Metallic Structures

Today's Lecture

1. **Historical Development of Iron Structures**

2. **Properties of Cast Iron, Wrought Iron, and Steel**

3. **Technical ideas:**

   -Combined axial and bending forces (middle 1/3 rule)

   -Plastic collapse of beam

4. **Conclusions**

Metal in Construction

•2000 yrs ago: Iron chain bridges in China

•Ancient Greece/Tiwanaku: lead/copper clamps

•Middle Ages: Iron ties in masonry buildings

•1779: Iron Bridge at Coalbrookdale

•19th C: Age of iron construction, beginning of steel structures

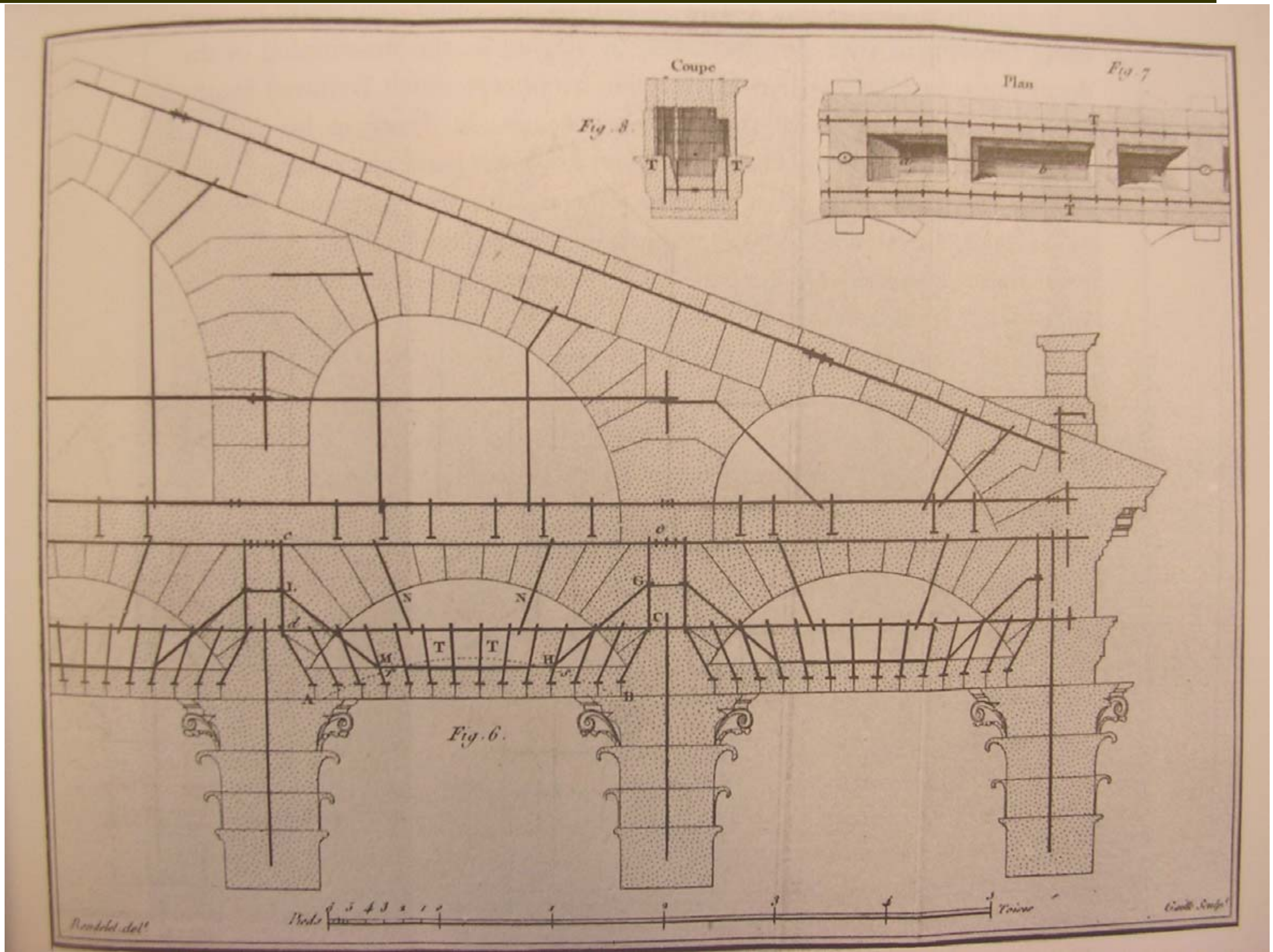
Iron Chain Suspension Bridges in China

From at least 3rd C AD and possibly from 3rd C BC

Wrought iron links?

