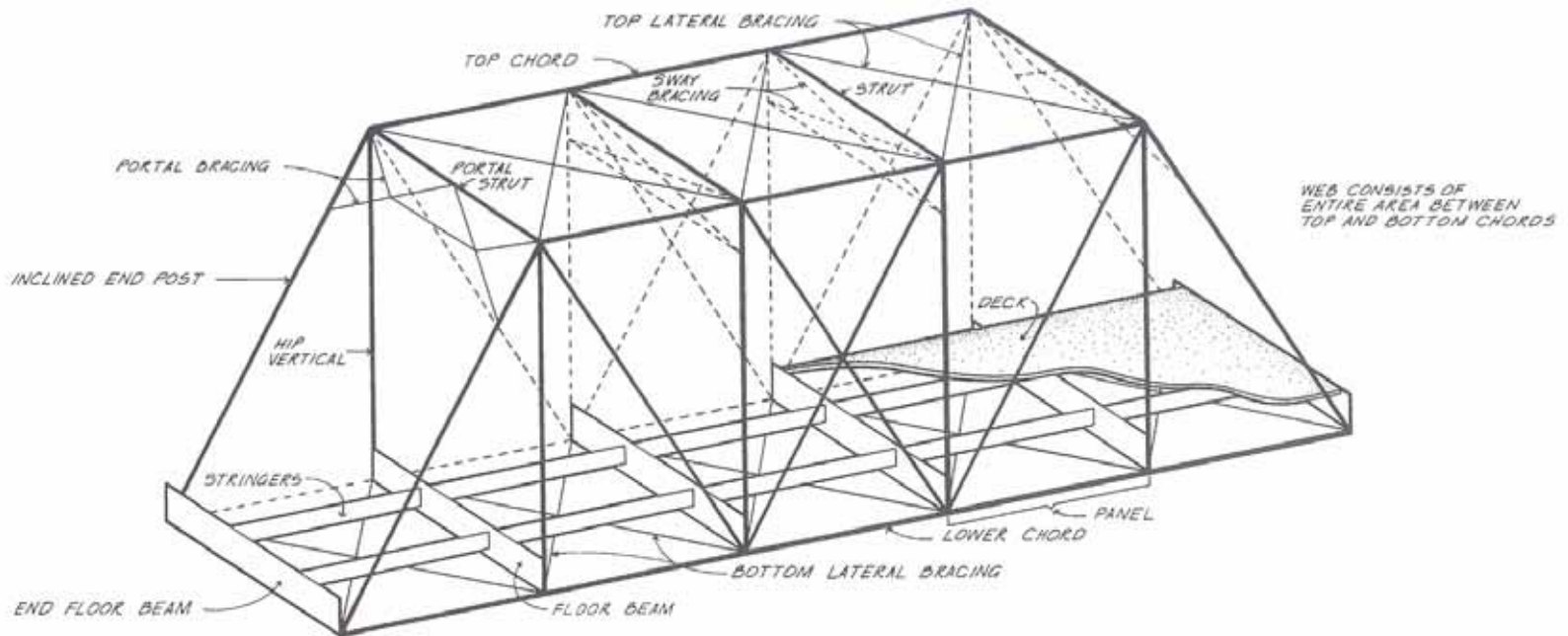


# **The Details: Design and Craftsmanship on Old Metal Truss Bridges**

**Dario Gasparini**

**Case Western Reserve University**



# TRUSSES

## A STUDY BY THE HISTORIC AMERICAN ENGINEERING RECORD

A TRUSS IS COMPOSED OF STRUCTURAL TRIANGLES JOINED TOGETHER WITH PINNED OR RIVETED CONNECTIONS. THE MAIN PIECES OR MEMBERS MAY BE EITHER STIFF HEAVY STRUTS OR THIN FLEXIBLE RODS. IT IS THE ARRANGEMENT OF THESE MEMBERS THAT DETERMINES THE SPECIFIC TRUSS TYPE.

STRUCTURAL MEMBERS RESIST FORCES IN TWO PRIMARY WAYS — COMPRESSION AND TENSION. HEAVY RIGID MEMBERS MAY RESIST BOTH COMPRESSIVE AND TENSILE FORCES BUT THIN RODS CAN ONLY RESIST TENSION AND THESE CHARACTERISTICS ARE MAJOR CLUES IN TRUSS IDENTIFICATION. NOTE THAT THE MAIN STRUCTURAL MEMBERS OF A TRUSS PANEL MAY BE SUPPLEMENTED BY LIGHT DIAGONAL TIES. BECAUSE TRUSS TYPES ARE DETERMINED BY THEIR MAIN STRUCTURAL MEMBERS THESE LIGHT DIAGONALS (INDICATED BY DOTTEN LINES) MAY BE IGNORED IN THE IDENTIFICATION PROCESS. AFTER MATCHING THE STRUCTURAL OUTLINE OF THE TRUSS IN QUESTION WITH THE DIAGRAM IT MOST RESEMBLES CHECK TO MAKE SURE THE ARRANGEMENT OF HEAVY COMPRESSIVE AND LIGHT TENSILE MEMBERS IS COMPATIBLE WITH THE DIAGRAM. IF THERE IS AGREEMENT, THEN

THE BASIC TRUSS TYPE IS IDENTIFIED.

THE SHEET OF TRUSS DIAGRAMS PRESENTS ONLY THE STANDARD FORMS OF THE MOST COMMON TRUSSES. THERE ARE ALSO MANY "HYBRID" TRUSSES THAT DO NOT FALL INTO EASILY-DEFINED CATEGORIES. IN SUCH CASES IDENTIFICATION SHOULD BE MADE AS CLOSELY AS POSSIBLE IN TERMS OF THE STANDARD DESIGNS. ADDITIONALLY TRUSSES ARE OFTEN INVERTED BECAUSE TENSION MEMBERS SOMETIMES BECOME COMPRESSION MEMBERS AND VICE VERSA. BEFORE ASSUMING A TRUSS IS NOT REPRESENTED ON THE DIAGRAM, CHECK TO SEE IF IT IS AN INVERTED FORM.

ALL BRIDGE TRUSSES ARE ONE OF THREE BASIC TYPES. IF A BRIDGE CARRIES ITS TRAFFIC LOAD LEVEL WITH THE BOTTOM CHORDS, IT IS A THROUGH TRUSS. A BONY TRUSS IS A THROUGH TRUSS WITH NO LATERAL BRACING BETWEEN TOP CHORDS. A DECK TRUSS CARRIES ITS TRAFFIC LOAD LEVEL WITH THE TOP CHORDS.

# Historical/cultural assessment of metal truss bridges

- **Entrepreneurial/industrial/professional context**
- **Materials technology**
- **Metal fabrication technology**
- **Engineering technology; judgments on behavior and performance**
- **Construction technology**

# **Entrepreneurial/industrial/professional context**

- **Inventors/builders-agents**
- **Iron and steel producers**
  - Materials, manufactured products**
- **Bridge companies (Victor C. Darnell directory)**
  - Amasa Stone – 1841**
  - American Bridge – 1900**
- **Railroads**
  - NYC, PRR, B&O, LSMS, et al.**
- **Structural testing agencies**
  - Government (Watertown arsenal - 1879)**
  - Bridge companies**
- **Engineering schools**
- **Consulting bridge design engineers**

# **Metal technology (applied to bridges)**

**Cast and wrought iron**



**Bessemer steel**

**Basic open hearth steel**

**ASTM A7 Specification - 1900**



**Alloy steels**

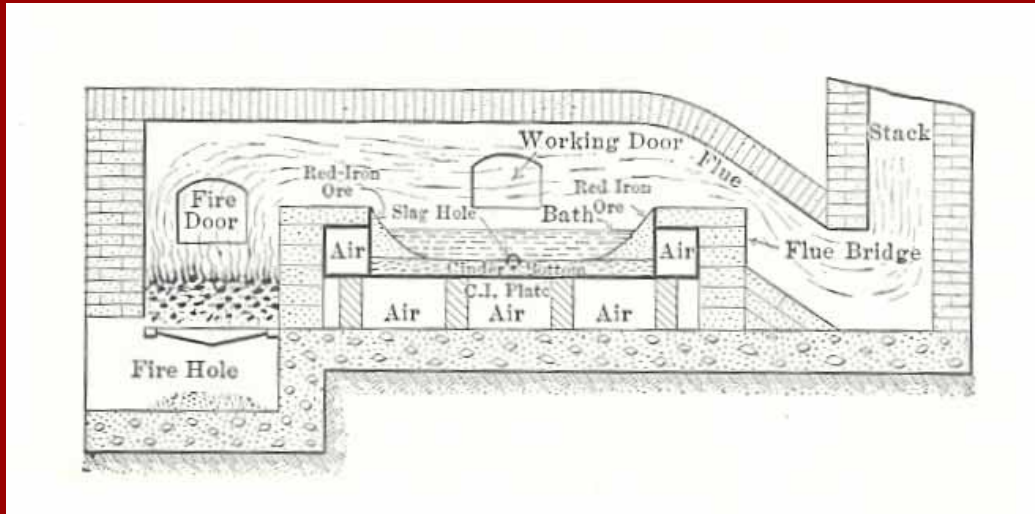
**Nickel steel (1903)**

**Silicon steel**

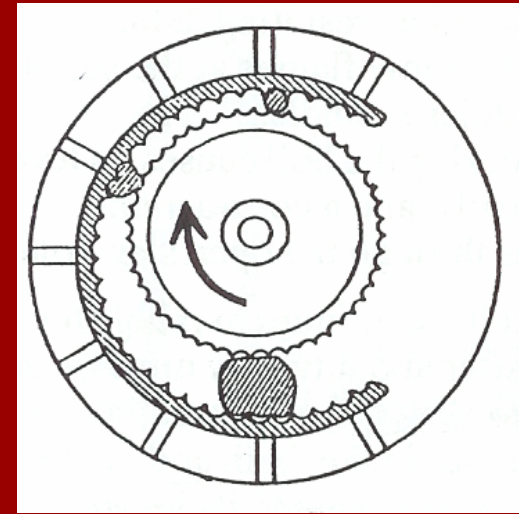
# The puddling process for making wrought iron

