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DYNAMIC ANALYSIS OF NAILED WOOD-FRAME SHEAR WALLS

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SUMMARY

Most design codes contain force modification factors to account for the energy dissipating characteristics of the structural system under earthquake loads. These factors are generally selected to result in designs that are consistent with the observed performance history. In order to assess the appropriateness of these factors, a methodology consisting of testing and dynamic analysis of wood-frame shear walls was developed.

First, a comprehensive database was established by testing wood-frame nailed shear walls under monotonic and cyclic displacement schedules. The testing program included wood-frame shear walls sheathed with plywood, oriented strandboard, and gypsum wallboard. A hysteretic model was then calibrated to the shear wall cyclic test data. A building which was designed in Vancouver, B.C., Canada was selected, and a two-dimensional time-history dynamic analysis of one of the shear walls was performed by utilizing the hysteretic model and twenty-eight earthquake accelerograms specially selected to be compatible with the seismic characteristics of the Vancouver area.

The results confirm the current Canadian seismic force modification factor (R=3) and the European behaviour factor (q=3) for lateral load resisting systems comprised of plywood nailed walls. The results also show that the presence of walls sheathed with gypsum wallboard has generally a positive influence on the response of the structure which was designed considering only plywood shear walls. When the contribution of the gypsum wallboard is accounted for in the seismic resistance of the building, a seismic force modification factor of R=2 is found to be appropriate.

INTRODUCTION

Most seismic design codes contain force reduction factors – for example, the "q" factor in Eurocode 8 (1994), and the "R" factor in NBCC (CCBFC 1995) – to account for the energy dissipating characteristics of the structural system. The lateral load resisting systems for most wood-frame buildings rely on nailed shear walls sheathed with plywood or oriented strand board (OSB). In order to assess the appropriateness of the R factor in the NBCC, and the q factor in EC8 for these buildings, time-history dynamic analyses using twenty-eight earthquake accelerograms and a hysteresis model for the shear wall components were performed on a four-storey platform frame wood structure. Based on these analyses, recommendations about R and q factors have been made.

APPROACH

The overall methodology for the assessment of "R" factors involves the following steps:

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Testing of full-size shearwall specimens under monotonic and cyclic displacement schedules, and determining the near-collapse criterion based on ultimate displacement (inter-storey drift) for each wall system,

Fitting a hysteresis model to the cyclic test data,

Selecting a wood-frame building, and designing the shearwalls in that building according to the code peak ground acceleration with several design scenarios,

Using the above hysteresis model and specially selected earthquake records, performing time-history dynamic analysis to obtain the Ultimate Peak Ground Acceleration (Au) for different design scenarios. To achieve Au, the PGA is initially set at a low value, and stepwise scaled upwards until the near-collapse criterion is met.

Checking if the Au values are greater than the PGAcode value to assess the appropriateness of the "R" values.

Performing shake-table tests to verify the overall methodology.

TESTING

A comprehensive database was established at Forintek Canada Corp. by testing wood-frame shear walls under lateral monotonic and cyclic displacement schedules. A shear wall test specimen with 2.44 m height and 4.88 m with blocking is shown in Figure.1 The test program included wood frame shear walls sheathed with plywood, oriented strand board (OSB) and/or GWB. The detailed description and results of the test program are given in (Karacabeyli and Ceccotti 1996). A schematic description of the cyclic testing, and performance parameters that were studied are shown in Figure.2