7th C bridge with oxen abutments

French Pantheon, ~1770, Iron reinforcing



Iron Bridge at Coalbrookdale, 1779

Iron Bridge Details

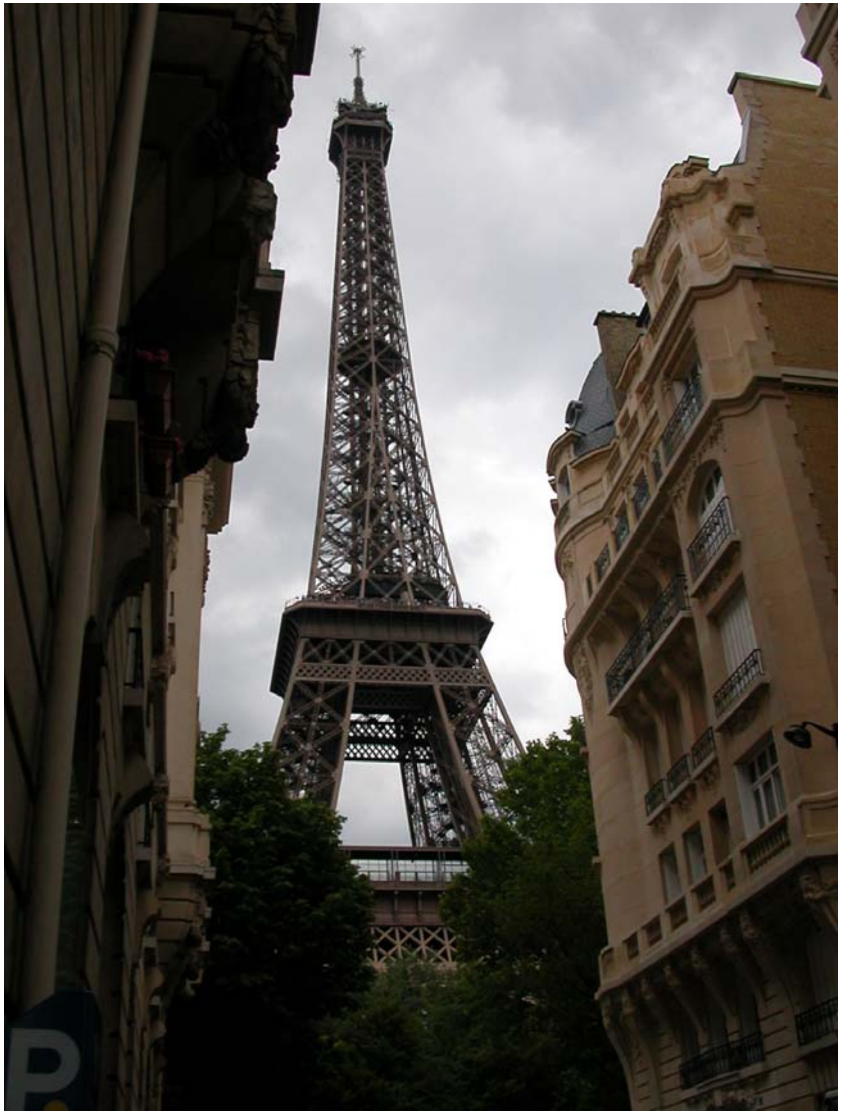
Arch Bridge by Gustave Eiffel

Garabit Viaduct, 1884, France

Image courtesy of Erich Baumgartner, structurae.de


AVENUE
GUSTAVE
EIFFEL

Eiffel Tower, 1889, wrought iron



Cast Iron, Wrought Iron, and Steel

- **Cast iron: high compression, lower tensile strength, *brittle*, like masonry**

- **Wrought iron: tension and compression, weaker than steel, like timber**

- **Steel: post-1850's, tension and compression, problems with corrosion**

- **All are iron + carbon + other impurities**

Cast Iron: 95-98% Iron

- Produced commercially after the introduction of cupola blast furnaces in 1794, was smelted at much higher temperatures in the liquid state, and so became saturated with carbon from the furnace fuel, up to about 5%.

