Retrofitting of Existing Buildings with Steel Joist

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Presented by:
Bruce Brothersen, P.E., Vulcraft
Walter Worthley, P.E., Valley Joist
Disclaimer

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Presentation Description

This presentation will have three parts:
First - We will discuss and show examples of joists needing to be retrofitted.

Second - We will demonstrate methods to evaluate existing open web steel joists and Joist Girders for revised loading conditions.

Third - We will demonstrate the methods with examples of how to modify existing open web joists. This presentation parallels the Steel Joist Institute publication, Technical Digest No. 12 “Evaluation and Modification of Open Web Steel Joists and Joist Girders.
Learning Objectives

1. Show an example of joists that can be retrofitted and an example where joists should not be retrofitted.

2. Identify the key characteristics of in place joists.

3. Demonstrate how to determine who the original manufacturer was and whether they can provide any additional documentation.

4. Show you how to verify the original design loads and evaluate the joist for the new loads.

5. Give several methods and practices to modify existing joists to increase the load carrying capacity.

6. Provide details that are commonly used to increase the load carrying capacity of a joist component.
Introduction

• Commercial manufacturing of open web steel joists began in 1923.

• The Steel Joist Institute was formed in 1928.
  – Open web steel joist use has continued to grow.
  – There are millions of open web steel joists in service.
Introduction

Evaluation and Modification of joists are required for many reasons:

• Building renovations
• Addition loads: roof top units, conveyors
• Field deviations – Dimensional changes
• Other changes not contemplated in the original design
• Damage to the joists
Open Web Products are a Great Solution!

Bowstring girders with rod joists
Field Problems

Is anything right?
Steel in a Corrosive Environment

Evaluation? Modification?
Field Problems

Bearing on the end of the top chord extension

- Deck joint disconnected. No leaks reported.
- Deck has deflected @ bend in joists
- Bent pipe

Bearing Seat
Field Problems

Missing end web. Is that web really needed?
Field Problems

Top chord section removed - whoops
Field Problems

Bent bottom chord
Field Problems

Top chord section removed
Field Problems

Top chord up?
Field Problems

Fire
Field Problems

Joist damage
Field Modification and Then an Evaluation

Removed webs
Field Modification and then the Evaluation

Joist Girder too long?
Field Modification and then the Evaluation

Remove the support wall and damage the joist.
Modification of Joist

Big brace on a little joist
Evaluation

Is this a joist?
Evaluation

What is major damage what is minor damage?
Joist BC Damage During Handling

Chord damage during handling
After Modification then Evaluation Again

Poor workmanship
Evaluation and Modification of Open-Web Steel Joists and Joist Girders

Price: $30

Order from: www.steeljoist.org
Glossary of Terms

- Bearing Seat Depth
- Tagged End
- Bottom Chord Extension
- Joist Depth
- Top Chord
- Webs
- Bottom Chord
- Span
- Main Compression Web
- Bearing Seat Extension
- End Web
Evaluation of Existing Joist

Best case investigation

• Find construction documents
  – Contract drawings and/or joist erection plan

• Onsite investigation
  – Joist metal tag

• Contact joist manufacturer
  – See if calculations are available

• Determine spec under which the existing joist were designed
Evaluation of Existing Joist

Worst case investigation

• Find construction documents
  – No contract drawings and/or joist erection plans available

• Onsite Investigation
  – No joist tag - then documentation of joist is in question

• Complete the Joist Investigation Form
  – Contact SJI for assistance
# Joist Investigation Form

**Steel Joist Institute assistance**

- Appendix A of TD 12
- Fill out the form online
- Download from SJI website – [www.steeljoist.org](http://www.steeljoist.org)
- Return to SJI office or manufacturer for assistance

```markdown
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<td>Other, describe</td>
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**Supplementary Information**

- What year was the building constructed or approximate age of the structure?
- Who was the joist manufacturer?
- Is there a tag on the joist? ☐ No ☐ Yes, provide tag information
- What type of trusses are the joists? ☐ Warren ☐ Modified Warren ☐ Pratt
  ☐ Other, describe or sketch
- What are the joists used for? ☐ Roof loading ☐ Floor loading
```
As-Built Design of Joists

How to determine

• Original contract structural documents
• Final joist erection drawings
• Year job was constructed
• Joist manufacturers identification tag
• Field investigation and measurements
Joist Drawings