Henry Cort 1784 ([www.henrycort.net](http://www.henrycort.net)) and Joseph Hall

## The puddling furnace

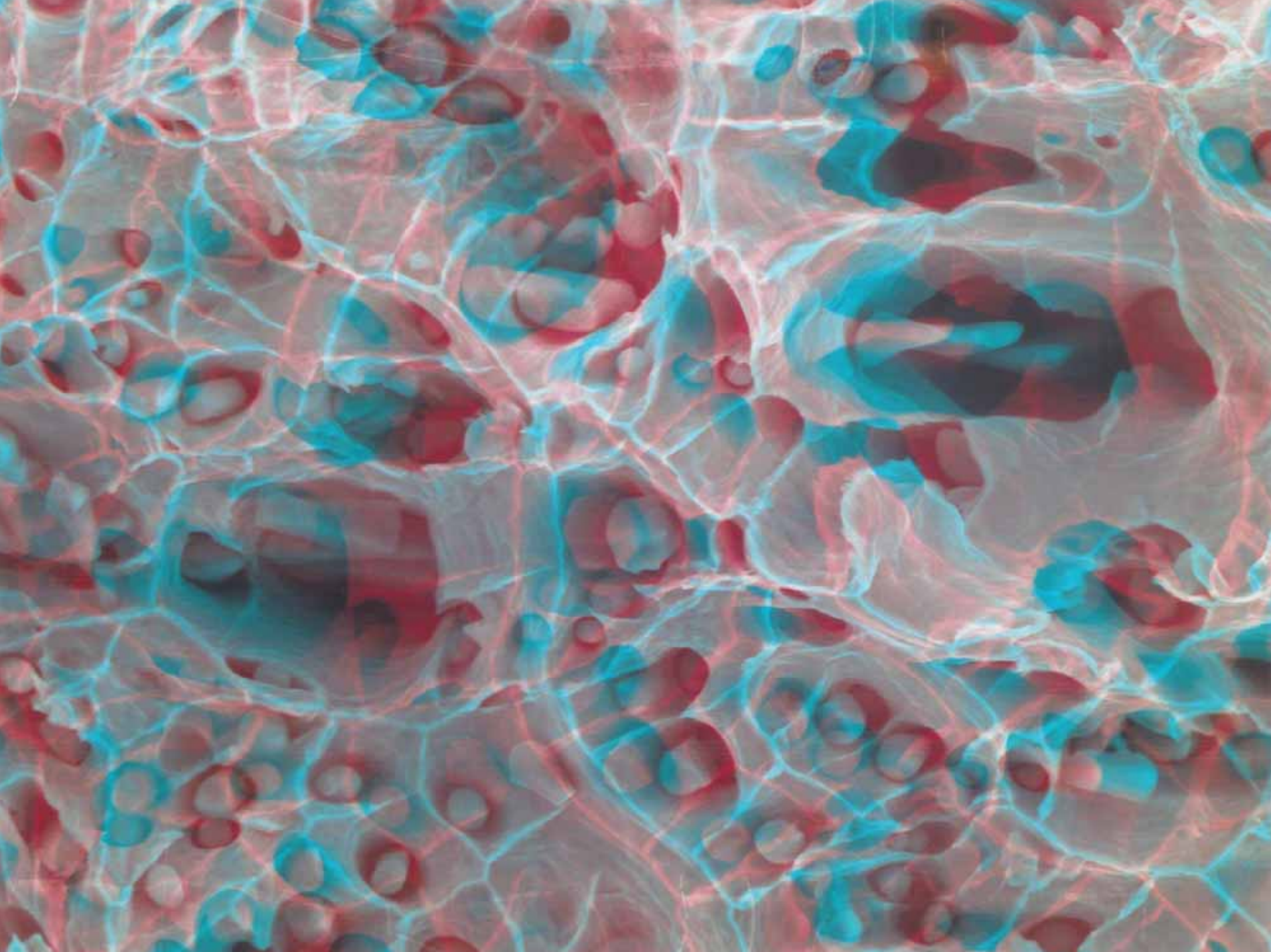


## The squeezer

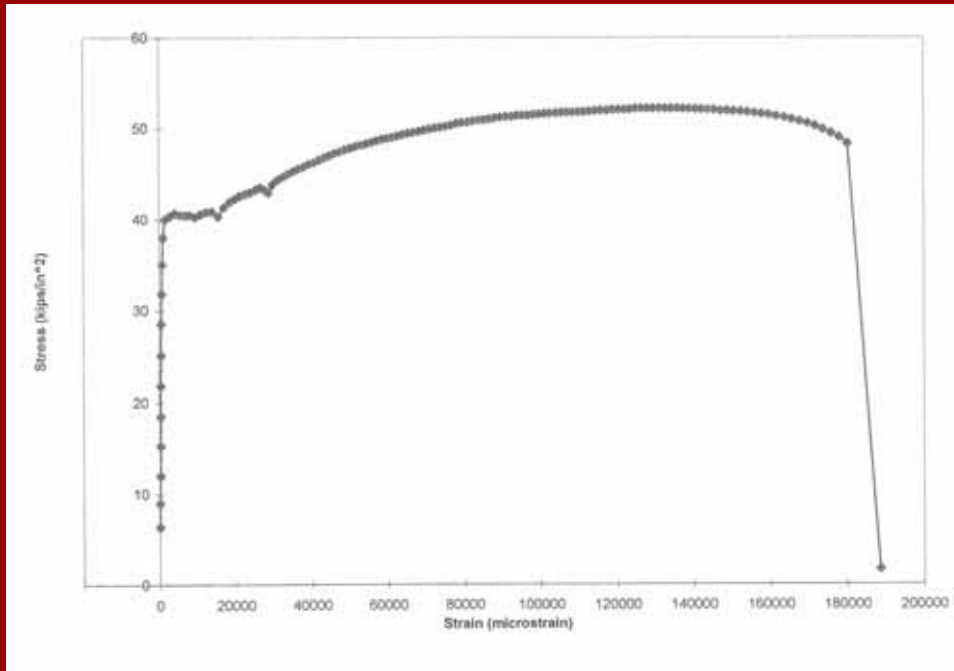


## The effects

	C	Si	S	P	Mn
Pig iron.....	3.5 -4.25	1-2	0.03-0.10	0.50-1.00	0.25-1.00
Wrought iron.....	0.05-0.25	0.10-0.20	0.02-0.10	0.05-0.20	Tr.-0.10



# Properties of wrought iron



**Anisotropic**

**Excellent corrosion resistance**

**Easily forge welded**

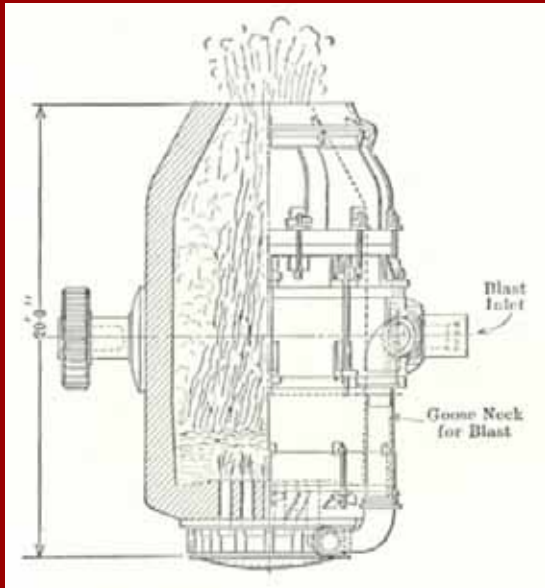
**High fracture toughness and good fatigue properties**

**Easily threaded and machined**

# Bessemer steel

Henry Bessemer-1856; Robert Mushet-1856;  
Joseph Martien-1857; William Kelly-1857

## The pneumatic “converter”



## The effects

	C	Si	S	P	Mn
Pig iron.....	3.5 -4	1-1.25	0.05	0.09	0.50-1.75
Steel.....	0.10-0.60	0.05-0.20	0.05	0.10	0.30-0.50

# **Cooper, T. (1879) “The Use of Steel for Bridges” ASCE Transactions**

**Lack of control of phosphorus and other elements**

**Presence of voids from the converter “blow”**

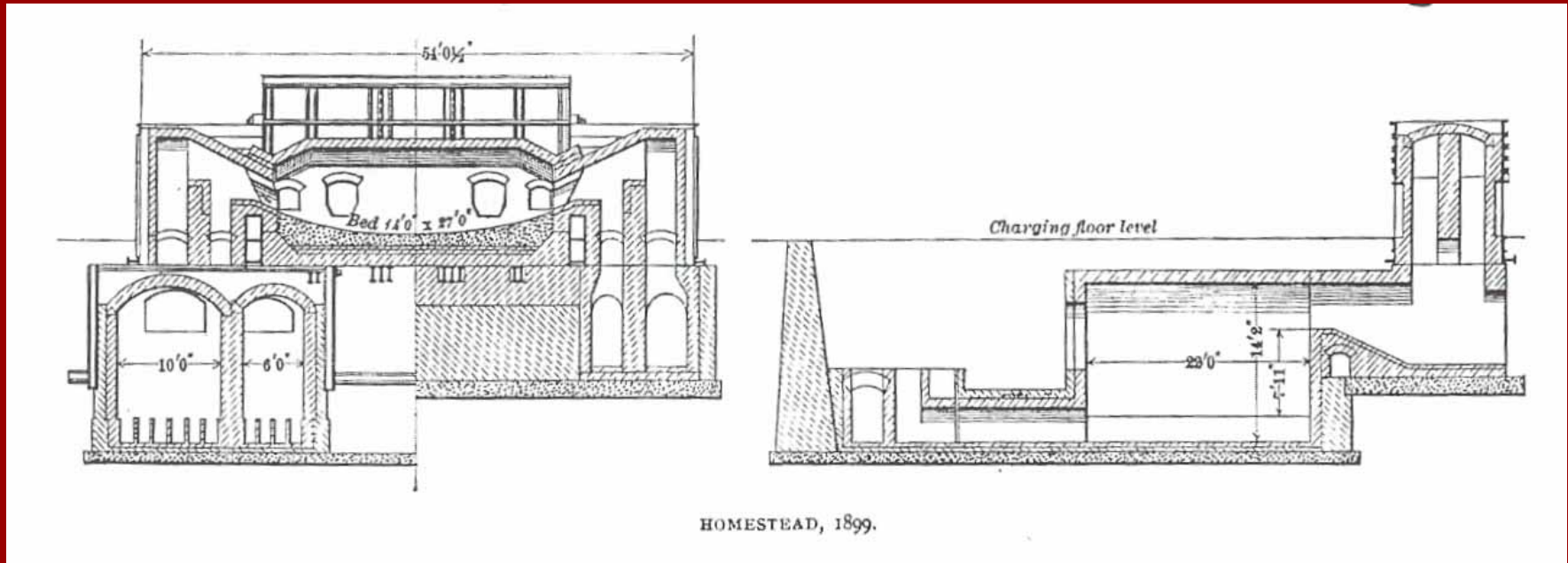
**Variability in properties, especially fracture toughness**

