Introduction

- We Will Cover the Following Topics
  - Introduction
  - Investigating existing conditions
  - Evaluation of concrete structures
  - Evaluation of iron and steel structures
  - Conclusion, Q&A
Selected References for Further Study

- SEI/ASCE 11, Guideline for Structural Condition Assessment of Existing Buildings
- SEI/ASCE 30, Guideline for Condition Assessment of the Building Envelope
- 2-day ASCE seminar Structural Condition Assessment of Existing Structures
- Webinars
  - Investigation and Repair of Fire-Damaged Framing
  - Deterioration and Repair of Concrete
  - Renovation of Slabs on Grade
  - Renovation of Steel-Framed Buildings
- Other sources mentioned on slides

Investigating Existing Conditions

Why Investigate?

- Establish fitness for intended or existing use
  - Typically because of planned renovations or pre-purchase
- Sometimes because of deterioration of framing, structural damage or failure
- Post-disaster evaluation
- Typical need: Determine deficiencies that require upgrade
Some Challenges

- Lack of access to structure
  - Physical entry
  - Framing covered with finishes
- Working with archaic/proprietary systems
- Lack of budgets
- Degree of damage uncertain

Guidance for Assessing Building Condition

- SEI/ASCE 11, Guideline for Structural Condition Assessment of Existing Buildings
- SEI/ASCE 30, Guideline for Condition Assessment of the Building Envelope
Investigating Existing Conditions

- Assessing Building Condition, Cont’d
    - Suggests min. scope of work and report format.
    - Assumes visual inspection.
    - Add'l work extra (entering confined spaces, removing finishes, moving furn.)
    - Appendix: ADA accessibility survey.

Investigating Existing Conditions

- Other Sources
  - S & P’s Structured Finance Rating Real Estate Finance: Property Condition Assessment Criteria (structural part)
    - Detailed protocol for inspection and report for different types of buildings (office, retail…) with examples
Investigating Existing Conditions

- **Field Investigation**
  - The first walk-through
  - Exploratory demolition
    - Extent depends on age and condition
    - A dangerous exercise (beams bearing on finishes; damage to tension rods…)
  - Detailed assessment

- **Office Analysis for Condition Assessment**
  - Looking for design information… some sources:
    - Client
    - The building department
    - Architect, contractors, suppliers
    - Old publications
  - Some detective work may be needed…
  - (example)
Investigating Existing Conditions

- **Office Analysis, Cont’d**
  - Analyzing existing framing
    - Try simple methods first
    - Look at the system: load path, connections, diaphragms
    - Using more accurate analysis methods than original vs. actual damage to members.

- **Detailed Assessment**
  - Second walk-through, etc.

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Investigating Existing Conditions

- **Suggested Report Format per ASCE 11**
  - Executive summary (optional)
  - Introduction
  - Description of the structure
  - Performance criteria (e.g., desired design loads)
  - Description of assessment and evaluation processes
  - Findings and conclusions
  - Recommendations
Investigating Existing Conditions

- Load Testing: Per Governing or Trade Code
  - When to use it
    - For proprietary structures, no drawings, deteriorated framing, theoretical overstress
  - Use procedure in trade code (e.g., ACI 318), or use IBC when trade code is silent
  - What kind of load?
    - Uniform
    - Concentrated

- Load Testing Per AISC Spec. -10, -05 App. 5
  - Tested strength: $1.2D + 1.6L$ (can use $L_r, S, R$ in lieu of $L$), but use more severe load combinations when code requires
  - After service load is reached and inelastic behavior begins, monitor deformations
    - Keep max. test load for 1 hr; deformations should increase < 10%
    - Also record deformations 24 hrs after test load is removed
      [but no limit on permanent set is given]
Investigating Existing Conditions

- **Load Test per Older (pre-2008) ACI 318 Editions**
  - Test load: \(0.85(1.4D + 1.7L)\)
    
    where \(D\) includes dead load already in place.
    
