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SHAKE TABLE TESTING ON MOVEABLE OFFICE PARTITIONS WITHOUT TOP RESTRAINT

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ABSTRACT

The partition wall systems of interest in this study are used in typical office building occupancies and one of their interesting architectural features is that they can be easily re-arranged on the floor area without damaging the interior building finishing. They comprise rigid panels clipped on steel light gage framing, glazed panels and doors that can be combined in several geometric layouts to create a closed work space. The bottom railing of the framework is attached to carpeted floors with adhesive carpet fastening strips while the partition system is left unrestrained at the top, with only non-structural fastening to the suspended ceiling above it for providing sound insulation. The purpose of the shake table tests is to study the load paths and overall performance of this type of moveable office partitions (MOPs) and verify their seismic capacities for use in office buildings in Canada. Two specimens were tested on the shake table at the Structures Laboratory of the École Polytechnique de Montréal, Canada. They both had the basic plan geometry of a C-shape 3m x 4m x 3m and a height of 2.6 m, which is typical of a single work unit area. Shake table inputs are unidirectional and perpendicular to the long side wall (front wall). They were mainly the top floor responses of two Montréal office building models in SAP2000 to the base accelerograms that match the seismic hazard in Montréal and Vancouver, as prescribed by the 2005 National Building Code of Canada. For comparison, three top floor responses to the 1999 Chi-Chi Earthquake in Taiwan were also selected as the input. The shake table test results indicate that with proper joint detailing and provided the installation is of good workmanship, the MOPs can perform well in moderate to large Canadian design earthquakes, with the maximum floor input level of 1.4g. However, they would not likely resist the near fault seismic events such as Chi-Chi 1999, with large peak floor acceleration up to 3.0g and displacement up to 115 mm.

Introduction

In North America, moveable office partitions (MOPs) are commonly used to create closed work areas in office buildings. Such partition systems are complex arrangements of

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vertical panels with glass or veneers, doors, posts and railings with metallic clipping and screw connectors, and are typically installed in areas equipped with suspended ceilings. However, direct attachment to the structural system would prevent the partition units to be easily re-arranged. In order to retain flexibility in architectural floor arrangements and minimize damage to interior finishing, the MOPs tested in this study are attached to carpeted floors with adhesive carpet fastening strips under a bottom railing while no mechanical restraint is provided to the ceiling above them. Instead of being inter-story drift sensitive like conventional drywall partitions (Lee et al., 2007), this kind of partition wall system is therefore considered as motion/acceleration sensitive. There is very little published research on the seismic behaviour of MOPs. One previous study performed shake table tests on a bookcase – dry partition wall system and concluded that overturning failure of the MOP with heavy bookcase might occur when no transverse wall restraint is provided (Filiatrault *et al*., 2004b).

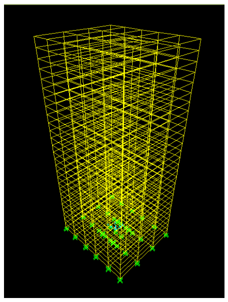
In this study, two specimens are tested with the basic plan geometry of a C-shape 3m x 4m x 3m and a height of 2.6 m, which is typical of a practical single work unit area. The purpose of the tests is to study the seismic load paths and overall performance of the MOPs unrestrained at the top and verify their seismic capacities for use in office buildings in Canada. The shake table tests were conducted at the Structures Laboratory of the *École Polytechnique de Montréal*, Canada. Excitation inputs are unidirectional, perpendicular to the long side of the specimens: they were mainly the top floor responses of two Montréal office building models in SAP2000 to base accelerograms that match the seismic hazard in Montréal and Vancouver, as prescribed by the uniform hazard spectra specified in the 2005 National Building Code of Canada (NBCC) (Atkinson and Beresnev, 1998; Filiatrault *et al.*, 2004a). For comparison, three top floor responses to the 1999 Chi-Chi Earthquake in Taiwan were also selected as the input. The results presented include the seismic capacity and the failure modes of the MOPs and, in conclusion, the authors present some recommendations to improve the seismic performance of the MOPs.