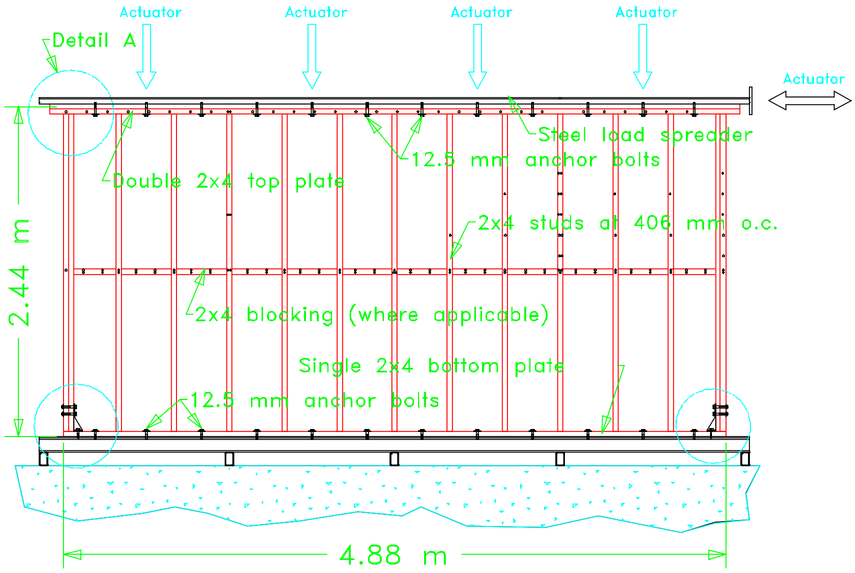

Figure 1 Specification of the Shear Wall Tests with Blocking

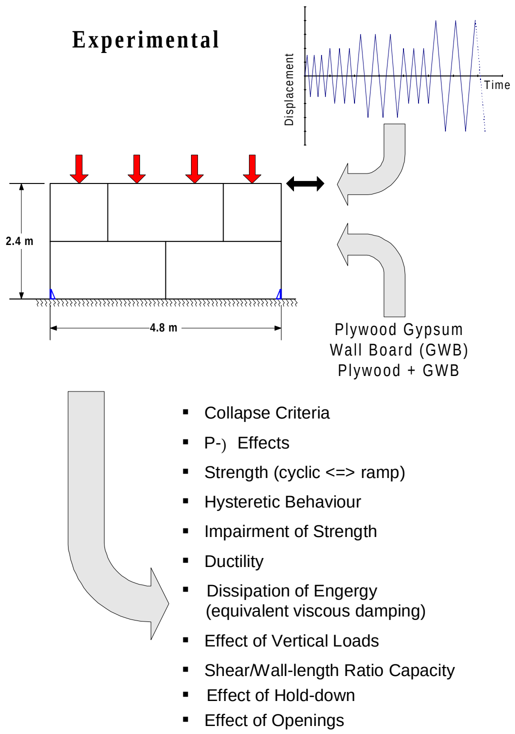

Figure 2 Cyclic Testing of Shearwalls

In establishing the skeleton curves for the hysteresis model for the shear walls, the effect of cyclic test schedule may play an important role. An examination of test results obtained with several cyclic test schedules revealed that the possible differences may be due to a) the different energy demand which depends on the magnitude and number of cycles; and b) the rate of loading (the velocity of the displacement). While a greater energy demand appears to result in a decrease in maximum loads and ultimate displacements, a faster rate of loading results in an increase on those properties (Karacabeyli and Ceccotti 1998).

DESIGN OF SELECTED BUILDING

The selected building was designed in accordance to the NBCC provisions for the City of Vancouver. This structure was selected by the members of the Wood Frame Committee of the Structural Engineering Consultants of B.C. (SECBC, Continuing Education for Engineering & Architecture, UBC 1995). In this paper, a two dimensional dynamic analysis of one of the shear walls parallel to the short dimension of the building was performed. Concrete floor topping was considered in the weight calculations. In the short direction, the building was symmetrical, and consequently torsional effects were not considered.

This building was designed a) with R=3 considering only plywood shearwalls; and b) with R=2 considering both plywood and GWB shearwalls.

MODELLING SHEAR WALLS

A pinching hysteresis model developed at the University of Florence (Ceccotti *et al.* 1989) was fitted to the cyclic test data (Figure 3). For systems containing shear walls sheathed with a combination of plywood and gypsum wall board (GWB), individual skeleton curves were superimposed. This method of superimposition has been shown (Karacabeyli and Ceccotti 1996) to be valid for displacements up to approximately 50 mm for monotonic, and up to 30 mm for the stabilized envelope (3rd in cyclic tests) curves (Figure 4).