    Test OK if deflection does not exceed \(\frac{L^2}{20,000h}\)
    
    where \(L\) is span and \(h\), thickness.

- **Load Test per ACI 318-11, -08***
  - Test load the larger of:
    1. \(1.15D + 1.5L + 0.4(L_r\ or\ S\ or\ R)\)
    2. \(1.15D + 0.9L + 1.5(L_r\ or\ S\ or\ R)\)
    3. \(1.3D\)

    where \(D\) includes dead already load in place.
    
    Test OK if max. deflection does not exceed \(\frac{L^2}{20,000h}\),
    
    where \(L\) is span and \(h\), thickness and residual deflection is \(\leq\) of \(\frac{1}{4}\) max.
    
    Test may be repeated as described.

*See ACI 318-11, -08 Sec. 20.3 for more info.
Investigating Existing Conditions

- Alternative Load Test for Concrete
  - New ACI 562-13, Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings…
    - Not yet adopted by IEBC
  - Refers to ACI 437.2-13, Code Requirements for Load Testing of Existing Concrete Structures and Commentary for load testing protocol
    - Different load magnitude and duration from ACI 318

Investigating Existing Conditions

- In-Situ Load Test per IBC-03, -06
  - IBC-03, -06, for gravity-load elements: (IBC-06 Para. 1713.3.2)
    - Gradually apply twice the “unfactored design load”
    - Keep in place 24 hrs
    - Test OK if design load deflection is within limit*, and within 24 hrs after load removal 75% of max deflection is recovered, and no evidence of failure during or after test

* IBC-06 Table 1604.3
Investigating Existing Conditions

- In-Situ Load Test per IBC-12, -09
  - IBC-12 Sec. 1710.3.1, IBC-09 Sec. 1715.3.1, Test Procedure, follows procedure above (uses 2 x “superimposed design load”)
  - Then adds another loading cycle to 2.5 x “superimposed design load,” or to destruction, or beyond deflection limits*
  - Allowable superimposed design load is the lesser of:
    1. Load that produces deflection limit*
    2. Failure load divided by 2.5
    3. Max. load divided by 2.5

* IBC-12, -09, -06 Table 1604.3

Concrete

- Historical Developments in U.S.
  - 1875: 1st RC house in NY state
  - U.S. concrete in 1900-20:
    - Concrete considered experimental, restricted to shallow floor arches
    - Many proprietary two-way systems

More info:
ASCE webinar Deterioration and Repair of Concrete
Properties of Early Concrete

- 1910 NACU spec.: 2000 psi, 1:2:4 mix (cement:sand:coarse), water not limited
- 1918: Duff Abrams introduced w/c ratio
- Check for voids and segregation in pre-1950 concrete

Properties of Early Reinforcement

- $F_y$ of plain and deformed bars:
  - A15 billet steel (1911-1966):
    - structural grade (“soft”) 33 ksi, intermediate 40 ksi, hard 50 ksi.
  - A16 rail steel plain, deformed, hot-twisted (1911-1966): 50 ksi.
  - Cold-twisted bars: 55 ksi.
Concrete

Properties of Early Reinforcement, Cont’d

- Estimating $F_y$ conservatively (unless tested or type known)
  - Pre-1968 bars 33 ksi; 1968-late 1970s 40 ksi; later 60 ksi.
- Bond and anchorage for pre-1947 (“high-bond-deformation”) bars
  - CRSI: All early rebar types 50% effective…
  - Take $L_d$ as twice today’s.
  - (For 33-ksi bars add 10% to $L_d$ of 60-ksi)
  - Often get deficient answers for bars > #6

Concrete: Performing a Condition Survey

- ACI 201.1R, Guide for Conducting a Visual Inspection of Concrete in Service (revised title)
  - Includes a lengthy checklist and many color illustrations of various concrete defects
- ACI 224.1R, Causes, Evaluation, and Repair of Cracks in Concrete Structures
- ACI 364.1R, Guide for Evaluation of Concrete Structures Before Rehabilitation
Concrete

