CE 479
CURTAIN WALL STRUCTURES

Guest Lecturer:
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Principal
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OBJECTIVES AND DISCUSSION TOPICS

1. What are curtain walls?
2. Are they architecture? Or engineering?
3. Two basic curtain wall systems
4. Curtain wall framing concepts
5. Infill panels
6. Glass
7. Special problems in structural behavior
8. Temperature effects
WHAT ARE CURTAIN WALLS?

1. Lightweight wall systems installed outside of building structure. Often not the design of the Structural Engineer of Record (EOR)
2. Designed to resist wind and rain. Must also accommodate building drift and seismic movements without distress
“CLASSIC” CURTAIN WALLS

1. Commonly aluminum-framed
2. Repetition of elements for economy and design simplicity
3. Infill panels “float” in framing
4. Glass as a unique infill panel

The Inland Steel Building 1957
Skidmore, Owings & Merrill Chicago
1. The engineering is left to others, often the manufacturer?
2. Usually design is performed by SE’s working for sub-contractors to the General Contractor for the building
1. Alloyed aluminum 6061-T5 or 6063-T6
2. Yield strength’s comparable to mild steel
3. Modulus of elasticity 1/3 of steel
4. Principal design load - wind. Loads either determined
5. Deflection often governs design
## Table 3.0-1
DIFFERENCES—ALUMINUM AND STEEL (1)

<table>
<thead>
<tr>
<th>Property</th>
<th>Steel</th>
<th>Aluminum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus of elasticity</td>
<td>$29 \times 10^3$ ksi</td>
<td>$10.1 \times 10^3$ ksi</td>
</tr>
<tr>
<td>Weight per volume</td>
<td>0.284 lb/in$^3$</td>
<td>0.10 lb/in$^3$</td>
</tr>
<tr>
<td>Thermal expansion</td>
<td>$7 \times 10^{-6}$ in/in/$^\circ$F</td>
<td>$13 \times 10^{-6}$ /in/in/$^\circ$F</td>
</tr>
<tr>
<td>Corrosion resistance</td>
<td>Needs protection</td>
<td>Often used unpainted</td>
</tr>
</tbody>
</table>
### Table 3.3-1
MINIMUM MECHANICAL PROPERTIES FOR ALUMINUM ALLOYS

