Building Response

Meinong Earthquake, Tainan, Taiwan

Team Members:

Daniel Zepeda, Principal
Kirk Johnston, Principal
Insung Kim, Project Engineer
Garrett Hagen, Design Engineer
Jiun-Wei Lai, Designer
# Impact of the 0206 Meinong Earthquake

<table>
<thead>
<tr>
<th>Date and Time</th>
<th>2016/02/06 03:57:26 (UTC+8)</th>
</tr>
</thead>
</table>

(source: Central Emergency Operation Center; NCDR; Construction and Planning Agency, Ministry of the Interior, Taiwan)

<table>
<thead>
<tr>
<th>Category</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deaths</td>
<td>117</td>
</tr>
<tr>
<td>Injuries</td>
<td>551</td>
</tr>
<tr>
<td>Left homeless</td>
<td>Over 900 families (as of 2016/02/14)</td>
</tr>
<tr>
<td>Population</td>
<td>23,490,724 (Taiwan)</td>
</tr>
<tr>
<td></td>
<td>1,885,550 (Tainan City)</td>
</tr>
<tr>
<td>Buildings destroyed</td>
<td>Completely Collapse: more than 11 Red Tagged: 247 (as of 2016/03/04) Yellow Tagged: 335</td>
</tr>
<tr>
<td>Financial Cost</td>
<td>&gt; $5.2 million USD (170,730,000 NTD, agriculture industry) &gt; $6.4 million USD (212,000,000 NTD, school buildings) &gt; $0.4 million USD (14,600,000 NTD, water pipeline damage) and more to be determined...</td>
</tr>
</tbody>
</table>
## Development of Reinforced Concrete Structure Design Code in Taiwan

<table>
<thead>
<tr>
<th>Year</th>
<th>Design Code Version</th>
<th>Corresponding ACI-318 Version</th>
<th>Note (source: Prof. S.J. Hwang and Mr. J.L. Wang)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1967</td>
<td>Civil 401-56</td>
<td>1963</td>
<td>Working Stress Design (WSD)</td>
</tr>
<tr>
<td>1970</td>
<td>Civil 401-59</td>
<td>1963</td>
<td>Ultimate Strength Design (USD) in appendix</td>
</tr>
<tr>
<td>1979</td>
<td>Civil 401-68</td>
<td>1977</td>
<td>Mainly USD, WSD (in appendix). Special seismic design provisions (in appendix)</td>
</tr>
<tr>
<td>1991</td>
<td>Civil 401-80</td>
<td>1989</td>
<td>Special seismic design provisions moved to main text</td>
</tr>
<tr>
<td>1995</td>
<td>Civil 401-84</td>
<td>1989</td>
<td>Added commentary</td>
</tr>
<tr>
<td>1997</td>
<td>Civil 401-86</td>
<td>1995</td>
<td>Unified Design Provisions for RC and PC</td>
</tr>
<tr>
<td>2000</td>
<td>Civil 401-86a</td>
<td>1995</td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>Civil 401-93</td>
<td>2002</td>
<td>Load Factors, Strength Reduction Factors, Strut-and-Tie Model, Concrete Anchorages etc.</td>
</tr>
<tr>
<td>2007</td>
<td>Civil 401-96</td>
<td>2005</td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>Civil 401-100</td>
<td>2005</td>
<td></td>
</tr>
</tbody>
</table>
# Evolution of Building Code Design Base Shear

<table>
<thead>
<tr>
<th>Year</th>
<th>Design Base Shear</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 1974</td>
<td>$V = KW = 0.1W$</td>
<td>Based on Japanese building code</td>
</tr>
<tr>
<td>1974 (February)</td>
<td>$V = ZKCW$</td>
<td>Ductile design guidelines for RC structures (3 seismic zones)</td>
</tr>
<tr>
<td>1982 (June)</td>
<td>$V = ZKCIW$</td>
<td>Based on UBC 76 adding importance factor (3 seismic zones)</td>
</tr>
<tr>
<td>1989 (May)</td>
<td>$V = ZKCIW$</td>
<td>Consider basin effect in factor C</td>
</tr>
<tr>
<td>1997 (May)</td>
<td>$V = \frac{ZI}{1.4\alpha_y} \left( \frac{C}{F_u} \right)_m W$</td>
<td>Major change, consider vertical ground motion component (4 seismic zones)</td>
</tr>
<tr>
<td>1999 (December)</td>
<td></td>
<td>Seismic zones reduced from 4 to 2</td>
</tr>
<tr>
<td>2005 (July)</td>
<td>$V = \frac{S_{adI}}{1.4\alpha_y F_u} W$</td>
<td>Seismic microzonation in Taipei basin</td>
</tr>
<tr>
<td>2011 (July)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

http://www.cpami.gov.tw/
Site Spectrum versus Code Design Spectrum

Station: TAI (Tainan city)

$V_{S30} = 198 \text{ m/sec} = 650 \text{ ft/sec}$

Site Class D

(source: NCREE, Taiwan)
Typical Building Construction
Map of Sites Visited
Buildings with Collapse / Partial Collapse:

