Seismic Evaluation of Three District Office Buildings Damaged during 2016 Meinong, Taiwan Earthquake using ASCE 41

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Tuesday, June 26 – Friday, June 29
2016 Meinong Earthquake

Date and Time  2016/02/06 03:57:26 (UTC+8)
Magnitude (M_l)  6.6
Deaths  117
Injuries  551
Buildings Damaged  Completely Collapse: more than 11
                  Red Tagged: 288
                  Yellow Tagged: 328

(sources: CWB; Central Emergency Operation Center; NCDR; Construction and Planning Agency, Ministry of the Interior, Taiwan)
Building Damage
District Office Buildings

Juo-Jhen

Shan-Shang

Guei-Ren
## Basic Building Information

<table>
<thead>
<tr>
<th>District Office Name</th>
<th>Year of Construction / Modification Phase(s)</th>
<th>Building Dimension (Long. × Trans.)</th>
<th>Nominal Material Properties</th>
<th>Observed Structural Performance Level per ASCE 41</th>
<th>Status in 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Juo-Jhen</td>
<td>1974/ 1984/ 1998</td>
<td>108.3 ft × 57.4 ft</td>
<td>$f_c' = 3,000 \text{ psi (RC)}$</td>
<td>Between Life Safety (LS) and Collapse Prevention (CP)</td>
<td>Retrofitted</td>
</tr>
<tr>
<td>Shan-Shang*</td>
<td>1984</td>
<td>108.3 ft × 57.4 ft</td>
<td>$f_y = 40 \text{ ksi (rebar)}$</td>
<td>Between LS and CP</td>
<td>Demolished</td>
</tr>
<tr>
<td>Guei-Ren</td>
<td>1974/ 1988/ 2012*</td>
<td>131.2 ft × 57.4 ft</td>
<td></td>
<td>Immediate Occupancy (IO)</td>
<td>In Use</td>
</tr>
</tbody>
</table>

*This building has a partial basement
**Seismic upgrade
Typical Floor Plan and Column Details

1st Floor Plan
(Juo-Jhen District Office Building; source: NCREE)
Ground Motion Records and Seismic Demands

CHY089, Measured PGA:
0.40g(EW), 0.28g(NS), 0.10g(Z)

CHY070, Measured PGA:
0.25g(EW), 0.15g(NS), 0.17g(Z)

(source: NCREE)
Response Spectrum (CHY089)
## Analysis Summary (ASCE 41, LDP)

<table>
<thead>
<tr>
<th>District Office Building</th>
<th>Build Weight (kip)</th>
<th>Periods (second) (Modes 1, 2 and 3)</th>
<th>Spectral Acceleration (g)</th>
<th>LDP in Longitudinal Direction (X-dir.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Base Shear (kip)</td>
</tr>
<tr>
<td>Juo-Jhen</td>
<td>3,752</td>
<td>0.58, 0.19, 0.19</td>
<td>1.06</td>
<td>3,717</td>
</tr>
<tr>
<td>Shan-Shang</td>
<td>3,100</td>
<td>0.53, 0.19, 0.18</td>
<td>0.93</td>
<td>2,701</td>
</tr>
<tr>
<td>Guei-Ren (retrofitted)</td>
<td>3,667</td>
<td>0.22, 0.21, 0.15</td>
<td>0.68</td>
<td>1,992</td>
</tr>
</tbody>
</table>
## Analysis Summary (ASCE 41, NSP)

<table>
<thead>
<tr>
<th>District Office Building</th>
<th>Build Weight (kip) and Height (ft)</th>
<th>NSP in Longitudinal Direction (X-dir.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Effective Periods (second)</td>
<td>Spectral Acceleration (g)</td>
</tr>
<tr>
<td>Juo-Jhen</td>
<td>3,752 36.4</td>
<td>0.58</td>
</tr>
<tr>
<td>Shan-Shang</td>
<td>3,100 36.4</td>
<td>0.54</td>
</tr>
<tr>
<td>Guei-Ren (retrofitted)</td>
<td>3,667 36.4</td>
<td>0.23</td>
</tr>
</tbody>
</table>

*The building model remains essentially elastic at target roof displacement*
Juo-Jhen District Office Building
Column Evaluation Results vs Actual Damage
Observed (Jho-Jhen District Office)

LDP, column shear DCRs (1st floor), LS performance level
- DCR < 1.0
- 1.0 ≤ DCR ≤ 2.0
- DCR > 2.0

NSP, column hinge distribution (1st floor), 82% of target roof displacement
- IO ~ LS
- LS ~ CP
- > CP

Observed Column Damage during Meinong Earthquake

Degenkolb
Shan-Shang District Office Building
Column Evaluation Results vs Actual Damage Observed (Shan-Shang District Office)

LDP, column shear DCRs (1st floor), LS performance level
- DCR < 1.0
- 1.0 ≤ DCR ≤ 2.0
- DCR > 2.0

NSP, column hinge distribution (1st floor), 100% of target roof displacement

Observed Column Damage during Meinong Earthquake
Guei-Ren District Office Building (Retrofitted)

- ASCE 41-13 LDP
  - DCR = 0.67 (LS)
  - DCR = 0.74 (IO)

- ASCE 41-13 NSP
  - DCR = 0.19 (LS)
Taiwan Earthquake Assessment for Structures by Pushover Analysis (TEASPA)

- ATC 40 based approach (capacity spectrum method)
- Performance point (for school buildings) is selected as one of the following points on the capacity curve:
  - Peak base shear
  - 2% roof drift
  - Failure of gravity load carrying components
- Focusing on global building performance

<table>
<thead>
<tr>
<th>Shan-Shang District Office Building</th>
<th>X direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Shear (tonf)</td>
<td>462</td>
</tr>
<tr>
<td>Roof Displacement (cm)</td>
<td>4.05</td>
</tr>
<tr>
<td>Seismic Capacity $A_p$ (g)</td>
<td>0.26</td>
</tr>
<tr>
<td>Ground Motion Record $A_{EQ}$ (g)</td>
<td>0.40</td>
</tr>
<tr>
<td>Capacity-Demand Ratio (CDR)</td>
<td>0.66</td>
</tr>
</tbody>
</table>

Retrofit required
ASCE 41 vs. TEASPA Results

### Jho-Jhen

<table>
<thead>
<tr>
<th>Building</th>
<th>TEASPA DCR</th>
<th>ASCE 41 LS DCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jho-Jhen</td>
<td>1.54</td>
<td>1.29</td>
</tr>
<tr>
<td>Shan-Shang</td>
<td>1.52</td>
<td>1.05</td>
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<td>0.40</td>
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</tr>
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**DCR Summary**
Main Findings

1) ASCE 41 LDP conservatively identified the over-stressed columns
2) ASCE 41 NSP captured the global performance well for all three buildings
3) LDP generally predicted higher DCRs compared to NSP
4) Both ASCE 41 and TEASPA provided reasonable estimations of building performance
5) Significant differences in the calculated strength and deformation capacity from ASCE 41 NSP and TEASPA
Thank you!