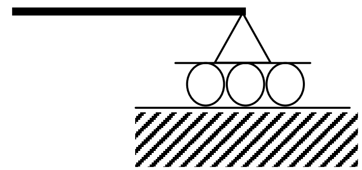
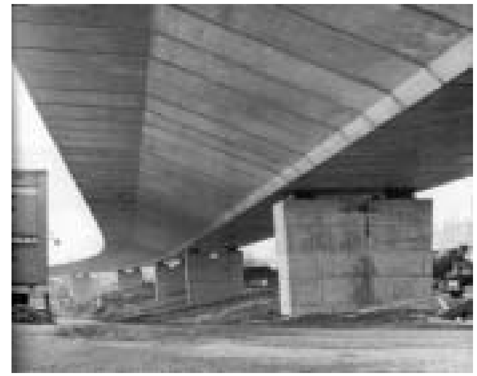
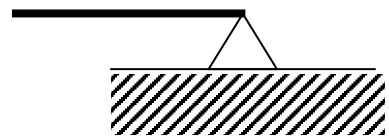
Designing Connections

- **Roller**

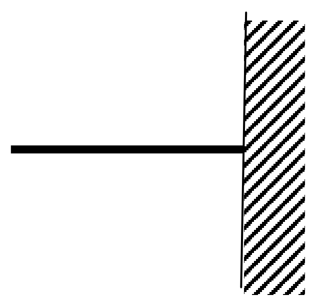


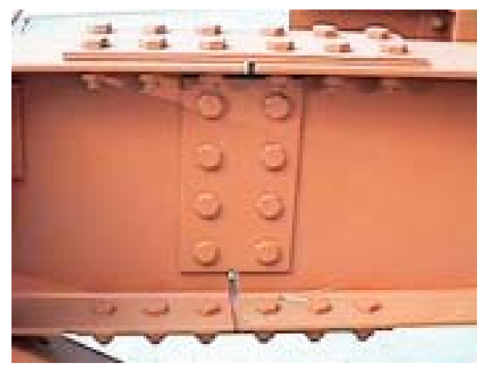


- **Pin (hinge)**



- **Rigid connection**





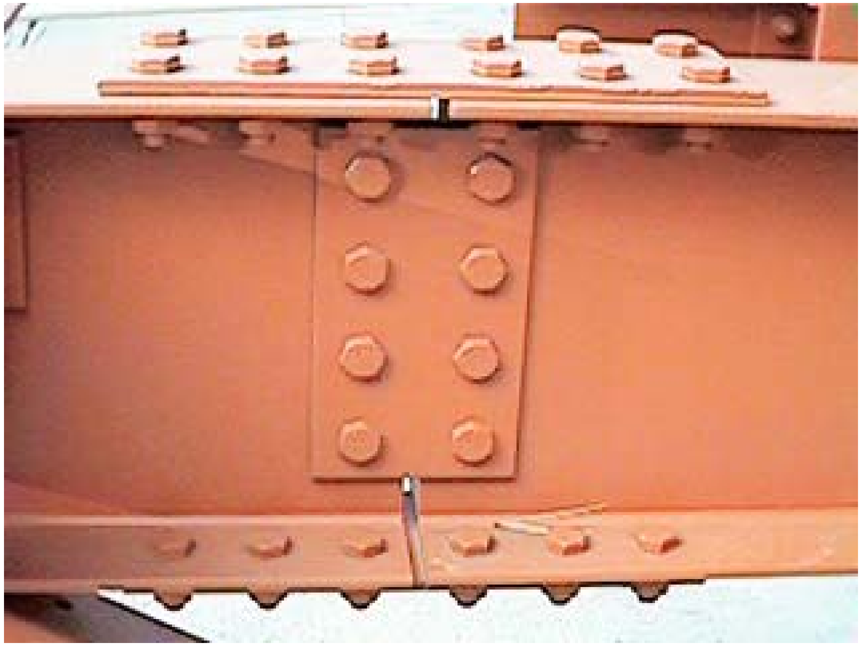
Connection Design

- Be clear in the function of the connection
  - What loads does it have to resist?
- How could it fail?
- Will it be easy to maintain in the future?

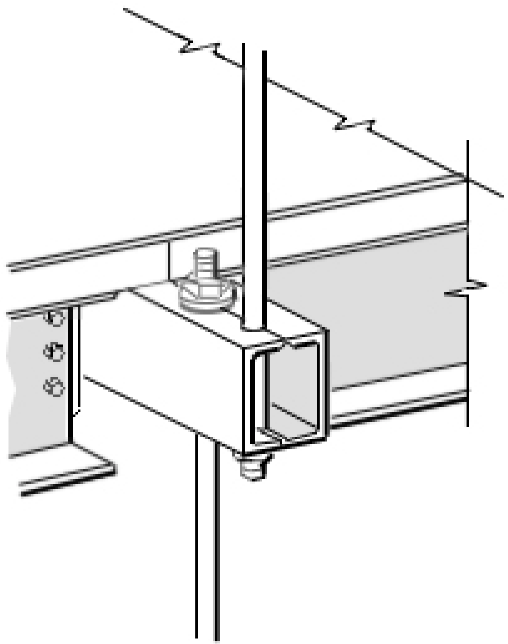
Connection Design for Strength

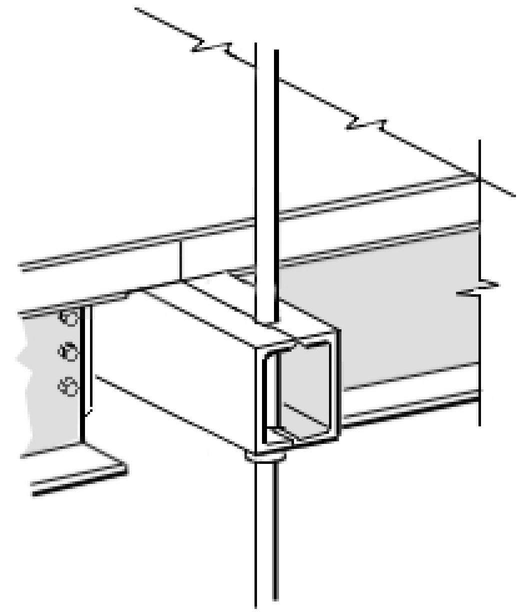
Must Resist:

- **Axial forces**
- **Moment forces**
- **Shear forces**



Suspended Walkway of the Kansas City Hyatt Regency, 1981



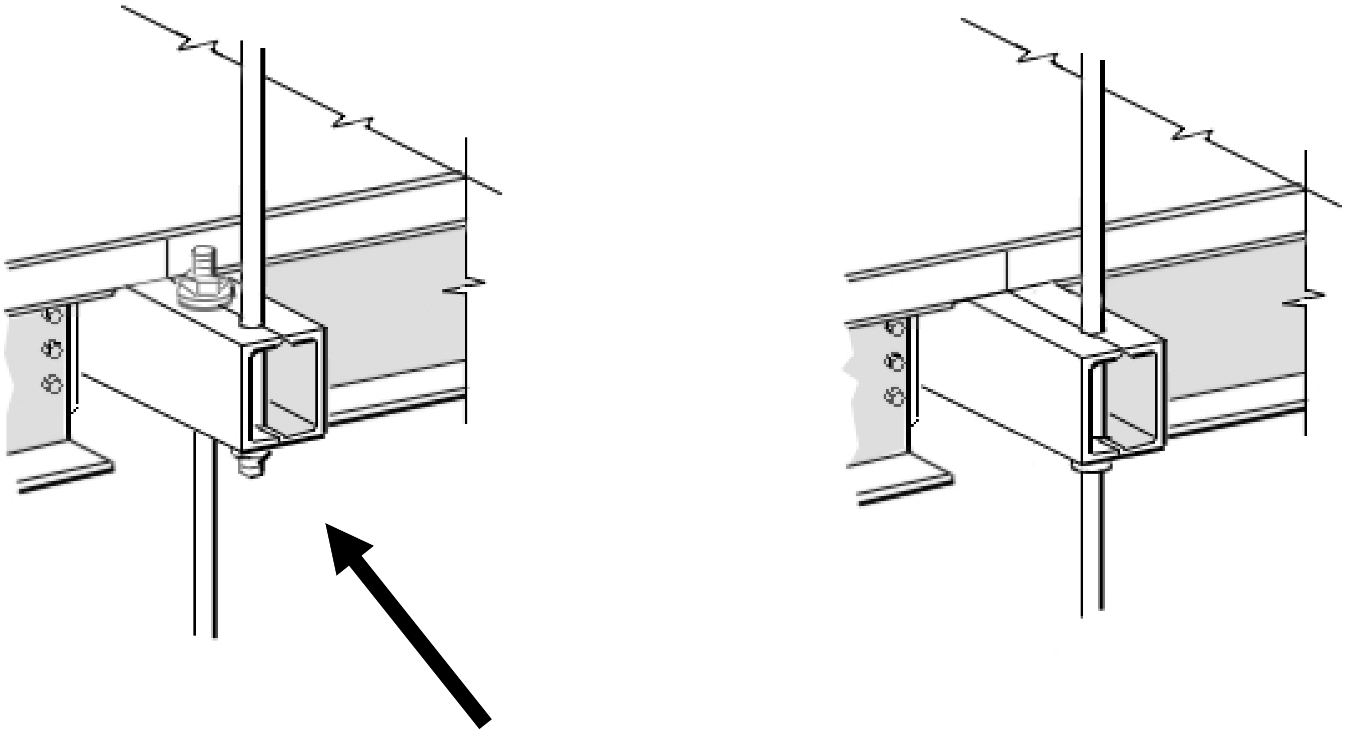


Is there a difference between these two connections?

-Technically?

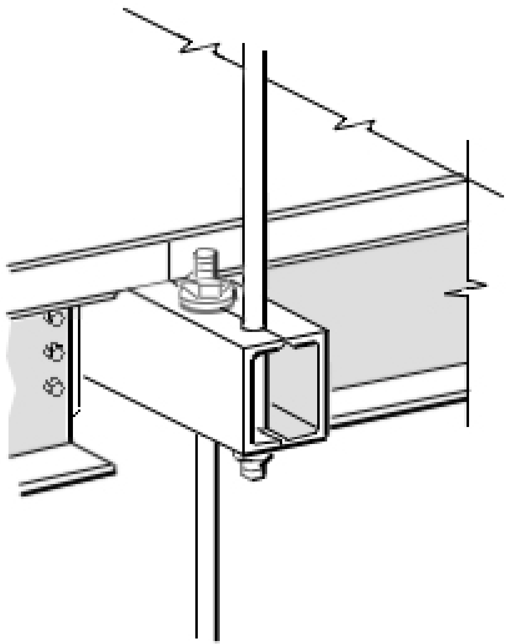
-Aesthetically?