Structural drawing
• Designation
• Joist Spacing

Erection drawing
• Designation
• Joist Spacing
• Mark Number (on metal tag)
Joist Identification Tag

Joist tag information

• Joist manufacturer’s name
• Joist manufacturer’s job number
• Erection mark number, e.g. J1 or T3
Field Investigation

Helpful and required information

- Loading on the joists
- Information from the joist tags
- Joist configuration
- Joist span
- Joist spacing
- Joist depth or height
- Bearing condition
  - Underslung or bottom bearing
  - Bearing length on structural support
Field Investigation

Type of Chord Members

- Double Angles
  - Separation distance
  - Fillers or ties
  - Ties for double angle webs

- Cold-formed sections

- Rods

- Splices
Type of Chord Members

CHORD

GAP
Field Investigation

Type of web members

• Rod webs

• Crimped angle webs

• Angles welded to the outside of chords

• Cold-formed sections
Type of Web Members

Rod webs
Type of Web Members

Crimped angle webs
Type of Web Members

Angles welded to the outside of chords
Field Investigation

Also take note of:

• End diagonal type

• Eccentricities

• Weld sizes and lengths - welded connections are sized for the design requirements not the overall strength of the member

• Panel point spacing
Weld Location
Bearing Eccentricity
Web Eccentricity
Welded Connections

Weld Sizes and Lengths are designed for the original design requirement, not the overall strength of the member.

Current SJI specifications require web connections be designed for 50% of the member capacity. Prior to 2015 SJI spec this was not required.
Field Investigation

Other items to note:

• Type of bridging and locations
• Quality of bridging connections
• Anchorage of bridging
• Interferences
• Condition of joists and existing deck
• Coupon samples to determine yield strength
Types of Bridging
90 Year Steel Joist Manual

- Specifications from 1928 to 2002
- Load Tables from 1928 to 2002
INVESTIGATION OF STEEL JOISTS IN EXISTING BUILDINGS

I. General

First and foremost, the investigating engineer, in performing his tasks, should continually be aware of one principal consideration: the determinations he makes affect the safety of the human beings who occupy the buildings he is investigating.

Secondly, the task of investigating steel joists in existing buildings is difficult, at best. Personal time, effort, and patience are all required to conduct a proper study.

Thirdly, the investigating engineer should scrupulously observe the following rules:

1) Make as few assumptions as possible.
2) Verify by actual observation and physical measurements all data whenever possible.
3) Consciously look for unusual and/or dangerous job site conditions not specified, shown, or recorded in any documentation.
4) Double check all data.
OSHA Federal Regulation
29 CFR 1926.757 (a)(7)

No modification that affects the strength of a steel joist or steel joist girder shall be made without the approval of the project structural engineer of record.
Design Methods to Reduce the Need for Minor Repairs

- 100 pound rule
- Add-loads
- Bend-check
- KCS joists
Although standard K-Series, including KCS-Series, and standard LH-Series joists are designed specifically to support uniformly distributed loads applied to the top chord, research conducted by the Steel Joist Institute, using second-order inelastic analysis, has demonstrated that the localized accumulation of uniform design loads of up to 100 pounds within any top or bottom chord panel has a negligible effect on the overall performance of the joist, provided that the load is applied to both chord angles in a manner which does not induce torsion on the chords.

Concentrated loads in excess of 100 pounds or which do not meet the criteria outlined above, must be applied at joist panel points, or field strut members must be utilized as shown in the detail above.
Add-Load

A single vertical concentrated load which occurs at any one panel point along the joist chord. This load is in addition to any other gravity loads.
Bend-Check

A vertical concentrated load used to design the joist top or bottom chord for the additional bending stresses resulting from this load being applied at any location between the joist panel points. This load shall be accounted for in the specified joist designation, uniform load or Add-load. It is used only for the additional bending check in the chord and does not contribute to the joist chord axial forces.
Top Chord Bend-Check
Bottom Chord Bend-Check
Option 3: For additional point loads with exact locations not known along the joist or for incidental loads, any one, or both, of the following can be specified on the structural plan in addition to option 1 or 2 above:

a) “Design for a (___) lb. concentrated load located at any one panel point along the joist”. This is referred to as an “Add-Load”.

