications of a period-dependent response modification factor R

This study also included the full design of selected reinforced concrete and masonry structural elements of the buildings, using the seismic analyses of both NCh'72 and NCh'89. The results indicate that the increase in seismic strength for low rise buildings specified in NCh'89 as compared to NCh'72 is not followed by an increase in cost (Hidalgo et al. 1990). This is due to the architectural configuration of one and two-story Chilean buildings, since they typically have more structural walls than would be strictly required by the code provisions.

## 5 CONCLUSIONS

The most important conclusions of this study may be summarized as follows:

1. UBC definitions of vertical regularity are not the proper way to select the method of seismic analysis between the static and the modal spectral analyses. Instead, it is suggested to use a comparison between the overall responses of both methods, and to allow the use of the static method when the differences are less than a given percentage of the modal spectral analysis results.

2. When the structure has symmetry in plan in the direction of seismic analysis, the alternative of using static torsional moments to consider accidental torsion results in angles of twist that are smaller than those obtained by shifting the centers of mass.

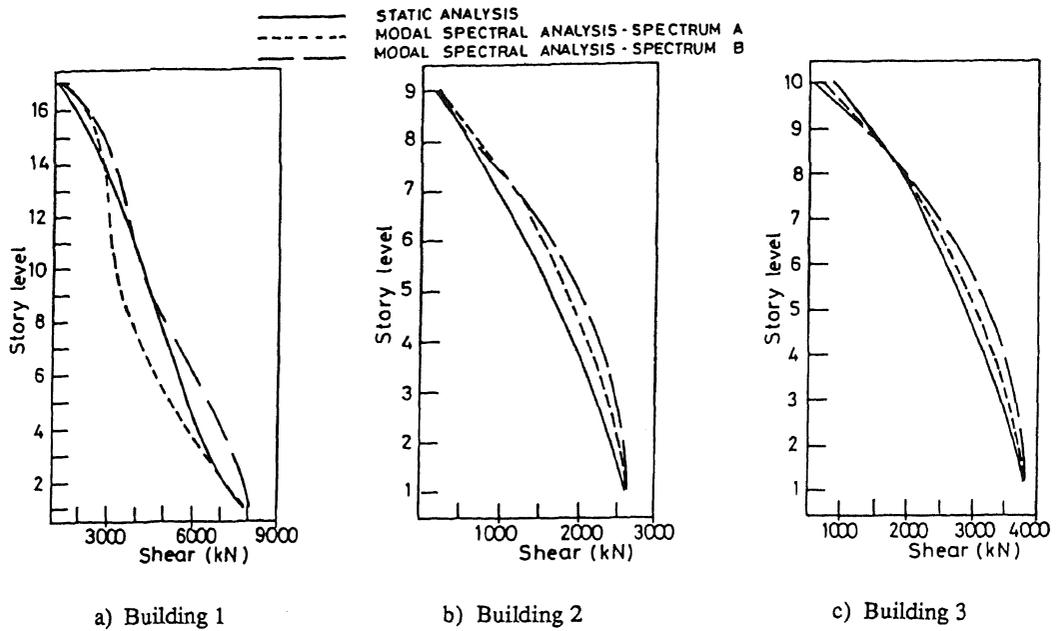


Figure 6. Story shear for different analyses in Y direction

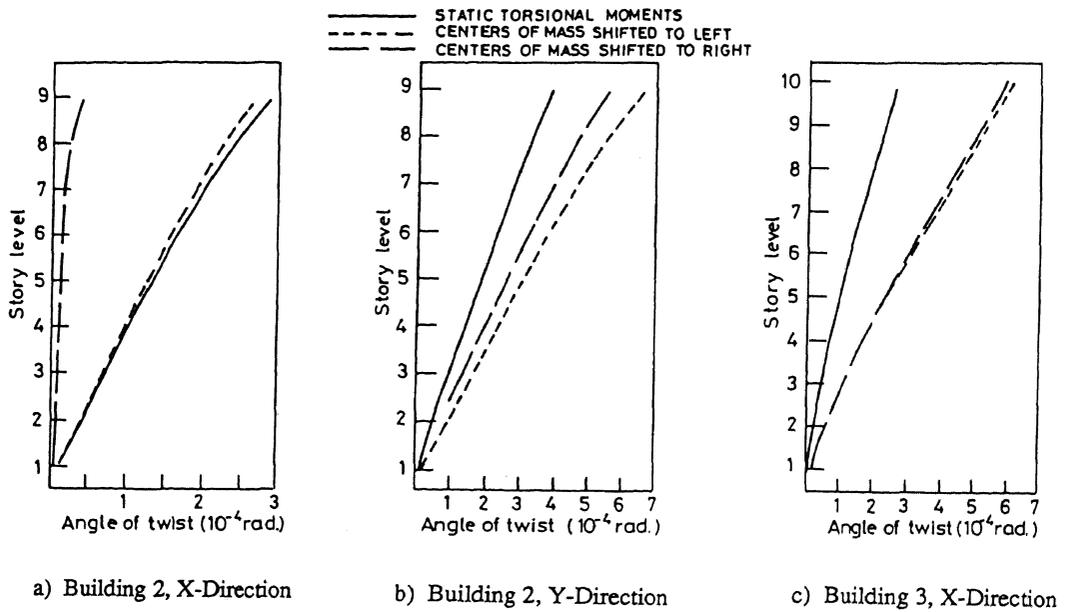


Figure 7. Angle of twist per story for different accidental torsional analyses

3. It is not convenient to prescribe a minimum value of the base shear in the modal spectral analysis in terms of the static analysis base shear. The specification of an absolute value of the minimum base shear, which only affects the long-period structures, is a better alternative.

4. On the basis of the structural configuration of Chilean buildings, the increase in seismic strength for low rise buildings, implied by a period-dependent response modification factor  $R$ , is not followed by an increase in cost.

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