Lesson Objectives
1. Define compact, non-compact, and slender-element sections and draw a qualitative M vs. \( \lambda \) curve.
2. Determine if a built-up or rolled shape is compact, non-compact, or slender element.
3. Compute the moment capacity of a beam with compact, non-compact, or slender element flanges.

Terminology, Etc.
Compact: a steel shape is “compact for bending” if its flanges and webs are stocky enough for the beam to reach the full plastic moment \( M_p \). Therefore, the nominal capacity \( M_n \) is \( M_p \). Note: nearly all rolled W shapes are compact for \( F_y = 50 \) ksi. Hence, non-compactness is typically an issue with non-standard beams that are built-up from thin plates that are welded together (these are called “plate girders” and they are commonly used on bridges).

Non-Compact: a steel shape is “non-compact for bending” if its flanges and webs are not stocky enough for the beam to reach the full plastic moment \( M_p \), but they are stocky enough for the beam to reach the \( M_r = 0.7M_p \). Therefore, the nominal capacity \( M_n \) is \( M_r \) because the beam cannot reach \( M_p \).

Slender element: a steel shape has slender elements if its flanges and webs are so slender (long and thin) that it cannot reach \( M_r \).

\( \lambda \): this is a slenderness ratio (AKA a “b/t ratio.” It is the ratio of length/thickness for flanges or webs. e.g., if a web is 10” tall and \( \frac{1}{4} ” \) thick, then \( \lambda = b/t = 40 \). This ratio is compared to \( \lambda_p \) and \( \lambda_r \). If all of the \( \lambda \)’s in a section (i.e., the \( \lambda \)’s for the flanges and the \( \lambda \)’s for the webs) are less than \( \lambda_p \), than the section is compact and we know that is will reach \( M_p \) as long as the other buckling mode, lateral-torsional buckling, is prevented.

\( \lambda_p \): this is the cutoff slenderness ratio for compactness. If \( \lambda < \lambda_p \), the section is compact and it reaches the fully plastic moment.

\( \lambda_r \): this is the cutoff slenderness ratio for slender element sections. If \( \lambda > \lambda_r \), the section is a slender element section and it cannot even reach the \( M_r \) moment (what a wimpy section!). If this is the case, its capacity \( M_n \) is equal to \( F_{cr}S \), where \( F_{cr} = 0.9E_{kc}/\lambda_r^2 \). If \( \lambda_p < \lambda < \lambda_r \), then the section is non-compact and the moment capacity \( M_n \) is determined by linear interpolation. Note: non-compact and slender flanges are perfectly fine and are within the scope of CE311. Non-compact or slender webs are a major problem and they are beyond the scope of CE311.

Other Local Buckling Terms
\( F_L = 0.7F_y \) = extreme fiber yield stress after accounting for residual stress.

\( k_r = \frac{4}{\sqrt{h/t_w}} \)

Reading/Reference
1. SEGUI: pp. 198 to 215.
2. CE311 Coverage of Local Buckling is limited to Compact Webs but Non-Compact or Slender Flanges. See AISC Table User Note F1.1 on Page 16.1-45. Our scope is limited to AISC Sections F2, F3, F6, F11.
3. Section B4: Member Properties
4. The Waffle House Menu: Table B4.1b on page 16.1-17
5. Key Equations: F3-1, F3-2, F6-2, F6-3, F6-4

Upcoming Bonus Point Opportunities in November:
1. Today, lunch: 5 homework bonus points for attending the ASCE discussion of the honor code
2. Attend the ASCE Career Fair: November 16th, 5pm to 8pm at Lehigh (10 homework bonus points, just for attending). Wear a suit, bring resumes, talk to company reps.
3. Attend the 11th Annual Lafayette-Lehigh Steel Bridge Presentation to the Alumni: Acopian Room 200, 6pm on November 18th – 10 homework bonus points. Come watch the alum trash the seniors
### The “Waffle House Menu” for Local Buckling Limits