Suspended Walkway of the Kansas City Hyatt Regency, 1981

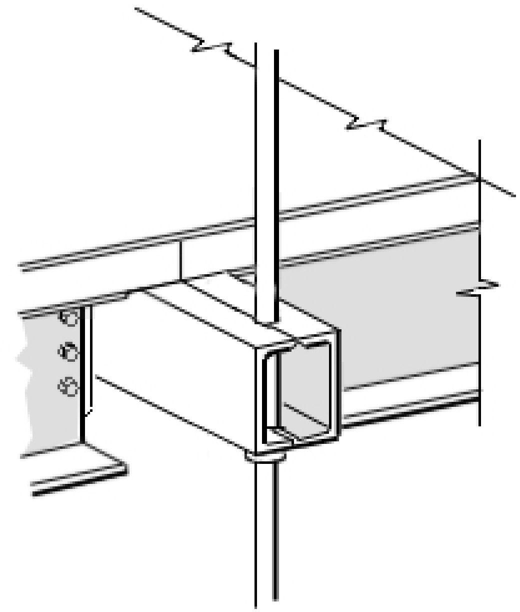


- **What is the force on this bolt?**

Suspended Walkway of the Kansas City Hyatt Regency, 1981



As-built connection



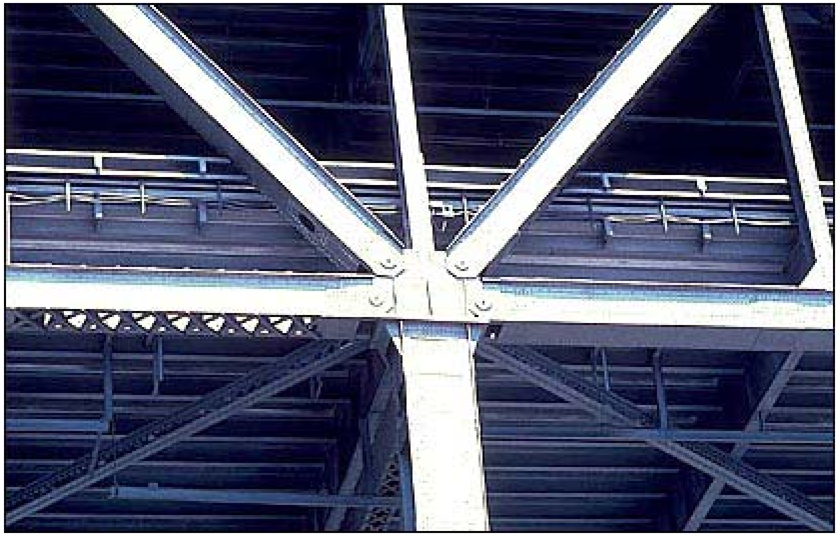
Initial connection design

- **Everyone agreed to the design change without thinking of the implication**

Lessons from the Kansas City Collapse, 1981

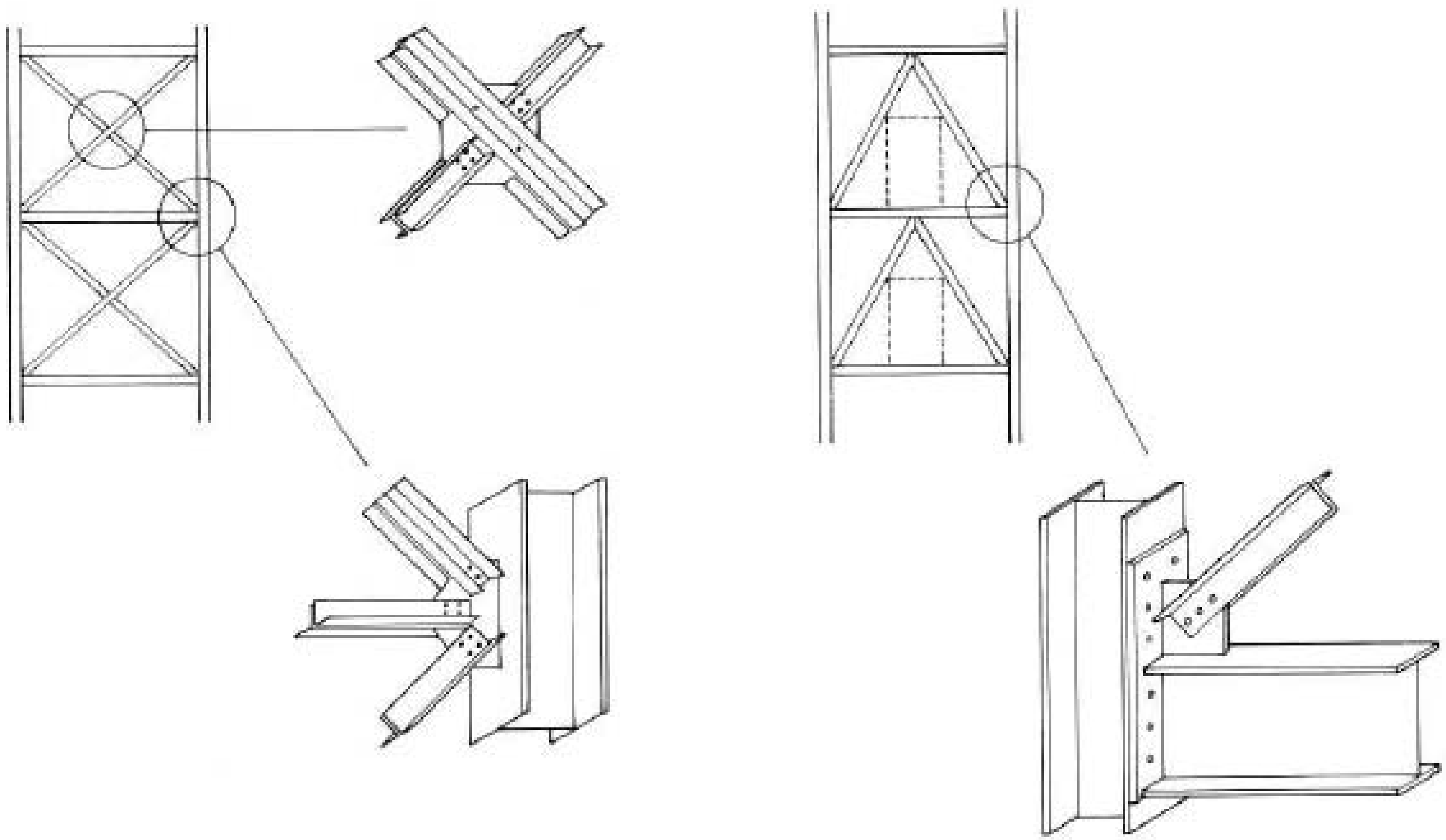
- **Imagine that you are the structural element or the connection: how could the forces be transferred from one member to the other?**
- **For axial force members, align each member so the connection reduces to a single point**

Connection Geometry



- **Centroid axis of each member should pass through the same point (particularly true for axial force structures like trusses.)**

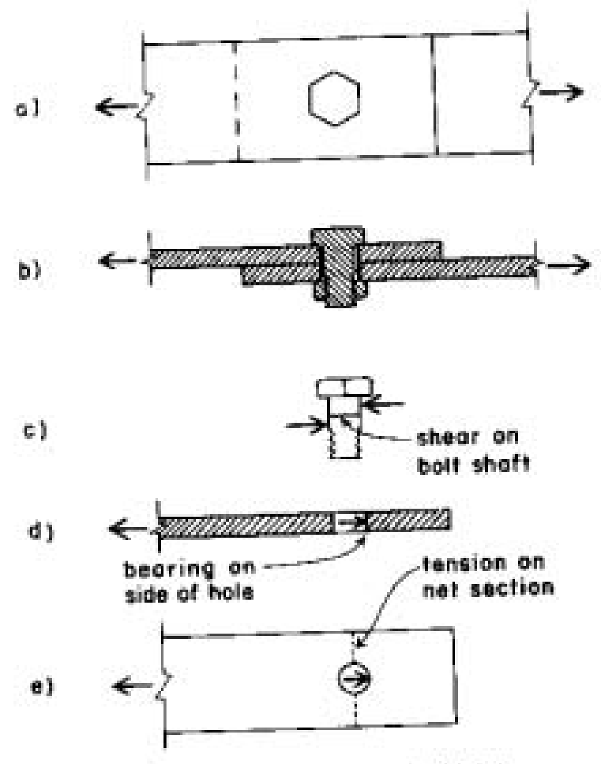
Steel Bracing Connections



- **Centroid axis of each member should pass through the same point**

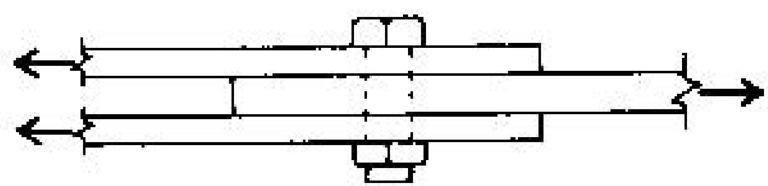
Bolt in Single Shear

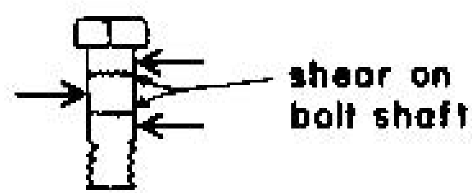
- Shear stresses try to "slice" the bolt
- Stress equals shear force divided by the cross-sectional area of the bolt