b) “Design for additional bending stresses resulting from (___) lb. concentrated load located at any location along (___) chord”. This is referred to as a “Bend-Check” and can be specified on top chord, bottom chord, or both top and bottom chords. This can be used when the concentrated load is already accounted for in the joist designation, uniform load, or specified Add-Load yet this specified amount of load shall be permitted to also be located at any location between panel points. The additional bending stresses as a result of this load are then designed for. A Bend-Check load shall not exceed (Add-Load + 400 lbs.) A Bend-Check load can be specified by itself without an Add-Load.

c) Both (a) and (b) above can be specified with equal concentrated loads for each; or simply denote “Design joist for a (___) lb. concentrated load at any location along the (___) chord.”
KCS Joists

KCS- Series joist advantages:
1. Provides a versatile K-Series Joist that can be easily specified to support uniform and non-uniform loads plus concentrated loads applied at panel points.
2. Eliminate many repetitive load diagrams required on contract documents and allow some flexibility of load locations.

KCS-Series joist chords are designed for a flat positive moment envelope. The moment capacity is constant at all interior panels.
All webs are designed for a vertical shear equal to the specified shear capacity and interior webs will be designed for 100% stress reversal.

Both LRFD and ASD KCS-Series joist load tables list the shear and moment capacity of each joist. The selection of a KCS-Series Joist requires the specifying professional to calculate the maximum moment and shear imposed and select the appropriate KCS- Series Joist.
Chapter 1
Evaluation of Existing Joist Strength

Determine Capacity of Existing Joist System

- As-built design of joists
- Existing joists possibly over specified
- Building usage may have changed
- Have joists been damaged
Analysis Considerations

To Analyze Joist Capacity

• Pinned connections are assumed for web members

• Prior to 2015, SJI Specifications for K-Series joists permitted bending to be neglected for uniformly loaded joists when the panel point spacing does not exceed 24 inches

• A first-order analysis is used

• The SJI permits eccentricities to be neglected:
  – For K-Series, the “3/4 Rule” is followed - Spec 4.5 (c)
  – For all other joist series, when the eccentricity “…does not exceed the distance between the centroid and back of the chord”
Web Eccentricity
Actual Member Load Carrying Capacity

• Evaluate the actual member to determine the actual member capacity.

• Evaluate any conservative design assumptions to see if a more accurate condition occurs.

• Evaluate the length and placement of weld.

• Determine the risk of repair verses the in place capacity.

• Use Engineering Judgment.
Example 1.1 Determine if a Joist Requires Reinforcement

Scenario

• A roof top unit is to be added to two 24K7 joists spanning 40 feet

• Unit adds two, 500 lb. point loads to each joist
  – Located 10 ft. and 15 ft. from one end

• It has been determined that the uniform load on the joist is 250 PLF

Determine if the joist must be reinforced
Load Diagram

**ORIGINAL DESIGN LOADS**

**ACTUAL LOADS**

TL = 253 PLF

TL = 250 PLF

10’-0”  5’-0”

500 lb  500 lb
Example 1.1
Shear Envelope for 24K7 Joist
Analysis Considerations

To Analyze Joist Capacity

- Pinned connections are assumed for web members
- Prior to 2015, SJI Specifications for K-Series joists permitted bending to be neglected for uniformly loaded joists when the panel point spacing does not exceed 24 inches
- A first-order analysis is used
- The SJI (Spec 4.5.4) permits eccentricities to be neglected when the eccentricity does not exceed:
  
  a) the lesser of ¾ of the over-all chord dimension or 2” for single component web members, or
  
  b) $1\frac{1}{2} \times$ the distance to the neutral axis from outside the chord.
Actual Member Load Carrying Capacity

- Evaluate the actual member to determine the actual member capacity.
- Evaluate any conservative design assumptions to see if a more accurate condition occurs.
- Evaluate the length and placement of weld.
- Determine the risk of repair verses the in place capacity.
- Use engineering judgment.
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Load Diagram

ORIGINAL DESIGN LOADS

10’-0”  5’-0”

500lb  500lb

ACTUAL LOADS

TL=253PLF

TL=250PLF
Example 1.1
Shear Envelope for 24K7 Joist

5687 lbs.
5060 lbs.

SJI

3187 lbs.

1265 lbs.
15'-0"

ACTUAL

5312 lbs.
5060 lbs.
Example 1.1
Moment Diagram for 24K7 Joist

ACTUAL

56.4 kip-ft.

SJI

50.6 kip-ft.
Joist Diagram
Existing Top Chord Review

- TC are continuous and segments 7 thru 12 have a larger axial force than the maximum in a 24K7.

