Period Estimates for Shear-Wall Structures with Reference to the National Building Code of Canada

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ABSTRACT

An estimate of the natural period, T, in the fundamental mode is a key parameter in the definition of the minimum lateral seismic force for the design of "other structures" in the National Building Code of Canada (NBCC). Whilst methods of structural mechanics can be used to calculate T, most Codes require calibration to a predicted T derived from field measurements. The present study compares various period predictions with measured data for two shear walled buildings and concludes that more field data is required to permit refinement of the current NBCC provisions.

INTRODUCTION

For more than half a century it has been the accepted practice to design an earthquake-resistant building structure based on an equivalent static lateral force. The key parameter selected to characterize the dynamic property of the structural system has been the fundamental period. Whereas the formulae in NBCC for estimating the periods of frame structures have seen several revisions, particularly in the 1985 edition, the shear wall formula can be traced directly to research in the late forties published in 1952 (Joint Committee, 1952). Given the widespread use of computer modeling of structures there is increasing interest in using computed periods (derived from the eigen problem solution) in preference to the approximate formulae. Current computer models, however, do not model the additional stiffness contribution from the so called "non-structural" elements and the computed period may err on the unconservative side.

Despite the elegance of empirical predictions, some of which will be reviewed in this paper, the period estimates can be calibrated for reliability only against actual building response measured during strong ground motion. A weakness in the original data set is that many data points correspond to low amplitude excitation. With the extensive instrument data obtained in the recent Californian earthquakes the opportunity exists to compare various empirical period predictions against measured building response.

Two shear-wall structures have been studied extensively in this paper. The building data and measured response characteristics were obtained from the study by John A. Martin & Associated, Inc. (1997).

The paper makes a tentative recommendation for the future edition of the National Building Code.

CURRENT 1995 NBCC FORMULA

In 1952 the Joint Committee of the San Francisco, California Section, American Society of Civil Engineers and the Structural Engineers Association of Northern California drafted a lateral force provision as a model for use in building codes. An integral part of the procedure required the designer to estimate the fundamental period of the building. The format and formulae have found their way into many national building codes, including that of Canada. Although the format has seen several cycles of change in Canada, the period estimate endures essentially unchanged for wall structures:

[1] $T = 0.09h_n / \sqrt{D_s}$ (The imperial coefficient is 0.05.)

where h_n is the height of the building above the base, in metres, and

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D_s is the length of the wall... which constitutes the main lateral-force-resisting system in the direction parallel to the applied forces; if the main lateral-force-resisting system does not have a well defined length then D, the dimension of the building in the direction parallel to the applied forces, shall be used in lieu of D_s.

The detailed alternative definitions of the building dimension, D_s and D, are a departure from the source document where the alternative D_s was not mentioned. Buildings can have a highly varied layout of walls within the same framing line, or spread over parallel framing lines, can be isolated or coupled, all within the same plan footprint. Recognising the variability in interpretation, the Code has attempted to clarify the definition of D for the designer but it is clear that confusion in interpretation still exists. The original source data for the period estimate comprised "approximately 1,600 vibration observations... made in 430 buildings, 150 observations on 42 elevated water tanks, 250 special observations, as well as more than 600 ground vibration measurements". Detailed dimensions of the variety of structural geometries have not been referenced, therefore it is not possible to justify the revised definition against the original data set.

Despite the eclectic mix of buildings, the different construction materials and practices of fifty years ago, and the probable low amplitude ambient vibration measurements, the quoted formula has remained the calibration point for wall structures.

ALTERNATIVE PERIOD ESTIMATES

With the data recorded in recent Californian earthquakes, beginning with the 1971 San Fernando Earthquake, SEAOC, UBC and NEHRP Codes have departed from the 1952 format. The strong motion data file is still very small compared to the total number of exposed buildings, and the period estimates must still carry a significant uncertainty. In this paper a comparison is made between several estimate formulae published in recent codes and papers.

Uniform Building Code (UBC)

The 1994 UBC offers the following formula for predicting the fundamental period

[2] $T = C_t (h_n)^{3/4}$

where h_n = the height of the structure, in feet

and $C_t = 0.020$, (the metric coefficient is 0.0488), or alternatively

$C_t = 0.1/(A_c)^{1/2}$

where A_c = the combined effective area of the shear walls in the first storey of the structure, in square feet

and $A_c = \sum A_e [0.2 + (D_e/h_n)^2]$

where A_e = the minimum cross-sectional area in any horizontal plane in the first storey of a shear wall, in square feet

and D_e = the length of a shear wall in the first storey in the direction parallel to the applied forces, in feet

NEHRP Recommended Provisions (1997)

The 1997 NEHRP provisions are identical to those listed for UBC with the exception of the alternative definition for the coefficient C_t which has been deleted in the most recent edition.

