The Learning Never Stops: Going Beyond a College Education

Outline

• Introduction
• How to make gravity framing efficient
• Load path, load path, load path
• Connection design basics
• Coordinating with trades
Outline

• Construction engineering introduction
• Importance of detailing for ductility
• Purpose of shop drawings
• AISC Code of Standard Practice (CoSP)
• Q & A

How to make gravity framing efficient

What is Efficiency
  • Optimal utilization?
  • Least time to design?

• Minimal construction labor?
• Minimal material?
• Fastest construction?
How to make gravity framing efficient

Optimization vs. Redundancy
• Lighter weight = less material therefore less expensive
• Buying in bulk = cost savings
• Group similar section sizes into like bins to minimize variety
  • Eliminate small quantity sections
  • Don’t jump weight TOO much

Material vs. Labor
• Steel is expensive*
• Man-hours are expensive*
  *May vary by location
How to make gravity framing efficient

Element Weight vs. Connection Complexity
Balance quantity of elements to reduce weight with the quantity and complexity of their connections
Topology optimization, weight reductions on the order of 20%
There are many tools available to help engineers use their judgement to make an informed decision, not make the decision for the engineer

How to make gravity framing efficient

Governing Criteria
There can be more to gravity framing floor design than strength and deflection from dead and live loads
Annoying floor vibrations
  • Light-weight floor design can often lead to a vibration phenomenon which may ultimately govern your design depending on the use type (i.e. office, residential, medical, etc.)
  • AISC Design Guide 11 provides excellent considerations to aid you floor calculations
Blast, ponding, corrosion resistance, etc
How to make gravity framing efficient

Take-Aways

• Computer-aided design is a great tool to give the designer information to make decisions, not a tool to make decisions for you
• Construction is more expensive than design so don’t neglect fabrication and erection efficiencies during design
• Know your location
• Keep it simple. Think outside the box.
• Understand the governing criteria before going too deep
• Check out AISC Design Guide 11 on floor vibrations

Load Path, Load Path, Load Path

Single most important concept in lateral and gravity design

• How does the initial load reach the earth without discontinuities or failures in the chain?
• Consideration of vertical and horizontal structural irregularities
• Consideration of weakest or susceptible links (connections, members, etc.) in chain and the consequence of their failure
Load Path, Load Path, Load Path

Vertical Irregularities

More buildings collapse in seismic events from structural irregularities than any other reason and are therefore restricted in ASCE 7

<table>
<thead>
<tr>
<th>Irregularity Type and Description</th>
<th>Reference Section</th>
<th>Seismic Design Category Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a. Stiffness-Soft Story Irregularity is defined to exist where there is a story in which the lateral stiffness is less than 70% of that in the story above or less than 80% of the average stiffness of the three stories above.</td>
<td>Table 12.6-1</td>
<td>D, E, and F</td>
</tr>
<tr>
<td>1b. Stiffness-Extreme Soft Story Irregularity is defined to exist where there is a story in which the lateral stiffness is less than 50% of that in the story above or less than 70% of the average stiffness of the three stories above.</td>
<td>12.3.3.1</td>
<td>E and F</td>
</tr>
<tr>
<td>2. Weight (Mass) Irregularity is defined to exist where the effective mass of any story is more than 150% of the effective mass of an adjacent story. A roof that is lighter than the floor below need not be considered.</td>
<td>Table 12.6-1</td>
<td>D, E, and F</td>
</tr>
<tr>
<td>3. Vertical Geometric Irregularity is defined to exist where the horizontal dimension of the seismic force-resisting system in any story is more than 150% of that in an adjacent story.</td>
<td>Table 12.6-1</td>
<td>D, E, and F</td>
</tr>
<tr>
<td>4. In-Plane Discontinuity in Vertical Lateral Force-Resisting Element Irregularity is defined to exist where an in-plane offset of the lateral force resisting elements is greater than the length of those elements or there exists a reduction in stiffness of the resisting element in the story below.</td>
<td>12.3.3.3</td>
<td>B, C, D, E, and F</td>
</tr>
<tr>
<td>5a. Discontinuity in Lateral Strength-Weak Story Irregularity is defined to exist where the story lateral strength is less than 80% of that in the story above. The story lateral strength is the total lateral strength of all seismic-resisting elements sharing the story shear for the direction under consideration.</td>
<td>12.3.3.1</td>
<td>D, E, and F</td>
</tr>
<tr>
<td>5b. Discontinuity in Lateral Strength-Extreme Weak Story Irregularity is defined to exist where the story lateral strength is less than 50% of that in the story above. The story strength is the total strength of all seismic-resisting elements sharing the story shear for the direction under consideration.</td>
<td>12.3.3.2</td>
<td>B and C</td>
</tr>
</tbody>
</table>

