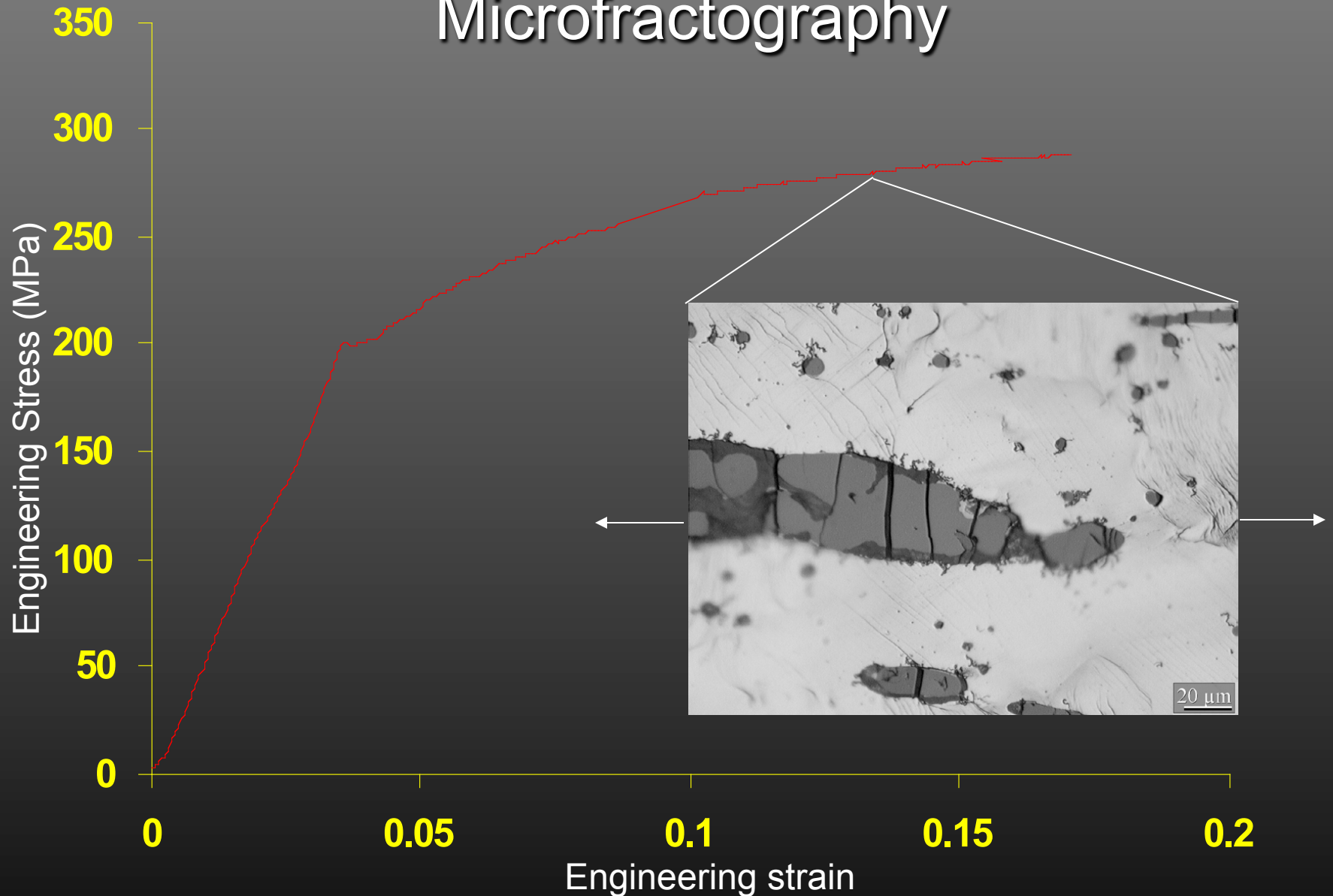


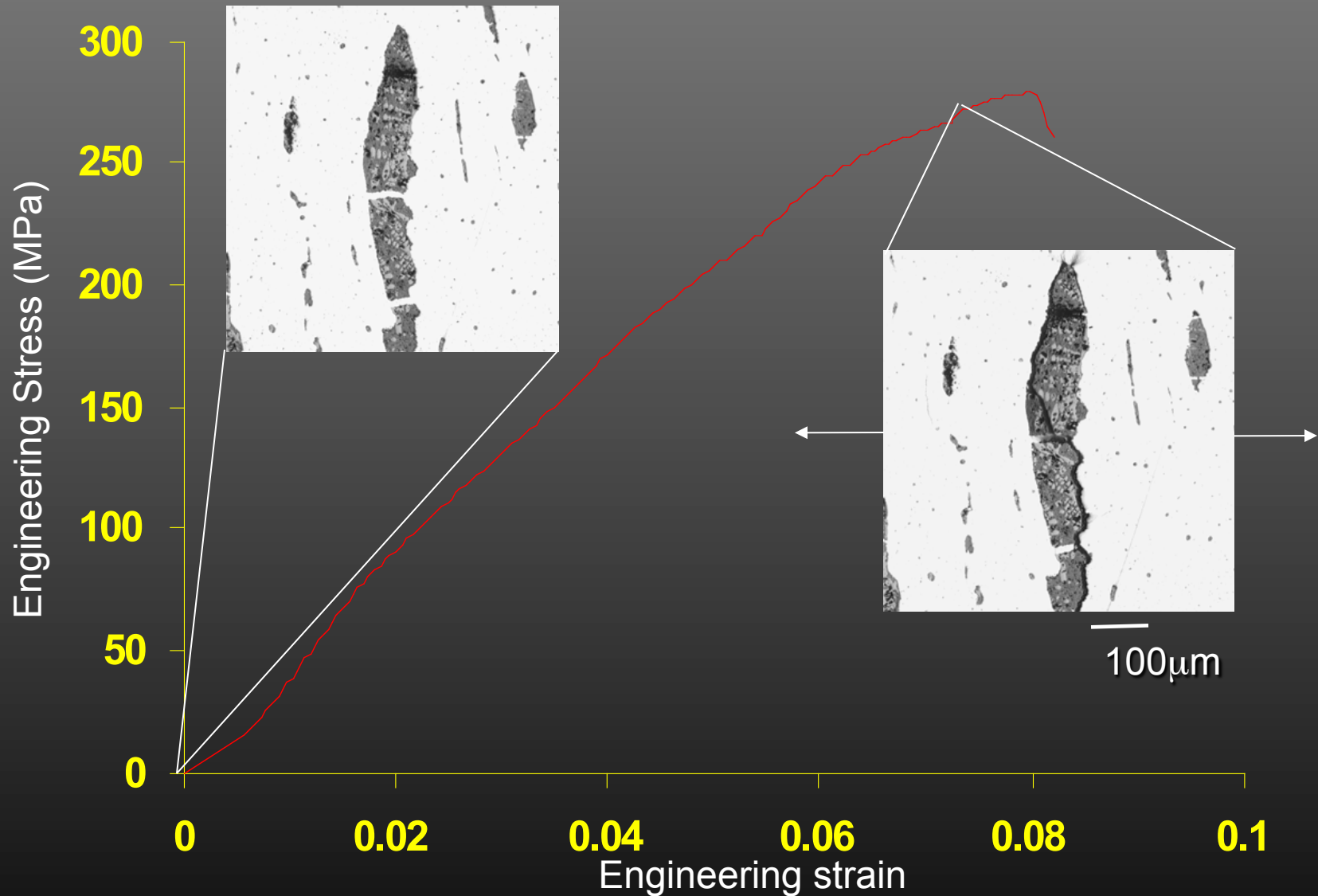
# Fracture Strength of Slag

## Microfractography



# Slag-iron Interfacial Strength

## Microfractography



# Finite Element Analysis

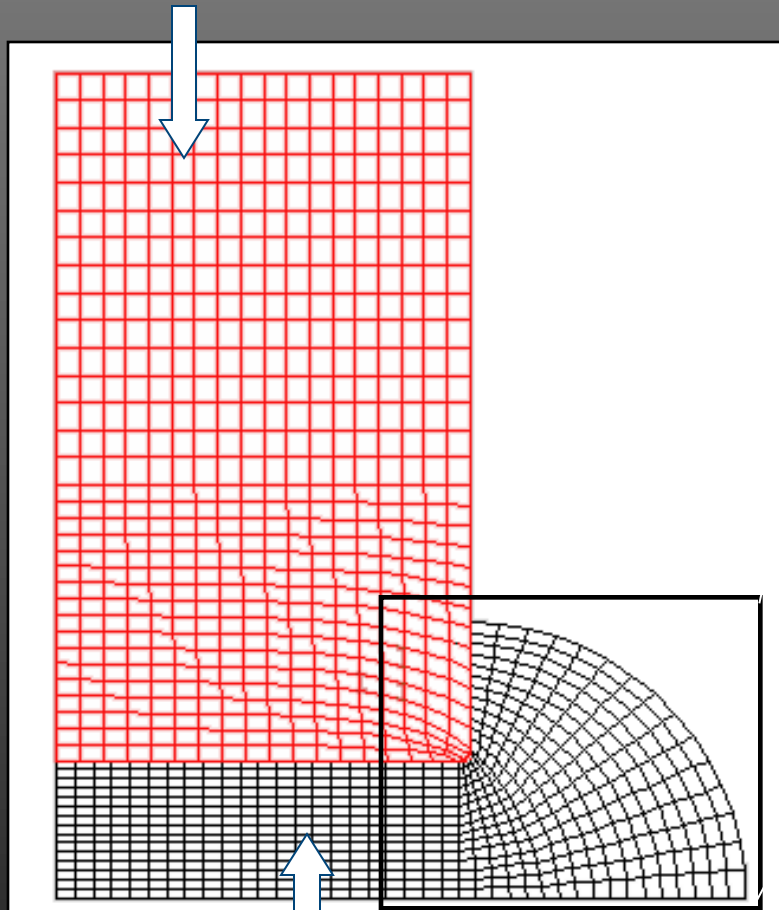
The study included analyzing the effects in stress distributions due to a variation in:

- rivet geometry
- initial riveting temperature
- coefficient of friction at the head-plate interface
- rivet material properties