- It was then poured out (ie cast) into a mold to produce blocks traditionally known as pigs, because the line of individual blocks connected to a channel looked like a litter of suckling pigs, hence the name "pig iron".

- The high carbon content makes cast iron very strong in compression, but weak and brittle in tension, even when red hot, so it cannot be forged or rolled. However it also lowers the melting point so it can be easily poured into molds to produce complex shapes.

Wrought Iron: 99.5-99.9% Iron

- Wrought iron was traditionally smelted at a relatively low temperature in the solid state to produce a spongy mass of metal called a bloom, from which the impurities were driven off as liquid slag by hammering, hence the term "wrought" ie "worked" iron.

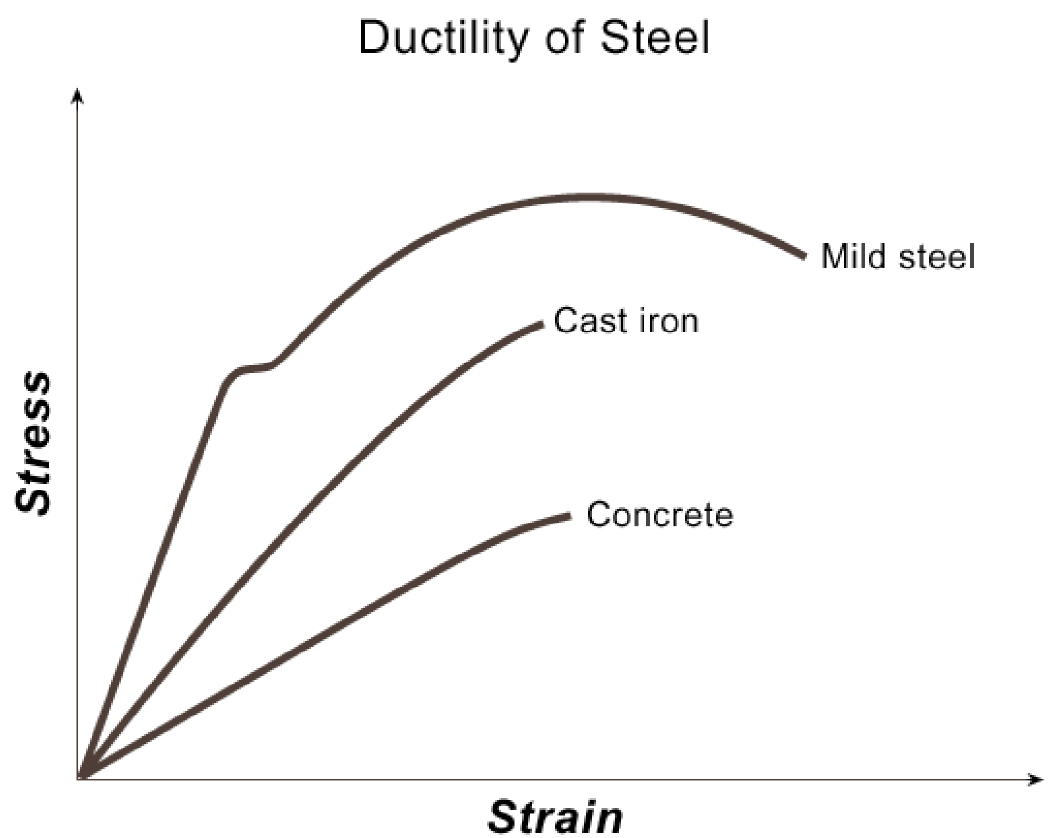
- Wrought iron is very pure, with a carbon content of less than 1%, which makes it resistant to corrosion, strong in tension and malleable. It was much used for gates and railings, and for structural members, but the early methods of production, (the iron cooled quickly and could only be worked in small quantities) limited the size of parts which could be easily made.