Load Path, Load Path, Load Path

Weak-Story / Soft-Story Irregularities

- May be apparent to the eye or could be well hidden behind architectural facades
- Significant reductions in strength and stiffness at a soft- or weak-story can lead to collapse of that story
- Common in mixed-use structures
- Occurs when story below is 70% the stiffness or 80% the strength (or less) of the story above
  - Also extreme cases and cases of multiple stories above
Load Path, Load Path, Load Path

Horizontal Irregularities

- Non-parallel systems
- Out-of-plane offsets
- Torsional irregularity
  - Measured displacement of parallel lines

Redundancy

- Redundant load paths have diminished over the decades
  - 1960s steel moment frame structures we predominately full space frame
  - 1970s saw a shift towards perimeter moment frames
  - 1980s reduced redundancy to partial perimeter moment frames
- ASCE 7 specifies minimum redundancy of lateral frames or force-amplification penalty
  - Specifies number of lines of resistance
  - Specifies lateral bays in line of resistance
Load Path, Load Path, Load Path

Connections
- Second to irregularities, more structures fail from poor connections than any other reason
  - Applies to gravity and lateral design
- Member ductility vs. connection ductility
- Capacity Design
  - Connections shall not be weakest link in chain

Fuses
Members or aspects of connections (such as RBS) are designed as “fuses” to cap the load delivered to a connections’ welds and bolts
Load Path, Load Path, Load Path

Take Aways
ASCE 7 -- Vertical and Horizontal Irregularity Table and minimum redundancy requirements
AISC 341 – Capacity Design
AISC 358 – Ductile Connections

Connection design basics

What is a steel connection?
• A connecting element (angles, plates, tees, gussets, etc.) used to transfer load from one structural member to another.

Bolted-bolted 2L  Single-Plate  Directly welded Flange MC
Connection design basics

What is a steel connection?

Plan Bracing – Bolted Flange Plates

2L to Embed

Beam to Column – Extended Plate

Truss

Vertical Bracing

Connection design basics

Selected design checks – Specification Chapter J

- Welds (J2)
- Bolts & Threaded Parts (J3)
- Shear, Flexure, Compression, Tension in Member & Connecting Elements (J4)
Connection design basics

Welds (J2)
- Consumables
  - AWS D1.1 Table 3.2
- Inspection
- Joint Type – Manual Table 8-2
  - Weld Type
    - Fillet
    - Groove (PJP, CJP)
- Welding Symbols

Check out Design Guide 21 – Welded Connections - A Primer for Structural Engineers

Connection design basics

Welding Symbols

NASCC: THE STEEL CONFERENCE
Connection design basics

Bolts & Threaded Parts (J3)

- Fastener Type:
  Group A (A325), Group B (A490), Group C (F3043)
  - “Standard”, “High-Strength”, “Super High-Strength”
  Bearing (N or X), Slip Critical (SC-A, SC-B)
- Load path via bearing, load path via friction
- Joint Type:
  Snug-Tight, Pretensioned, Slip-Critical
  - Standard, load reversal/fatigue, reversal/fatigue/hole

Connection design basics

Shear, Flexure, Compression, Tension in Member & Connection Elements (J4)

- Similar to member design checks (yield)
- Additional limit states (rupture)
- Factor of safety may be different than member checks
- Whitmore section (J4.1)
- Block Shear (J4.3)
Connection design basics

Shear, Flexure, Compression, Tension in Member & Connection Elements (J4)

- Whitmore section (J4.1)

Connection design basics

Shear, Flexure, Compression, Tension in Member & Connection Elements (J4)

- Block Shear (J4.3)
Connection design basics

- Manual has design aids for many typical shear connections
  - Help to reduce and simplify design work
  - Design aids do part of the design work
  - Make sure to read discussion section for additional required checks

Connection design basics

Considerations for connection design

- Delegated design
  - SER requests fabricator/engineer complete design
  - CoSP Section 3.1.1 Option 3
    - SER provides:
      - connection design forces***
      - restrictions on permitted connections
      - ASD/LRFD
    ***Avoid % of UDL to report design forces
  - Refer to Manual discussion page 2-28
Connection design basics - Resources

ANSI/AISC 360-16 Specification for Structural Steel Buildings

- Part 7 Bolts
- Part 8 Welds
- Part 9 Connecting Elements
- Part 10 Simple Shear Connections
- Part 11 Partially Restrained Connections
- Part 12 Fully Restrained Moment Connections
- Part 13 Brace/Truss Connections