- Visual Survey Can Find...
  - Sagging
  - Cracking
  - Spalling
  - Creep
  - Efflorescence

Concrete

- Strength Determination: Destructive Testing
  - Determination of concrete strength: Taking cores (ASTM C42) for compression testing (ASTM C39)...min. of 3
  - Petrographic examination (ASTM C295)
    - Proportions, air %, presence of reactive aggregates
  - Tension test of rebars (ASTM E8) (12” lg)
Concrete

Strength Determination: Nondestructive Testing

- Windsor probe (ASTM C803): A gun drives probe; depth of penetration $\sim f'_c$
- Rebound hammer (ASTM C805): Strikes surface, rebound distance is converted to $f'_c$

Finding Rebars

- Pachometers, cover meters, rebar locators
  - Generate magnetic field
  - Rebars affect magnetic field and are detected
  - Either size (if cover known) or cover, not both
- X-ray and gamma-ray radiography
  - Emissions help locate rebars
  - Gamma-rays can find concrete voids, determine bar size
  - Not effective for concrete $> 12”$ thick, $$, health hazard
Concrete

- Causes of Concrete Deterioration
  - Environmental damage
    - Chemical attack
    - Rebar corrosion
    - Carbonation
    - Fire
    - Freeze-thaw

Concrete

- Causes of Concrete Deterioration, Cont’d
  - Internal chemical distress
    - Alkali-aggregate reaction
    - Delayed ettringite formation
Concrete

- Cracks and Surface Damage
  - Cracks
  - Scaling
  - Popouts

Cracks and Surface Damage

- Cracks
- Scaling
- Popouts

Cracks

- Learning to Identify Cracks
- Types of Cracks

Types of Cracks

- Shrinkage cracks
  
  - A theory of shrinkage: Surface tension of water within capillary pores formed in paste after evaporation, pulls particles together.
  
  - Role of water content (not w/c ratio) and curing.
Cracks

Drying vs. Plastic Shrinkage Cracks

- Drying: Often hairline (< 0.003”) and cosmetic, (a $ bill is 0.0043”), but can also become wide and full-depth
  - May take months to develop: Some say 75% shrinkage in 3 mo., 90% in 1 year

- Plastic: Often wide and deep, form 30 min to 6 hrs after placement, when wind and heat are excessive. Can be repaired by fine spray.

Cracks

Cracks from Restrained Shrinkage in Elevated Slabs

- Perp. to span, through thickness, evenly spaced, uniform width... usually form within 3-4 months, dormant after
- Can lead to cracks in supporting elements (e.g., mid-height of walls, diag. cracks near foundation wall ends).
Cracks

- Thermal Expansion-Contraction
  - Example: Corners of doors and windows, at dapped ends of beams.

Cracks

- Structural Cracks
  - Can appear at any time
  - Torsional cracks are diagonal & parallel, inclined in opposite directions on 2 sides of beam
Cracks

- Other Cracks
  - Plastic settlement & formwork-shifting cracks above bars and // to formwork
  - Mechanical damage
  - Corrosion (often years after)

- One Type May Invite Another

Concrete

- Dormant vs. Active Cracks
  - How to tell
    - Plaster, paint over
    - Use crack monitor
Detecting Concrete Deterioration

- Façade: carbonation, salt-water spray or mist
- Interior structure: chlorides or other chemicals
  - Sources of chlorides: Deicing salts, admixtures (esp. CaCl₂), unwashed beach sand, fumes, acid etching Interior structure

Carbonation of Façade

- Carbon dioxide CO₂ reacts with Ca(OH)₂ and forms Ca carbonate CaCO₃ + H₂O, reduces pH to 8-9.
- Similar reaction between sulfur dioxide and cement
- Slow process, rarely > 1/8 to ¼” in 30 yrs, but faster in industrial buildings with CO₂ emission
- Cracked concrete, corners most vulnerable.
Concrete

- **Assessing Corrosion Activity**
  - Visual clues: Cracking, rust stains
  - May be too late if chloride attack starts at top and bottom bars are rusted
  - Can find depth of carbonation by using 1% phenolphthalein solution to a core. Concrete section will be pink except for carbonated areas (gray).

