Assessment of Seismic Design Parameters for Midply Wood Shear Wall System

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Summary

A midply shear wall provides greater lateral load capacity per unit length than a standard shear wall. The improved performance is achieved by placing the sheathing between wall stud members, which subjects the nails to double-shear when the wall is loaded in shear. Tests have shown that the average lateral load capacities and energy dissipations of midply walls can be more than three times that of standard shear walls, while their stiffness can be between two to three times the average stiffness of standard shear walls. A proposal for implementation of the midply wall system in wood design codes in North America is presented. Non-linear dynamic analyses of a four-storey wood-frame building were used to determine the seismic design parameters for midply shear walls. The analysis utilized a suite of 22 selected earthquake records scaled to the peak ground acceleration stipulated in the National Building Code of Canada 2005 for Vancouver, British Columbia. The probability of failure was determined for building built with both standard and midply shear walls. Using the standard shear walls as the bench mark, this study indicates that a ductility-related force modification factor R_d = 3 could be safely assigned for the midply shear wall system to achieve the same safety level as the standard shear wall system.

1. Introduction

In the last few decades, wood frame construction has evolved to include 3 or 4 storey multi-family residences. In some of these applications, garages at the first storey, large openings in the exterior walls, large floor spans, concrete topping on floors, and heavy tiles on roofs became common practice. Thus, while wood frame construction has generally performed well during severe earthquakes and hurricanes, the evolution in construction practices at times has created additional demands on the lateral load resistant system, consequently necessitating innovation in designs and construction methods to increase the lateral resistance of wood frame shear walls.

A new shear wall system named the midply wall system was developed at FPInnovations (formally Forintek Canada Corp.) Test results for midply walls under static, cyclic and dynamic loading are presented in Varoglu et al. [1,2]. Compared with standard shear walls under similar loading conditions, the average lateral load capacity of a midply wall is more than three times higher. The ultimate displacement of a midply wall is approximately 20% higher than the ultimate displacement of a standard shear wall, and the energy dissipation capability is more than three times that of a standard shear wall.

The midply wall system consists of standard shear wall components used in regular shear walls but re-arranged in such a way that the lateral resistance and the dissipated energy of the system significantly exceed that provided by standard wall arrangements. Figure 1 illustrates a cross section of a standard shear wall and that of a midply wall that uses the same 38 × 89 mm lumber studs.

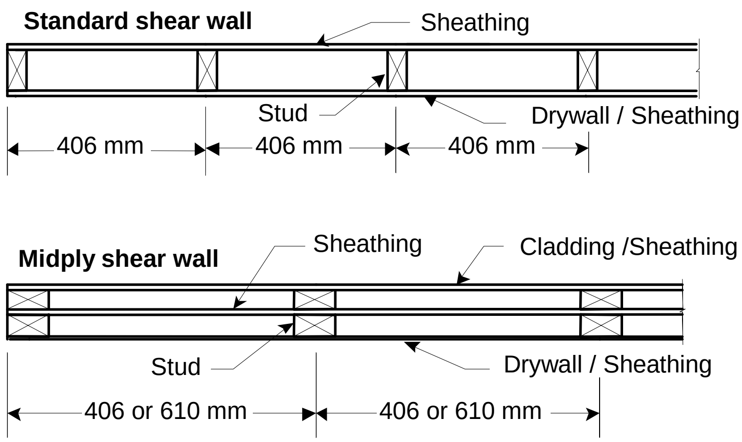


Fig. 1 Cross-section of a standard shear wall (top) and a midply wall (bottom) with two exterior panels

The superior performance of midply wall under lateral loading is attained through the following means:

1. A wood based panel is used at the centre of the wall to provide the lateral resistance of the wall without increasing the nominal thickness of the wall. Nails connecting this panel to the framing work in double shear as illustrated in Figure 2 (or in triple shear if additional exterior wood based sheathing is used), providing the increased lateral load carrying capacity;
2. Studs in the midply wall system are rotated for 90 degrees relative to those in standard shear walls. Sheathing material is fastened to the wide face of the studs instead of the narrow face of the studs as in the case of standard walls. This increases the lateral load capacity of the midply wall by providing more edge distance for fasteners on the perimeter of the sheathing panels placed in the mid plane and at the exterior face of the wall. Increased edge distance reduces the possibility of nail tear out failures and makes it easier for framers to nail the sheathing to the studs;
3. The heads of nails are kept away from the surface of the mid-panel; consequently nail pull through failure at the mid panel is physically prevented. Also, poor construction practices such as over driven sheathing nails and nails going through the panels missing the studs are practically eliminated.