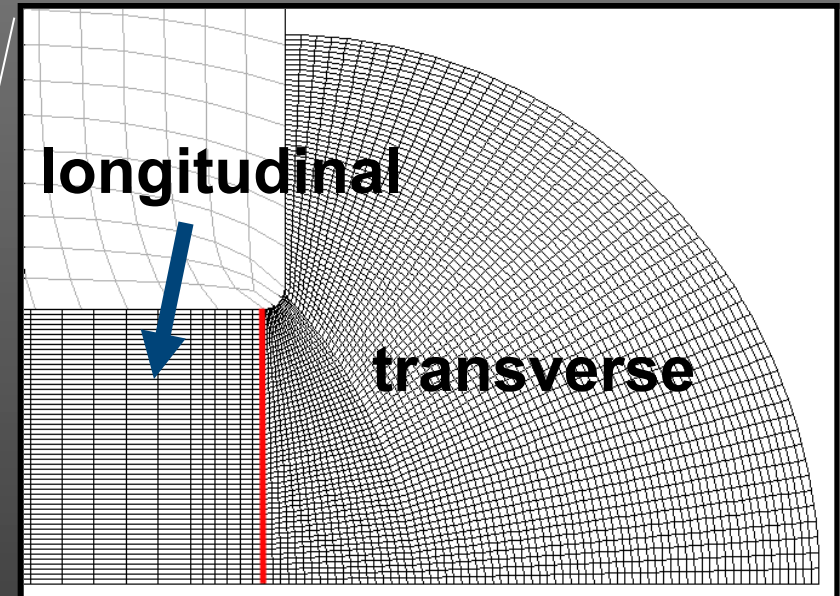
# Modeling of a Rivet

Finite Element Analysis

1018 steel plate



Wrought iron rivet



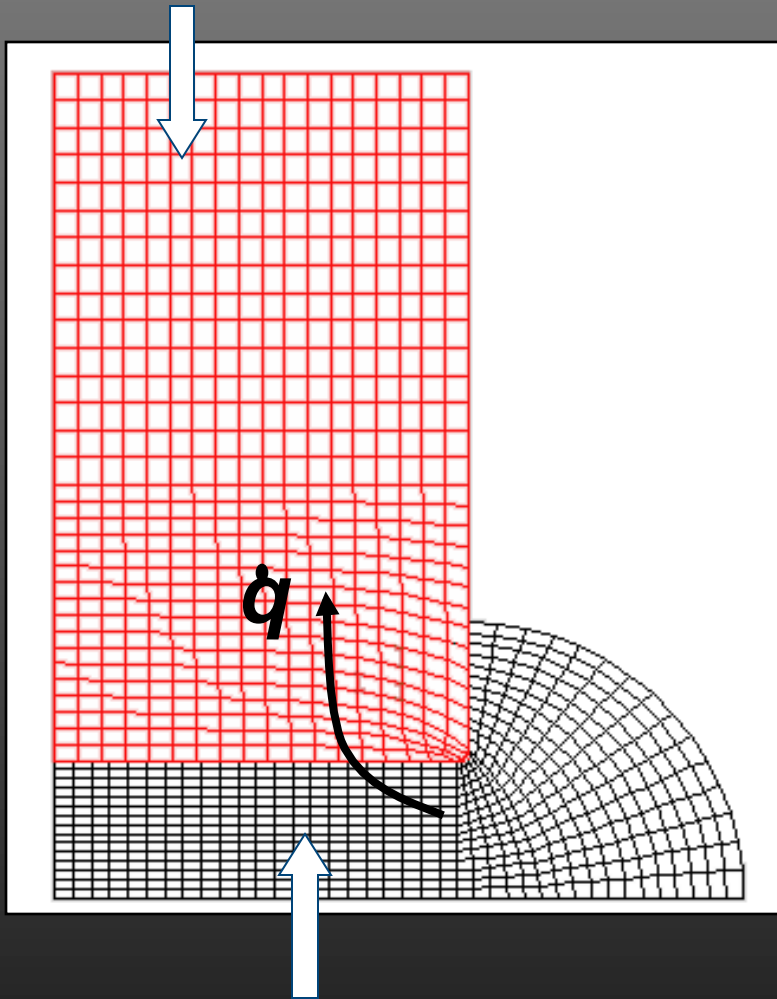
Thermomechanical analysis assuming an axisymmetric model about the tensile axis of the rivet, using input from tensile testing results