Wang Lin Hotel

(Google street view)
Buildings with Collapse / Partial Collapse: Wang Lin Hotel
Buildings with Collapse / Partial Collapse:

Wang Lin Hotel

EERI Taiwan Earthquake Reconnaissance Briefing Webinar
Buildings with Collapse / Partial Collapse: Xinfu Building

(Google street view)

(Bureau of Public Works, Tainan City)
Buildings with Collapse / Partial Collapse:

Xinfu Building
Buildings with Collapse / Partial Collapse:
Weikuan Jinlong Complex

(source: NCREE)
Buildings with Collapse / Partial Collapse:
Weikuan Jinlong Complex

(source: Mr. Wang 王品翰)
Buildings with Collapse / Partial Collapse:

Weikuan Jinlong Complex

- PGA = 0.15g
- Sa = 0.29g
- PGA = 0.23g
- Sa = 0.63g
Buildings with Collapse / Partial Collapse:
Weikuan Jinlong Complex

Credit:  施忠賢 Justin C.H. Shih

EERI Taiwan Earthquake Reconnaissance Briefing Webinar
Buildings with Collapse / Partial Collapse:
Weikuan Jinlong Complex

1st Floor plan provided by netizen(PTT), **Original Design Drawing?**

（圖摘自PTT八卦版）

**completed drawing?** South Side became one supermarket

Credit: 施忠賢 Justin C.H. Shih

平均分割為店舖 Shop space is divided averagely

五戶變成一戶 five rooms is merged into one
Buildings with Collapse / Partial Collapse:

Weikuan Jinlong Complex

Credit: EERI Taiwan Earthquake Reconnaissance Briefing Webinar

依原始設計圖 original drawing

Credit: 施忠賢 Justin C.H. Shih

依竣工圖 complete drawing
Buildings with Collapse / Partial Collapse:

Weikuan Jinlong Complex

Credit: EERI Taiwan Earthquake Reconnaissance Briefing Webinar

依竣工圖 complete drawing

Credit: 施忠賢 Justin C.H. Shih

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Buildings with Collapse / Partial Collapse:

King’s Town Bank

(Google street view)

(source: Dr. Tu Yi-Hsuan, NCKU)
Buildings with Collapse / Partial Collapse:
Dachih Marketplace
Damaged Buildings:

Yujing Junior High School (0.22g)
Damaged Buildings:
Yujing Junior High School (0.22g)
Damaged Buildings:

ShanShang District Office
Damaged Buildings:

ShanShang District Office

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Strengthened Buildings:

Gueiren District Office
Strengthened Buildings: Gueiren District Office

EERI Taiwan Earthquake Reconnaissance Briefing Webinar
Strengthened Buildings:
Deguang Catholic High School
Strengthened Buildings:
Deguang Catholic High School

Credit: Justin C.H. Shih Structural Engineer & Associates
Strengthened Buildings:
Deguang Catholic High School

Images provided by Justin C.H. Shih Structural Engineer & Associates

• 磚牆貼附RC牆補強，不影響原空間，粉刷後外觀看不出來有補強。
Strengthened Buildings:
Typical Strengthening Methods

Images provided by Justin C.H. Shih Structural Engineer & Associates

School Building Seismic Program:

- 334 “Safe” Buildings: 1 Damaged
- 75 “Unsafe” Buildings: 18 Damaged

Images provided by Justin C.H. Shih Structural Engineer & Associates
Final Thoughts:

- Vertical irregularity
- Plan irregularity
- Torsional effect
- Soft (weak) story issue
- System redundancy issue
- Ductile details
- Construction quality
Final Thoughts:

“The Mystery of Nature” - Insung
Final Thoughts:

Lateral System

1999

1999 CHI-CHI EARTHQUAKE

2010

2016 TAINAN EARTHQUAKE

2016 TAIWAN EARTHQUAKE

SPECTRAL ACCELERATION

RNDC

SPECTRAL DISPLACEMENT

NDC + MI

KEY:

NDC = NON-DUCTILE CONCRETE
MI = MAJOR IRREGULARITIES
RNDC = REGULAR NON-DUCTILE CONCRETE
Webinar Briefing Speakers & Agenda

1. **Introduction** by Charles Huyck, *Executive Vice President, ImageCat, EERI LFE Chair*

2. **Geology & Seismology** by Kevin Clahan, *Principal Geologist, Lettis Consultants International (representing GEER Team)*

3. **Ground Response** by Joseph Sun, *Principal Engineer, PG&E (representing GEER Team)*

4. **Liquefaction-induced building damage (& GEER-team remote sensing efforts)** by Tara Hutchinson, *Professor, UC San Diego (representing GEER Team)*

5. **Building Response** by Jiun-Wei Lai, *Designer, Degenkolb Engineers (representing Degenkolb Team)*

6. **Infrastructure Response In a Resiliency Context** by Kevin S. Moore, *Principal, Simpson, Gumpertz & Heger (representing SGH Team)*

7. Question & Answer Session