Concrete

- **Assessing Corrosion Activity, Cont’d**
  - Rapid soluble-chloride test
    - Trimmed ends of cores ground up
    - Find acid-soluble chlorides as % wt of concrete
  - Chloride thresholds:
    - Min. 1.2 lb/yd³ to initiate,
    - 3 lb/yd³ to accelerate,
    - 7 lb/yd³ - major loss of steel.
    - 700 ppm = 2.6 lb/yd³ = 0.07% by weight
  - Construct chloride distribution through thickness
Concrete

Nondestructive Testing for Assessing Corrosion

- Half-cell potential (ASTM C876)
  - Finds electric potential of rebars by portable equipment at grid points
  - Copper/copper sulfate half-cell is connected to voltmeter and rebar
  - Corrosion probable if > 0.3 or 0.35V (less for exterior concrete).

Detecting Delamination

- Chain drag: Hollow sound indicates delamination
- Hammer strike
- Impact-echo: Sim. principle, but steel ball is tapped against concrete; stress waves reflect internal flaws, recorded, frequency content analyzed
- GPR: Radar emits electromagnetic impulses, reflected by voids. Results influenced by moisture % and rebars.
- Pulse velocity: Ultrasonic waves generated by sonoscope
- Infrared thermography: Infrared radiation applied to one side of object; voids distort the flow, are detected
**Concrete**

- Case Study of an Attempted Evaluation

- **Iron and Steel**

  - The Easiest Material to Evaluate?
    - Condition evaluation starts with finding construction date
    - If uncovered, relatively easy to measure and identify
    - Corrosion can be readily observed

  - Learn to Identify Iron Materials

  More info:
  - 2-day ASCE seminar Steel-Framed Buildings: Practical Issues in Design and Renovation
  - ASCE webinar Renovation of Steel-Framed Buildings
Identifying Cast Iron

- John Smeaton (mid-1700s)…Pure iron extracted by heating ore layered with fuel inside furnace, then forging or casting into shapes
- High carbon (> 1.5%, often 2.5-4%), silicon, sulphur
- Sandy texture
- Columns, beams, lintels
- Columns since 1830s

Can be identified by "spark test" – using a grinding wheel and see color and type of sparks (need expert contractor)

Seattle's Pioneer Sq. cast iron pergola redone in 2001

Cast & Wrought Iron Columns

- Typ., bolted (welding was problematic)
- Inclusions were common => reduced $F_a$
- Connections unique to engineer & local building code
- One article in mid 1890s stated that the same design could support 100 tons in NYC, 89 tons in Chicago, 79 in Boston

FEMA 274
Evaluation of Cast Iron Columns

- Columns cast in halves w/ separate or integral caps and bases
- Can measure thickness by drilling

Cast Iron: Evaluation of Strength

- Typ. for 1830-1910 period: \( F_{u,\text{compr}} = 80 \text{ ksi}, \ F_{u,t} = 10-15 \text{ ksi} \)
- ASCE 41* Sec. 5.10 for pre-1900 cast iron:
  - Lower-bound \( F_y = 18 \text{ ksi}, E = 25,000 \text{ ksi} \)
- ASCE 41 lower-bound column strength \( Q_{CL} = A_g F_{cr} \)
  - where \( A_g = \text{Gross area of column} \)
    \[ F_{cr} = 12 \text{ ksi} \quad \text{for } L_c/r \leq 108 \]
    \[ F_{cr} = \frac{1.4 \times 10^5}{(L_c/r)^2} \text{ ksi} \quad \text{for } L_c/r > 108 \]
- Per ASCE 41, cast iron columns shall only carry axial compression