- Long thin sections were impossible until the development of the rolling mill, which is still used in steel production, during the eighteenth century. The rollers could be shaped to produce bars of different sections.

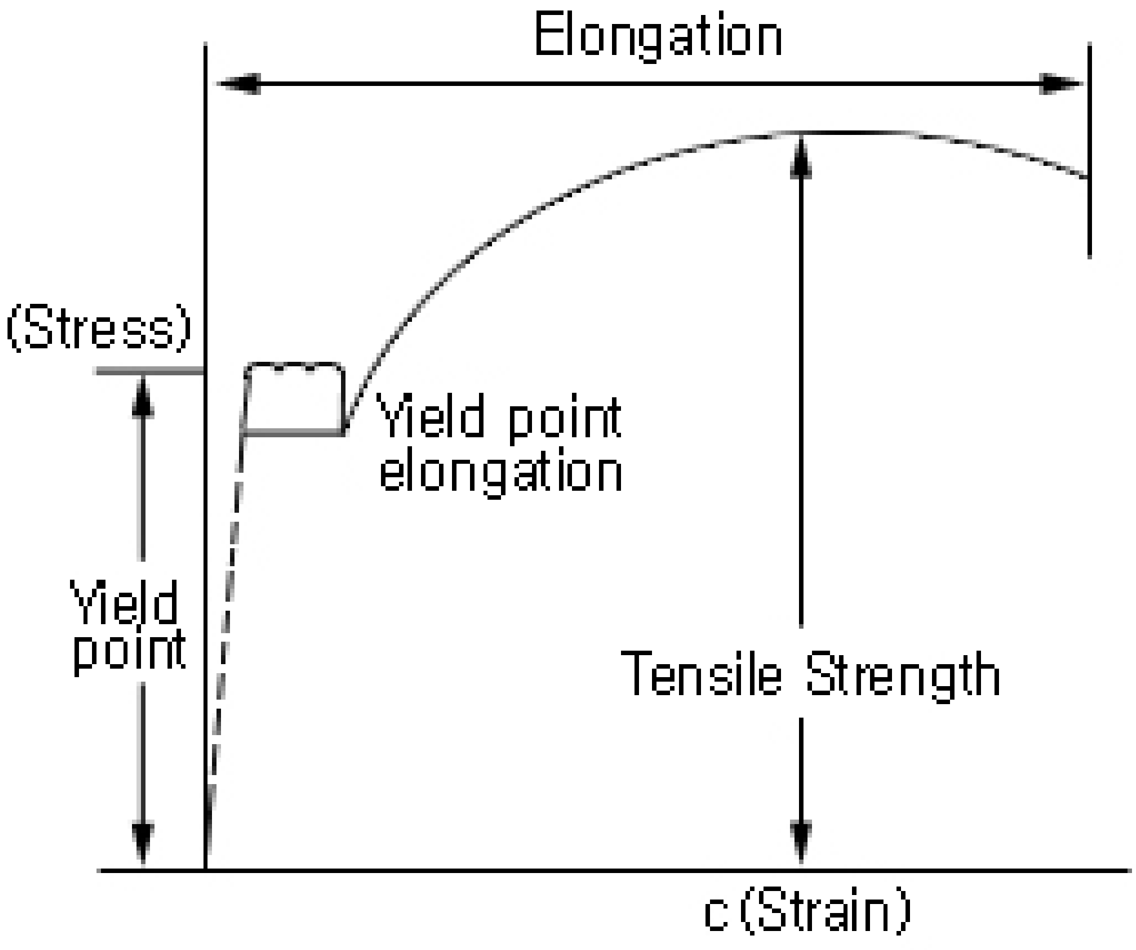
Steel: 98.5-99.9% Iron + Carbon and other impurities (Si, Mn, etc)