<table>
<thead>
<tr>
<th>ALLOY AND TEMPER</th>
<th>PRODUCT</th>
<th>THICKNESS RANGE</th>
<th>$F_{tu}$ ksi</th>
<th>$F_{ty}$ ksi</th>
<th>$F_{cy}$ ksi</th>
<th>$F_{su}$ ksi</th>
<th>COMPR. MODULUS OF ELASTICITY²</th>
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</thead>
<tbody>
<tr>
<td>6005-T5</td>
<td>Extrusions</td>
<td>up thru 1.000</td>
<td>38</td>
<td>35</td>
<td>35</td>
<td>24</td>
<td>10,100</td>
</tr>
<tr>
<td>6061-T6, T651</td>
<td>Sheet &amp; Plate</td>
<td>0.010 to 4.000</td>
<td>42</td>
<td>35</td>
<td>35</td>
<td>27</td>
<td>10,100</td>
</tr>
<tr>
<td>-T6, T6510, T6511</td>
<td>Extrusions</td>
<td>All</td>
<td>38</td>
<td>35</td>
<td>35</td>
<td>24</td>
<td>10,100</td>
</tr>
<tr>
<td>-T6, T651</td>
<td>Cold Fin. Rod &amp; Bar</td>
<td>up thru 8.000</td>
<td>42</td>
<td>35</td>
<td>35</td>
<td>25</td>
<td>10,100</td>
</tr>
<tr>
<td>-T6</td>
<td>Drawn Tube</td>
<td>0.025 to 0.500</td>
<td>42</td>
<td>35</td>
<td>35</td>
<td>27</td>
<td>10,100</td>
</tr>
<tr>
<td>-T6</td>
<td>Pipe</td>
<td>All</td>
<td>38</td>
<td>35</td>
<td>35</td>
<td>24</td>
<td>10,100</td>
</tr>
<tr>
<td>6063-T5,</td>
<td>Extrusions</td>
<td>up thru 0.500</td>
<td>22</td>
<td>16</td>
<td>16</td>
<td>13</td>
<td>10,100</td>
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<tr>
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<td>22</td>
<td>16</td>
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<td>10,100</td>
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<tr>
<td>-T5</td>
<td>Extrusions</td>
<td>0.500 to 1.000</td>
<td>21</td>
<td>15</td>
<td>15</td>
<td>12</td>
<td>10,100</td>
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<tr>
<td>-T6</td>
<td>Extrusions &amp; Pipe</td>
<td>All</td>
<td>30</td>
<td>25</td>
<td>25</td>
<td>19</td>
<td>10,100</td>
</tr>
<tr>
<td>6066-T6, T6510, T6511</td>
<td>Extrusions</td>
<td>All</td>
<td>50</td>
<td>45</td>
<td>45</td>
<td>27</td>
<td>10,100</td>
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<tr>
<td>6070-T6, T62</td>
<td>Extrusions</td>
<td>up thru 2.999</td>
<td>48</td>
<td>45</td>
<td>45</td>
<td>29</td>
<td>10,100</td>
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<tr>
<td>6105-T5</td>
<td>Extrusions</td>
<td>up thru 0.500</td>
<td>38</td>
<td>35</td>
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<td>24</td>
<td>10,100</td>
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<tr>
<td>6351-T5</td>
<td>Extrusions</td>
<td>up thru 1.000</td>
<td>38</td>
<td>35</td>
<td>35</td>
<td>24</td>
<td>10,100</td>
</tr>
<tr>
<td>6351-T6</td>
<td>Extrusions</td>
<td>up thru 0.750</td>
<td>42</td>
<td>37</td>
<td>37</td>
<td>27</td>
<td>10,100</td>
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<tr>
<td>6463-T6</td>
<td>Extrusions</td>
<td>up thru 0.500</td>
<td>30</td>
<td>25</td>
<td>25</td>
<td>19</td>
<td>10,100</td>
</tr>
<tr>
<td>7005-T53</td>
<td>Extrusions</td>
<td>up thru 0.750</td>
<td>50</td>
<td>44</td>
<td>43</td>
<td>28</td>
<td>10,500</td>
</tr>
</tbody>
</table>

1. $F_{tu}$ and $F_{ty}$ are minimum specified values (except $F_{ty}$ for 1100-H12, H14 Cold Finished Rod and Bar and Drawn Tube, Alclad 3003-H18 Sheet and 5050-H32, H34 Cold Finished Rod and Bar which are minimum expected values); other strength properties are corresponding minimum expected values.

2. Typical values. For deflection calculations an average modulus of elasticity is used; this is 100 ksi lower than values in this column.
WIND LOADS

1. Wind is the principal structural design load (rain and thermal resistance uses other principles)
2. Loads determined from code either by SER or curtain wall SE
3. Usually ASCE 7 based
4. Wind tunnel modeling is used for significant buildings
5. Other loads - “missile” impact during hurricane, bomb blast loads
BASIS FOR WIND LOAD DESIGN
WIND TUNNEL TESTING TO DETERMINE WIND LOADS

- 1:100 scale models
- Instrumented with pressure taps
- Placed in Wind-tunnel and subjected to winds from each direction
HURRICANE KATRINA – CASE STUDY

- Category IV Storm
- 140 mph gusts at landfall
- Eye passed 50 miles east of New Orleans
HURRICANE KATRINA – CASE STUDY
TESTING GLASS FOR RESISTANCE TO DEBRIS (MISSILES)
GLASS EXPOSED TO EXTREME FORCES