*ASCE 41-06, Seismic Rehabilitation of Existing Buildings
Iron

Malleable (1841-85+) & Wrought Iron (1850-90s)

- Wrought iron: Repeated hammering of pig iron by steam hammer, folding over for more... forged into bars, plates
- Rolled, not cast => smooth surface
- Pure iron w/slag (carbon < 0.1%); wrought iron may be separated by slag layers... fibrous structure vs. crystalline CI
- Can be identified by minor delamination at ends from corrosion

Iron

Malleable & Wrought Iron: Evaluation of Strength

- Allowable bending stress (1920-1923): 12,000 psi or 14,500 psi
- Mid-19th century WI often had $F_y = 32-34$ ksi*
- For exist bridges, some use 15 ksi design values for tension*


<table>
<thead>
<tr>
<th>Material</th>
<th>Maximum allowable bending stress, psi</th>
<th>Average modulus of rupture, psi</th>
<th>Implied safety factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolled steel</td>
<td>16,000</td>
<td>60,000</td>
<td>3.75</td>
</tr>
<tr>
<td>Wrought iron</td>
<td>12,000</td>
<td>50,000</td>
<td>4.17</td>
</tr>
<tr>
<td>Cast iron</td>
<td>3,000</td>
<td>40,000</td>
<td>13.33</td>
</tr>
</tbody>
</table>

Source: References 1 and 11.
Steel

Early Structural Steel

- Bessemer converter (1856), open-hearth process led to iron with < 1% carbon (steel liquefied => slag rises to surface)
  - Today’s A992 carbon equivalent $E_c = 0.45\%$ or $0.47\%$ for heavy shapes
- First steel I-beams, C, T, angles in 1884
- Standard shapes agreed upon in 1896
- First W in early 1900s; max. 15” (1884), 24” (1900), 36” (1927)
  - 1927: First W’s by Carnegie Steel called CB-sections, became the basis of today’s

Early Structural Steel Buildings in the U.S.

- 1st columns – latticed (until 1930s)
  - See design example in book pp. 115-117
- 1854: Cooper Union Building, NYC, 1st to use rolled beams (rail-like sections…)
- 1885-1889: First all-steel skyscrapers
- 1927: 2000 skyscrapers in Manhattan alone

Allowable Stresses in Early Steel

- Late 1800s: Each producer used own steel materials
- ASTM formed in 1898 after frequent rail breaks
- 1900: ASTM A7 for bridges and A9 for buildings
  - ASTM A9-21: Min. $F_u = 60$ ksi, min. $F_y = 30$ ksi
- Both consolidated in A7 steel in 1939
  - A7 was primary steel until early 1960s (ASTM A36)
  - Exception: WWII (War Production Board issued National Emergency Specification)

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Steel

Allowable Stresses in Early Steel, Cont’d

ASCE 41 for pre-1900 steel: Lower-bound $F_y = 24$ ksi, $F_u = 36$ ksi
See AISC Design Guide No. 15 for an expanded table
See ASCE 41 and FEMA 356 for L.B and expected strength tables