**Waddell, J.A.L. (1916) - “The first important use of steel for bridgework in the United States was in 1869-73 for the St. Louis Bridge.... Its employment for eye-bars developed next, then flat plates suitable for floor-beam webs became procurable. The first American bridge of any consequence in which steel was used exclusively was the Glasgow Bridge over the Missouri River on the line of the Chicago and Alton Railway, built in 1879...”**

# Open hearth furnaces

William Siemens, Emile and Pierre Martin - 1860's

Basic open hearth steel – Homestead Works, PA - 1888



Control of sulphur and phosphorus

Cold charge; utilization of scrap metal

Large capacities, dominant process by 1907-8

# **Basic open hearth steel**

**Control of Carbon, Phosphorus, and other elements**

**Isotropic properties - small variability and controllable**

**Cost effective**

**Waddell, J.A.L. (1916) – “ The production of steel increased steadily, and in 1890 all the usual structural shapes could be procured at the same prices as for wrought iron; and by 1895 its adoption for bridges was practically universal, and the production of wrought iron in large quantities was a thing of the past.”**

## **Alloy steels – Nickel steel and Silicon steel**

**Nickel steel – 3.5% to 4.25% Nickel; 0.15-0.4% Carbon**

**Greater strength**

**Improved corrosion resistance**

**Cost premium**

**Waddell, J.A.L. (1916) - Nickel steel was first used for the forged eyebars for the Queensboro (Blackwell's Island) Bridge in 1903, in order to decrease the size of the tension chord.**

# **Metal fabrication technology**

**Casting – ornamental and structural**

**Rolling**

**Forge welding**

**Forging in closed dies**

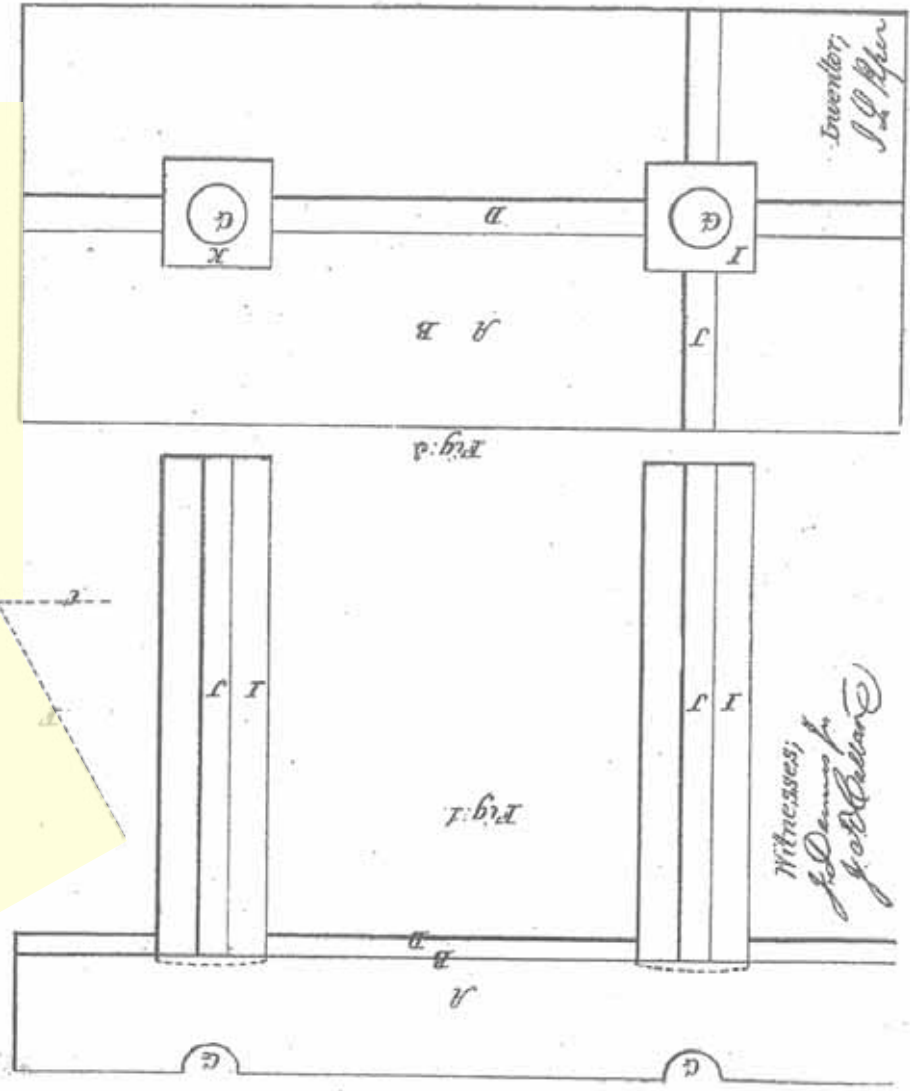
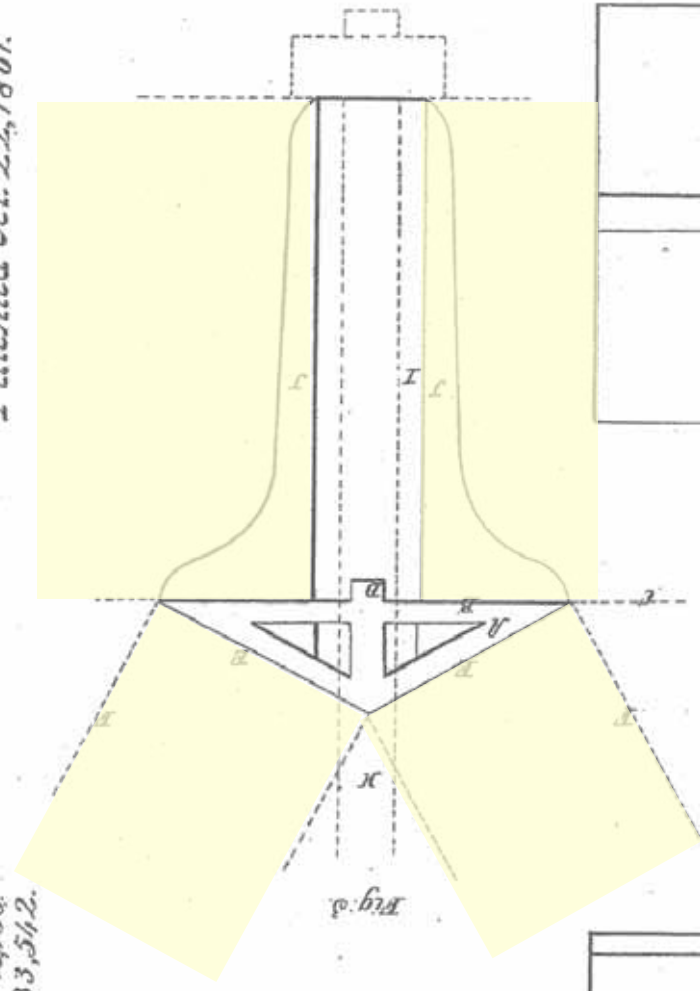
**Riveting and “built-up” sections**