Simulation of the Floor Input Seismic Events

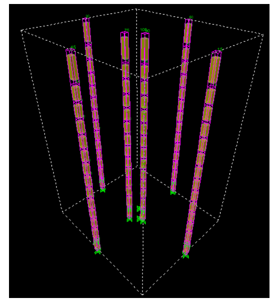
Numerical models of two Montréal existing reinforced concrete shear wall (RCSW) buildings of 27-storey (Building A) and 14-storey (Building B) in height are simulated in SAP2000, as shown in Fig. 1. In both models, the joints at the same floor elevation level are constrained together to create rigid floor diaphragms. The floor masses are lumped at the center of the mass of each level. For Building A, all columns and beams have been simulated in the model, while only six equivalent stick elements of side walls and center core have been modeled in Building B. Although two different approaches were used to establish the models, they have been verified by the results obtained from ambient vibration tests (AVT). (Gilles and McClure, 2008) Table 1 shows the agreement between the SAP2000 analytical and AVT results, confirming the reliability of the two simulation models.

Table 1. Modal periods comparison between the AVT and SAP2000 analytical results

Building	AVT (s)		SAP2000 (s)	
	Mode 1	**Mode 2**	**Mode 1**	**Mode 2**
A	2.17	1.98	2.17	1.99
B	0.71	0.68	0.71	0.68



(a) Building A, 27-storey height



(b) Building B, 14-storey height

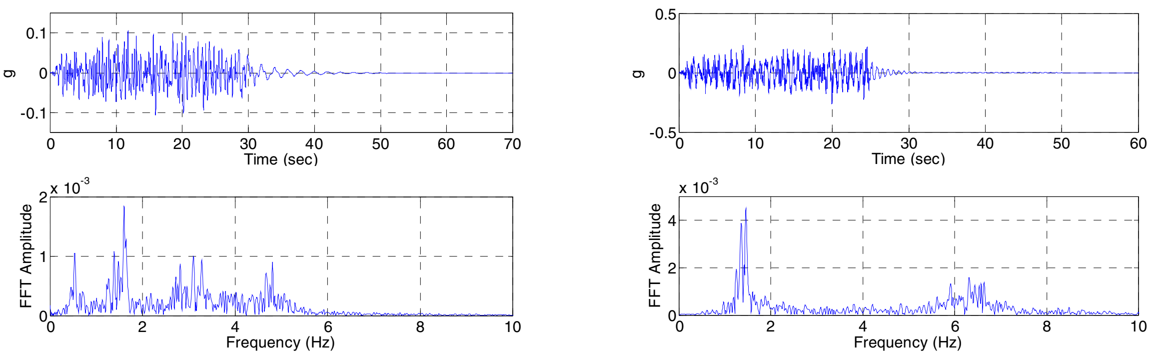
Figure 1. Building models in SAP2000

Several seismic events compatible with the uniform hazard spectra of NBCC 2005 (Atkinson and Beresnev, 1998; Filiatrault *et al*., 2004a) were selected as the input to the building models in SAP20000, and their top floor peak acceleration responses are listed in Table 2 as the Target Peak values. These values show that with the same exceedance probability in 50 years, the western Canadian (Vancouver) seismic events have higher intensity than eastern Canadian (Montréal). Moreover, the floor acceleration responses of Building B are larger than those of Building A under the same excitation level, because the taller Building A has a longer fundamental period. However, comparing their FFT spectra, as shown in Fig. 2, Building A has more abundant frequency components than Building B. It is noteworthy that Building A floor responses show a peak at the frequency component of 4.8Hz, which is close to the natural frequency of the specimen tested in this study. This leads to a larger acceleration amplification of the MOP specimens when subjected to the floor input of Building A, as will be shown in the experimental study section.