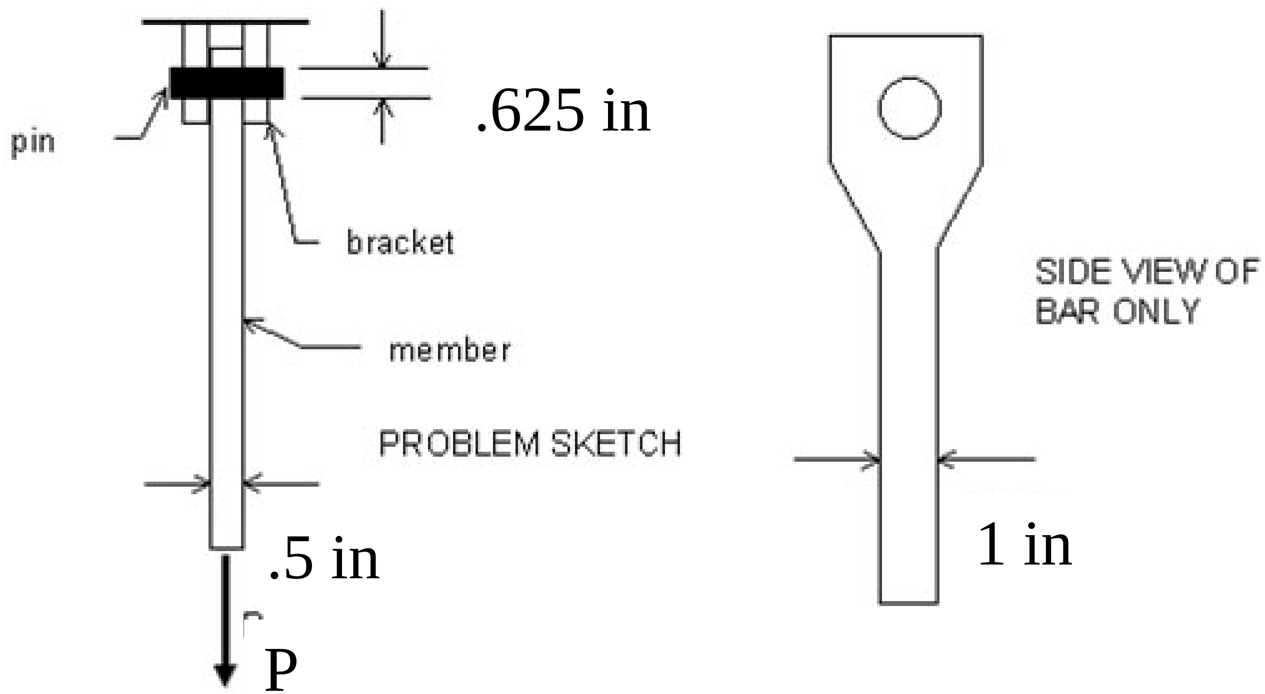
Bolt in Double Shear

- **Shear stress is *one half* the value of the applied load**



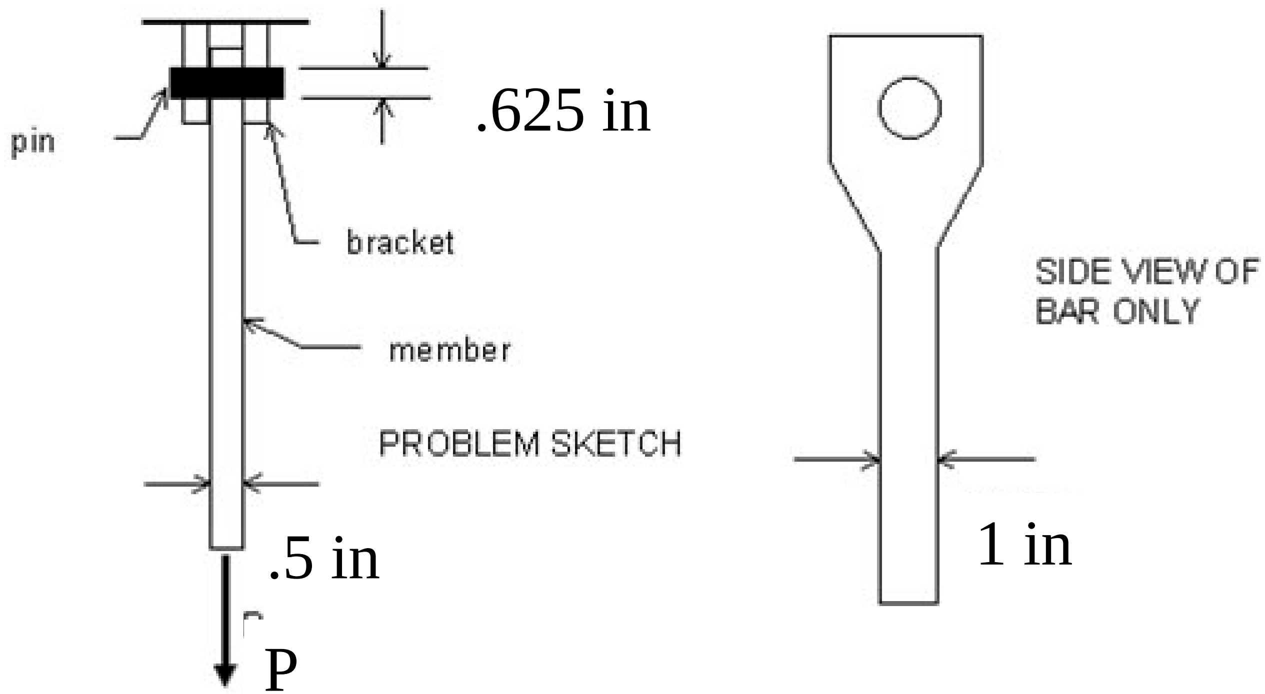


Example problem



- **What are the ways this connection could fail? (allowable stress = 10 ksi)**

Example problem

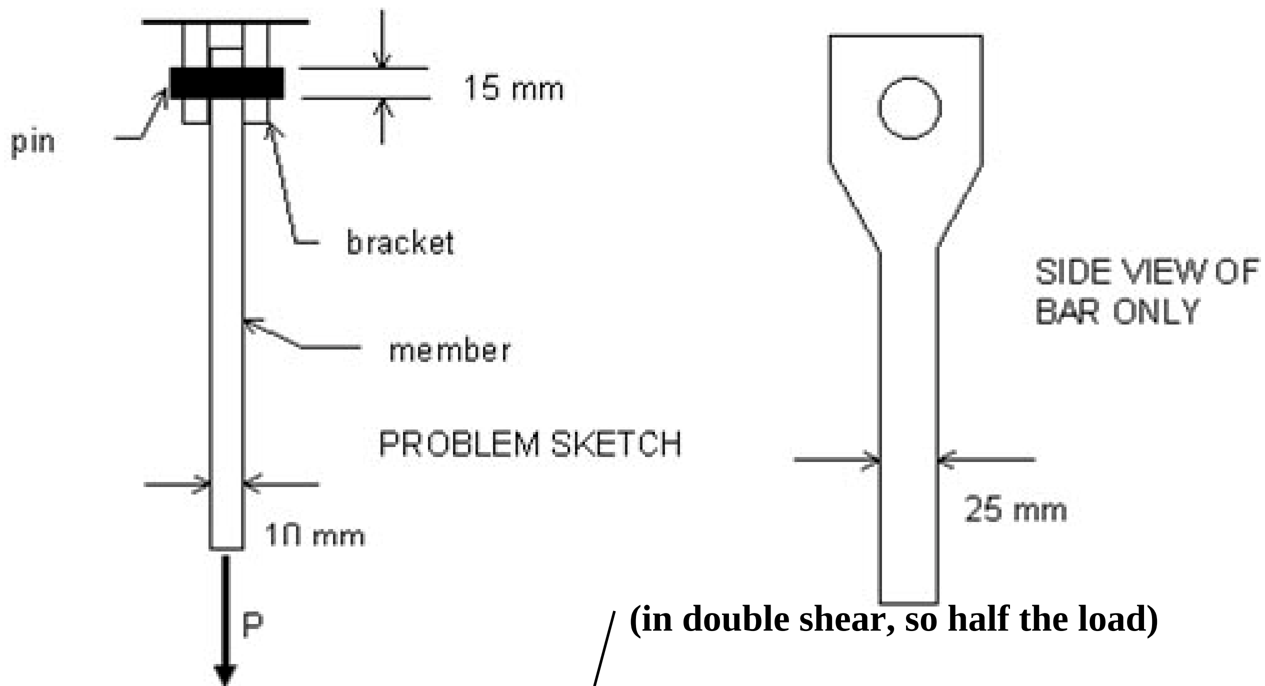


1. Maximum axial stress on the bar:

F = (Stress)(Area) = (10 ksi)(1 in)(0.5 in)