# Modeling of a Rivet

Finite Element Analysis

1018 steel plate



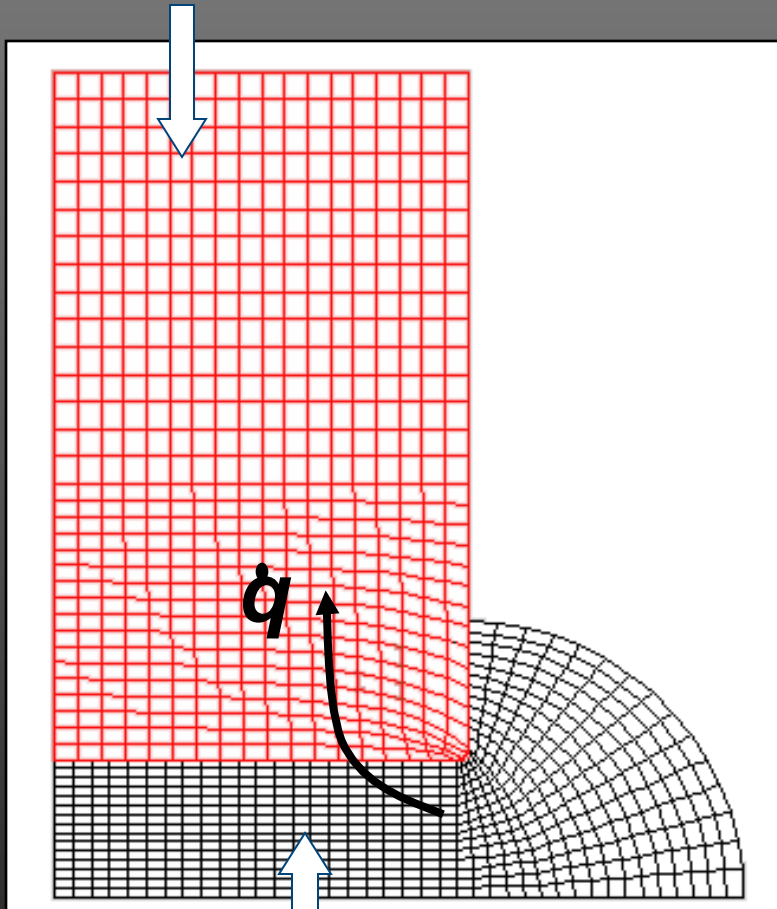
Wrought iron rivet

STEP 1:  
Extent of residual stress  
Cooling of the rivet from  
400°C to 25°C

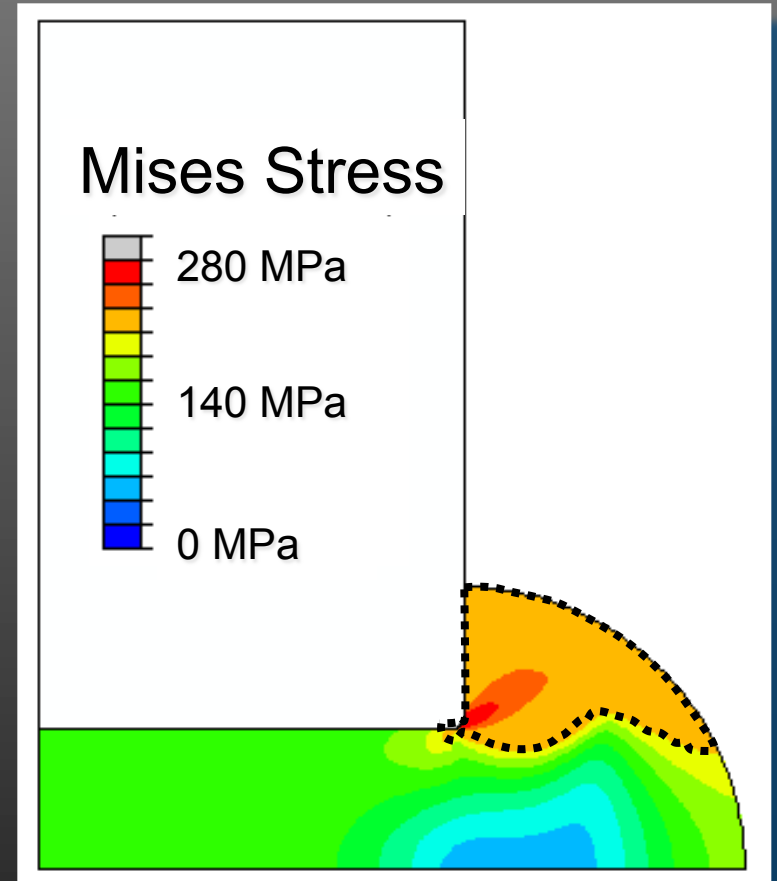
# Modeling of a Rivet

Finite Element Analysis

1018 steel plate

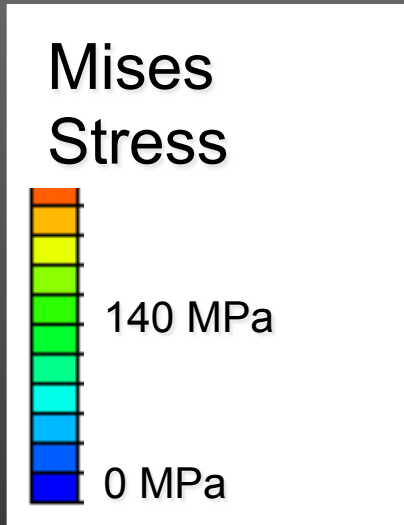


Wrought iron rivet

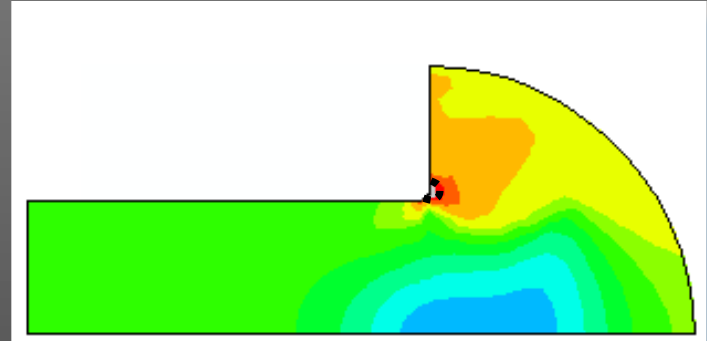