Table 2. Seismic events input to the shake table

Seismic event	Target Peak (g)	Achieved Peak in Testing(g)
A_M10%_E70_300*	0.11	0.15
B_M10%_E70_200	0.26	0.35
A_V10%_W72_100	0.35	0.33
B_V10%_W60_50	0.55	0.90
A_ChiChi_T76_50	0.46	0.64
B_ChiChi_T76_50	0.40	0.60
A_M2%_E70_100	0.53	0.69
A_V2%_W72_70	0.67	0.74
B_M2%_E70_70	0.74	1.23
B_V2%_W65_50	1.04	1.45
A_ChiChi_T76_15	1.38	3.19

*Notes to Table 2:
A_M10%_E70_300: Top floor acceleration response of Building A under Eastern earthquake input with magnitude 7.0 at 300 km from the epicenter.
A and B indicates top floor response of Building A and Building B, respectively.
M: Montréal; V: Vancouver
%: Percentage probability of exceedance in 50 years



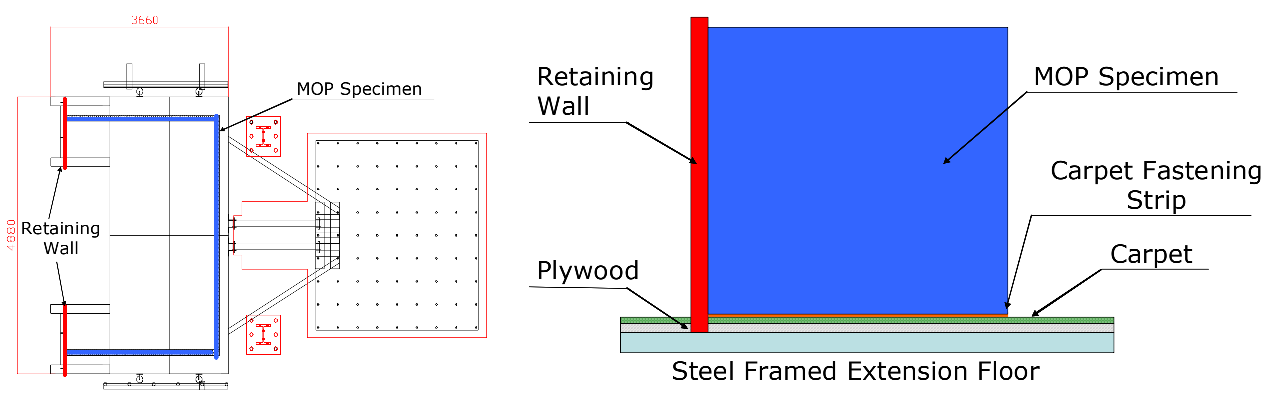
(a) Building A (b) Building B

Figure 2. Top floor responses of two building models and their FFT spectra to the Eastern Canadian (Montréal 10%) design earthquakes

The Experimental Study

Testing Setup

The tests were performed using the 3.4m x 3.4m uni-directional shake table of the Structures Laboratory of the École Polytechnique de Montréal, Canada. The peak-to-peak stroke of the shake table is 300 mm, and its operating frequency range is up to 50Hz. The capacity of the specimen payload and driving actuator is 135kN and 250kN, respectively. Due to the table dimension limitation, a 4.8m x 3.6m steel framed extension floor was constructed to carry the 3m x 4m x 3m MOP specimens, as shown in Fig. 3(a). In practical applications, the MOPs are usually installed with attachment to the existing drywall partitions or to the structural walls (masonry or concrete). Therefore two 0.85m wide x 2.75 m high retaining wall strips were built on the extension floor to restrain the side panels of the MOP specimens. Their plan and lateral views are shown in Figs. 3(a) and 3(b), respectively.