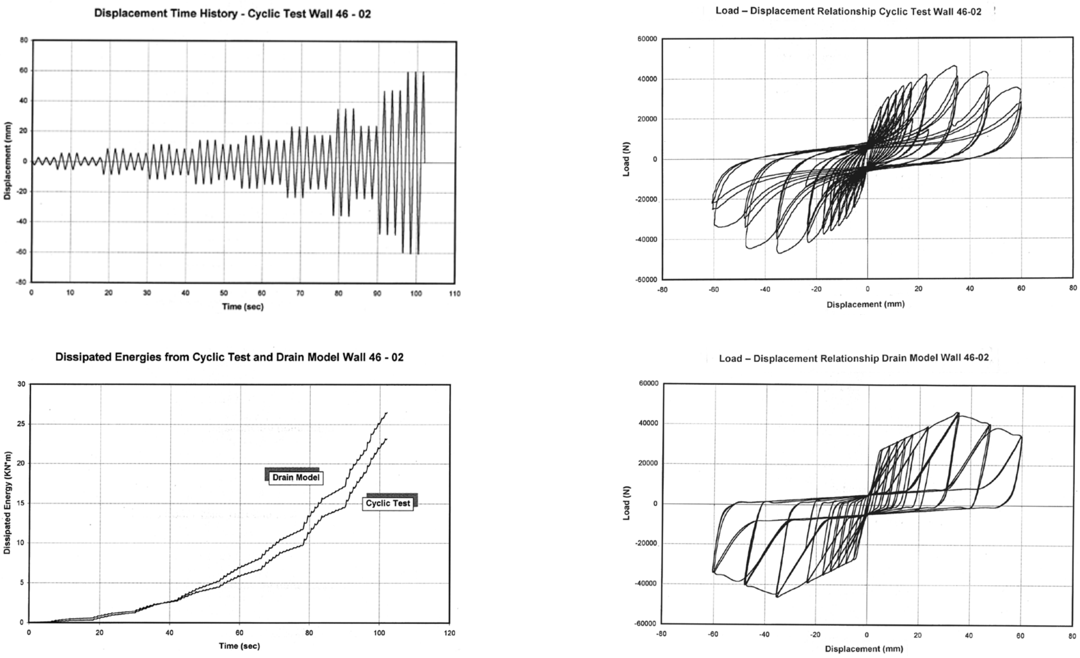

Figure 3 Fit of Hysteresis Loop

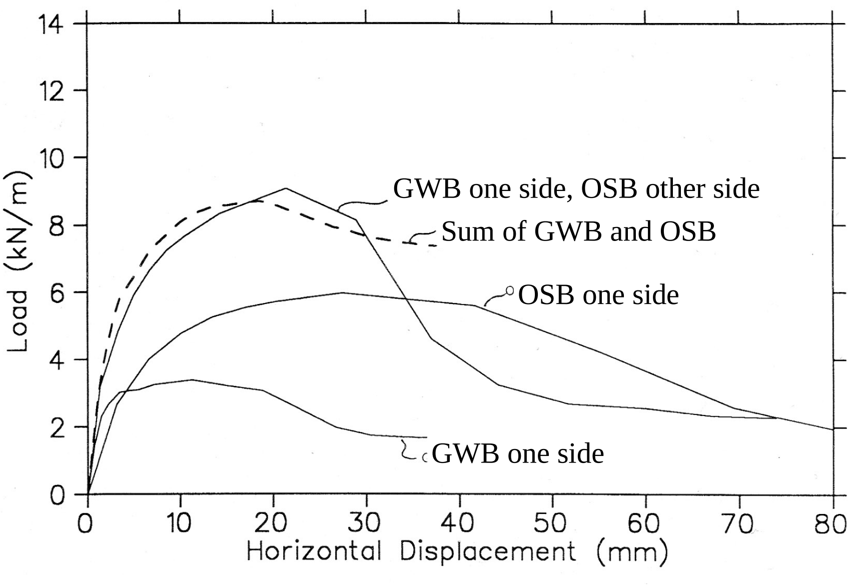

Figure 4 Contribution of Gypsum Wall Board to the Stablized (3rd Envelope Curves) Load Carrying Capacity When Used in Combination with OSB.