# Modeling of a Rivet

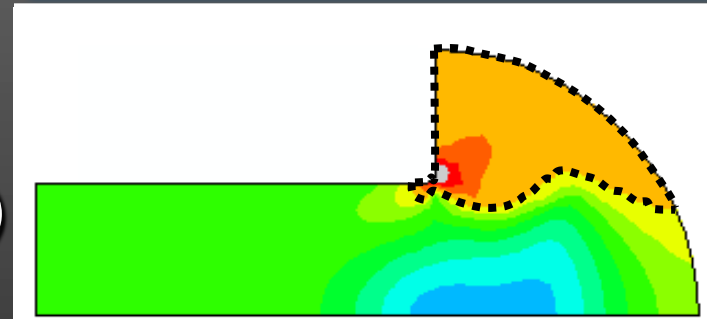
## Finite Element Analysis



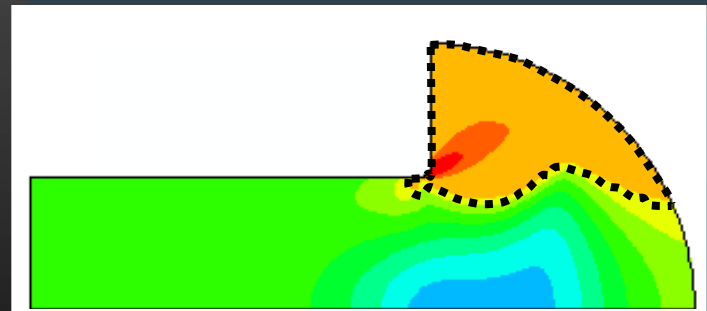
Isotropic steel



Isotropic iron  
(only longitudinal)



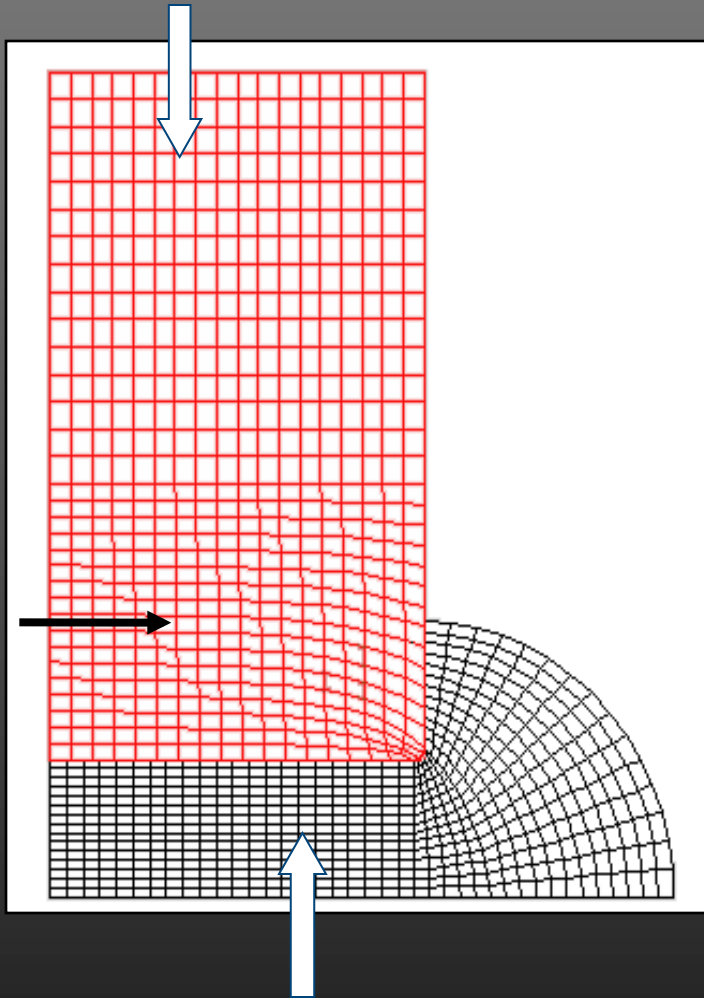
Anisotropic iron



# Modeling of a Rivet

Finite Element Analysis

1018 steel plate

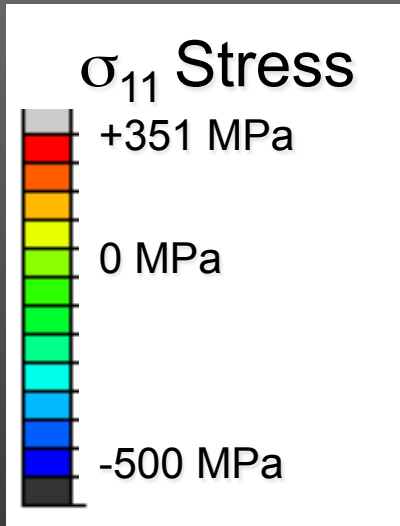
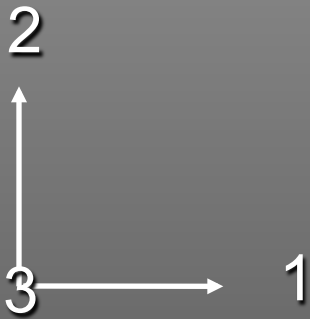