Testing at White Sands, New Mexico

Courtesy: 3M Corp.
HOW GLASS AND FRAME RESIST BLAST FORCE

Glass - Shattering with Impact

Glass with Safety Film - Bending with Impact

Courtesy: 3M Corp.
1. Sections optimized for in-plane bending efficiency
2. Extruded aluminum sections optimized for efficiency
3. Manufacturers have standard dies and sections
# SLENDER BEAM ELEMENTS

<table>
<thead>
<tr>
<th>Type of Stress</th>
<th>Type of Member or Element</th>
<th>Allowable Stress</th>
<th>Slenderness Limit $S_1$</th>
<th>Allowable Stress $S_1 &lt; \text{Slenderness} &lt; S_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMPRESSION IN BEAMS,</td>
<td>Single web shapes</td>
<td>$-I-T-E-$</td>
<td>$\frac{F_{cy}}{n_y}$</td>
<td>$L_b \frac{1.2(B_c - F_{cy})}{D_c}$</td>
</tr>
<tr>
<td>extreme fiber, gross section</td>
<td></td>
<td></td>
<td></td>
<td>$\frac{1}{n_y} \left( B_c - \frac{D_c L_b}{1.2 r_y C_b} \right)$</td>
</tr>
</tbody>
</table>

*References: Aluminum Design Manual 2005*
1. Sections can have “thermal breaks” to reduce thermal conductivity
2. Engineered sections include performance of plastics bonded to aluminum
BASIC CURTAIN WALL ASSEMBLIES

1. Two basic ways to assemble curtain wall systems
2. Stick: Piece-built and glazed on site
3. Unitized: Pre-built with glazing in a shop. Erected on site
4. Selection may be specified. Often decision is based on contractor’s cost analysis
CURTAIN WALL COMPONENTS

1. Anchors
2. Mullion
3. Horizontal Rail
4. Spandrel Panel
5. Vision Glass
1. Vertical elements: Mullions
2. Horizontal elements: Rails (sometimes mullions) - typically frame short distance from mullion to mullion and transfer gravity weight of glass to mullions
ISOMETRIC OF PRESSURE PLATE SYSTEM
VERTICAL MULLIONS

1. Typically span from floor to floor
2. Two-story “stick” possible due to ease of extruding 25 foot long sections
3. Anchorage to slab edge requires integration with SE’s system
4. SE remains responsible to carry curtain wall loads imposed at anchor through structure
TYPICAL WIND LOAD TRIBUTARY AREAS
1. Gravity anchors
2. Wind anchors necessary for two-story systems
3. Adjustability and ease of erection issues
4. Unitized panel anchors must accommodate setting large panels
1. Design must account for thermal expansion of aluminum
   - $100^\circ$ F $\Delta$ $300'' \times 0.00128 = \frac{3}{8}''$
   - Silicone sealant $\pm$ 50% $\Rightarrow \frac{3}{4}''$ joint necessary

2. Slip joints may need to transfer shear or moment
1. Metal or glass are conventionally used
2. Architects are very sensitive to design of infill panels
1. Glass design to resist loads is unique
2. Glass behaves as elastic thin-plate under out of plane loading; however,
3. Glass is a brittle material without a well-defined characteristic breakage strength
4. Glass is designed usually probability theory and relatively large “factor of safety”
1. Current national standard for structural design of glass infills
2. “Plug and chug” with charts; or,
3. Proprietary computer program
GLASS (cont.)

- SAP analysis for complex glass geometry
- Stress risers occur at glass with connection holes
1. Compression fiber bracing?
2. Adequate resistance to rotation of individual members
EXAMPLE OF INADEQUATE ROTATION RESISTANCE

Laboratory Structural Overload Test
1. Curtain walls are unique “engineered” systems
2. Curtain walls may come in many appearances; but,
3. Engineering principles rely on basic statics
4. Aluminum is a predictable material for flexural members;
5. Glass is not
6. The devil is in the details
QUESTIONS?