= <u>5 kips</u> (5000 pounds)

Example problem

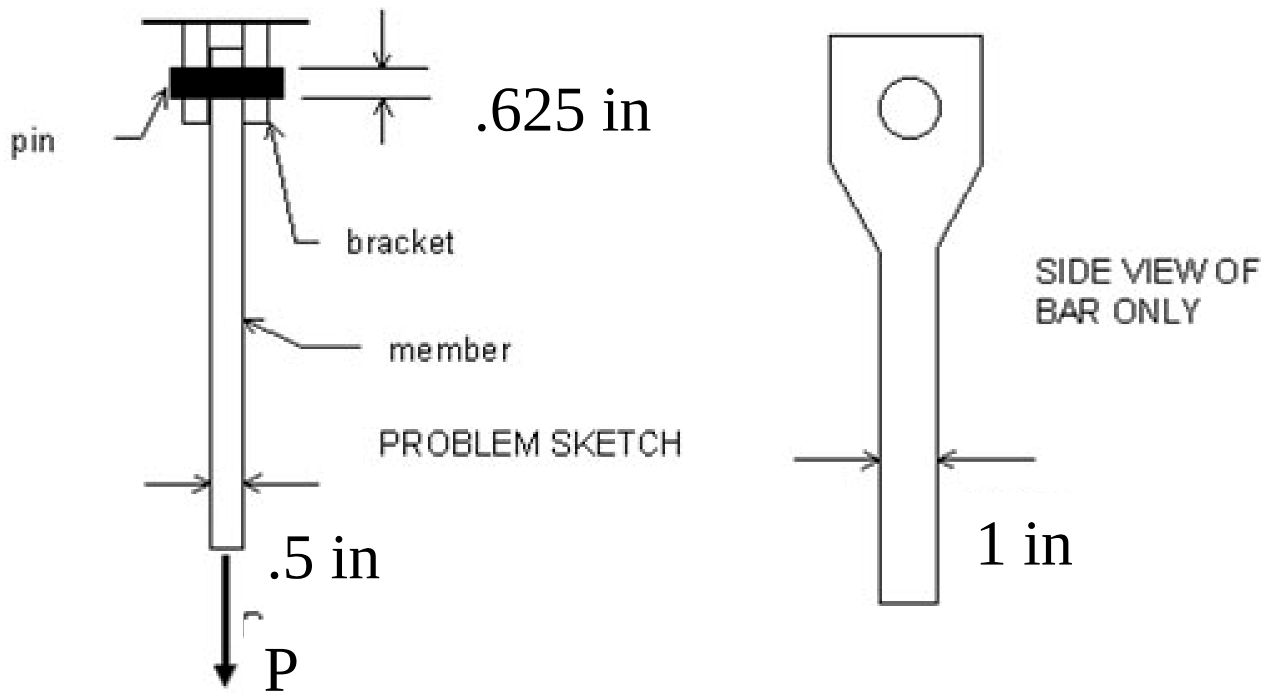


(in double shear, so half the load)

2. Maximum shear across the pin: (area = 0.31 in^2)

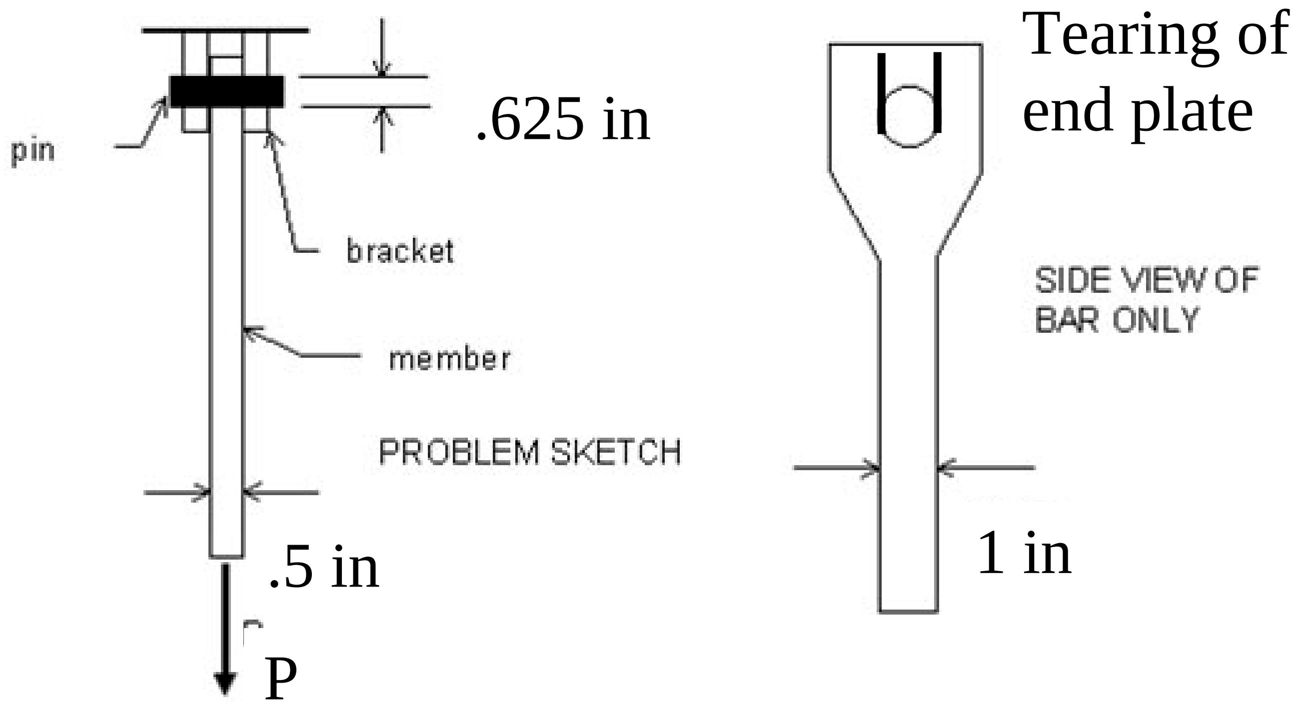
F = (Stress)(Area) = (2)(10 ksi)(0.31 in^2) = <u>6.2 kips</u> (6,200 pounds)