The above hysteresis model was implemented in a time-history dynamic analysis program (DRAIN 2DX). The ultimate displacement, used as the near-collapse criteria, is defined as the displacement at 80 percent of the maximum load on the descending portion of the skeleton curve.

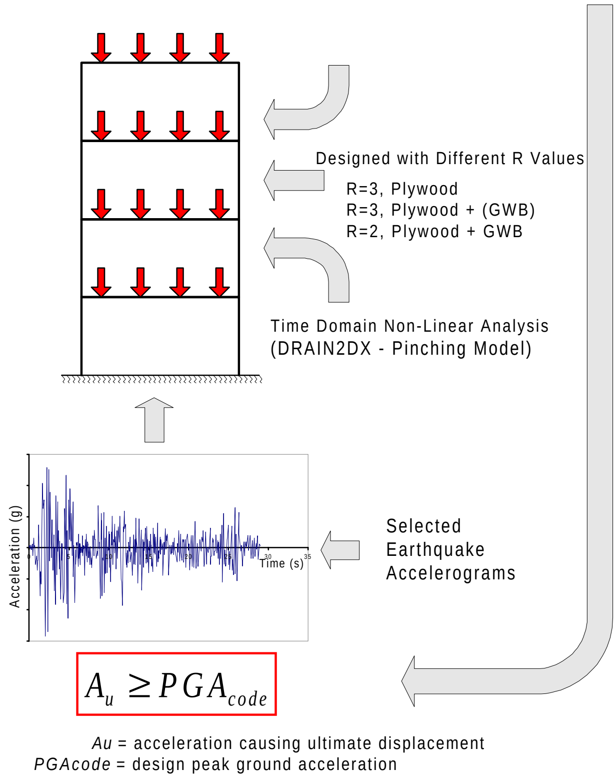

Figure 5 Dynamic Analysis

TIME-HISTORY DYNAMIC ANALYSIS

In the analysis, the skeleton curve for the hysteresis model is selected based on the 5th percentile (determined by assuming a 10 percent coefficient of variation and a normal distribution) of the first envelope curves obtained in the cyclic tests. No further adjustments for safety were used. The analyses were performed using twenty-eight earthquake accelerograms which are compatible with the seismic conditions in Vancouver area. The peak ground acceleration for each accelerogram was initially set at a low value (0.05g), and stepwise scaled upwards until the ultimate displacement (inter-storey drift) is achieved. This acceleration is then called "A_u" (Figure 5).

Three design/analysis cases (Figure 6) were considered:

Case 1:R=3; Designed and analyzed only considering plywood shear walls. The effect of the GWB walls was neglected in the dynamic analysis.

Case 2:R=3; Designed only considering plywood shear walls. In the dynamic analysis, considered plywood shear walls and accounted for the effect of the GWB walls.

Case 3:R=2; Designed and analysed considering plywood and GWB shear walls. This case is proposed by the Wood Frame Committee of the SECBC (SECBC, Continuing Education for Engineering & Architecture, UBC 1995).

For Cases 2 and 3, the ratio of GWB to plywood walls was kept at 2.5, 2.5 and 5.0 for the first three storeys, respectively. No restriction was applied for the fourth floor. A 1 kN/m factored shear resistance for GWB walls is used in the design.

For Case 1, the European (Eurocode 8, 1993) seismic behaviour factors (q) for lateral resisting systems with nailed shear walls were also determined for the twenty-eight accelerograms. The factor "q" is calculated as the ratio of A_u and the acceleration which caused the yielding of the structure, A_y (as defined in CEN 1994).

The fundamental period of vibration of the structure (T_0) is calculated by using the NBCC, and also by dynamic analysis. The value of T_0^{NBCC}=0.2 sec was found to be much less than those (Figure 9) found for the three cases by dynamic analysis. In determining the design shear force, however, we used T_0^{NBCC}=0.2 sec.