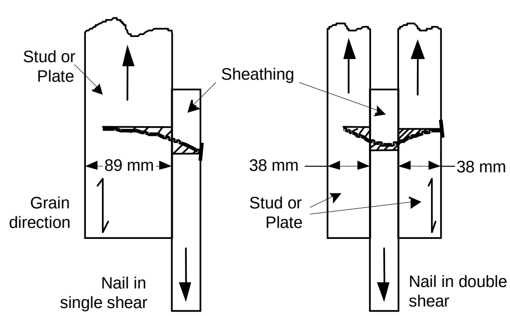


Fig.2 Nailed joints working in single shear in a standard shearwall and in double shear in a midply wall

Implementation of the midply wall system in the Canadian wood design code CSA O86-01 [3] was discussed in Ni et al. [4]. In this paper, the seismic ductility-based force modification factor, R_d, for midply wall system was evaluated. Non-linear dynamic analyses of a four-storey wood-frame building were used to determine the seismic design parameters for midply shear walls. The analysis utilized a suite of 22 selected earthquake records scaled to the peak ground acceleration stipulated in the National Building Code of Canada 2005 [5] for location such as Greater Vancouver, British Columbia. Using the building with standard shear walls as bench mark, ductility-based force modification factors R_d for midply shear walls were evaluated.

2. Methodology

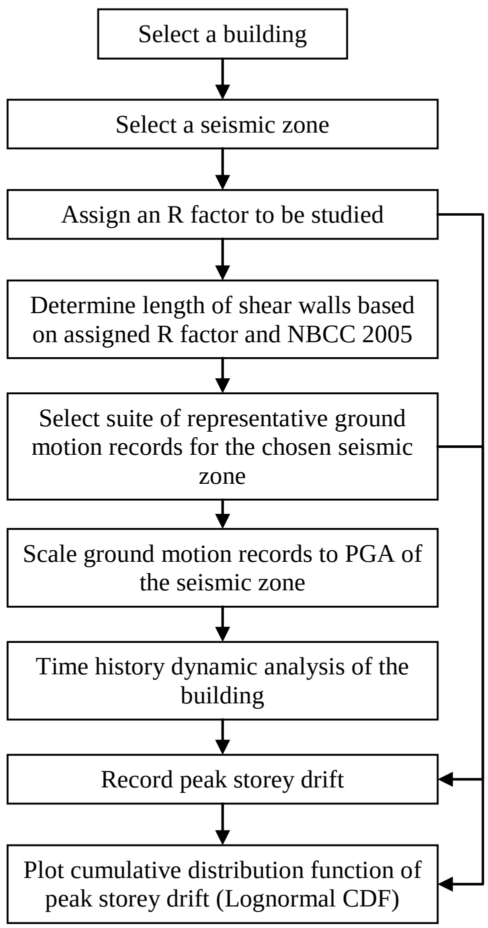


Fig. 3 Methodology for the assessment of force modification factor R_d

A flow chart for the procedure used for assessment of the force modification factor R_d is provided in Figure 3. As the force modification factor reflects the capacity of a structure to dissipate energy through inelastic behaviour, it requires the determination of the inertia forces corresponding to elastic response and those corresponding to the nonlinear response up to “near-collapse”. In NBCC 2005, the near-collapse drift limit is set at 0.025 for the very rare earthquake event (1 in 2500 year return period). However, as different shear wall systems have different characteristics, the true “near-collapse” status of the walls may differ from the standard drift limit. In this study, in addition to the drift limit stipulated in NBCC 2005, the actual ultimate displacement of the walls is used as one of the criteria for determining whether the building reaches its “near-collapse” status. The ultimate displacement is defined as the displacement which corresponds to 80% of the maximum lateral force on the descending portion of the force–deformation envelope curve.

3. Case study

In this paper, a four-storey platform wood frame building was modeled to assess the force modification factor for midply walls. This building has been used in the validation of the force modification factor for standard wood shear wall systems [6].

A plan view of the building is shown in Figure 4. In the short direction the building is symmetrical, and consequently torsional effects were not considered.