Wrought iron rivet

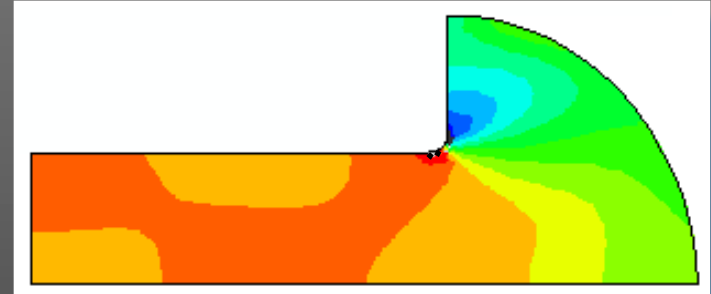
STEP 2:  
Stress due to loading  
Displacement of the plate

# Modeling of a Rivet

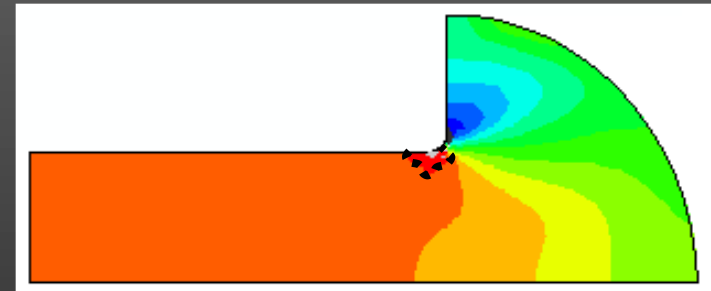
## Finite Element Analysis



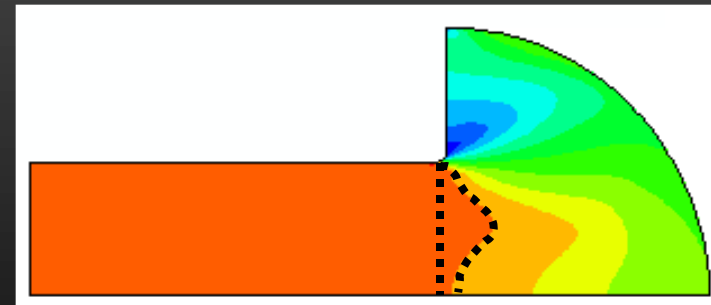
Isotropic steel



Isotropic iron  
(only longitudinal)



Anisotropic iron



Was it simply an engineering  
or a metallurgical mistake?

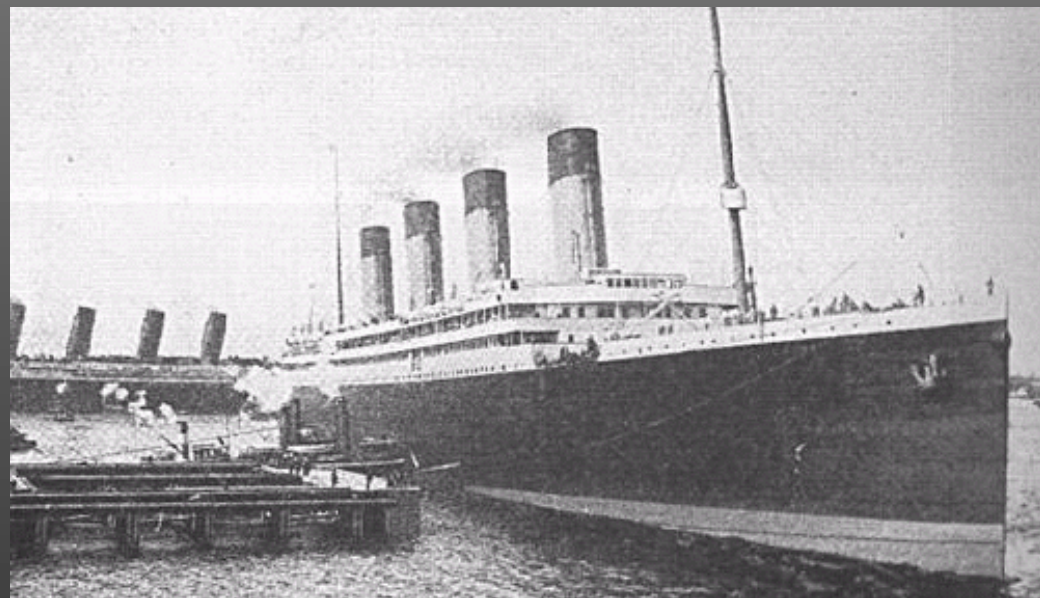
Was it simply an engineering  
or a metallurgical mistake?

Consider her sister ships.