*J. L. Piper.*  
*Truss Bridge.*

*No 2,538.*  
*33,512.*

*Patented Oct. 22, 1861.*



*Witnesses;*  
*J. O. Deming*  
*J. O. Callahan*

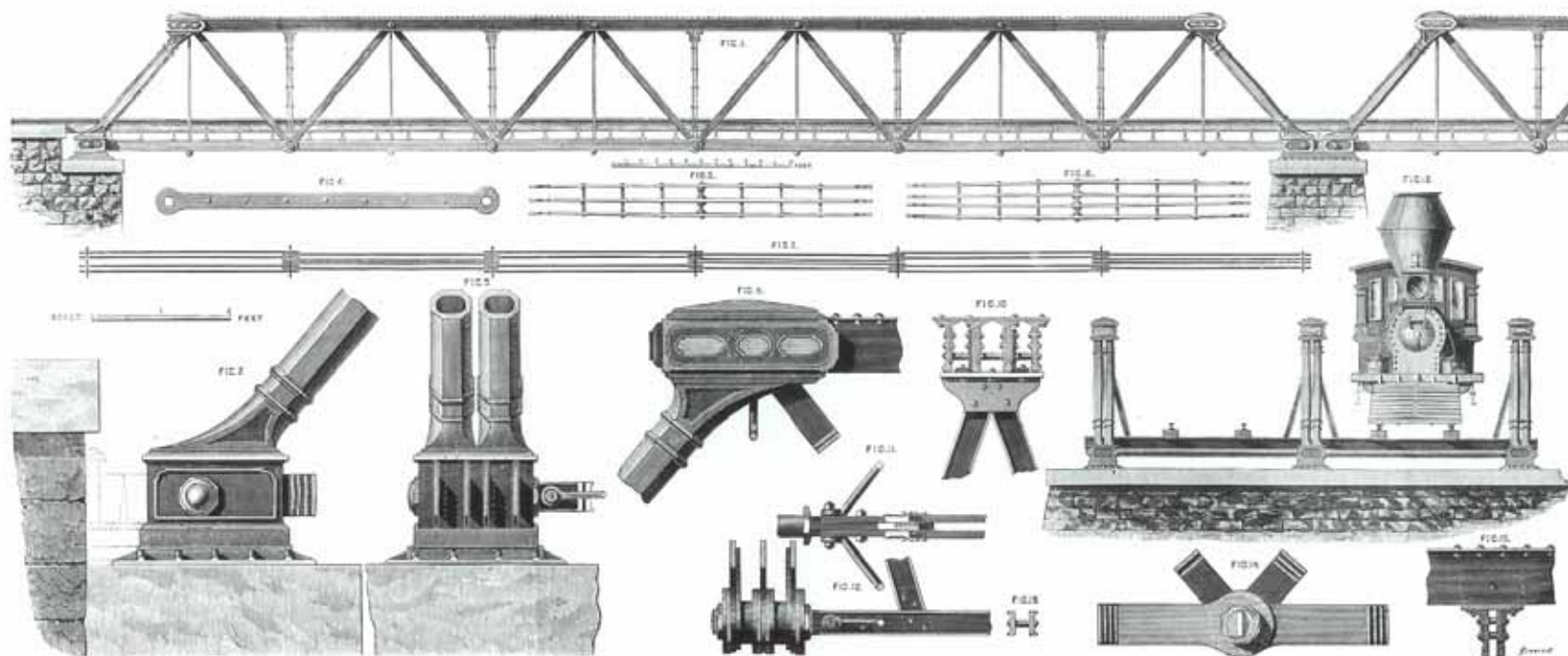
*Inventor;*  
*J. L. Piper*

# The Pennsylvania Railroad - 1869

THE PENNSYLVANIA RAILROAD. SECTION IV. BRIDGES.

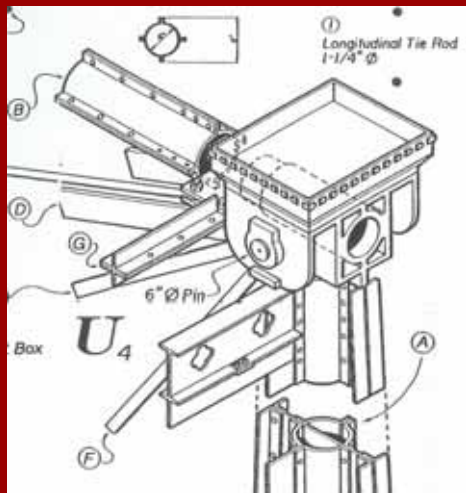
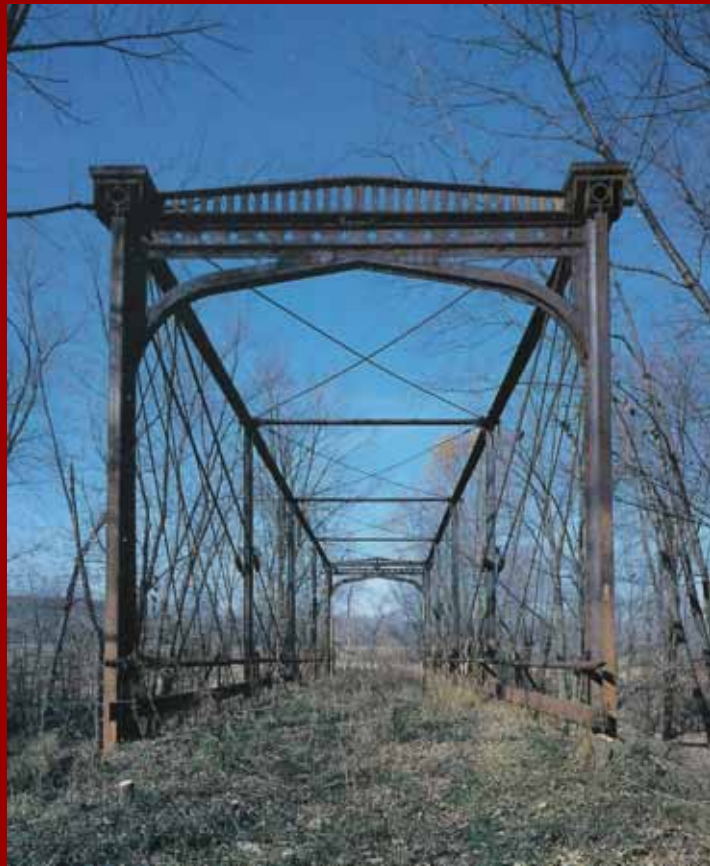
PLATE IX.

BRIDGE OVER THE LITTLE JUNIATA RIVER.

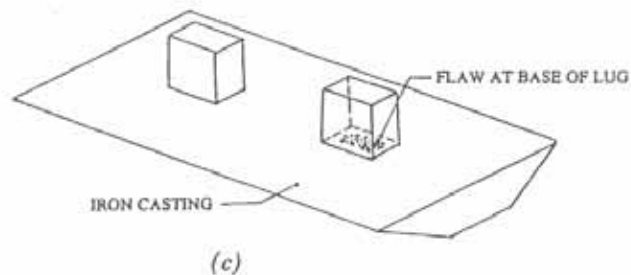
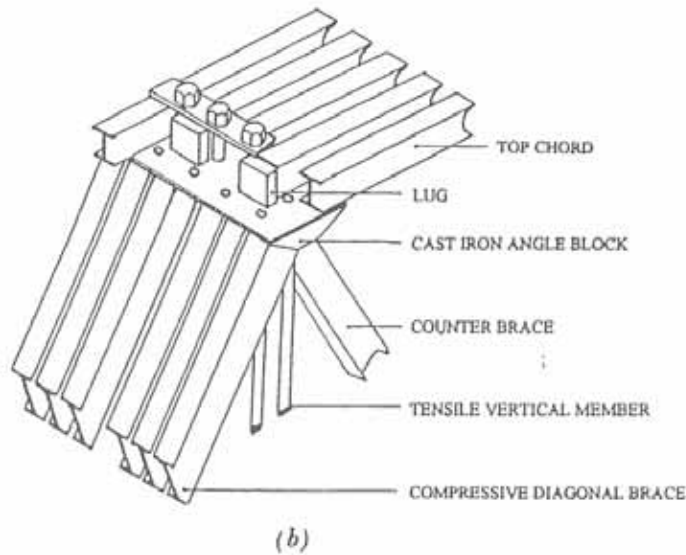
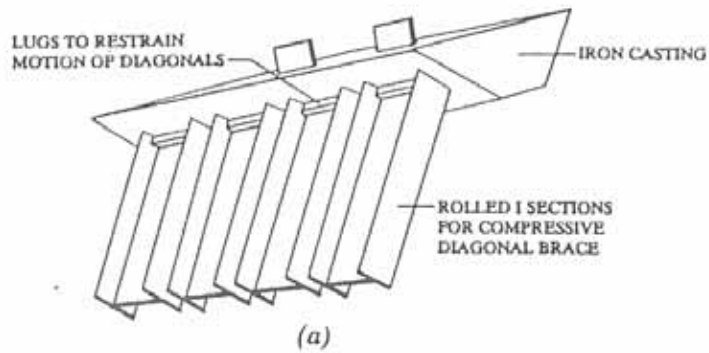