AISC Manual v15.1 Companion Volume 1 Design Examples

Connection design basics - Resources

AISC Design Guides

- DG 1 Base Plate and Anchor Rod Design
- DG 4 Extended End-Plate Moment Connections
- DG 8 Partially Restrained Composite Connections
- DG 13 Wide-Flange Column Stiffening at Moment Connections
- DG 16 Flush and Extended Multiple-Row Moment End-Plate Conx
- DG 17 High Strength Bolts-A Primer for Structural Engineers
- DG 21 Welded Connections-A Primer for Structural Engineers
- DG 24 Hollow Structural Section Connections
- DG 29 Vertical Bracing Connections-Analysis and Design
Coordinating with the trades

• The structural elements of a building (not including the façade) represent less than 10% of the building construction cost, even less in critical facilities like hospitals

• Majority of cost lies in trades
  • Mechanical equipment and systems
  • Plumbing and gas distribution
  • Electrical power and data
  • Fire protection

• And in architectural finishes

Coordinating with the trades

• Coordination between structure and distribution systems is key
• Several approaches
  • Typical pass-through locations
  • Discrete locations
  • Protected zone
Coordinating with the trades

- Preparing for conflict
  - Predefined details and guidelines can go a long way

Mediating congestion and load
- Various trades may not coordinate their locations with each other
- Typically assumed loading does not always apply – need to check for these congested cases
Construction engineering

Why? When do you need CE?
- Maintain stability of partially completed structure
- Temporary bracing and support
- Provide fit-up and adjustment
- Lifting & Rigging
- Personnel Safety and access
- Extreme weather events (Hurricane)

Temporary bracing and support
- SER designs structure for final condition
- Lateral load system is missing or partially complete
- Higher wind load during construction
- Assemblies are limited by:
  - Trucking
  - Crane capacity
Construction engineering

AISC Code of Standard Practice for Steel Buildings (CoSP)

Section 1.8 Means, Methods and Safety of Erection

1.8.1 “The erector shall be responsible for the means, methods and safety of erection of the structural steel frame.”

1.8.2 “The structural engineer of record shall be responsible for the structural adequacy of the design of the structure in the completed project…”

Construction engineering

Temporary bracing and support
Construction engineering
Temporary bracing and support

Temporary Wire Rope Bracing
Plumb Cables
Permanent Bracing
Construction engineering

Temporary bracing and support

Shoring Towers

Construction engineering

Provide fit-up and adjustment

Field Welded Joints
Construction engineering
Provide fit-up and adjustment

Check out Modern Steel Construction
“Focusing Energy”
June 2015
Construction engineering
Lifting and rigging

- Shackle
- Sling
- Shackle
- Sling
- Shackle
- Lifted Load
- Spreader Bar
- C.G.

Construction engineering
Lifting and rigging

- Lifting Device
- Lifting Frame
Construction engineering
Lifting and rigging

Construction engineering
Lifting and rigging
Construction engineering

Personnel safety and access

Field welded connections

Temporary Member Brace

Scaffold Support

Horizontal Lifeline

Access Ladders

Scaffold

Hurricane contingency plans

- July 1 – October 31
- Structures near Gulf Coast and Eastern Seaboard
- Full wind speed
- Increase in exposed area
- Requires additional bracing in short time frame
Construction engineering - Resources

- ASCE/SEI 37-14 Design Loads on Structures During Construction
- AISC Design Guide 10 Erection Bracing of Low-Rise Structural Steel Buildings
- ASME BTH-1-2017 Design of Below-the-Hook Lifting Devices

The Importance of Detailing for Ductility

Series of New York Times articles on Pre-Northridge Steel Moment Frame Structures in San Francisco
The Importance of Detailing for Ductility

“Strength is essential, but otherwise unimportant.”
- Hardy Cross

In a seismic event, rarely are structural elements designed to remain elastic
  • Economically impossible
Ductile elements reach their peak strength then “hold on” through inelastic deformation
The issue arises when actual performance falls short of desired and expected performance

Pre-Northridge Beam-Column Connections
  • Brittle weld material
  • Small initial flaw or notch in weld
  • Lead to early fracture in the connection rather than deformation in member
The Importance of Detailing for Ductility

Pre-Northridge Column Splices
- Partial joint penetration welds of varying sizes from tf/3 to tf – 1/8"
- The failure of beam-column joints in Northridge potentially protected the column splices therefore no column splice failures were observed in 1994
- 1995 Kobe earthquake did cause column splice failures
- Column splice failure is potentially more consequential than beam-column connection failure

- Ground motion response show little non-linearity, structure behaves similar to elastic response with exception of few ground motions
- Most drift responses are below 1% maximum interstory
- Average drift response is at 1% interstory drift
- No certain collapses
The Importance of Detailing for Ductility