# RMS Olympic

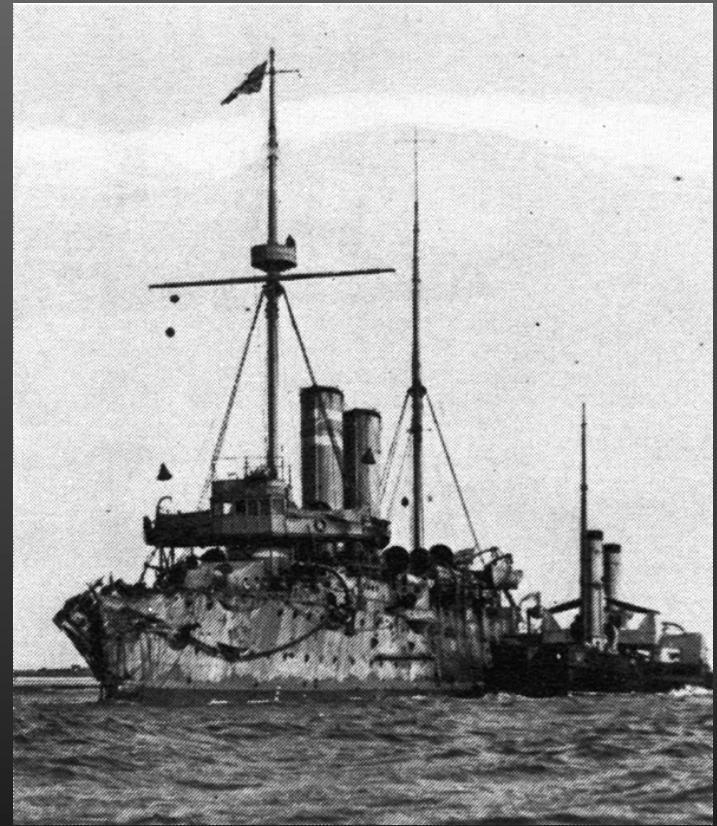
- Built alongside Titanic
- Same design
- Same materials
- Same builders



In her career, Olympic ran into a few things too. . .

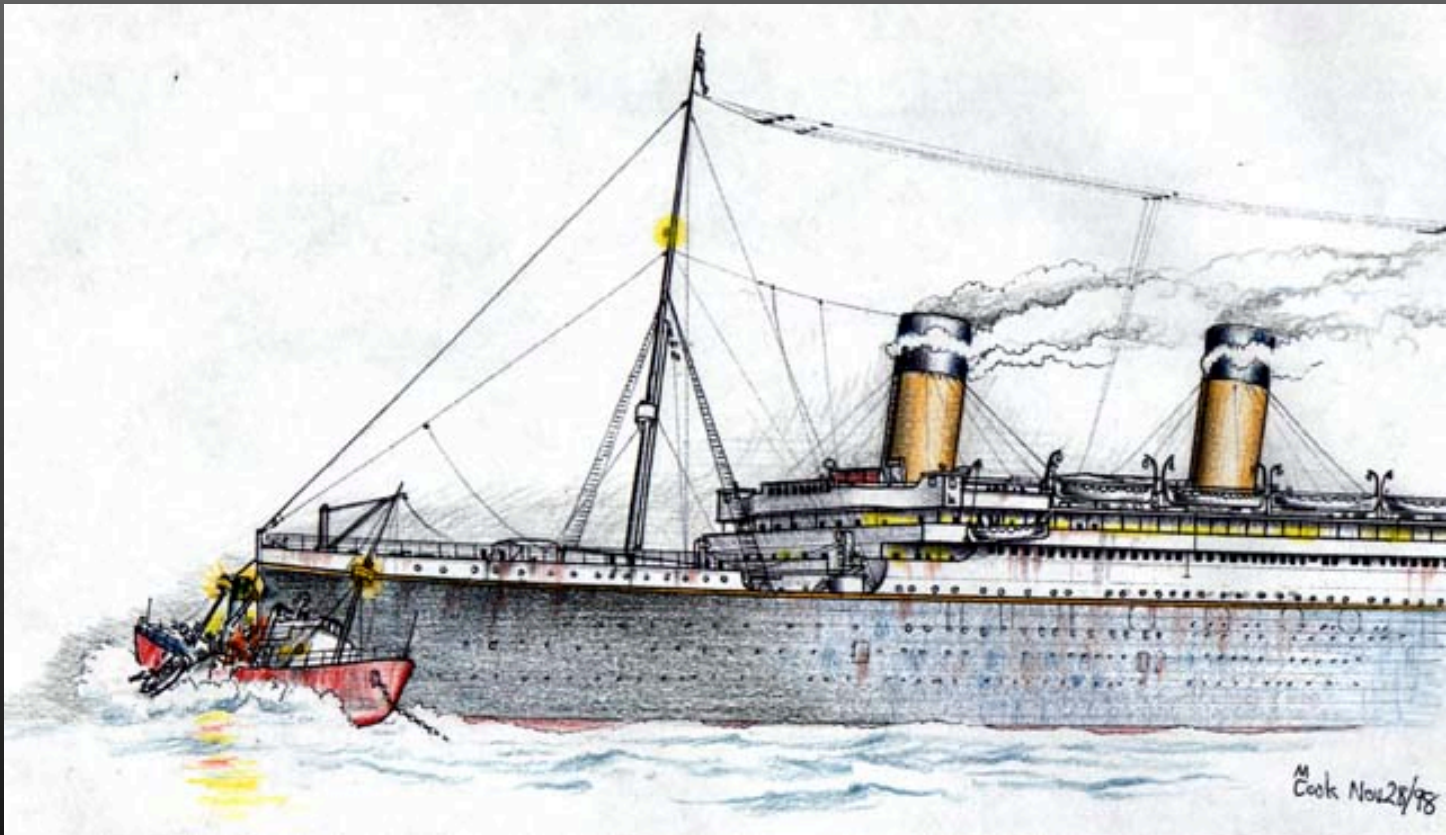
# RMS Olympic

- She ran into the Hawke (or vice versa) . . .



# RMS Olympic

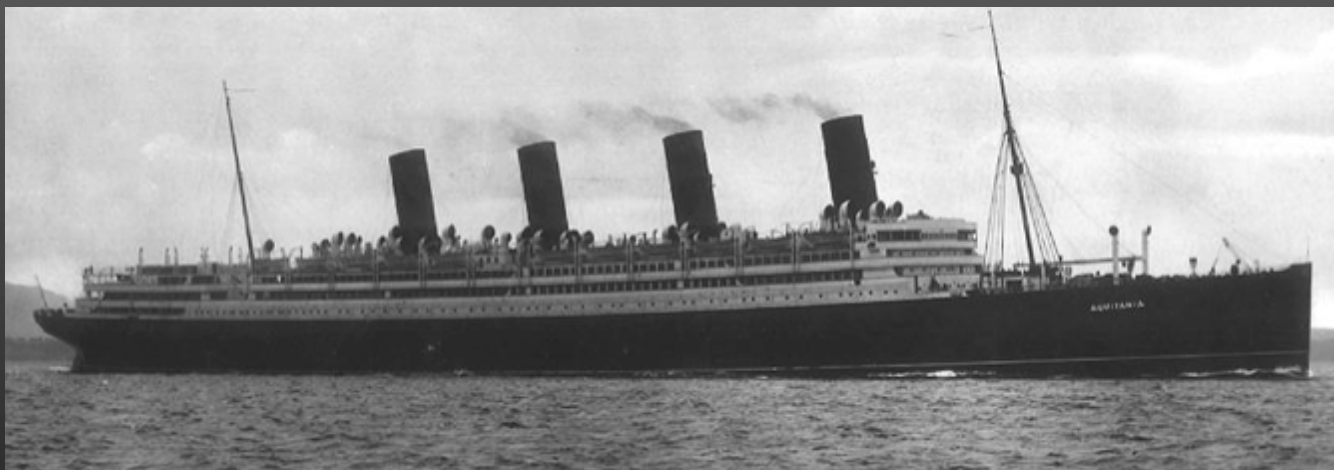
- She ran into the Hawke (or vice versa) . . .
- She rammed and sank the Nantucket Light Ship . . .