<table>
<thead>
<tr>
<th>Period</th>
<th>ASTM Specification</th>
<th>$F_u$ (tensile strength), ksi</th>
<th>$F_y$ (minimum yield point), ksi</th>
<th>$F_b$ (maximum bending stress), ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900–1908</td>
<td>A9 (medium)</td>
<td>60–70</td>
<td>50% of $F_u$</td>
<td>16</td>
</tr>
<tr>
<td>1909–1923</td>
<td>A9 (structural)</td>
<td>55–65</td>
<td>50% of $F_u$</td>
<td>16</td>
</tr>
<tr>
<td>1923–1931</td>
<td>A140–32T</td>
<td>55–65</td>
<td>60% of $F_u$ but at least 30</td>
<td>18</td>
</tr>
<tr>
<td>1932</td>
<td>A9 (structural)</td>
<td>60–72</td>
<td>50% of $F_u$ but at least 33</td>
<td>18</td>
</tr>
<tr>
<td>1933–1936</td>
<td>A9 (structural)</td>
<td>60–72</td>
<td>40% of $F_u$ but at least 30</td>
<td>18</td>
</tr>
<tr>
<td>1936–1960</td>
<td>A7 (structural)</td>
<td>60–72</td>
<td>50% of $F_u$ but at least 33</td>
<td>20</td>
</tr>
<tr>
<td>1960–1963</td>
<td>A7 (or A36)</td>
<td>60–72 (58)</td>
<td>50% of $F_u$ but at least 33 (36)</td>
<td>22</td>
</tr>
<tr>
<td>1963–present</td>
<td>A36</td>
<td>58</td>
<td>36</td>
<td>24</td>
</tr>
<tr>
<td>1970s–present</td>
<td>A572, Gr. 50</td>
<td>65</td>
<td>50</td>
<td>33</td>
</tr>
</tbody>
</table>

**Source:** References 11, 17, and 26.
Steel

Early Steel Fasteners: Rivets

- First to be used; hot vs. cold-formed; clamping effects for hot rivets debatable...bearing or friction?
- Sizes: ½” to 1 ½”; most common ¾” and 7/8” with button head.
- Identifying size: Per AISCM 5th ed. (1961)...
  - Driven head dia. = 1.5D + 1/8” (1 ¾” for ¾”, 1 7/16” for 7/8”)
  - Manuf. head = 1.5D + 1/32” (1 5/32” for ¾”, 1 11/32” for 7/8”)

Rivets, Cont’d

- Determine allow. rivet values from current AISC spec. as for high-strength bolts.
- 1923 AISC spec. allow. values: 10 ksi shear or hand-driven, 13.5 ksi for power-driven, no tension stress given.
- 1949 AISC spec. allow. values: 15 ksi shear, 20 ksi tension

<table>
<thead>
<tr>
<th>TABLE 3.3</th>
<th>Typical Design Values for Rivet Steel Used in Buildings in 1900–1950</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period</td>
<td>ASTM Specification</td>
</tr>
<tr>
<td>1900–1908</td>
<td>A9</td>
</tr>
<tr>
<td>1909–1913</td>
<td>A9</td>
</tr>
<tr>
<td>1914–1923</td>
<td>A9</td>
</tr>
<tr>
<td>1924–1931</td>
<td>A9</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>1932–1949</td>
<td>A141</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Bolts

- First “unfinished” bolts: weak and loose; revisited in 1930s because of rivet noise, fire, $.
- Common (rough, unfinished, unturned, ordinary) bolts: square nuts, similar to hand rivets.

TABLE 3.4 Some Typical Shear Values for Fasteners Used in Buildings in the 1950s and 1960s

<table>
<thead>
<tr>
<th>Fastener</th>
<th>Allowable shear, ksi</th>
<th>3/16-in diameter</th>
<th>5/32-in diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power-driven rivets and turned bolts in reamed holes</td>
<td>15</td>
<td>6.63</td>
<td>9.02</td>
</tr>
<tr>
<td>Unfinished bolts</td>
<td>10</td>
<td>4.42</td>
<td>6.01</td>
</tr>
<tr>
<td>High-strength A325 bolts:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>friction and bearing type, threads included in shear plane</td>
<td>15</td>
<td>6.63</td>
<td>9.02</td>
</tr>
<tr>
<td>bearing type, threads excluded from shear plane</td>
<td>22</td>
<td>9.72</td>
<td>13.23</td>
</tr>
</tbody>
</table>

NOTES:
1. Bearing value of connected members may control—check by current AISC Specification.
2. Values indicated are for single shear, values for double shear are twice those shown.
SOURCE: Reference 23.

