Effect of plywood retrofit on dynamic response of URM house subjected to forced vibration

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Contents

- Introduction
- Construction details
- Instrumentation
- Experimental procedure
- Results
- Conclusions
Introduction

URM material
(late 19\textsuperscript{th} century & early 20\textsuperscript{th} century)

Major destruction
(1931 Hawke’s Bay Earthquake)

Legally prohibited
(1965 – NZS 1900)

Constructed between
1880 and 1950

[Photo Credit: Alexander Turnbull Library, National Library of New Zealand]
Major cause of URM building failures (1931 Hawke’s Bay EQ)

- no connections between walls and floor or roof diaphragms (Blaikie and Spurr, 1992)

Out-of-plane wall (tension anchors required to avoid separation between wall and diaphragm)

In-plane wall (shear anchors needed to avoid sliding of diaphragm)

Earthquake loading

act as cantilever wall over the total height of building
Current problems in URM buildings

- wall-diaphragm connections were only applied at joist perpendicular to wall

**East-West earthquake direction**

- east and west walls are subjected to out-of-plane failure
- pounding between diaphragm and east/west walls
• all perimeter walls of URM buildings were anchored
• east and west walls were anchored to the transverse beams instead of directly to the joist
• load transfer to diaphragm are not efficient as the timber joists are only seated on the transverse beams without positive connections
• also, these connections were too far apart and may not sufficient in strength to hold east and west walls
Gisborne Earthquake, 2007

out-of-plane wall failure
Gisborne Earthquake, 2007

parapet failure

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Gisborne Earthquake, 2007

connection failures
Objectives

- to determine the dynamic properties of the as-built URM structure
- to investigate the force path through the as-built URM structure
- to evaluate changes in the dynamics structural characteristics and the force path due to retrofit implementations
Construction details

- recycle clay bricks
- mortar - 1:2:9 (cement:lime:sand)
- timber joists
  - supported by the interior leaf (pocket) of the east and west walls
- floor planks
  - staggered pattern to avoid the diaphragm being overly stiff

as-built (north view)
Retrofit implementations

plywood retrofit

wall-diaphragm connection retrofit

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Bolted timber connection details (two bolts)
Instrumentation

desktop with MatLab application

amplifier for shaker

data acquisition box

electrodynamic linear mass shaker

accelerometer (horizontal)

small accelerometer (horizontal)
Experimental Procedure

As-built

Plywood retrofit

Wall-diaphragm connection retrofit
# Summary of forced vibration tests

<table>
<thead>
<tr>
<th>Stage</th>
<th>Shaker excitation</th>
<th>Freq. range (Hz)</th>
<th>Freq. step (Hz)</th>
<th>Excitation (s)</th>
<th>Delay (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>As-built</td>
<td>NS</td>
<td>10.0-15.0</td>
<td>0.1</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>EW</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plywood</td>
<td>NS</td>
<td>14.5-19.5</td>
<td>0.1</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>EW</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anchor</td>
<td>NS</td>
<td>17.0-22.0</td>
<td>0.1</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>EW</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- stepped sine input motion
- 500 data per second
- total time each test = 17 minutes
Results

Transfer function curves – NS excitation

- natural frequency and amplitude was changed significantly due to the retrofit implementations
Transfer function curves – EW excitation

Test point 11 (as-built)
16.6 Hz

Test point 11 (plywood retrofit)
11.8 Hz

Test point 11 (wall-diaphragm anchor)
18.3 Hz

Frequency (Hz)

Txy (g/N)
NS mode shapes (as-built vs plywood vs anchor)

2.98
plywood retrofit
N
0.04
0.08

0.95
as-built

0.30
as-built

0.08
0.12

plywood retrofit
+ anchor

0.85

0.03
0.04

0.81

3.35
EW mode shapes (as-built vs plywood vs anchor)
Normalised amplitude ratio

<table>
<thead>
<tr>
<th></th>
<th>As-built</th>
<th>Plywood retrofit</th>
<th>Plywood retrofit + Wall-diaphragm anchor</th>
</tr>
</thead>
<tbody>
<tr>
<td>NS</td>
<td>1</td>
<td>0.47</td>
<td>0.08</td>
</tr>
<tr>
<td>WE</td>
<td>1</td>
<td>0.40</td>
<td>0.26</td>
</tr>
</tbody>
</table>

- the successive retrofitting improves the force transfer mechanism.
- the bending failure of the out-of-plane walls can be controlled.
- the structure works as a single unit.
Conclusions

• the dynamic properties and force path through the as-built URM were investigated

• the retrofit implementations affect the dynamic properties of the structure

• the force distribution to the URM walls was significantly improved by the plywood diaphragm and connection
Acknowledgements

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Coherence function curves

- Test point 2 (NS excitation)
- Test point 11 (WE excitation)
Blockings

Nail connections

Joists