Example problem



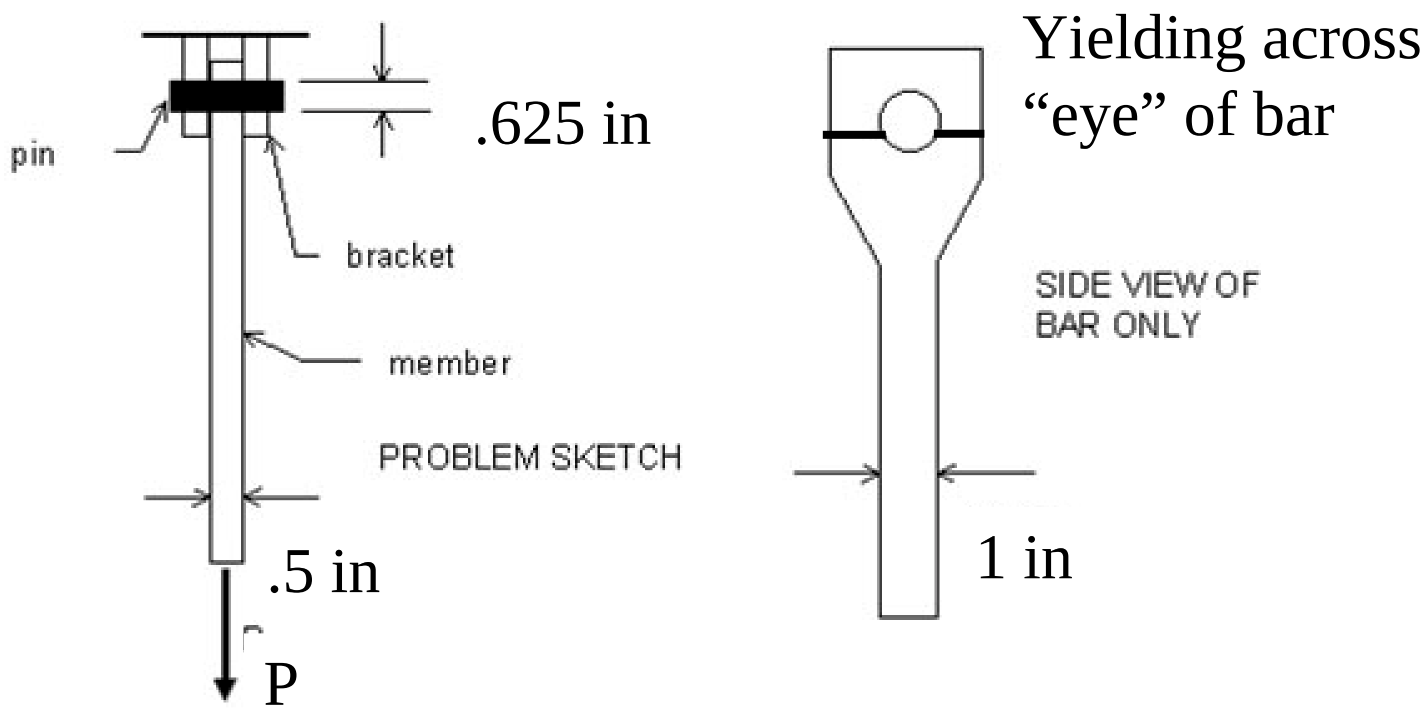
- **Other modes of failure? (at least 3)**