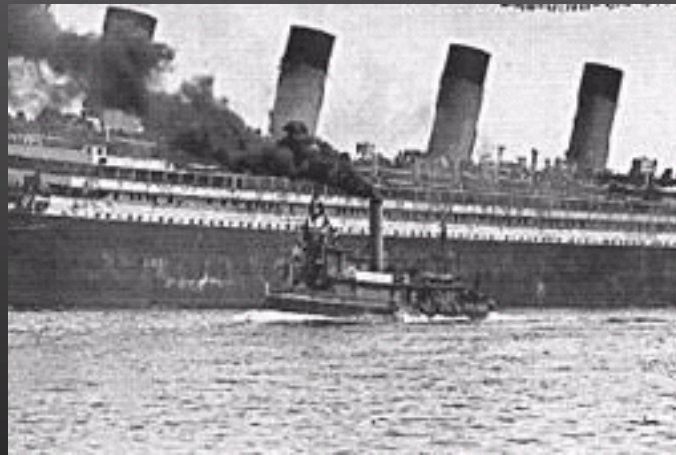
# RMS Olympic

- She ran into the Hawke (or vice versa) . . .
- She rammed and sank the Nantucket Light Ship . . .
- She bumped into the Aquitania . . .



# RMS Olympic

- She ran into the Hawke (or vice versa) . . .
- She rammed and sank the Nantucket Light Ship . . .
- She bumped into the Aquitania . . .
- (and the tug pushing Aquitania) . . .



# RMS Olympic

- She ran into the Hawke (or vice versa) . . .
- She rammed and sank the Nantucket Light Ship . . .
- She bumped into the Aquitania . . .
- (and the tug pushing Aquitania) . . .
- She was hit by a dud WW I torpedo . . .



# RMS Olympic

- She ran into the Hawke (or vice versa) . . .
- She rammed and sank the Nantucket Light Ship . . .
- She bumped into the Aquitania . . .
- (and the tug pushing Aquitania) . . .
- She was hit by a dud WW I torpedo . . .
- and rammed and sank the sub that fired it . . .



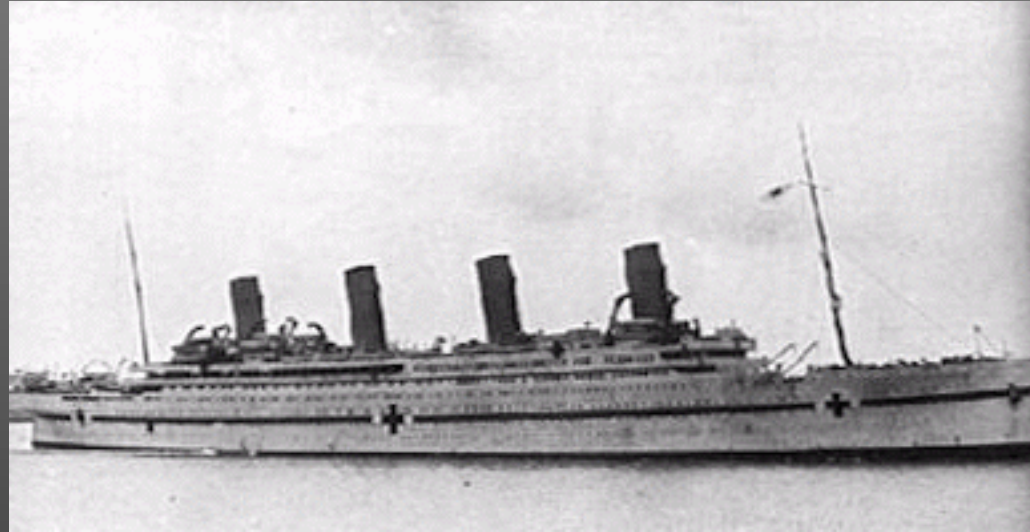


. . . and was scrapped in 1936 with the nickname “Old Reliable”



# Consider further HMHS Britannic

- Re-designed in the ways
  - complete double hull
  - higher watertight bulkheads
  - better watertight door controls



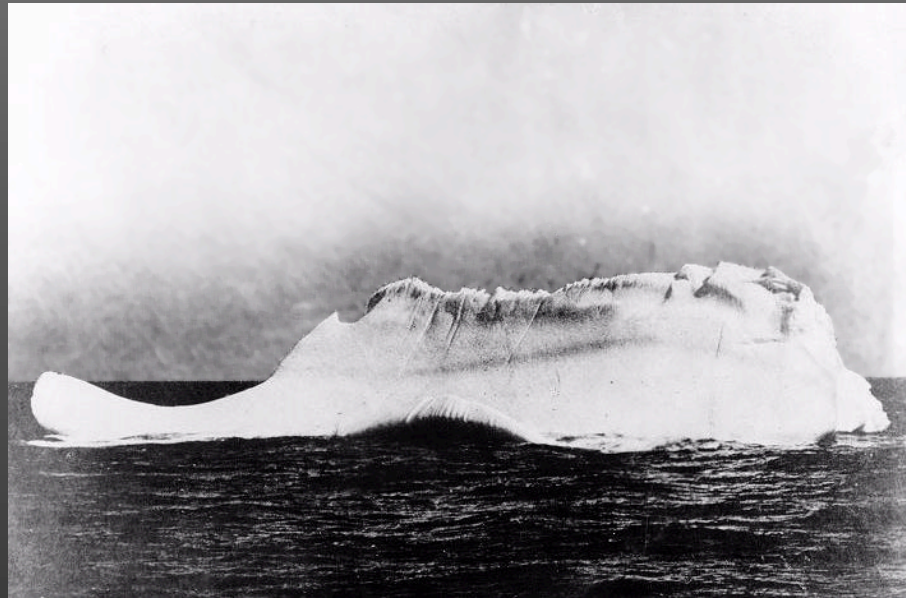
- Was commissioned a hospital ship in 1914
- Was making her 6th run to the Crimea when she was mined
- 40 foot diameter hole in her port bow opened two compartments





What Sank the RMS Titanic?