- Iron ore is a common element, which requires processing before it becomes a recognizable metal. It has an ability to combine with other elements and so can occur in a number of forms, but the three major types are wrought iron, cast iron and steel.
- Steel is now the most important, but its production dates only from the 1850s. Cast and wrought iron on the other hand are processes which have been known for thousands of years, but it is only comparatively recently that technology advanced to allow widespread production.
- The early iron working sites are among our most important industrial monuments. Good cast and wrought iron are much more resistant to corrosion and rusting than steel.
- Steel: Up to 1.5% Carbon, plus other impurities that determine properties

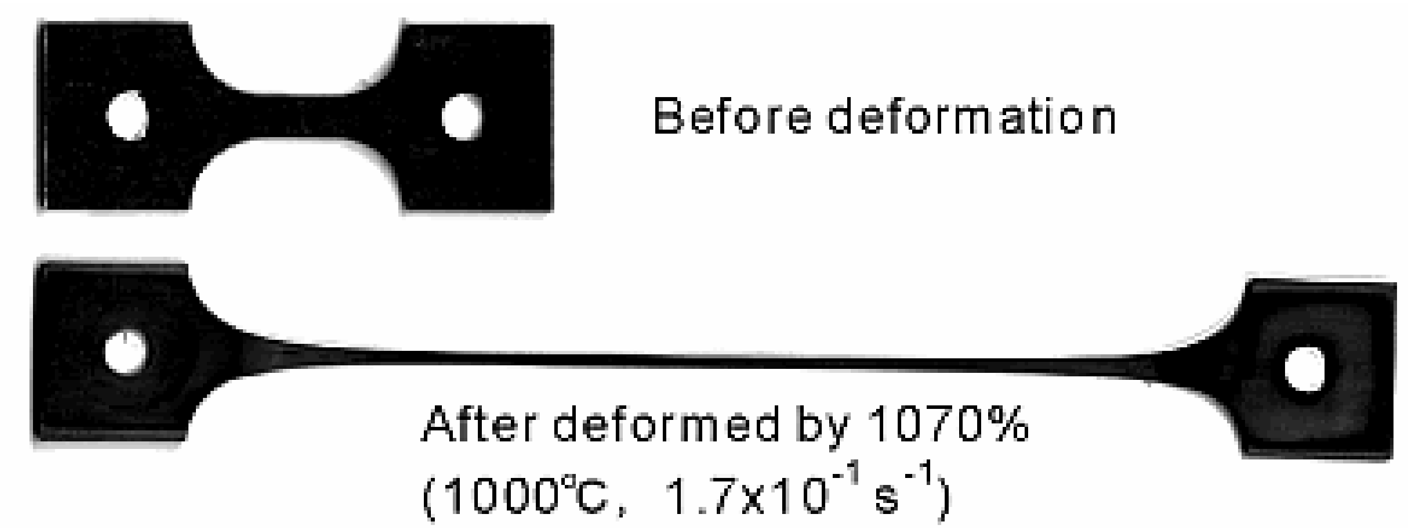
Ductility of Iron and Steel



Ductility of Steel



Hi-Ductility Steel



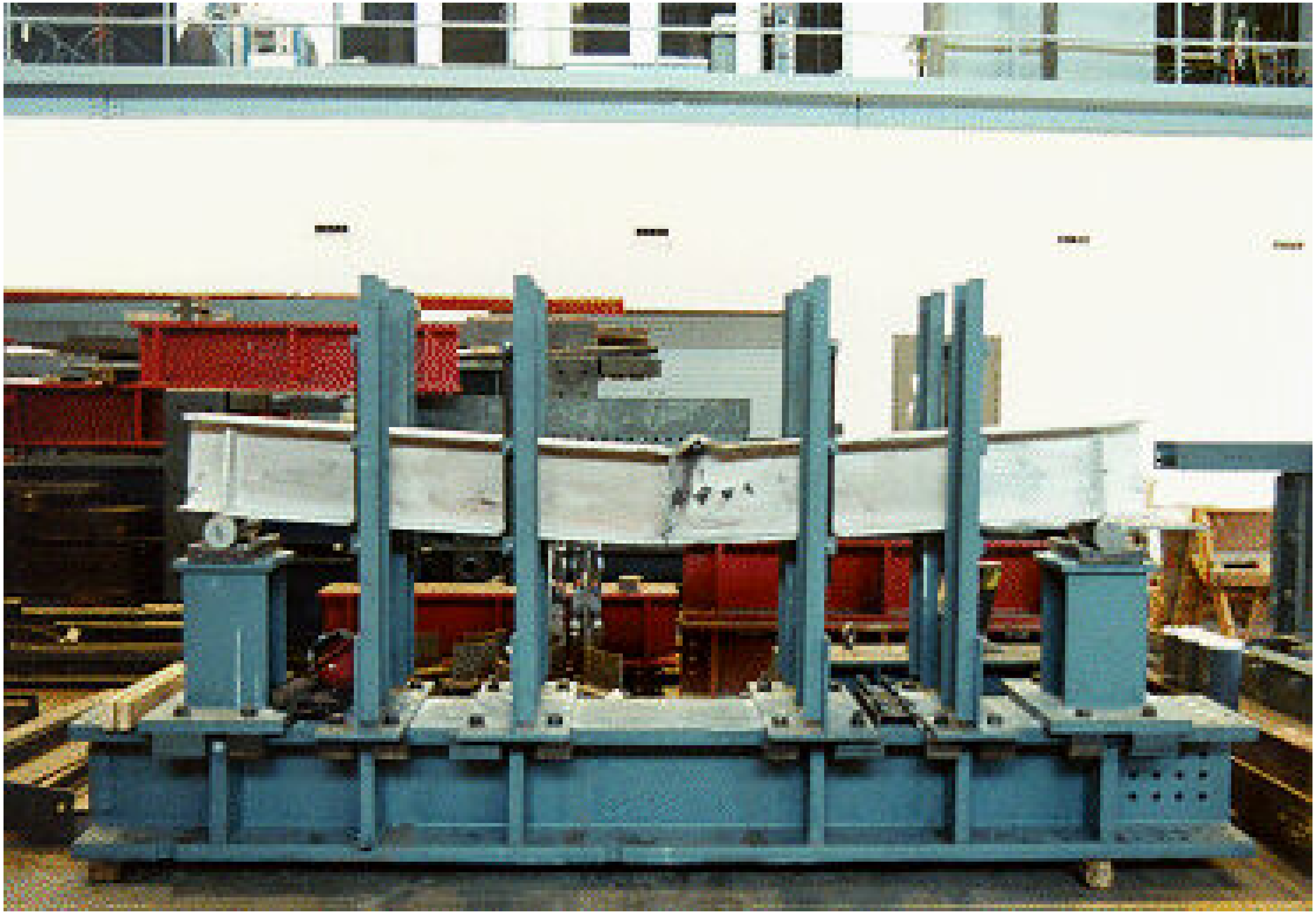
Superplasticity of an Fe-Cr-Ni-Mo stainless steel

Importance of Ductility

- **Large displacements before collapse (as opposed to a *brittle* material, which fails suddenly)**

- **Energy dissipation as the steel yields (important for resisting overloading)**

Ductility and Plasticity



Design vs. Assessment of Indeterminate Structures

- **Design: find one possible set of forces and the structure can find one (Lower bound theorem)**
- **The design values of stresses cannot be observed in practice (only the structure knows)**
- **Assessment: Same is true, but you can look for clues that give you an idea where the forces are (or not), ie cracks, displacements, etc.**

Design vs. Assessment of Indeterminate Structures

- **Always ask:**

WHAT WOULD CAUSE THE COLLAPSE OF THE STRUCTURE?

Use the UPPER BOUND THEOREM to find the collapse load.

Stresses due to Axial Forces

- **Stress due to axial force: = P/A**
- **Stress due to bending moment: = My/I**
- **Combined axial and bending: = $(P/A) +/- (My/I)$**
- **Eccentric axial force causes $M = (Pe)$ where e is the eccentricity of the force**
- **This leads to middle-third rule: eccentricity greater than 1/3 of section causes tension**

Metallic Structures: Conclusions

- The type of metal is crucially important
- Ductility of metal determines type of analysis
  - Brittle (cast iron) can be calculated with thrust lines
  - Ductile (wrought iron/steel) can be calculated using plastic collapse mechanisms
- Determine stresses and possible failure mechanism
- Thrust lines can be used to calculate stresses by considering the eccentricity of the thrust