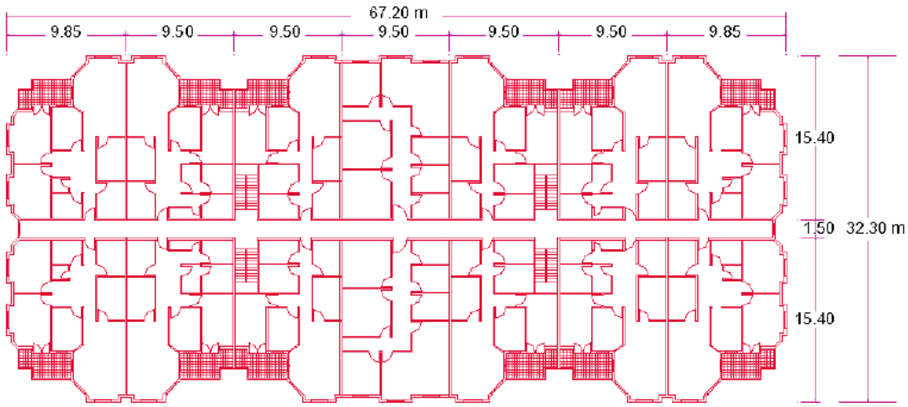


Fig. 4 Plan view of the four-storey building for analysis

The shear wall system in the short direction of the four-storey platform wood-frame building was designed according to the provisions of the 2005 NBCC. The City of Surrey in British Columbia, which has the highest spectral response acceleration in Greater Vancouver area, was chosen in this study. The building was designed with $R_d = 3$ where midply and standard shear walls were the only lateral force resistant elements. In determining the design base shear force, the period T = 0.2 s was used.

The wall was designed according to the CSA O86-01 values for lateral load resisting shear walls. For the midply shear wall, the specified shear capacity is taken as twice the specified shear capacity of a one-sided standard shear wall [4]. In this study, design values for midply walls consisting of Spruce-Pine-Fir (SPF) framing members and 12.5 mm wood-based sheathing were used, with sheathing connected to the framing members with 3.0 mm diameter common nails spaced 100 mm along the panel perimeter and intermediate studs. The specified shear capacity of the midply wall is 18.45 kN/m.

For the standard shear walls, Spruce-Pine-Fir (SPF) framing members and 9.5 mm wood-based sheathing are specified, connected to the framing members with 3.0 mm diameter common nails spaced 150 mm along the panel perimeter and 300 mm elsewhere. The specified shear capacity of the standard shear wall is 5.8 kN/m.

To determine the seismic behaviour of the four-storey building, a nonlinear time-history dynamic analysis was performed of the behaviour in the direction parallel to the short dimension of the building. Structural analysis program DRAIN-3D was used, with a user-defined pinching hysteresis model for wood shear walls developed at the University of Florence [7]. A total of 22 accelerograms were chosen for the time-historey dynamic analysis. These accelerograms were selected from real earthquake records, but had ground motion characteristics similar to those expected in Greater Vancouver seismic zone. Each accelerogram was scaled to 0.51g peak ground acceleration (PGA), a value for the City of Surrey in NBCC 2005.

The building model is shown in Figure 5. In the model, each wall at each floor was considered as a fictitious frame that consists of four straight rigid elements and is able to deform in shear only.

Shear deformation in this frame is represented by four identical rotational springs at each corner of the frame. The stiffness and strength characteristics of these springs were derived from the force–displacement relationship obtained from cyclic tests of the shear walls.

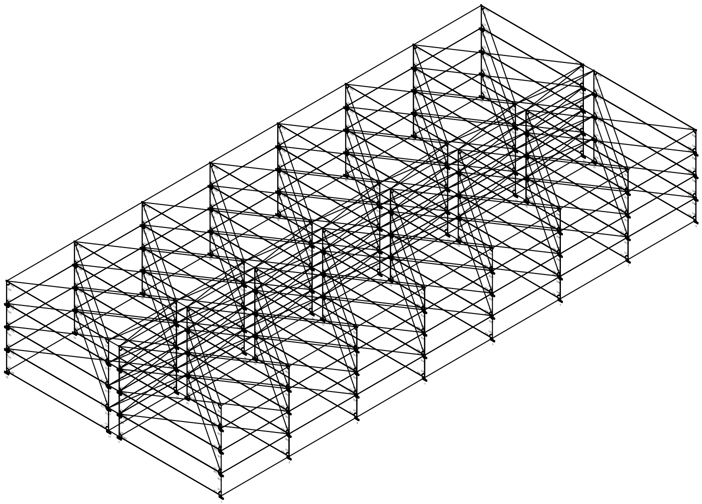
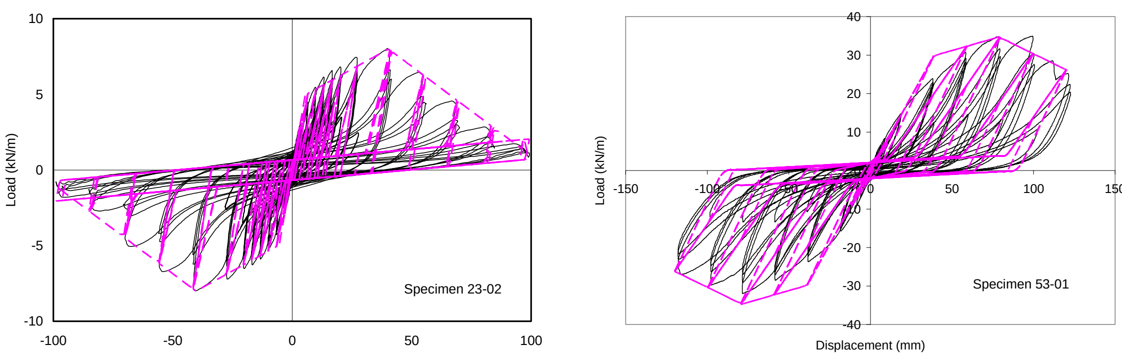