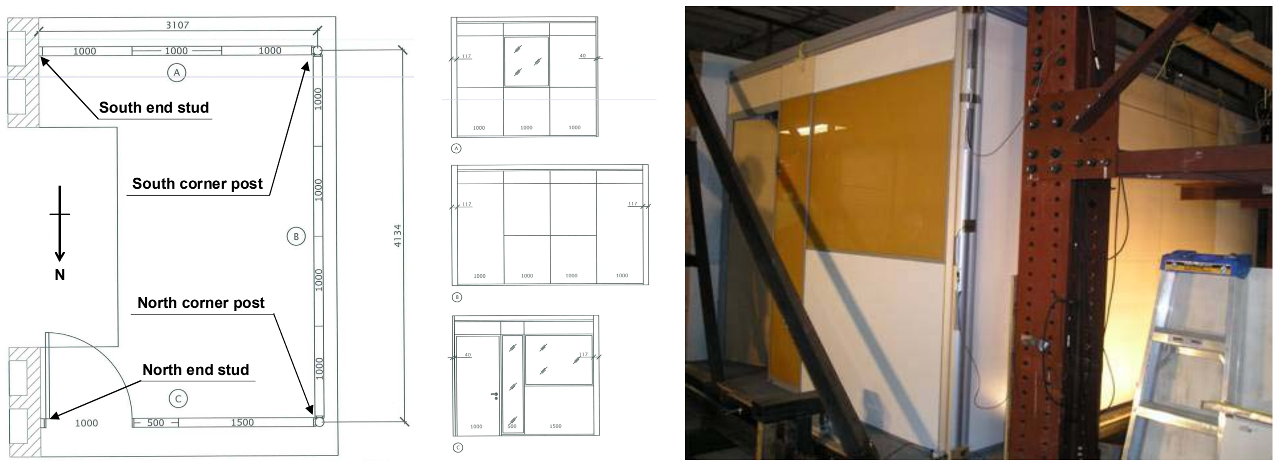


(a) Plan view (b) Side elevation view

Figure 3. Testing setup

Testing Specimens

Two specimens were built in a C-shape 3m x 4m x 3m plan and a height of 2.6 m, which represents a typical single work unit area. Their layouts are identical in plan and elevation views, as shown in Fig. 4, while their joint details differ to compare the effectiveness of some joint reinforcements for seismic loadings. The special features of the two specimens tested are summarized in Table 3, where MOP-2 and MOP-2R identify the specimens before and after joint reinforcement, respectively. The door of the specimen was located at the side wall, as shown in Fig. 4(a), and the stud brackets were to fasten the studs of the side wall frames to the bottom and top railings. The most different features of the two specimens are the attachment mode of the end studs to the retaining walls: for MOP-2, two-sided tape strips were applied along the entire length of the studs, while three toggle bolts were installed at the bottom, mid-height, and top of the end-stud/retaining wall joint for MOP-2R.



(a) Plan view (b) Elevation (c) Installed specimen

Figure 4. MOP test specimen (A and C are defined as the side walls, and B is the front wall)

Table 3. .Features of the MOP test specimens

Specimen	Door at side wall	Two-sided tape	Toggle bolts	Stud brackets
MOP-2	Y	Y	N	N
MOP-2R	Y	N	Y	Y

Note:
Y: the specimen is constructed with the feature.
N: the specimen is constructed without the feature.

Instrumentation

The instrumentation used in the tests is shown schematically in Fig. 5. For the extension floor, four accelerometers and one displacement meter were used to measure the motions of the floor as well as the retaining walls in the main shaking direction. For the MOP specimens, five accelerometers and five displacement meters were used to measure the motion parallel to the input excitation, and two displacement meters were used to measure the motion of the front wall perpendicular to the shaking direction. The arrows shown in Fig. 5 indicate the measuring direction of the instrumentation sensors.