Take Aways
ATC – 114 Reports
- NIST-GCR-17-917-45
  - See image on right
- NIST-GCR-17-917-46v1
  - Nonlinear analysis guidelines
- NIST-GCR-17-917-46v2
  - Steel Moment Frames

- High non-linearity in response, very different from elastic response
- 4 ground motions exceed 3% drift
- Average drift response is 3%
- Several collapses predicted
Purpose of shop drawings

- Why do we need them?
  - Transfer of information to ensure that design can be built and assembled.
  - Part of a critical process:

  Design Drawings → Shop Drawings → Fabrication → Erection

Purpose of shop drawings

Design Drawings

Elevation

Section
Purpose of shop drawings

CoSP Section 3 Design Doc’s & Spec
- Size, section, material grade, and location of all members
- Geometry and working points
- Connections

Elevation
Purpose of shop drawings

CoSP Section 4.2 Fabricator Responsibility

- Transfer information from contract documents (design drawings, model, specifications) into accurate and complete approval documents (shop drawings)
- Includes detailed dimensional information to provide for fit-up of parts in the field.
Purpose of shop drawings

Shop Drawings

CoSP Section 4.4 Approval
- SER to perform design and construction review
  - Confirmation that fabricator has correctly interpreted the contract documents
  - Confirmation that connection design has been reviewed and approved
  - Release to begin fabrication

Check out Modern Steel Construction
“Reviewing Shop Drawings”
March 2003
Purpose of shop drawings

Fabrication

CoSP Section 6 Shop Fabrication

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Purpose of shop drawings

Fabrication

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Purpose of shop drawings

Design Drawings → Shop Drawings → Fabrication → Erection
Shop Drawings - Resources

- National Institute of Steel Detailing (NISD)
- AISC/NISD Detailing for Steel Construction, 3rd Edition

AISC Code of Standard Practice (CoSP)

- Why?
  - Sets the criteria for the trade practices involved in steel buildings, bridges and structures.
  - Industry standard
  - Available for free download at www.aisc.org
**AISC Code of Standard Practice (CoSP)**

- Classification of Materials – Section 2
- Design Documents & Specification – Section 3
- Approval Documents – Section 4
- Materials – Section 5
- Fabrication – Section 6
- Erection – Section 7

Also: 8. Quality Control, 9. Contracts, & 10. AESS

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**Classification of Materials – Section 2**

- Includes:
  - Structural Steel: *elements of the structural frame that are shown and sized in the structural design documents, essential to support the design loads…*

- Excludes:
  - Steel Joists / Joist Girders (SJI)
  - Metal Buildings (MBMA)
  - Steel Stairs/Rails (AISC DG 34)

Check out
Design Guide 34 – Steel Framed Stairway Design
AISC Code of Standard Practice (CoSP)

Design Documents & Specification – Section 3
- Indicates required information that SER provides
- Drawings, specifications, 3D models
  - Keep in mind that many times the Architect will create the project specifications – *Be sure to review and edit sections that pertain to your scope of work!*

AISC Code of Standard Practice (CoSP)

Approval Documents – Section 4
- Structural steel shop drawings, erection drawings, embedment drawings and/or digital models.
- Transfer of design information from Design Documents into Approval Documents
- RFI Process
AISC Code of Standard Practice (CoSP)

Materials – Section 5

- Mill Materials
- Tolerances per ASTM A6/A6M

AISC Code of Standard Practice (CoSP)

Fabrication – Section 6

- Identification
- Preparation
- Fitting and Fastening
- Fabrication Tolerances
- Cleaning and Painting
- Marking (Piece marks)
- Delivery
AISC Code of Standard Practice (CoSP)

Erection – Section 7

- Method
- Job-Site Conditions
- Installation of Anchor Rods / Embeds
- Grouting
- Temporary Support of Structural Steel Frame
- Erection Tolerances

AISC Code of Standard Practice - Resources

- NASCC 2019:
  - “Your Code of Standard Practice – Sections 3 and 4”
    - Wednesday 5:00 – 6:00 pm
    - Friday 8:00 – 9:00 am
  - “Your Code of Standard Practice – Sections 5, 6, and 8”
    - Friday 9:15 – 10:15 am
Assessment Question

Following a seismic event, do you know how you expect your steel building to behave and will it still be there next week?

Yes, you should know.
Assessment Question

If a shop drawing includes an error on a connection plate, who is responsible for review and corrective action?

Follow CoSP Section 4.4 – SER should provide annotations with any corrections or comments. However, if connections are delegated to the fabricator, the fabricator’s engineer should provide feedback with any additional input from SER. Fabricator/detailer then makes the correction and resubmits the document, if required.
Q&A

Questions?

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