Goel and Chopra (1998)

Goel and Chopra have used regression analysis to fit a recommended formula to the data set of measured structure periods from the recorded motions of seven significant North American earthquakes from San Fernando in 1971 through to the 1994 Northridge earthquake. The proposed formula is

[3] $$T_L = 0.0019 \frac{1}{\sqrt{\bar{A}_e}} H$$

where H = height of building in feet above the base

and $\bar{A}_e = 100 A_e / A_B$

A_B = building plan area of one floor

$A_e = \sum_{i=1}^{NW} (H / H_i)^2 A_i / \{1 + 0.83(H_i / D_i)^2\}$

A_i = area of the i_{th} shear wall and NW is the total number of shear walls

H_i and D_i are the height and plan dimension in the direction under consideration of the i_{th} shear wall

SUPER-ETABS Solution

Modeling of both of the structures was undertaken using the structural analysis program SUPER-ETABS. The characteristic period was calculated by the eigen problem solution. The period should not be based on properties of uncracked concrete or masonry sections, as it is the period associated with elastic response at just below flexural yield which is of relevance (Paulay and Priestley, 1990). Several models were evaluated using gross section properties, 60% gross representing a cracked section, and 60% gross only in the first storey with full I above.

INSTRUMENTED BUILDING RESPONSES & COMPARISONS

Two shear walled buildings have been extracted from the Instrumented Buildings Information System database (Naeim, 1997). The first is a 10-storey Burbank residential building and the second a 6-storey parking structure in Los Angeles. The estimated periods of the first mode in each plan direction are given in Table 1, along with height and plan dimensions.

TABLE 1(a) Measured Structure Periods for 10 Storey

Building	Direction	Distance D (m)	Period (secs)
Burbank 10-storey Height 26.8 m	N-S W-E	22.86 65.5	0.57 0.62

TABLE 1(b) Measured Structure Periods for 6 Storey

Building	Direction	Distance D (m)	Period (secs)
6-Storey Parking Structure Height 18.6 m	N-S W-E	78.9 93.3	0.5 0.4

For each building the period estimate formulae were applied, as well as the SUPER-ETABS solution. The results of the analyses are presented in Tables 2 and 3. Notice that in Table 2 the NBCC formula has been applied with a variety of interpretations for the distance D_s.

TABLE 2 Comparison of Measured versus Estimated Building Periods

Building	Design	Measured	NBCC			UBC	UBC	Goel
	Direction	Period (s)	1 wall	sum walls	full D	Ct = 0.02	Ct = alt.	Formula
10 Storey	N-S	0.57	0.93	0.66	0.50	0.57	0.86	0.41
	E-W	0.62	0.90	0.45	0.30	0.57	0.57	0.41
6 Storey	N-S	0.50	0.53	0.31	0.20	0.44	0.28	0.43
	E-W	0.40	0.36	0.36	0.18	0.44	0.20	0.30