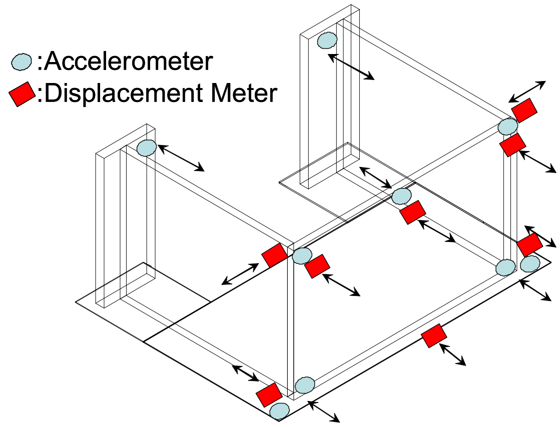
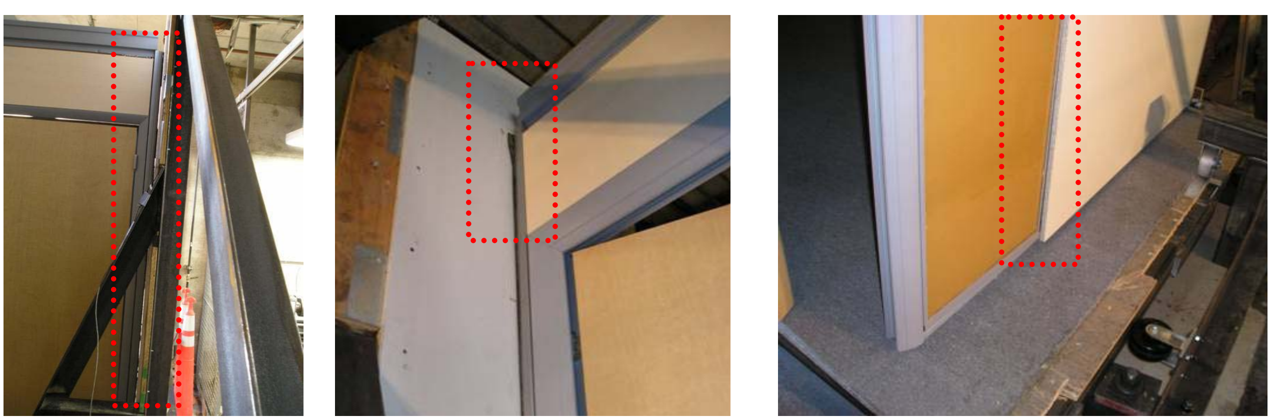