Example problem



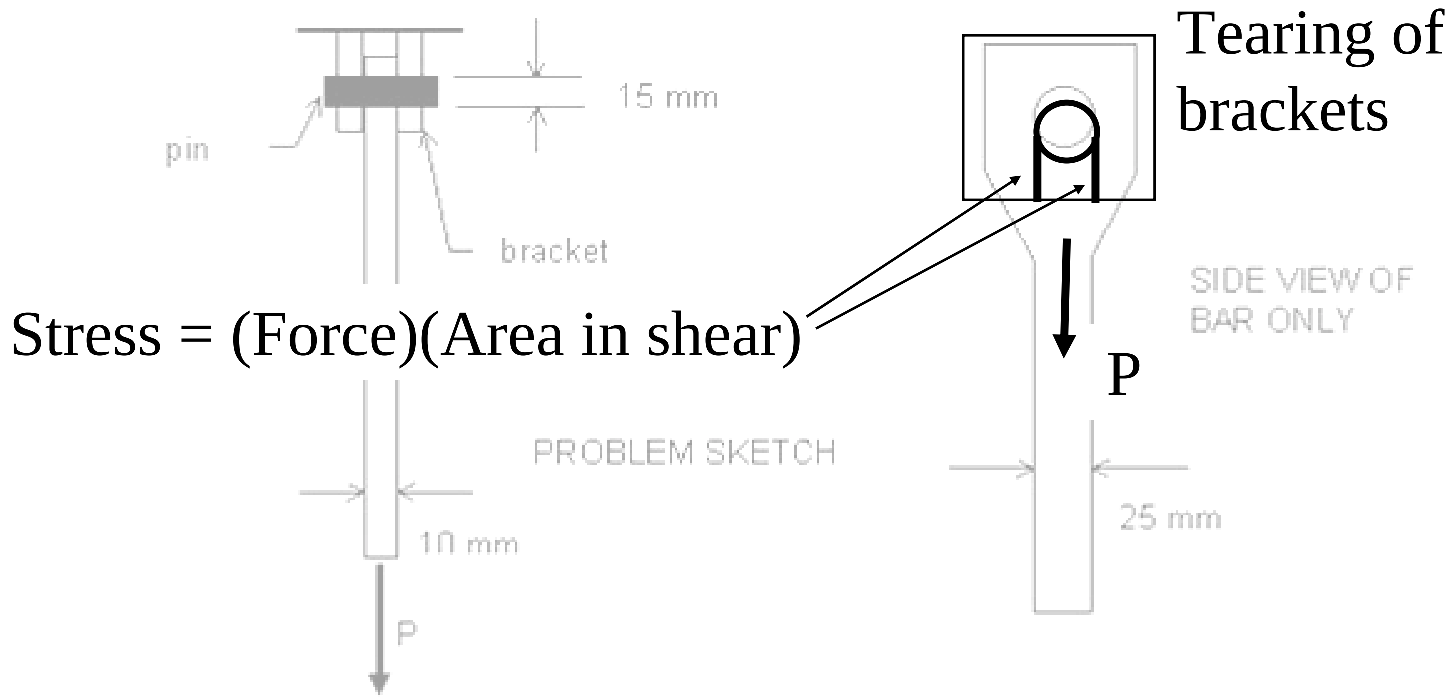
- **Other modes of failure?**

Example problem



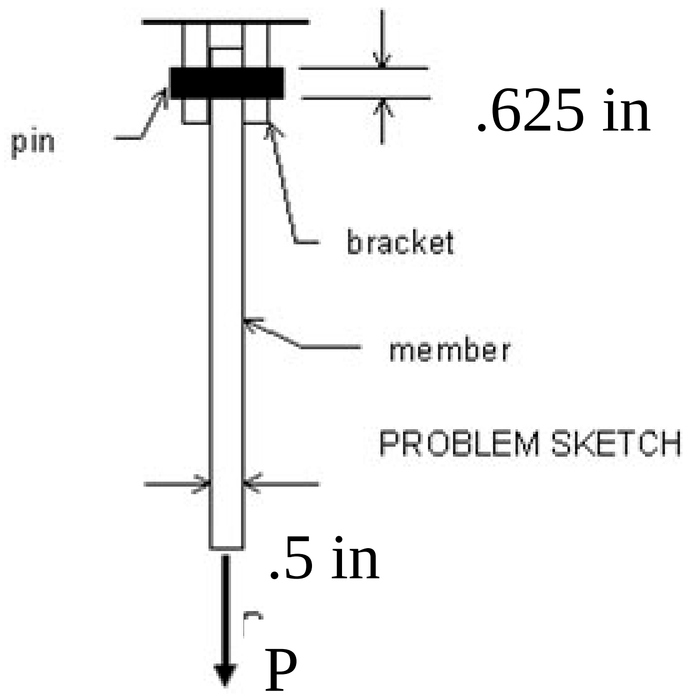
- **Other modes of failure?**

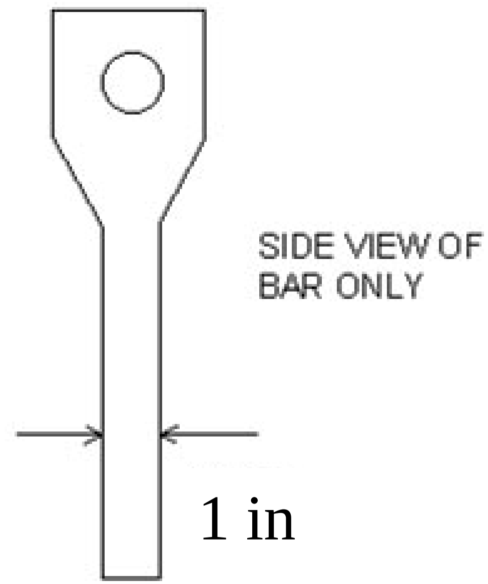
Example problem



- **Other modes of failure?**

Example problem



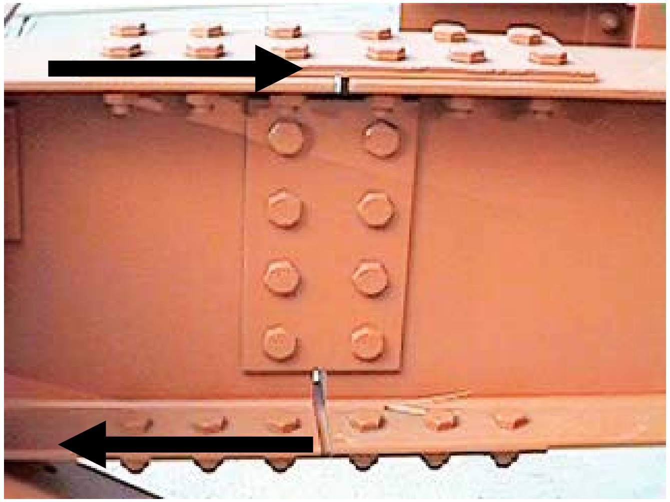


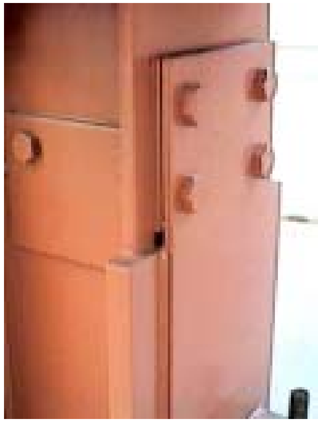
- **Conclusion: Even the simplest connections can fail in many ways**

Axial Force Connections

- Consider all sections of material where failure could occur
- Compare allowable force for each section, and the lowest force value governs the design load capacity
- If the joint acts in compression, beware of buckling (typically in plates)