**Wendel Bollman bridge at Savage, MD - 1869**

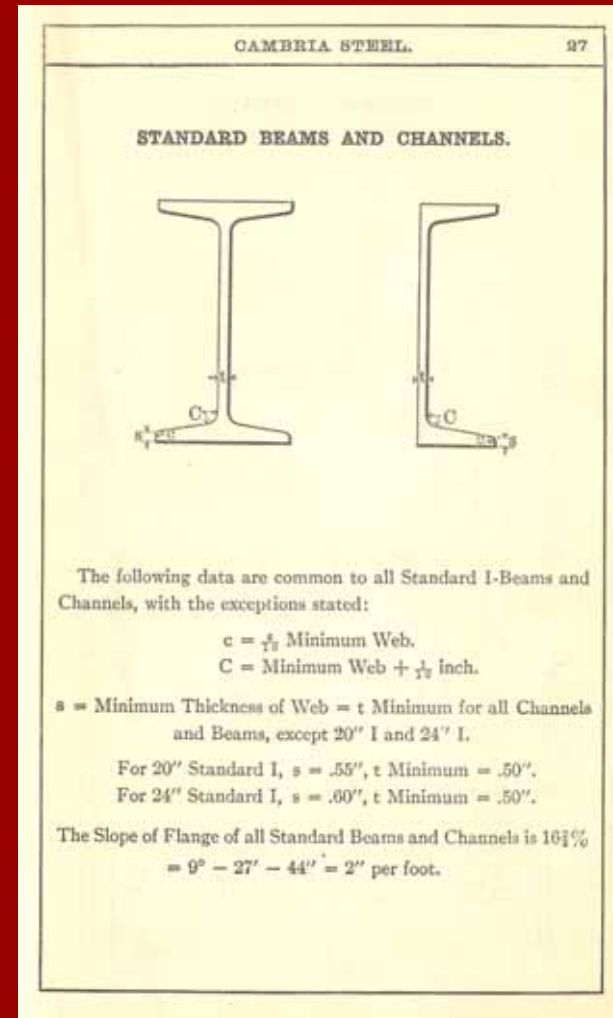
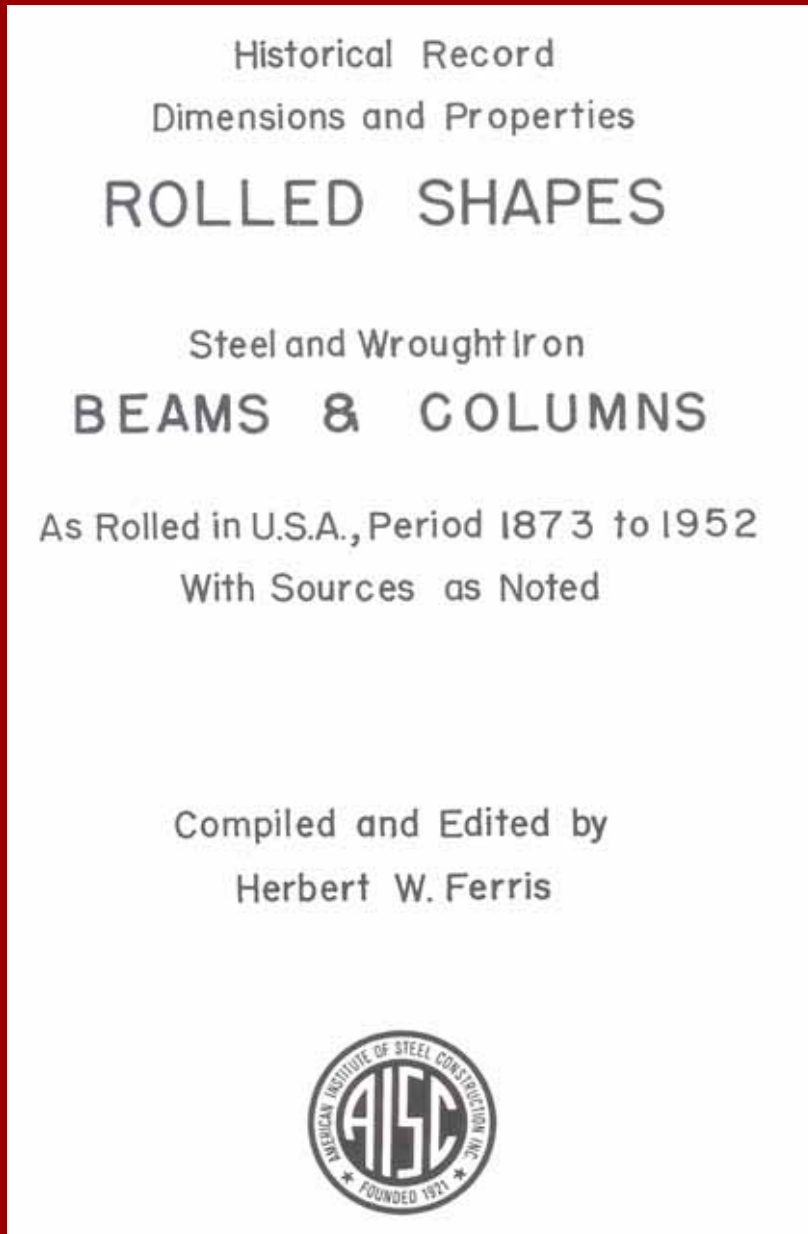


# Zoarville Station Bridge, Zoarville, Ohio 1869



**Collapse of the LSMS  
Ashtabula Bridge on  
December 29, 1876**

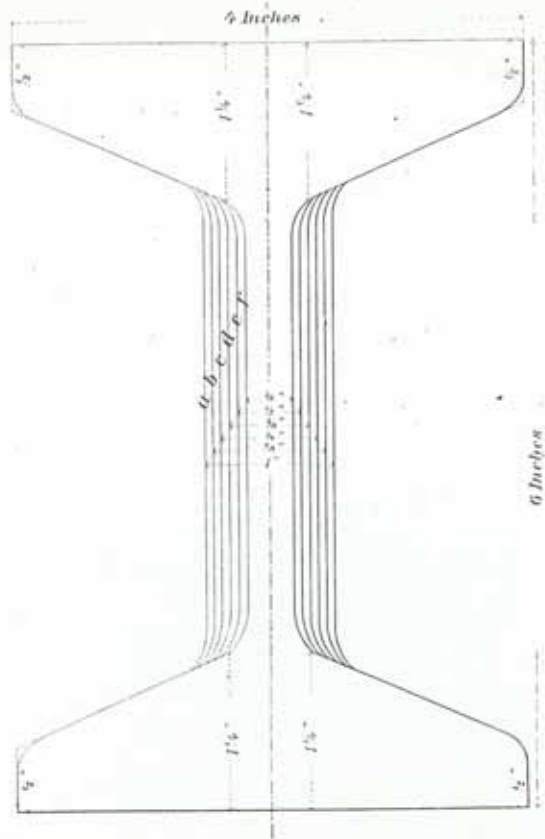
# Metal technology – rolling of wrought iron and steel



**American Standard Beams –  
adopted January 17, 1896**

# ASHTABULA BRIDGE.

## TEMPLETS OF I BEAMS

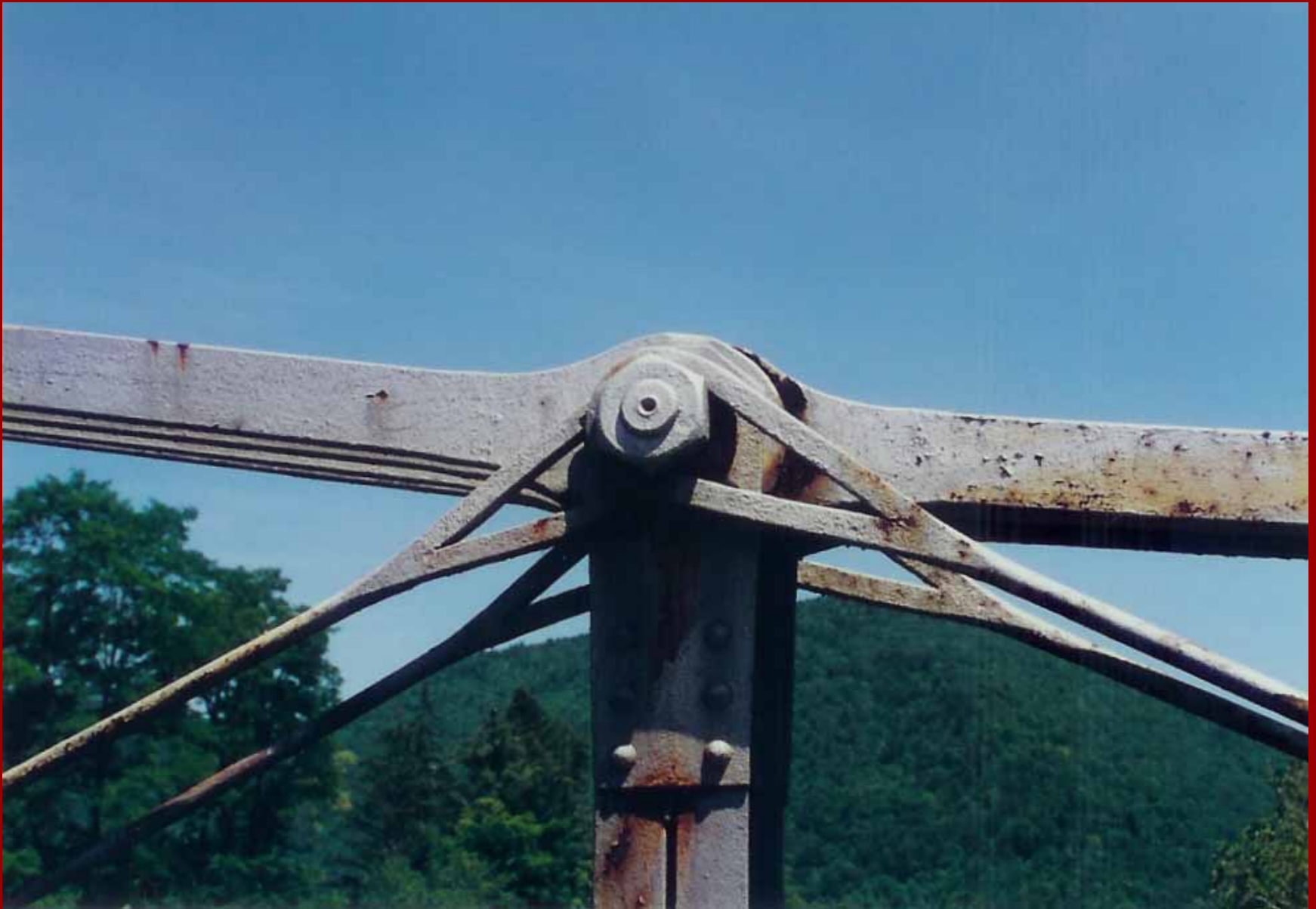


Form	Area	W <sup>2</sup> per Ft.	Volume of 11'	Ultimate Strength of 11' long	Ultimate Strength of 10' long	
	sq. in.	lbs	cu. ft.	Round ends	Square ends	
a	4125	37.5	0.7087		39,820 lbs	119,500 lbs
b	1072	33.7	0.8295		38,900 "	116,700 "
c	10187	33.93	0.8590	38,575 lbs	115,723 lbs	
d	966	32.2	0.8954	37,624 "	112,872 "	37,045 "
e	9125	30.52	0.8382	36,070 "	110,010 "	36,115 "
f	8594	28.65	0.9872	35,700 "	107,100 "	35,185 "

a, b, d, e & f were used as Top Chord members.  
 c, d, e & f " " Braces & Counters.  
 d " " Floor Beams

LSMS Ashtabula Bridge -  
 Erected 1863-65; beams  
 rolled by Stone, Chisholms  
 and Jones at the "Newburgh  
 mills," near Cleveland