- Forces shown are compression.

<table>
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<th>Revised Loading Required Axial Force</th>
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Existing Bottom Chord Review

- BC are continuous and segments 3 thru 6 have a larger axial force than the maximum in a 24K7.

- Forces shown are tension.

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Existing Web Review

- All the webs have higher axial loads.
- Note the 25% minimum axial force.
- Design software can change the values.

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+ tension
- compression
Example 1.1a

Original loads

• Assume 20 psf DL
• Assume 30 psf LL
• Assume 5’ joist spacing
• Total uniform load 250 plf

Revised loads

• Assume 15 psf DL
• Assume 30 psf LL
• Assume 5’ joist spacing
• Total uniform load 225 plf
Example 1.1a

Load diagram

![Load Diagram]

**ORIGINAL DESIGN LOADS**

TL = 253 PLF

10’-0”

500 lb

5’-0”

500 lb

**ACTUAL LOADS**

TL = 225 PLF
Example 1.1a

Top chord review

- TC are continuous and fewer segments have ratios over 1

- Forces shown are in compression.

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Example 1.1a

Bottom chord review

• BC are continuous and segments 4 thru 5 have a larger axial force than the maximum in a 24K7.

• About a 3% greater force.

• Forces shown are in compression.

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Example 1.1a

Web review

- Many webs have higher axial loads.
- Note the 25% minimum axial force.
- Actual capacities need to be reviewed verses required forces.
- Actual weld length need to be verified.

+ tension

- compression

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Example 1.1b

• An alternate approach would be to check the manufactured joist using the actual design dead and live loads in lieu of the load capacity from the SJI tables.

• From a review of the structural drawings the joist spacing is found to be 4’-10” o.c. and the roof slope is ½:12.

• A check of the roof materials found that the actual roof dead load, including an allowance for the joist weight, is 15 psf.
Methods of Supporting Additional Load

Options Before Strengthening

• Capacity of joist needs to be determined
  – Can joist safely support new loads?
  – What are the actual loads?
  – What are the actual load cases?
  – Are stress ratios over 1.0 permitted?
Methods of Supporting Additional Load

Options Before Strengthening

• Extensive reinforcement may not be practical
  – Option #1 - Load distribution
  – Option #2 - Add new joists or beams
  – Option #3 - Reinforce existing joists
Load Distribution

Member with suitable stiffness required

• Place member under or through the joists

• Concentrated load distributed to several joists
Design Approaches for Strengthening Joists

Two design approaches to reinforce individual joist members

• Approach I
  – Ignore the existing member strength
  – Simply design the reinforcing members to carry the total load

• Approach II
  – Make use of the strength of the existing member
Design Approaches for Strengthening Individual Joist Members

Considerations for either approach

• Cost of materials for reinforcement is insignificant to the cost of labor

• Safest to reinforce the joist in the shored position
  – Welding can generate enough heat to cause temporary loss of steel strength
  – Transverse field welds should be avoided

• Best to reinforce the members with dead and live loads removed
  – Jack the joist up to a calculated deflection

• Pay close attention to eccentricities caused by the reinforcing
Design Approaches for Strengthening Individual Joist Members

For Approach II

• It is assumed that applied forces are distributed between the existing member and the reinforcing member
  – Direct proportion to their areas
• If joists are shored to remove existing load
  – The preload is then zero
• If joists are not shored
  – Preload can be calculated based on load present at the time of reinforcing
• Shoring and jack placement is the responsibility of the specifying professional
Chord Reinforcement

Typical reinforcement details

• Top chord
  – More difficult to reinforce since the floor or roof deck is usually in place
  – Overhead welds may be required

• Bottom chord
  – Easier to access
  – No overhead welds required
Chord Reinforcement

Top chord reinforcement – rods
Chord Reinforcement

Top chord reinforcement – plates
Chord Reinforcement

Top chord reinforcement – angles
Chord Reinforcement

Top chord reinforcement – angles
Chord Reinforcement

Angle interference with top chord reinforcement
Chord Reinforcement

Top chord reinforcement – rods

Cut Diagonal Leg
Chord Reinforcement

Top chord reinforcement requiring notch

N.S. & F.S. Typ.

Cut Leg As Req’d.