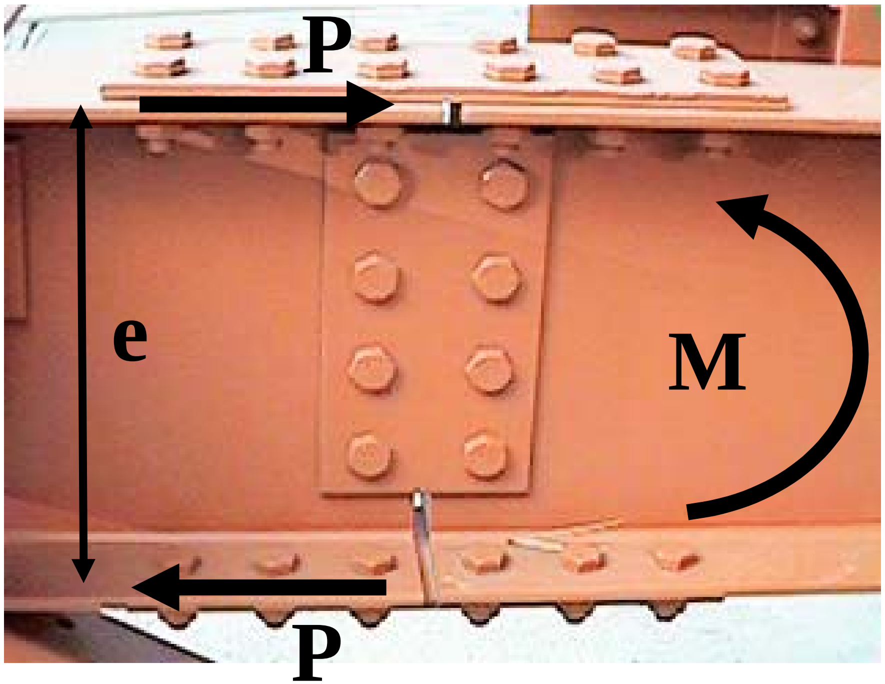
Moment Connections

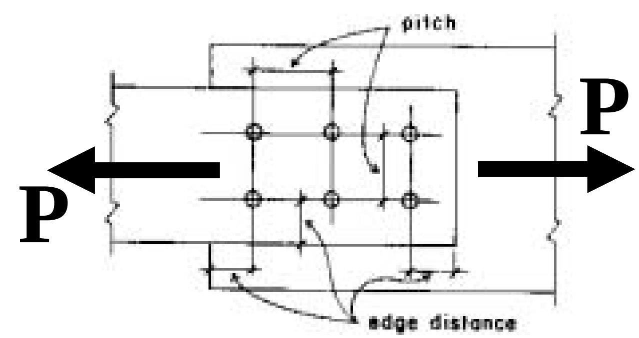




- Tie flanges together to transfer moment

Moment Connections





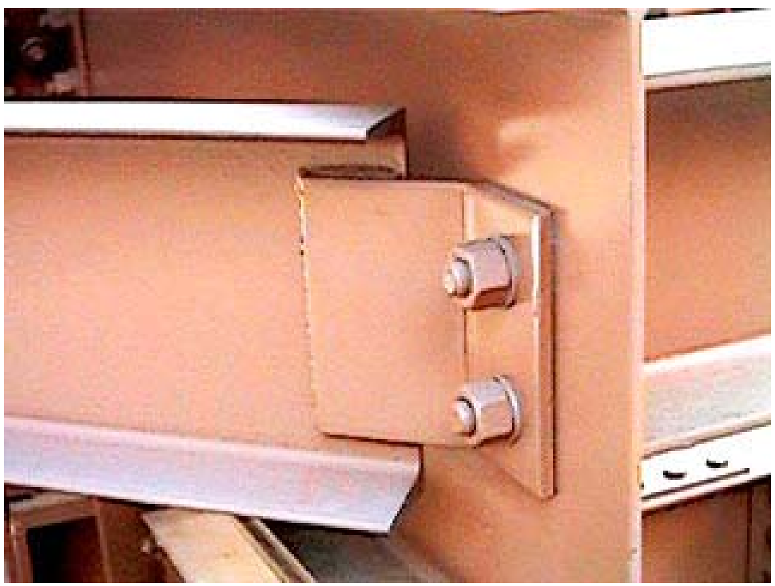
- Moment, M = Pe

- Design for axial force, P

Shear Connections

- **Use the web of the beam to transfer shear**

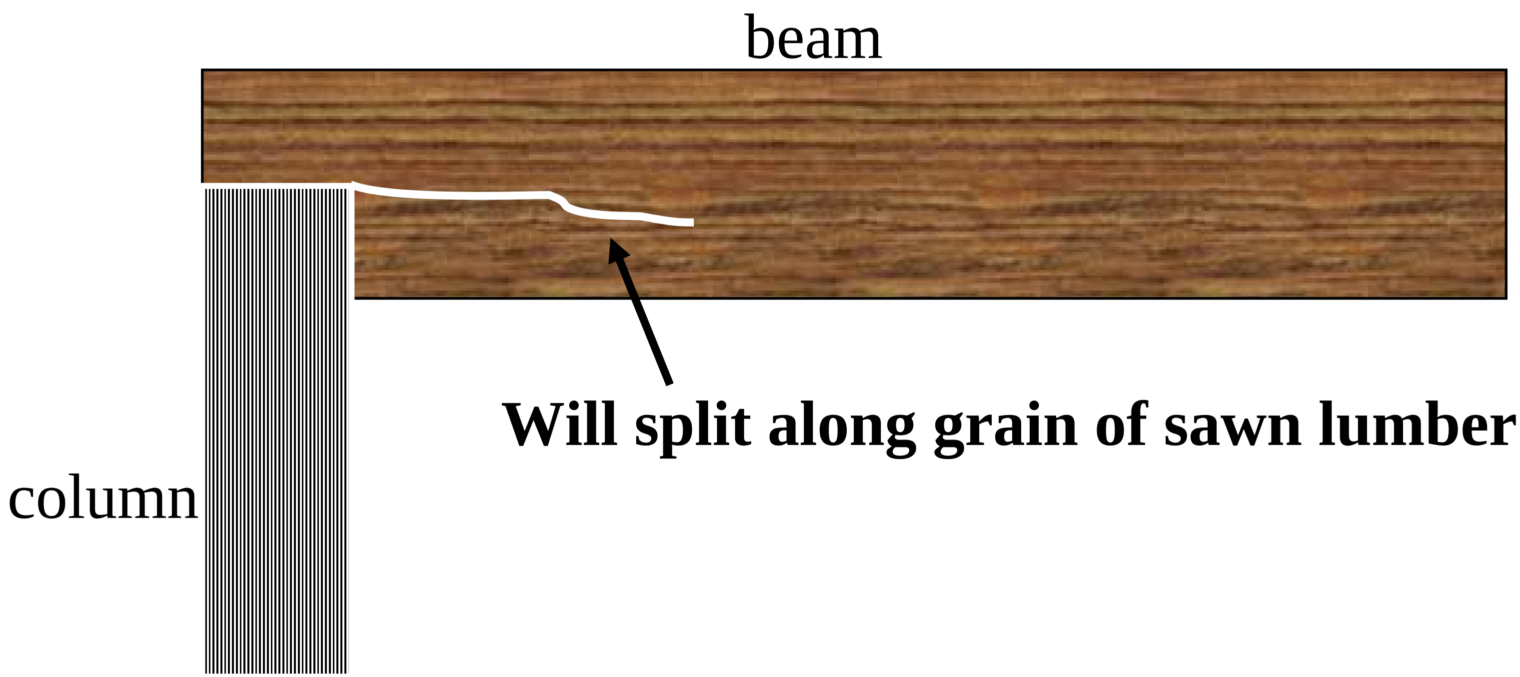
Shear Connections



- Use the web of the beam to transfer shear

Connections: Beware!

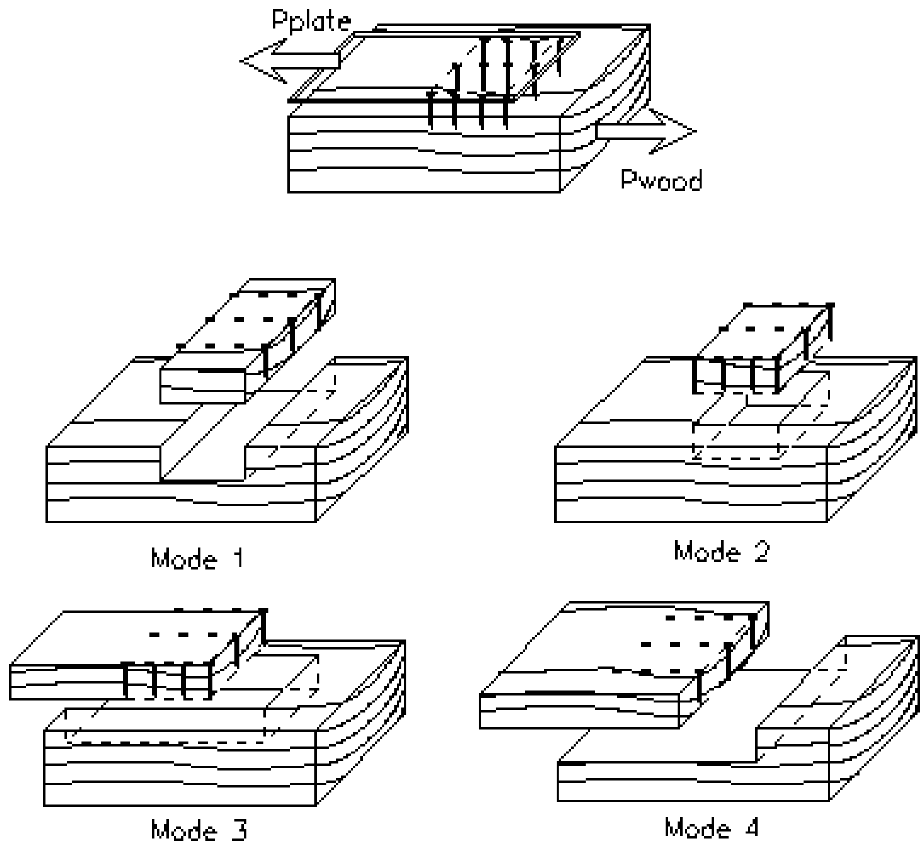
2. **Wood has different properties with and against the grown: beware of splitting**



Properties of Timber

- Cellular structure is very efficient
- Handles both compression and tension well
- Different strengths with and against the grain
- Inhomogeneous material with imperfections

Metal Shear Plate on Wood



- Must consider various possible failure modes

Connections: Beware!

4. Someone will have to disassemble your connection in the future: your construction today will be somebody's problem in the future

- Case study:

  Williamsburg Bridge

Williamsburg Bridge

- Carried traffic and trains throughout the 20th century
- But maintenance was neglected badly for decades
- In 1988 the poor condition of the bridge became an emergency

Decay of Williamsburg Bridge

- **Main cables had corroded badly (were not galvanized)**
- **Pin joints in the main trusses were corroded**
- **Rusted girders**

1990-2005: Rebuilding the Williamsburg Bridge

- **New cables, new girders, new roadways, new bearings, new paint, etc…**
- **Original designers didn't consider how to repair many elements**

Designing for Maintenance and Deconstruction

- Develop a maintenance plan for your structure
- Design components which are accessible and replaceable
- Avoid toxic materials which are hazardous for future repairs or demolition

Connection Conclusions

- **Design for strength: how could it fail?**
- **Design for serviceability: can it be maintained easily?**
- **To design a good connection you must know exactly what it has to do: seek clarity in design**

Steps in Finite Element Analysis

1. Define geometry
2. Connect nodes with members
3. Assign section properties (A, E, and I)
4. Define fixity of nodes and connections
5. Apply loads
6. Run analysis and examine output