TABLE 3 SUPER-ETABS Calculated Period compared to Measured Period

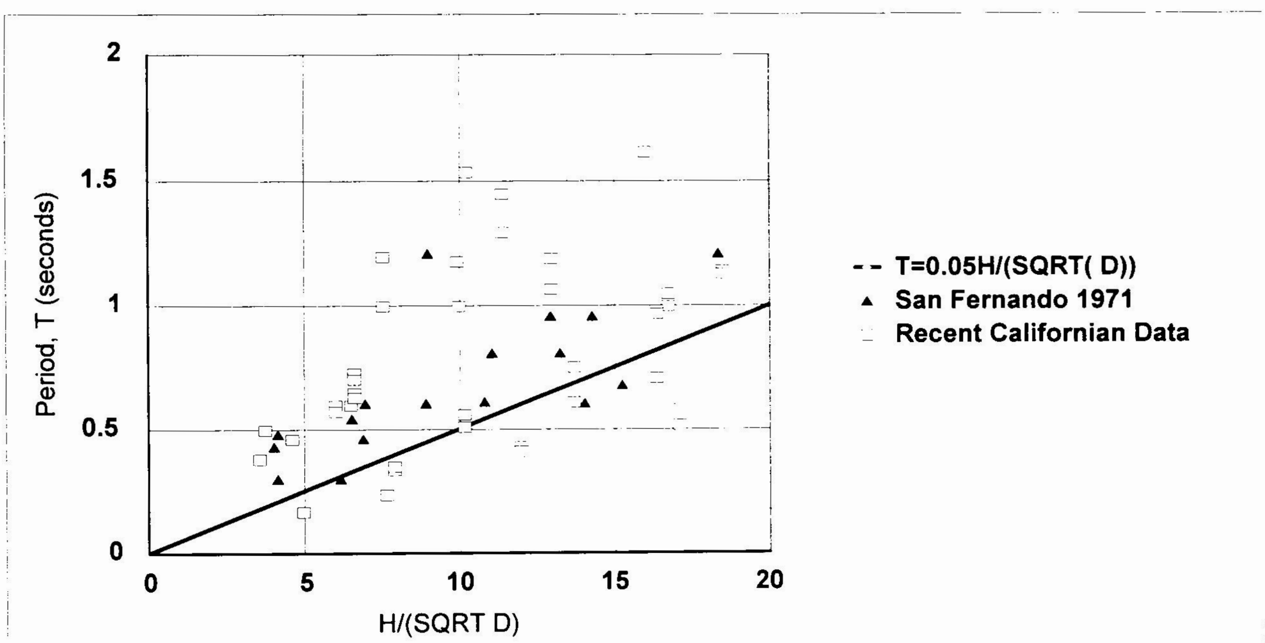
Building	Design Direction	Measured Period T (secs)	Calculated T		
			Igross	0.6 Igross 1st fl.	0.6 Igross all fl.
10 Storey	N-S	0.57	0.60	0.63	0.69
	E-W	0.62	0.61	0.64	0.69
6 Storey	N-S	0.50	0.52	0.55	0.59
	E-W	0.40	0.34	0.35	0.36

DISCUSSION OF RESULTS

Referring to Table 2, for the 10 storey building, NBCC predicted periods show reasonable agreement with the measured values, although the error (on the conservative side) for the E-W direction is high when the full building dimension is used for D_s. The alternative definition based on the width of the lateral load resisting system also seems satisfactory. The UBC prediction is also exact in this instance, but there is significant discrepancy between the two design directions for the UBC alternative definition. The Goel prediction errs on the conservative side. In the case of the 6 storey building, all the predictions are close to, or considerably under, the measured period and would be deemed acceptable for design.

The computed periods using SUPER-ETABS show close agreement with the measured values, with the uncracked section model being the closest. There was no apparent structural damage observed in either of these buildings after the earthquake. There was minor damage to non-structural components on the roof of the 10 storey building. It is possible the structures remained essentially elastic in their responses. It should be noted that no attempt was made to model any foundation flexibility in the computer mathematical modeling.

FIGURE 1 Comparison of NBCC formula and Californian Measured Periods for Shear Wall Structures



The new data from the recent Californian earthquakes (Goel & Chopra, 1998) is shown superimposed on the data from the 1971 San Fernando earthquake (NEHRP 1997 Commentary) in Figure 1. There is still reasonable confidence demonstrated in the simple estimate based on the original formula in terms of a lower bound estimate of building period

CONCLUSION

This study has compared estimates of the fundamental period of shear wall building structures with measured values interpreted from strong motion instrument records. There is considerable scatter in the data and the current NBCC formula still seems as good an estimate within the limits of a simplistic model. The alternative formula derived from regression analysis by Goel shows promise, however it requires detailed building geometry for application and is not suited as a first estimate in design. It should be explored further as a basis for calibration when more sophisticated mathematical models are used for the period determination.

There is a trend in each new edition of a building code to refine the analytical modeling, including modifications to the spectrum shape to match elastic or inelastic response spectra shapes. Idealised spectra often have steep slopes in the shorter period range which make derived design loads sensitive to period estimates. In the endeavour to introduce more sophisitication into the analyses, the reliability of the structural parameters upon which the design values are dependant must not be overlooked.

It would seem wise for the NBCC code to retain a calibration base shear to cover the circumstances when unconservative assumptions are made in the modeling, and to address "non-structural" contributions not normally included in dynamic modeling. In this circumstance calibration to a refined estimate of the building period based on a Goel-type model may be rational. It must be noted, however, that the regression model is based solely on Californian earthquakes and building types and may need calibration for Canadian application.

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