# Forge welding; forging in closed dies

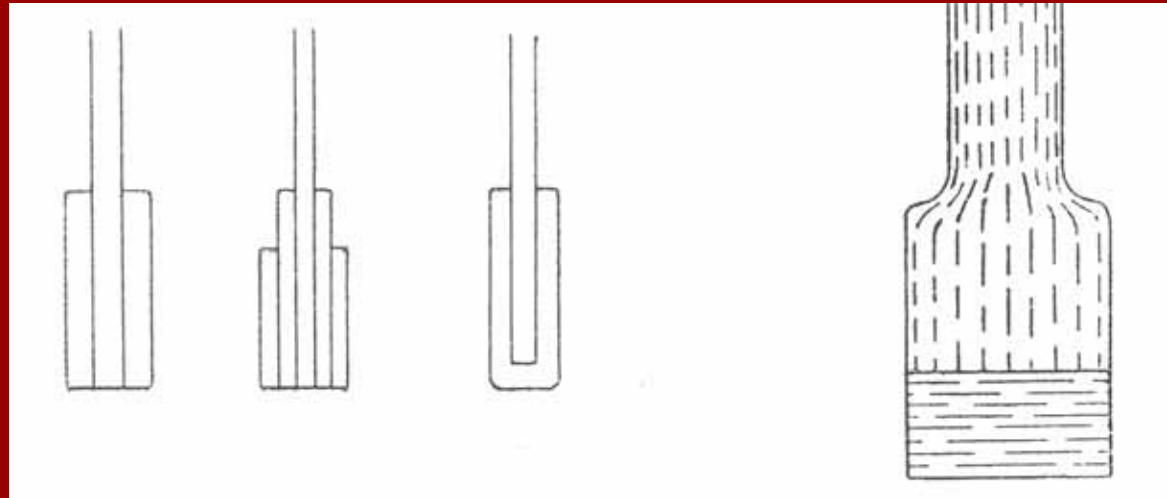


# **Metal fabrication technology – Forging of eyebars**

**Loss, H.V. (1893, 1894). “The Forging of Eyebars and the Flow of Metal in Closed Dies” *The Railroad Gazette*, 1893: 846-847, 903-904; 1894: 5-6, 43-45.**

**Barkhausen, G. (1893). “Mitteilungen von einer Studienreise nach den Vereinigten Staaten von Nordamerika” *Zeitschrift des Vereines Deutscher Ingenieure*, Berlin, Germany, 37, 1512-1520.**

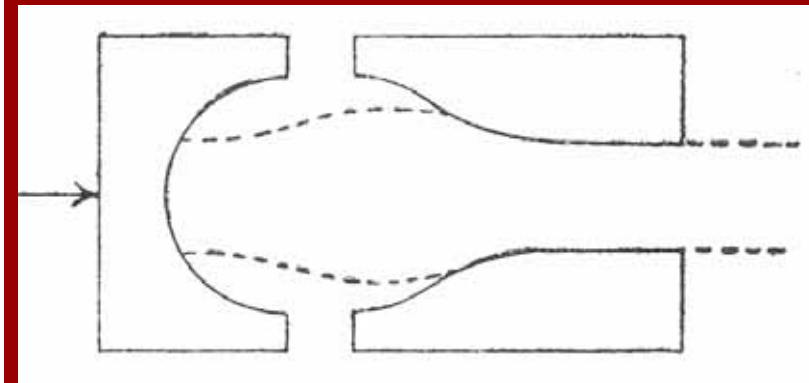
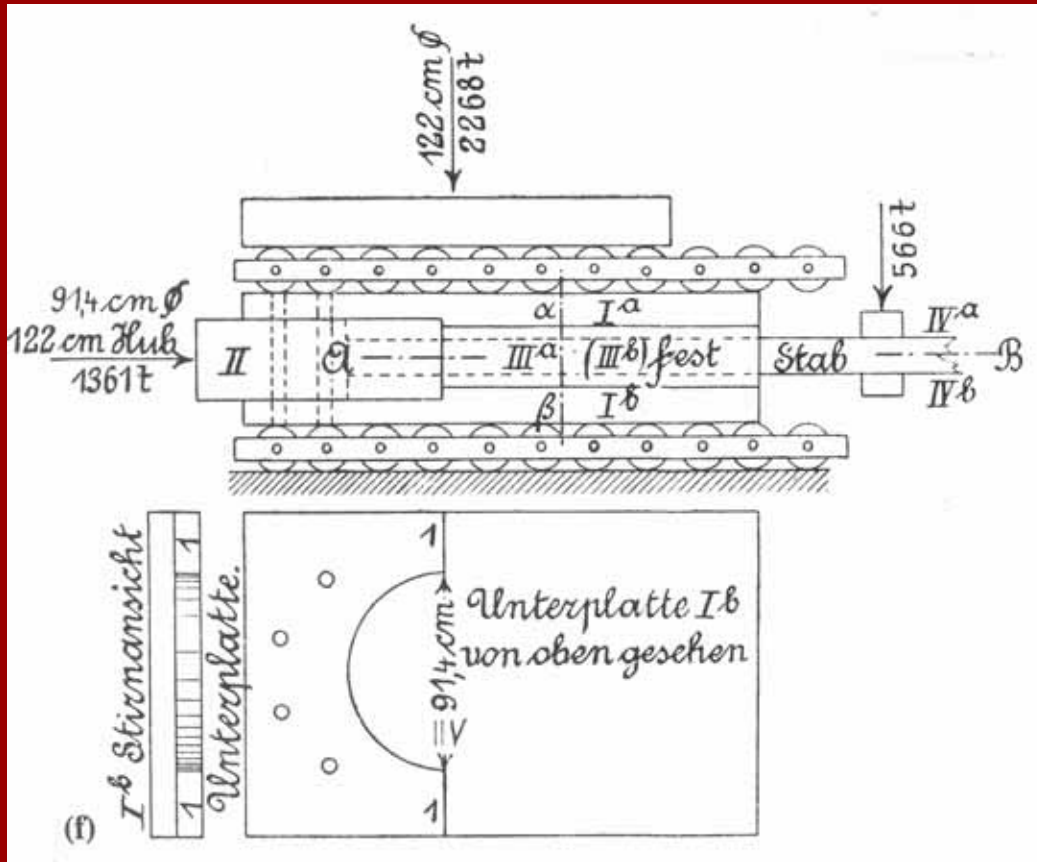
# Wrought iron eyebars – Piling of wrought iron plates with orthogonal “grain”



**Hammer forging**

Steel eyebars – Hydraulic forging press with closed dies  
Punching and shearing  
Annealing  
Straightening, boring, and painting

Pencoyd Iron Works forging press, Philadelphia, PA



**Chanute, O. (1879) – “..we take the utmost pains to secure accuracy of finish of several parts – planing or turning all joints and bearings, boring all eyebars at the same temperature to fit the pins within one-fiftieth of an inch, and rejecting them if, when all bars of one system are piled on top of each other, the pins do not pass through at both ends simultaneously without driving..”**

# Metal fabrication technology – Shop riveting

## RIVETED JOINTS

A Critical Review of the Literature  
Covering their Development,  
with  
Bibliography and Abstracts of the  
Most Important Articles  
by  
A. E. Richard de Jonge, Dipl.-Ing.  
Member A.S.M.E.

A RESEARCH PUBLICATION  
1945

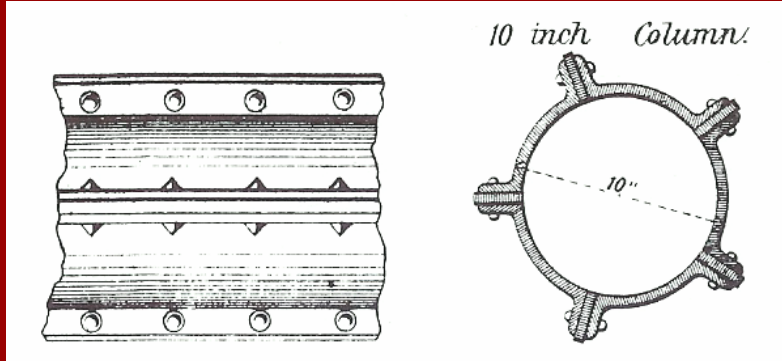
PUBLISHED BY  
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS  
29 WEST 39TH STREET, NEW YORK 18, N. Y.

**Mechanization (shop riveters) and standardization**

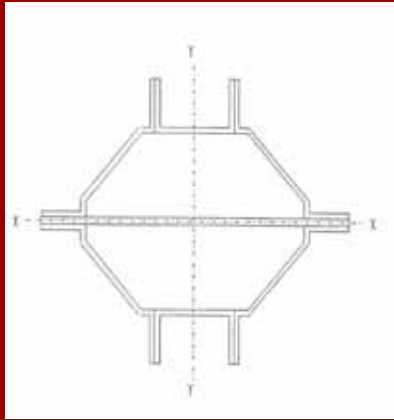
**Built-up compression members**

**Hip joints, splices**

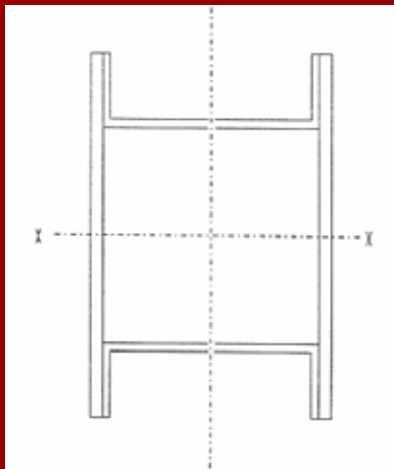
# Built-up compression members



**David Reeves, Phoenix  
Bridge Company, 1864**



**David Hammond, Wrought  
Iron Bridge Co., 1878**



**Zenas King, King Bridge  
Company, 1875**



# **Engineering technology – Conceptualization of behavior, modeling, and structural analysis of trusses**

# Engineering technology: Metal Howe trusses



## The Philadelphia and Reading Railroad

Richard B. Osborne 1845

- Adjustable elements
- No “positive” connections for diagonals
- Counters along entire span
- With contact maintained, both diagonals add to stiffness
- No advantages to loss-of-contact
- Approximate analysis; no joint-by-joint equilibrium