Bolts, Cont’d

- Turned (high-strength) bolts (c. 1950s) ~ similar to power rivets; replaced rivets by mid-1960s.
- For both types of bolts c. ’50s & ’60s, use tensile-strength table values w/ “stress area” = \(0.785(D-0.9743/n)^2\), where
  \[D = \text{nom. bolt size}, \ n = \text{number of threads per in.}\]

Welding

- Developed around 1915, structural use since 1920s.
- Poor quality in first welds.
Open-Web Steel Joists

- First appeared in 1923; SJI in 1928; adopted SJ series
- Nailable joists popular

Identifying Joists

- Depth of bearing
  - SJ, S, J, H, and K: 2.5"
  - L, LA, LJ, LH: 5"
  - DLJ, DLH: 5" for chord sizes 10-17; 7.5" for 18-20
  - Joist girders: 6" (changed by SJI-02 to 7.5"

- Depth of joist; type and configuration of diagonals
  - Often, rod webs in K, H series < 24", crimped webs > 24"
Steel

Identifying Joists, Cont’d

- Looking for design data: Search for drawings, tags at ends, age
- If no drawings – measure and analyze as trusses?

<table>
<thead>
<tr>
<th>Year</th>
<th>Joist series</th>
<th>Maximum tensile stress, ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1929–1958</td>
<td>SJ</td>
<td>18</td>
</tr>
<tr>
<td>1962–1965</td>
<td>J</td>
<td>22</td>
</tr>
<tr>
<td>1965–1978</td>
<td>J</td>
<td>22 (sometimes 30)</td>
</tr>
<tr>
<td>1961–1966</td>
<td>LA</td>
<td>20 or 22</td>
</tr>
<tr>
<td>1961–1986</td>
<td>H</td>
<td>30 (sometimes 22)</td>
</tr>
<tr>
<td>1962–1988</td>
<td>LH</td>
<td>0.6F_y (22–30)</td>
</tr>
<tr>
<td>1967–1978</td>
<td>LJ</td>
<td>0.6F_y (22–30)</td>
</tr>
<tr>
<td>1970–1972</td>
<td>DLJ</td>
<td>0.6F_y (22–30)</td>
</tr>
<tr>
<td>1970–1988</td>
<td>DLH</td>
<td>0.6F_y (22–30)</td>
</tr>
<tr>
<td>1986–present</td>
<td>K</td>
<td>30 or 22</td>
</tr>
<tr>
<td>1978–present</td>
<td>Joist girders</td>
<td>0.6F_y (22–30)</td>
</tr>
</tbody>
</table>

SOURCE: References 24 and 25.

Or, try http://www.steeljoist.org/investigation/

Steel Material Testing

- ASTM A 370: tensile, bend, impact, hardness properties
- Can test in situ materials with smaller specimens, but scale down dimensions proportionally
- AISC Spec. App. 5 suggests destructive testing needs
  - Requires determination of an appropriate ASTM standard and using $F_y$ allowed by it, not just measured strength*
- FEMA 356 requires testing of $F_y$, $F_u$, carbon equivalent of both base and connection material if design drawings with ASTM Spec. are not available

*S. Zoruba, AISC, Answer in Steel Interchange, MSC, Nov. 2006
Common Destructive Tests of Steel

- Tension (ASTM E8): Most common; finds $F_y$, $F_u$, $E$
- Compression (ASTM E9): Finds $F_y$, $F_c$, $E$
- Chemical (ASTM E30): Finds chemical composition, incl. carbon content
- Bend (ASTM E190, E290): Specimen bent into U shape with certain inside radius, outside checked for cracks (measures ductility of metal and welds)
- Fatigue (ASTM E466, E606): Repetitive stretching, twisting, or bending

Other Destructive Tests

- Charpy, Izod, drop-weight impact (ASTM E23, E208, A673): A specimen notched in std way is fractured by impact of dropped weight (measures brittle-fracture potential and toughness)

Nondestructive: Hole Drilling Test (ASTM E837)

- Finds existing stress in steel
- A hole of std size drilled in flange, 3 strain gages attached around hole. The stresses around the hole are relaxed, measured by gages. From those, principal surface stresses are found.
Steel

Nondestructive: Hardness Test (ASTM E10, E18)

- Test: A steel ball or hardened object is forced into object, the mark measured, establishes Brinell or Rockwell hardness (resistance to deformation) number.
- Helps determine cold-working effects and tensile strength
  (+) Simple, inexpensive, can be done on site
  (-) Requires surface prep.