Fig. 5 A DRAIN-3D model for the four-storey building

Test results of standard and midply shear walls matching the wall configurations in the above design were used in the dynamic analysis. Parameters of the pinching hysteresis model for the standard and midply walls were developed by fitting to the test data. Comparison between the test results and the model fitting is shown in Figure 6.



a) standard shear wall *b) midply shear wall*

Fig. 6 Load-displacement curves of the test results and hysteresis model

4. Analysis and discussion

For engineering construction, the greatest source of variability in peak response of a structure to an earthquake arises from the ground motions themselves. In the paper by Ellingwood et al. [8], results obtained from each of the ground motions were presented in the form of a cumulative distribution of peak displacements. Once the peak displacement distributions are determined, the probability of failure can be determined non-parametrically as the relative frequency of the peak displacement exceeding the specified drift limit.

In this paper, the cumulative distribution function of peak storey drift was used to evaluate the probabilities of wall systems exceeding the “near-collapse” drift limits. Using the building with standard shear walls (for which the force modification factor is well established in NBCC) as the bench mark, the force modification factors R_d can be developed for midply shear walls.

Figure 7 shows the peak storey drifts of four-storey building with standard and midply shear walls with force modification factor R_d = 3. As suggested in this figure, the resulting cumulative distribution curves were quite close for the standard and midply shear walls. This indicates that with the force modification factor $R_d = 3$, the midply shear wall system would achieve the same safety level as the standard shear wall system.

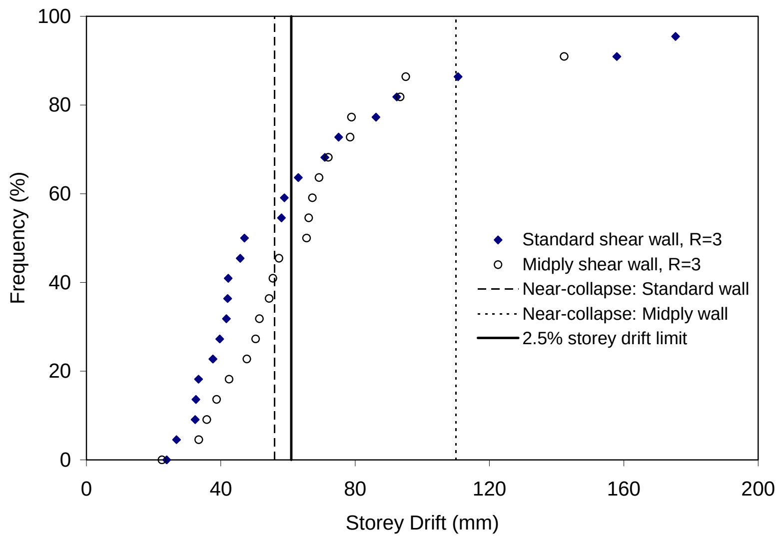


Fig. 7 Cumulative distribution of peak storey drift

5. Conclusions

The midply wall system is a new wall system designed to provide superior resistance to earthquake and wind loads. The improved performance is achieved by rearrangement of wall framing components and sheathing used in standard shear walls. Test results have shown that the midply walls have at least twice the lateral load capacity and stiffness of comparable standard shear walls with the same framing members, panel sheathing, nail diameter and spacing.

Non-linear dynamic analyses of a four-storey wood-frame building were used to determine the seismic design parameters for midply shear walls. Results show that standard and midply shear walls have similar cumulative distributions of peak storey drift. This indicates that for a midply shear wall system with specified shear capacity taken as twice the specified shear capacity of a comparable standard shear wall, a ductility-based force modification factor $R_d = 3$ could be safely assigned to achieve the same safety level as the standard shear wall system for the storey drift limit stipulated in NBCC 2005. The midply wall system outperforms the standard shear wall where 'near-collapse" displacement is considered.

6. References

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