## **Engineering technology: Metal Pratt trusses**

**Dredge, J. (1879) “The Pennsylvania Railroad”  
*Engineering***

**“That portion of the road from Altoona and Pittsburgh, however, being a few years later in its construction, dating from 1851 to 1853, iron bridges were erected.... They were what are denominated deck bridges, having a track on top, and were constructed on the Pratt principle, having cast-iron upper chords of the inverted U form, cast iron vertical posts and wrought-iron lower chords, inclined ties, and counters. A cast iron arch was also introduced.....”**

# **Engineering technology: Metal Pratt trusses and the Pennsylvania Railroad**

## **Joseph M. Wilson**

- **In charge of the PRR Department of Bridges and Buildings in 1865, at age 27**

## **Henry Pettit**

- **Joined PRR as draftsman in 1862**
- **Resigned from PRR in 1874**

# **Engineering technology: Pratt trusses and the PRR**

- **Elimination of cast iron**

- **Reasons for adjustable elements**

  - Ease of erection**

  - Affect slight adjustments in geometry**

  - Pretension to make both diagonals active, but element forces from live loads “indeterminate”**

- **Behavior of non-pretensioned Pratt diagonals**

  - With a large slenderness ratio, diagonals cannot carry significant compressive force**

  - If only one diagonal active, it is possible and correct to use joint-by-joint equilibrium for analysis**

# Engineering technology: Pratt trusses and the PRR

- **Design of Pratt trusses with a single diagonal in each panel**

**Dredge, J. (1879) “...two single diagonal deck Pratt trusses were built in 1870 with a 78ft and a 98ft span..”**

**Merriman, M. and Jacoby, H. (1907) “The first Pratt truss with only one diagonal in each panel was built in 1870 on the Pennsylvania Railroad..”**

# Engineering technology: Pratt trusses and the PRR

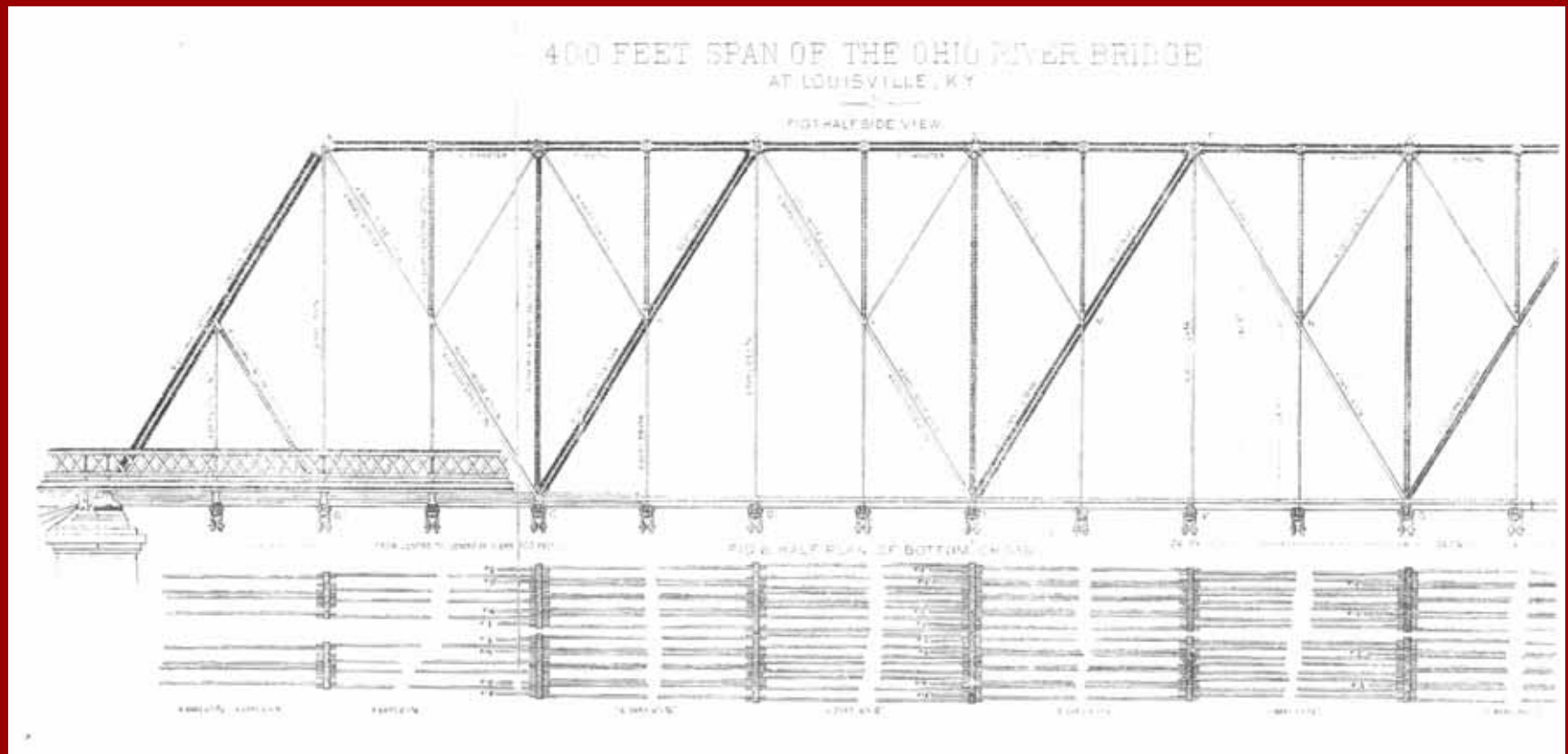
- Design of “subdivided” Pratt trusses (1871-74?)  
“Pennsylvania” or “Pettit” or “Baltimore” trusses



## **Engineering practice – PRR, prior to 1879**

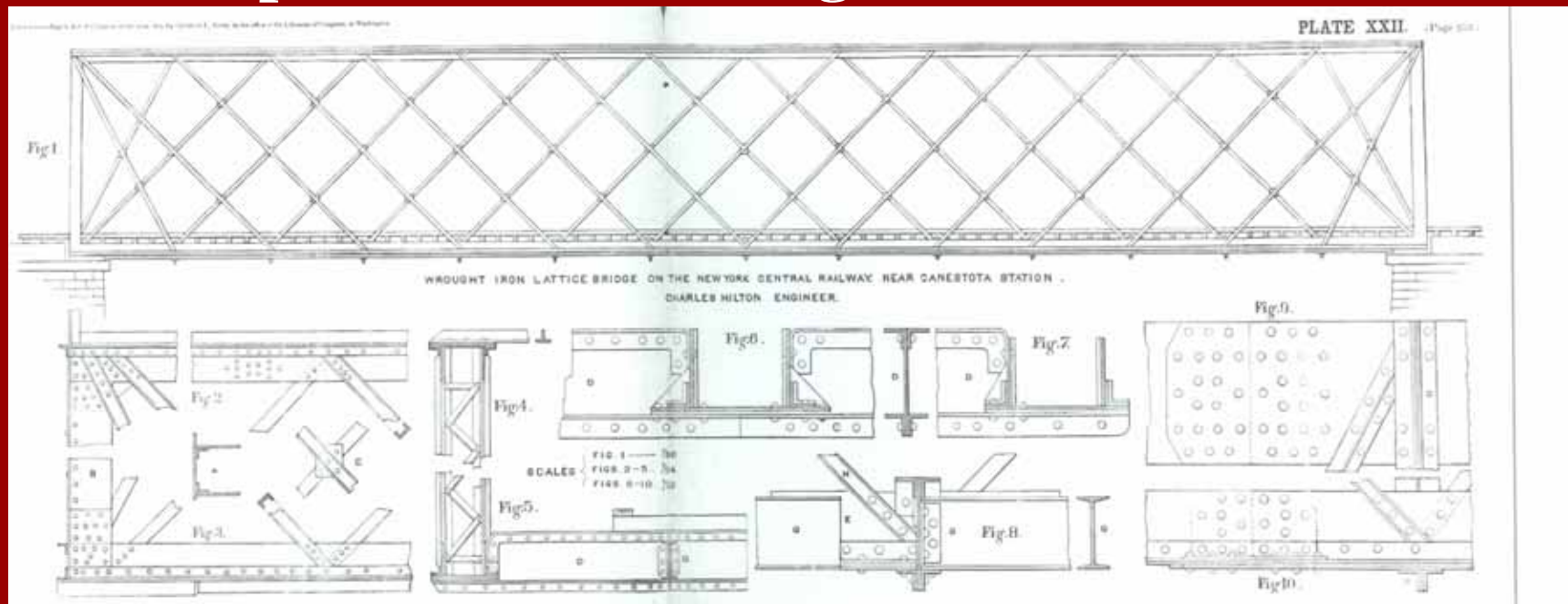
- **Design drawings and specifications for bidding by contractors/fabricators**

# Engineering technology: Albert Fink and “subdivided” Warren-Monzani trusses Ohio River Bridge at Louisville 1868-1870



# Engineering technology: Metal Town lattice trusses and the New York Central Railroad

George E. Gray, Howard Carroll, Charles Hilton, George H. Thompson – Riveted designs from 1857 to late 1880s