Plate Reinforcement

Plate Reinforcement With Notch Cut Around Diagonals
Chord Reinforcement

Rod splice

Grind
Chord Reinforcement

Bottom chord reinforcement

2-12
3" At
Panel Joint
6" At Ends

N.S. & F.S. Typ.

Reinforcing Plate
Web Weld Location for Crimped Angles and Solid Rounds or Square Bars
Rod Web Reinforcement

Angle reinforcement on rod web joist
Rod Web Reinforcement

Angle reinforcement on rod web joist
Crimped Web Reinforcement

Joist with crimped web members
Crimped Web Reinforcement

Angle reinforcement on crimped web joist
Crimped Web Reinforcement

Angle reinforcement on crimped web joist
Crimped Web Reinforcement

5/8" Dia. Rod or Plate
N.S. & F.S.

Reinforcing Plate

SECTION A-A
Double Angle Web Reinforcement

Angle web reinforcement with rod
Double Angle Web Reinforcement

Angle web reinforcement with rod
End Diagonal Web Reinforcement

End diagonal reinforcement with angle

Reinforcing Angle (N.S. & F.S.)

Typ. At Each End, Each Angle

SECTION A-A

Reinforcing Angle
End Diagonal Web Reinforcement

Bar added for additional weld on end diagonal
Reinforcing vs Replacing vs Adding

Considerations

• Cost – Field labor costs lots of money
• Time – Time is money
• Difficulty of repair – Interferences, Access
• Effectiveness of reinforcing
• Skill of workman
Considerations

• Existing interferences
  – Piping, electrical conduits, other interferences
  – Removing or relocating could be at a greater expense than reinforcement

• Camber
  – May need to reduce camber in new joists
  – Joists can be ordered with shallower seat depths and then shimmed in the field
  – The joist can be supplied with a splice so two individual pieces can be installed and bolted at the center
Reinforcing vs Replacing vs Adding

Camber – Joists manufacturers rigging tables are set up for SJI standard camber. If replacing or adding a joist, specify zero or no camber.
Reinforcing vs Replacing vs Adding

Splice – When adding a joist into an existing building, a field bolted splice allows each half of the joist set in place and then mated together.
Reinforcing vs Replacing vs Adding

Bearing seat depth – Specify a shallower seat depth and then shim to raise top chord to deck.

INSTALLED BEARING SEAT FOR EXISTING JOIST

NEW JOIST W/ SHALLOWER BEARING SEAT PRIOR

NEW JOIST W/ SHALLOWER BEARING SEAT AND SHIMMS
Reinforcing vs Replacing vs Adding

Considerations

• Lateral stability of the joist top chord
  – Shoot pins through the chord, decking, and slab
  – Rely on bridging to provide lateral support
Reinforcing Existing Joists

The following will impact reinforcement of both chord and web members:

• Rod web joists
  – New reinforcing webs can be easily added on the outside of the chords.
  – Chords are typically thin angles.

• Crimped angle web joists
  – New reinforcing webs can be easily added on the outside of the chords.
  – If chords and webs need to be reinforced there could be interferences which affect how the reinforcement is done.
Reinforcing Existing Joists

For larger LH-Series and Joist Girders - Double angle diagonal webs may intersect at a bottom chord panel point there will not be room to add and weld a reinforcing web at that panel point to pick up a load. The chord will have to be checked for local bending.
Reinforcing Existing Joists

The following will impact reinforcement of both chord and web members:

• Chord and web yield strength
  – Recent manufacturing (15 – 20 years) has used 50 ksi steel for chord and webs.
  – Older joists may have been manufactured using 36 ksi steel and test coupons may be required to determine the Yield Strength of the joist members.
Other Considerations

Deflections

• Deflection control is often required in addition to strengthening joists for load

• Project deflection requirements must be considered
  – A live load deflection less than L/240 may not be met if a joist is only strengthened for added loads from a snow drift.
Other Considerations

• When shortening or lengthening a joist, camber needs to be maintained whenever removing any web members

• Bridging Effects for Additional Loads
  – Bridging may need to be added or modified
    • Providing the required lateral support to compression chord members is critical.
    • Bottom chord may be subjected to compression during uplift loads.
  – Refer to the SJI Specifications for bridging requirements.
Other Considerations

• Additional supports can be added to a joist to increase capacity. This will drastically alter the web shears and may cause load reversal in webs.

• If the support is added between bottom chord panel points, Support Pt. B, reinforcing webs must be added to support the bottom chord.
Questions?