Steel

Nondestructive Tests for Welds, Surface Defects

- Ultrasonic Testing (UT) per ASTM E164
  - Detection of cracks, voids, inclusions, porosity
  - Ultrasound waves (0.1-25 MHz) are applied to steel, reflected by interior defects

From FWHA Guidelines for Installation, Inspection, Maintenance and Repair of Structural Supports for Highway Signs, Luminaries, and Traffic Signals (FWHA)
Ultrasonic Testing, Cont’d

- Reflections show on screen as peaks (horiz. scale is distance thru metal)
- Pluses:
  - Fast, efficient
  - Can detect minute (< 1/64”) flaws
  - Portable equipment
  - Only one surface needed

Variations in UT reflection caused by defects at the weld boundary

Ultrasonic testing of anchor rods
Radiographic Testing (RT) per ASTM E94

- X-rays or gamma rays show internal voids, defects as dark spots (sim. to medical X-rays).
- Used to find cracks, voids, inclusions, porosity, also undercutting & incomplete penetration of welds
- (+) Portable and reliable equipment, permanent record created
- (-) $$, dangerous, req’s shielding, difficult to use with objects of complex shapes (and tubes, fillets, tee, corners), a lot of electric power and cooling may be needed
- As UT, difficult or impossible for PJP welds (OK for CJP)

Radiography, Cont’d

- Largely supplanted by UT, but...

...UT finds better linear defects parallel to surface better than RT, but RT finds defects perp. to surface better than UT (MSC Steel Interchange, 7/2000)
Magnetic-Particle Testing (MT) per ASTM E709

- Object is magnetized, covered with magnetic powder (blown by squirt bulb); metal flaws change orientation of particles
- Used to locate surface (< 1/10” deep) cracks, voids, seams
- Record by using clear plastic tape

Magnetic Particle, Cont’d

(+) Fast, simple, inexpensive...OK for PJP welds
(-) Shallow depth, object must be clean & demagnetized. To magnetize, need a source of electric power & careful surface prep...messy. May not detect defects parallel to magnetic field & may need two perp. Applications. Need to demagnetize.
Steel

- **Infrared**
  - A radiation source is applied to 1 side; flow of energy analyzed. Voids, defects alter radiation flow => detected
  - Finds cracks, voids, porosity, inclusions, changes in composition
  - (+) Very sensitive, can handle complex shapes; results can be recorded on computer
  - (-) Slow; coatings and colors can distort results

- **Liquid Penetrant Testing (PT) per ASTM E165**
  - Red dye penetrant applied to surface by spray, gets into defects by capillary action. When coated w/ white developing solution, becomes visible.
  - Finds surface cracks, seams, incomplete fusion, porosity
  - (+) Simple, inexpensive, can handle complex shapes
  - (-) Can detect only small surface defects. Messy, slow. Requires expertise and careful cleaning & surface prep.
Steel

- Eddy Current (ASTM E566)
  - Electromagnetic induction: A conductor placed in changing magnetic field generates circular elec. currents (resembling tornados or eddies in water). Those generate their measurable magnetic field, affected by defects.
  - Test: A probe coil is moved along object, generates eddy currents. Defects affect eddy currents and are detected.
  - Finds cracks, voids, porosity, inclusions, changes in composition. Used to monitor thickness of produced metal. Can find repair welds in machined / ground surfaces.

Steel

- Eddy Current, Cont’d
  (+) Easily automated, moderate cost, can produce hard copy
  (-) Comparative, not absolute test – and only for shallow objects. Many factors can affect flow of electricity. Requires expertise.
Q & A

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