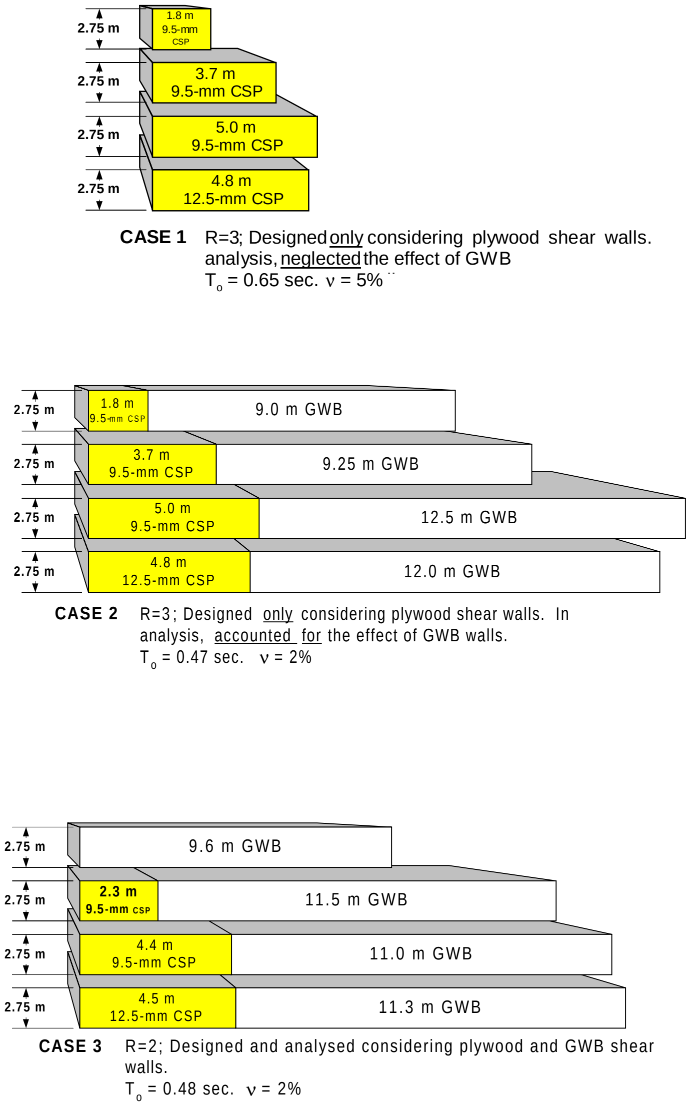

Figure 6   Three Cases Considered in the Design and Analysis

RESULTS

The results of non-linear dynamic analysis are shown in Figures,7,8 and 9 where the peak ground accelerations (A_u) that "caused" the inter-storey drift to reach the shear wall's ultimate displacement are shown against the twenty-eight accelerograms, and also against the Peak Ground Acceleration (PGA_{Code}) given in the NBCC. These results lead to the following conclusions:

a) For Case 1, all values of A_u were found to be greater than PGA_{Code} which confirms that the current force modification factor, R=3, is appropriate for plywood nailed shear walls. The median value of A_u was found to be three times the PGA_{Code}.

b) For Case 2, most values of Au were found to be generally greater than those found for Case 1 suggesting that the existence of GWB walls did not impair the lateral resistance of the structure. In other words, GWB contributed positively to the response of the structure compared to Case 1 where only plywood shear walls were considered.

c) For Case 3, all values of A_u were also found to be greater than the PGA_{Code} which shows that the alternate force modification factor, R=2 is appropriate. Although the median value of A_u was found to be smaller than that found for Case 1, the lower quartile values of A_u for Case 1 and Case 3 were similar. This is due to the smaller variability obtained in the results of Case 3.

d) All values of q (Figure 10) were found to be greater than 3 which confirms that the seismic behaviour factor in Eurocode 8, q=3, for plywood or OSB nailed shear walls is appropriate. The median q was found to be between 5.0 and 6.0.

e) Under the Canada/Japan Agreement in cooperation with Science and Technology, staff from Building Research Institute, Disaster Prevention Centre and Forintek Canada Corp. carried out shake table tests and pseudo-dynamic tests. The results of these tests confirmed that the theoretical model reasonably predicts the behaviour of a shear wall subjected to a selected earthquake record.