<table>
<thead>
<tr>
<th>Case</th>
<th>Description of Element</th>
<th>Width-to-Thickness Ratio</th>
<th>Limiting Width-to-Thickness Ratio</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Flanges of rolled I-shaped sections, channels, and tees</td>
<td>$b/t$</td>
<td>$0.38 \frac{E}{F_t}$</td>
<td>$1.0 \sqrt{\frac{E}{F_y}}$</td>
</tr>
<tr>
<td>11</td>
<td>Flanges of doubly and singly symmetric I-shaped built-up sections</td>
<td>$b/t$</td>
<td>$0.38 \frac{E}{F_t}$</td>
<td>$0.95 \sqrt{\frac{E}{F_y}}$</td>
</tr>
<tr>
<td>12</td>
<td>Legs of single angles</td>
<td>$b/t$</td>
<td>$0.54 \frac{E}{F_t}$</td>
<td>$0.91 \sqrt{\frac{E}{F_y}}$</td>
</tr>
<tr>
<td>13</td>
<td>Flanges of all I-shaped sections and channels in flexure about the weak axis</td>
<td>$b/t$</td>
<td>$0.38 \frac{E}{F_t}$</td>
<td>$1.0 \sqrt{\frac{E}{F_y}}$</td>
</tr>
<tr>
<td>14</td>
<td>Stems of tees</td>
<td>$d/t$</td>
<td>$0.84 \frac{E}{F_t}$</td>
<td>$1.03 \sqrt{\frac{E}{F_y}}$</td>
</tr>
<tr>
<td>15</td>
<td>Webs of doubly-symmetric I-shaped sections and channels</td>
<td>$h/t_w$</td>
<td>$3.76 \frac{E}{F_t}$</td>
<td>$5.70 \sqrt{\frac{E}{F_y}}$</td>
</tr>
<tr>
<td>16</td>
<td>Webs of singly-symmetric I-shaped sections</td>
<td>$h_c/t_w$</td>
<td>$0.54 \frac{E}{F_t}$</td>
<td>$0.99 \sqrt{\frac{E}{F_y}}$</td>
</tr>
<tr>
<td>17</td>
<td>Flanges of rectangular HSS and boxes of uniform thickness</td>
<td>$b/t$</td>
<td>$1.12 \frac{E}{F_t}$</td>
<td>$1.40 \sqrt{\frac{E}{F_y}}$</td>
</tr>
<tr>
<td>18</td>
<td>Flange cover plates and diaphragm plates between lines of fasteners or welds</td>
<td>$b/t$</td>
<td>$1.12 \frac{E}{F_t}$</td>
<td>$1.40 \sqrt{\frac{E}{F_y}}$</td>
</tr>
<tr>
<td>19</td>
<td>Webs of rectangular HSS and boxes</td>
<td>$h/t$</td>
<td>$2.42 \frac{E}{F_t}$</td>
<td>$5.70 \sqrt{\frac{E}{F_y}}$</td>
</tr>
<tr>
<td>20</td>
<td>Round HSS</td>
<td>$D/t$</td>
<td>$0.07 \frac{E}{F_t}$</td>
<td>$0.31 \sqrt{\frac{E}{F_y}}$</td>
</tr>
</tbody>
</table>

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*Specification for Structural Steel Buildings, June 22, 2010*

*American Institute of Steel Construction*
HOMEWORK (DUE MONDAY)

0. (Do on your own, but do not hand in). Local buckling rarely applies to rolled shapes (they have been engineered to avoid local buckling). However, there are several shapes that have non-compact flanges for bending, if \( F_y = 50 \) ksi. Reading Sect. F2 in the specifications, list the W shapes that are non-compact in bending for \( F_y = 50 \) ksi (In addition, the tables in Part 1 indicate non-compact shapes with the superscript \( f \) to denote non-compact in flexure. Example W6x15\( f \), found on page 1-28)

0. (Do on your own, but do not hand in). TRUE or FALSE. For the flanges of W shapes, \( \lambda_p \) and \( \lambda_r \) are the same, whether for strong or weak-axis bending.

0. (Do on your own, but do not hand in). TRUE or FALSE. A non-compact beam that has its compression flange continuously laterally supported by a concrete slab would reach its fully plastic moment \( M_p \), if loaded to failure.

0. (Do on your own, but do not hand in). TRUE or FALSE. If the slenderness of the flange exceeds the cutoff of \( \lambda_r \), then the section will fail by local buckling at a moment that is less than \( M_p \), assuming that the web is compact and that LTB is prevented by continuous bracing.

0. (Do on your own, but do not hand in). TRUE or FALSE. A W8x10 is compact if it is A992, but non-compact if it is A36 material.

1. An A992 W8x10 is continuously braced against LTB, while bent about its strong axis. Determine \( M_n \) per AISC.

2. An A992 simply-supported A992 W8x10 beam spans spanning 12 feet is subjected to a center-point load of \( P \), bent about its strong axis. It is considered to have LTB bracing at its ends and at its midpoint. \( L_r = 8.52 \) feet. Ignore self-weight. Determine:
   - \( M_n/\Omega \) for the beam, considering all failure modes (plastic, LTB, Local Buckling)
   - The maximum safe centerpoint load \( P \) that may be applied per ASD

   Hint: Do not forget the \( C_b \) factor.

3. Consider the welded built-up I shape, below, made from A572 grade 50 steel. It has 18” x 3/8” flanges and a 32”x 3/8” web. The beam is simply supported over a span of 30 feet. It has lateral bracing at its ends, only. It is subjected to constant moment over the span due to equal end-moments that cause positive bending about the strong axis. It is Given that \( L_r = 34.5 \) feet. Using ASD:

   - Determine \( M_p \)
   - Determine \( M_n \) with respect to LTB
   - Determine \( M_n \) with respect to Local Buckling
   - Determine the controlling \( M_n/\Omega \)