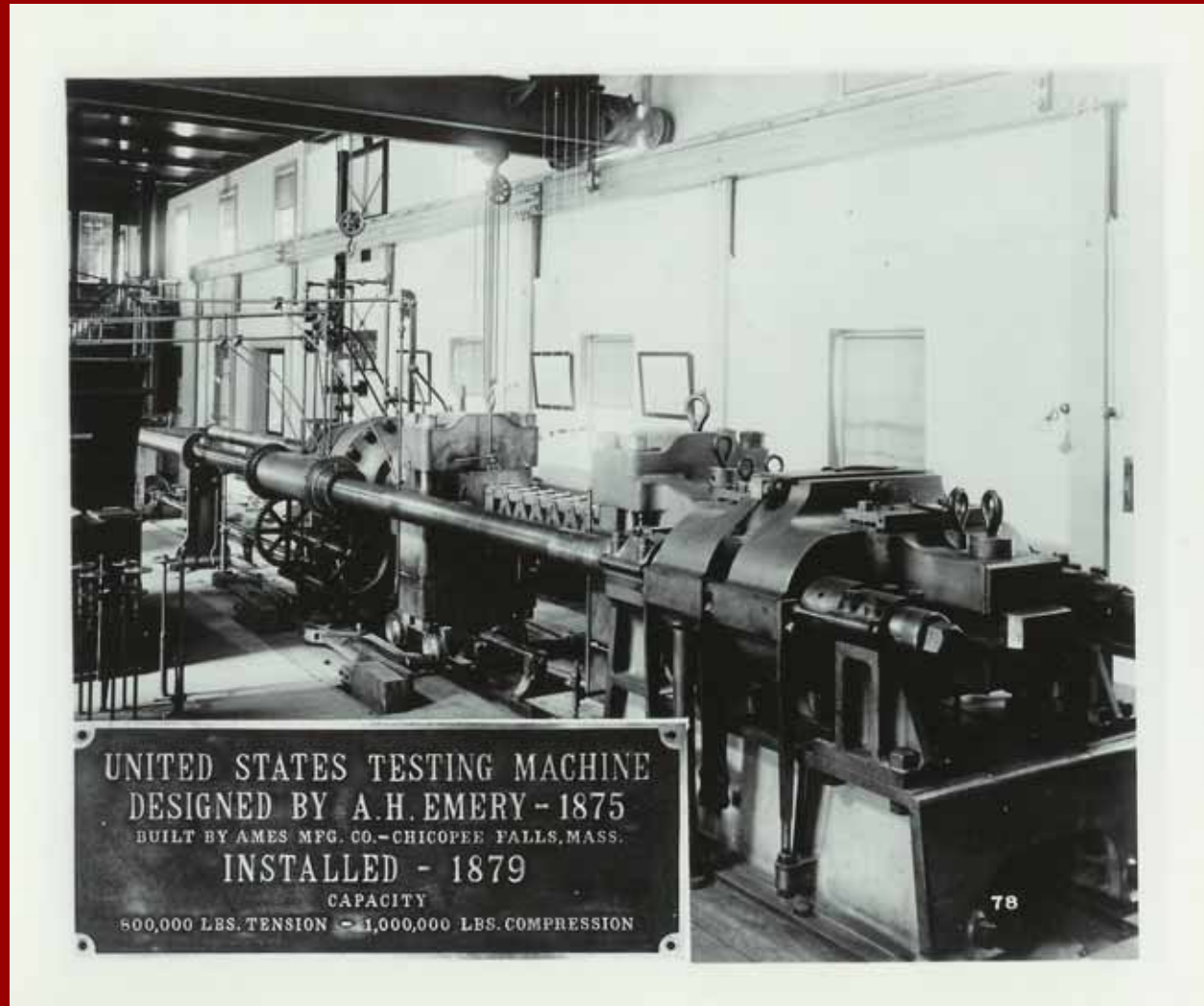


Approximate structural analysis

Standardization of riveting - specifications

# Engineering technology: Structural testing

## Watertown arsenal – 1879



## Bridge companies – Phoenixville, 1880's?

## **Engineering technology – Statically determinate trusses**

**Merriman, M. and Jacoby, H. (1907 6<sup>th</sup> Edition) “The statement that there is no rational method for designing trusses with double or multiple web systems is therefore justified, and experience has proved that the greatest degree of security and economy in the construction of simple trusses is obtained by the use of systems in which all stresses are statically determinate.”**

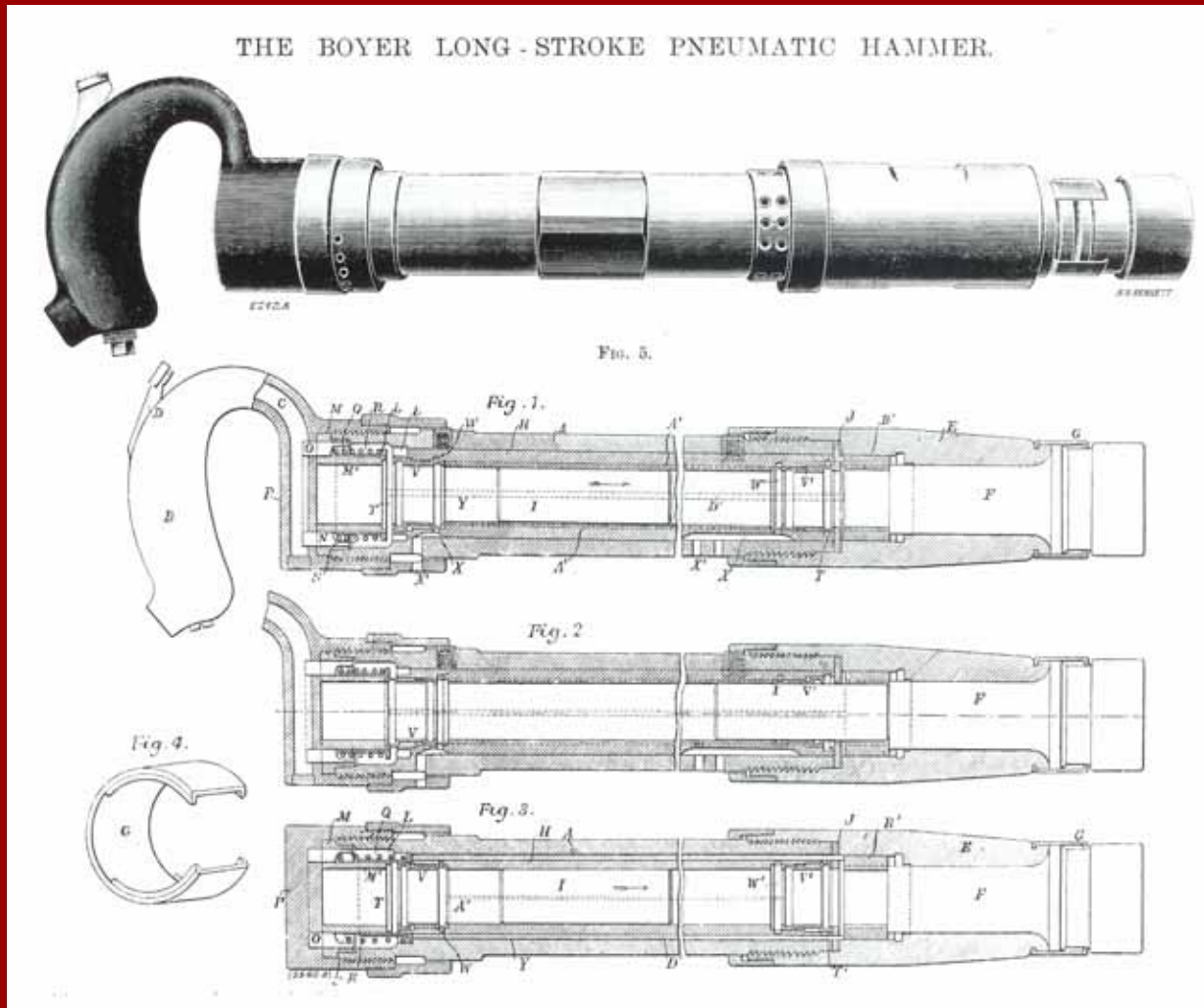
**Waddell, J.A.L. (1916) “... the great majority (of engineers) concede that a single system of cancellation is the only one which is truly scientific, and that bridges built thus possess all the advantages claimed for multiple-system trusses and none of their characteristic disadvantages.”**

# Engineering technology – Standardization of design; design specifications

PERIOD	DATE	
1830	1836	Col. S.H. Long Booklet
	1837	D. H. Mahan Book
1840	1846	D. H. Mahan Revised Edition
	1847	S. Whipple Book
1850	1851	H. Haupt Book
	1857	Specifications for Riveted Work by Howard Carroll for N.Y.C. R.R.
1860	1860	D.H. Mahan Revised Edition
1870	1871	Clarke and Reeves - Phoenix Iron Co.
	1872	Carnegie Pocket Companion 1893, 1896-1934
	1875-1881	L.F. G. Bouscaren Specifications
	Dec. 29, 1876	Collapse of Ashtabula Bridge
	May 1877	Proposed Specifications as a result of Ashtabula Bridge Collapse
	July 1877	Specifications for Kilbourne and Rockton Bridges by D.J. Whittemore and C. Shaler Smith
	July 1877	Lake Shore & Michigan Southern Railway Specifications by Charles Hilton
	1878-9	Erie Railway Specifications by Theodore Cooper
	Dec. 29, 1879	Collapse of Firth of Tay Bridge
1880	1886	Specifications for Iron Bridges by Joseph M. Wilson (PRR)
		General Specifications for Railroad Bridges
	1887	C.C. Schneider - Pencoyd Iron Works

# Construction Technology – Practical field riveting

Simmons, D. (1997) “The continuous clatter: practical field riveting” IA, Vol. 23, Number 2



## **Entrepreneurial/industrial/professional context**

**Products of bridge companies**

**Railroad bridge designs**

**Early designs of “consulting bridge engineers”**

## **Materials technology**

**Cast and wrought iron – 1845-1890**

**Early Bessemer steels – 1875-1885**

**Early basic open hearth steels - 1888-1895**

## **Fabrication technology**

**Iron castings**

**Wrought iron and early steel eyebar forgings**

**Early rolled sections 1850s to 1870s**

**Early built-up sections**

**Early all-riveted truss designs**

## **Engineering technology**

**Developmental forms of the Pratt truss – 1870s**

**Early uses of design specifications**