# What Sank the RMS Titanic?



She hit an iceberg.



# Conclusions

1. Fracture toughness of the hull steel at ice brine temperatures was adequate for the application.
2. Steel was state-of-the-art for 1911.
3. Variability in wrought iron feedstock was considerable, and caused variability in rivet properties
  - Due to inconsistent fabrication procedures
4. She is rusting at roughly a ton/day, and will collapse into herself in 25-40 years.



You can request copies of a report  
and videotaped presentation from  
the Public and Business Affairs  
Office at NIST

Email to:

[Inquiries@nist.gov](mailto:Inquiries@nist.gov)

and ask for NISTIR 6118, “Metallurgy  
of the RMS Titanic”, and the video  
“What Sank the RMS Titanic”

and

[www.csititanic.com](http://www.csititanic.com)

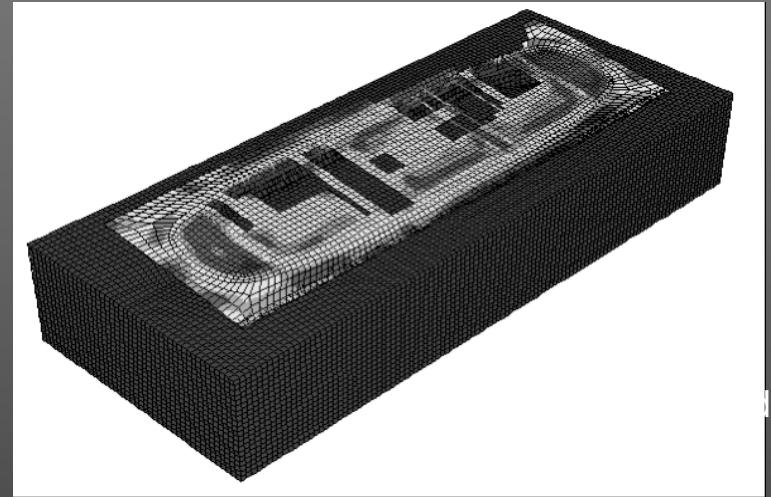




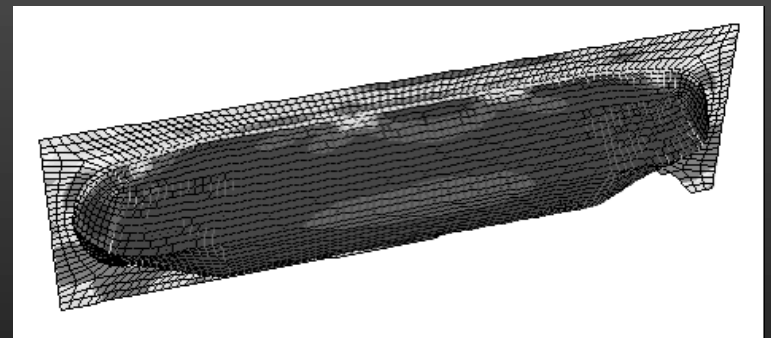
# Ferryboat *Ellis Island*: Decision Time

- Operated between Ellis Island and Manhattan / New Jersey from 1901 to 1953
- 40% of the US population can trace ancestry to a passenger
- Neglect from sinking in 1968 to today has left her a mess
- Significant historical interest - National Park Service asks NIST: Do we salvage or not?

- We calculated stresses under different salvage scenarios - found that mud is holding it together
- Based on our data, National Park Service has decided to leave wreck alone and preserve pieces
- Techniques learned in treating mud being applied to conservation of wreck of *USS Arizona* (funded by US Navy and US Park Service).



Ellis Island Ferry



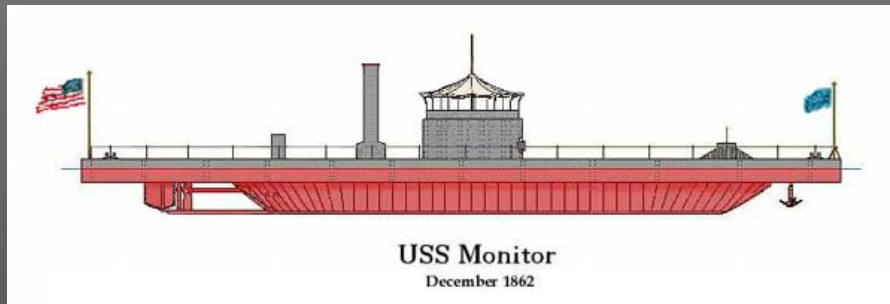
# *HL Hunley*: Preservation Post-Recovery

- Confederate submarine, built 1863
  - First submarine to sink a ship (*USS Housatonic*)
  - Sunk before returning from that attack (1864)
  - Located 1996, raised 2000, in Charleston, SC
  - Made of wrought iron plates and rivets
- 
- Navy funding conservation project
  - Approached NIST for wrought iron and marine forensics experience
- 
- Analysis shows wrought iron likely made from scrap
    - very high slag content
  - Delamination failures see on *HL Hunley* can be traced to microstructure
  - NIST helping with conservation and estimation of remaining strength





# USS Monitor: The Most Complicated



- Navy and NOAA want to raise more of her
- Problem: Corrosion is extensive, non-uniform
  - Hard to estimate mechanical stability
- Ex: coal has fallen into turret, acting as an anode and accelerating corrosion
- NIST asked to help with property determination, mechanical characterization
- Proposal in prep, to be submitted to Navy, to fund NIST involvement (~\$50-75K)

- First all iron warship
- 50 patentable inventions on her
- Sank in a gale off Outer Banks, NC in 1864
- Lying in sand, upside down