Figure 5. The testing instrumentation

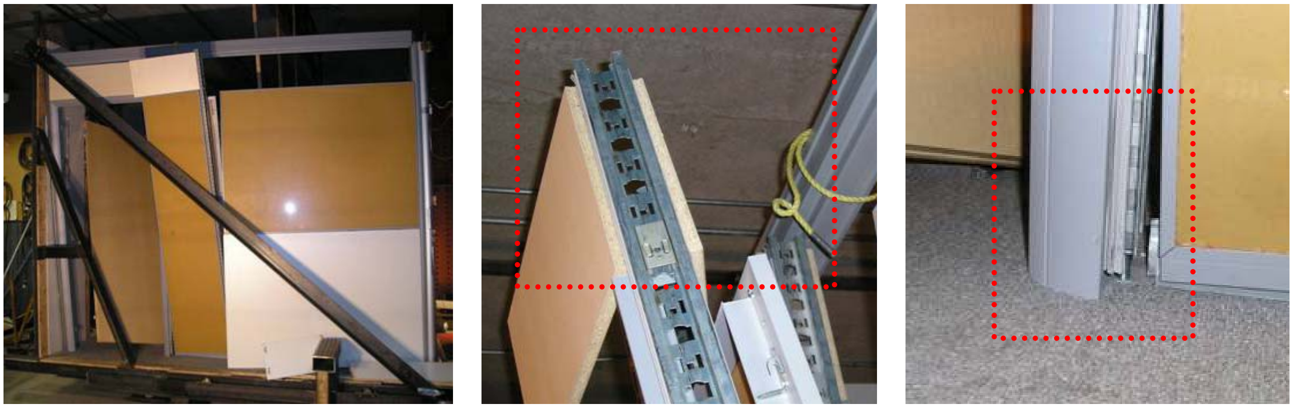
Testing Results

Specimen MOP-2

During the installation of the specimen, we found small gaps between the end stud and the retaining wall of the north side, as shown in Fig. 6(a). It reflected that in practical situations, the two-sided tape strips would not be seismically secure since normal construction tolerances make it difficult to provide ideal contact between the end stud and the retaining wall. By performing a free vibration test, the natural frequency of the specimen in the shaking direction was found to be 4.0 Hz before any seismic input was applied. At the A_V10%_W72_100 input level (the shake table achieved 0.33g), the specimen showed slight damage. The end stud detached from the retaining wall and a panel on the north side wall moved slightly, as shown in Figs. 6(b) and 6(c). However, the whole MOP system remained functional. The front wall showed no damage. After repair, the test kept proceeding. At B_ChiChi_T76_50 input level (the shake table achieved 0.62g), the specimen collapsed, as shown in Fig. 6(d). The end studs completely detached from the retaining walls and the panels showed large inclinations, while the studs of the side walls came off the top beam and the bottom railing, as shown in Figs. 6(e) and 6(f), leading to the collapse of the specimen and the end of this testing series. However, no sliding of the bottom railing with carpet fastening strips has been observed.



(a) (b) (c)



(d) (e) (f)

Figure 6. Views of tested specimen MOP-2

From this test series, we concluded that the seismic capacity of the MOP-2 specimen is less than 0.62g of floor acceleration input. Considering its unsafe failure modes, some joint reinforcements must be provided to increase the fastening strength of the end studs to the horizontal railings and the robustness of the entire wall frame structure.

Specimen MOP-2R

Fig. 7 shows the joint reinforcements installed in the MOP-2R specimen. Fig. 7(a) shows the toggle bolts used to fasten the end stud to the retaining wall. Figs. 7(b) and 7(c) show the stud brackets to integrate the studs with the top and bottom railings, thus providing between continuity of the side wall framework and improving the robustness of the MOP structure.

(a) Toggle bolts (b) Top stud bracket (c) Bottom stud bracket

Figure 7. Joint reinforcement details in MOP-2R

Before proceeding with the shake table tests, the natural frequency of the MOP-2R specimen in the shaking direction was measured at 4.5Hz (MOP-2 was at 4.0 Hz), showing the effectiveness of the joint reinforcements provided. Consequently, as shown in Fig. 8(a), no major damage to MOP-2R was observed after being subjected to the selected Canadian floor seismic events with maximum floor peak acceleration up to 1.4g. The specimen remained functional during the test and only some minor damage, such as the toggle bolts loosening or failures of some screws were observed. The specimen eventually collapsed (Fig. 8(b)) when the input level went up to 3.0g, generated by the near fault event of A_ChiChi_T76_15. During this test input, damage occurred in the front wall, as shown in Fig. 8(c), while the framework of side walls remained undamaged. From the testing results, it is concluded that the MOP system can maintain its functionality during Canadian design earthquakes when joint reinforcements are provided to ensure framing continuity: however, it might not resist strong near-fault earthquakes.

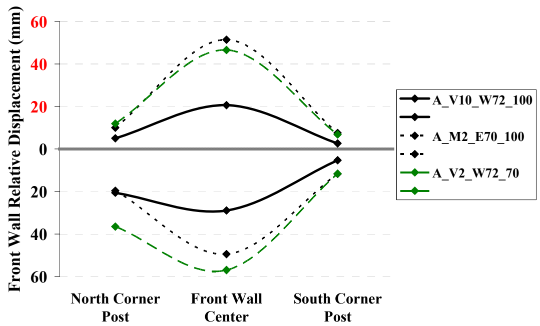
(a) (b) (c)