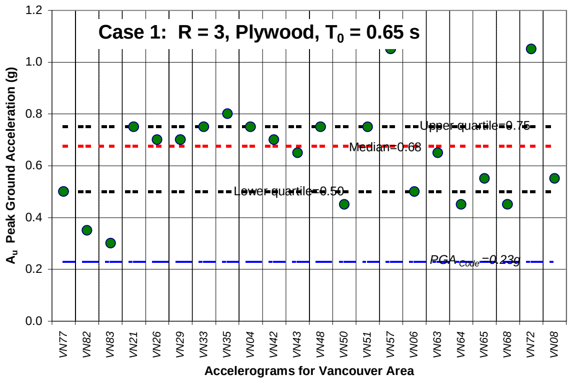

Figure 7 Results for Case 1

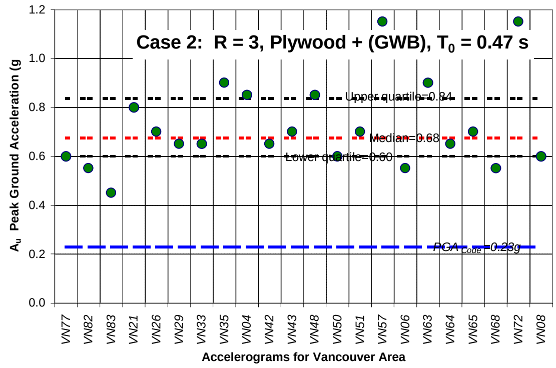

Figure 8 Results for Case 2

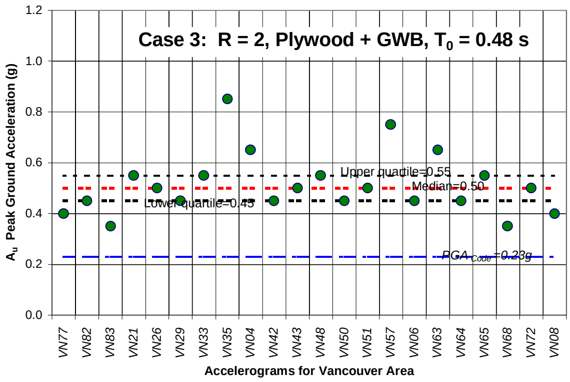

Figure 9 Results for Case 3

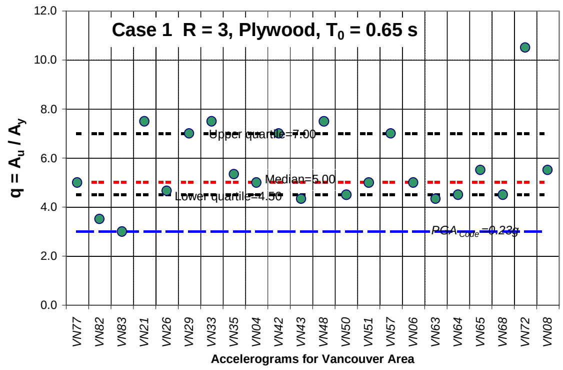

Figure 10 European Behaviour Factor for Case 1

CONCLUSIONS

The results confirm the current Canadian seismic force modification factor (R=3) and the European behaviour factor (q=3) for lateral load resisting systems comprising of plywood nailed shear walls.

The results also show that the presence of walls sheathed with GWB has, in general, a positive influence on the response of the structure which was designed considering only plywood shear walls. An alternate seismic modification factor (R=2, recommended by the SECBC) which accounts for the contribution of the GWB walls in design is found to be appropriate

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