Figure 8. Views of tested specimen MOP-2R

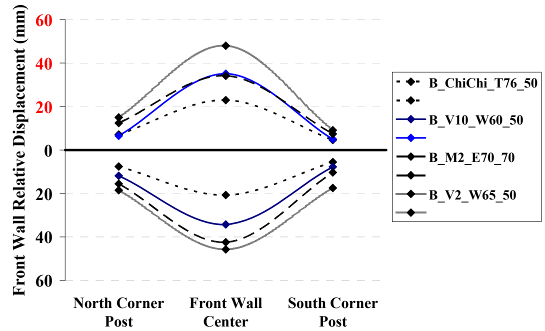
Discussion

Since the non-reinforced MOP-2 specimen could sustain only the first four inputs, it was found inadequate, and the following discussion pertains only to the response of MOP-2R. In this test series, the accelerations at the top of the front wall were amplified more when subjected to the Building A floor seismic events than subjected to the Building B floor events. This is explained by the frequency coincidence between the fundamental period of the specimen and the frequency content of the inputs of Building A at approximately 4.5 Hz. Comparing the response displacements of the front wall in Fig. 9, it is seen that the Building A inputs also caused larger displacements than Building B inputs did. The displacements of the north corner were larger than the south corner, which was caused by the loosening of the toggle bolts on the north end studs during the test.

Fig. 10 shows a schematic of the evolution of the failure modes of the specimens during the tests. The effectiveness of the joint reinforcement in increasing the seismic resistance of the MOP system is obvious. We also stress that the damaged system MOP-2R retains its functionality and is therefore safe for occupants in the event of a Canadian design earthquake.



(a) Responses to building A input



(b) Responses to building B input

Figure 9. Response displacements of MOP-2R front wall

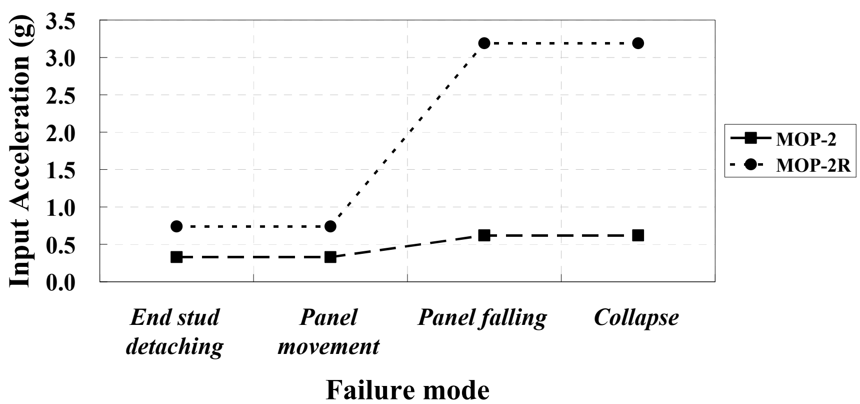


Figure 10. Evolution of the failure modes of the specimens during the tests

Conclusion

In this study, two moveable office partition specimens unrestrained at the top were constructed and tested on the shake table extension floor. Several Canadian design earthquakes, matching the NBCC 2005 seismic hazard in Montréal and Vancouver, were considered as the inputs representing the east and west Canadian seismic events, respectively. Some records from the 1999 ChiChi Earthquake in Taiwan, including one near-fault event, were also considered. In the experimental study, the input excitation is parallel to the side walls, and no additional mass is attached to the specimens; i.e., they carry only their self-weight. The retaining walls on the testing platform proved capable to restrain the partition wall specimens until the specimen collapse. After the test series have been completed, the analysis of the results has yielded the following significant findings:

- The seismic capacity of the specimens tested in this study is about 1.4g and 0.6g with and without joint reinforcement, respectively.
- No visible sliding of the bottom railings with the carpet fastening strips has occurred during the test.
- The failure mode sequence is the end stud detaching from the retaining wall first, followed by rocking and the panel movement, then the panel falling, and finally either the side wall or

the front wall collapse, leading to the complete failure of the specimen.

- The partition wall system without top restraint can perform well in moderate to large Canadian design earthquakes provided the installation and the joint details are of good workmanship. However, it would not likely resist severe near-fault seismic events.

Acknowledgments

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