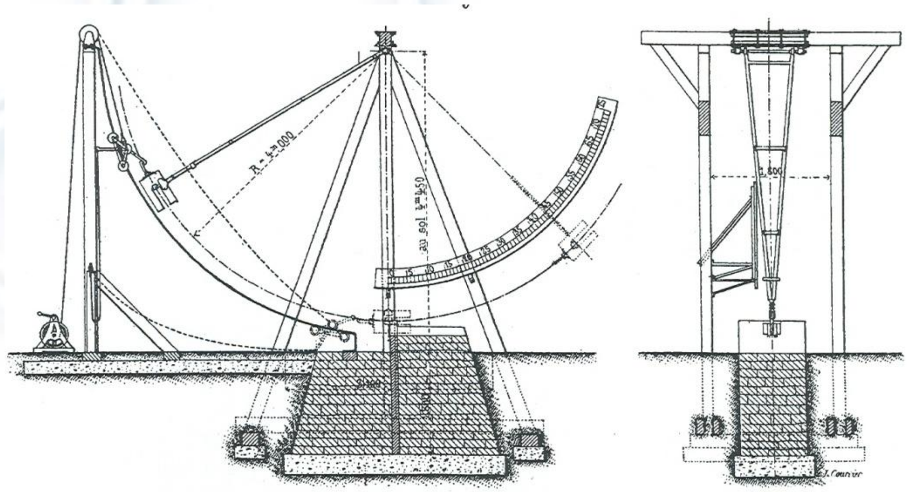

Impact Testing Yesterday and Today

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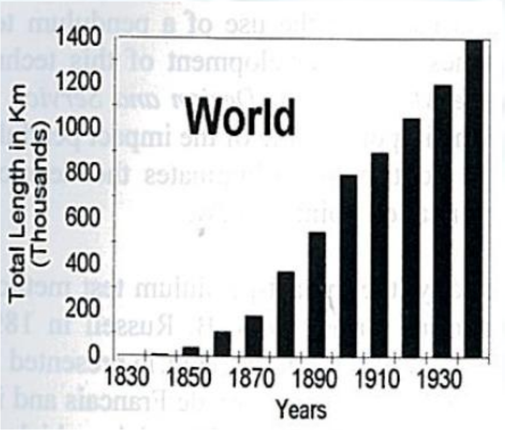
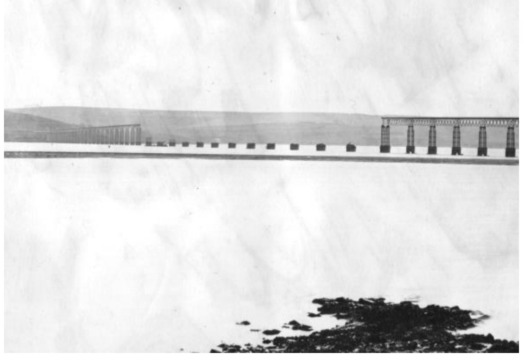
Yesterday…

The Early Years of Material Testing - 19th Century -

- The early development of material testing was driven by the rapid expansion of the **railway network** between 1830 and 1900
- A large number of catastrophic accidents caused by **brittle failures** of rails and axles were recorded in all industrialized countries



- The use of **metals** for construction increased from 20 % to 80 % at the expense of traditional materials (wood, brick, stone, etc.)
- A new type of material, **steel**, was developed around the mid-1800s
- In 1858, David Kirkaldy opened the first public **material testing laboratory** in Southwark, London
- He contributed to the inquiry on the causes of the railway **Tay Bridge disaster** (Scotland, 12/28/1879 - 75 victims)



The Dawn of Impact Testing - 1824 to 1895 -

- Earliest known publication: T. Tredgold (1824), on the ability of cast iron to resist **impulsive forces**
- In 1849, a commission was formed in Great Britain to study the use of iron in the railroad industry, focusing on **practical approaches to impact testing**
- In 1857, Captain T.J. Rodman devised a **drop-weight machine** for improving the performance of gun steels, using smooth rectangular bars (unsuitable for ductile materials)

- The use of **notched specimens** was introduced by H. L. Le Châtelier, while conducting drop-weight tests in 1892. He observed that the presence of a notch caused brittle fracture on steels that showed ductile behavior when tested in unnotched form

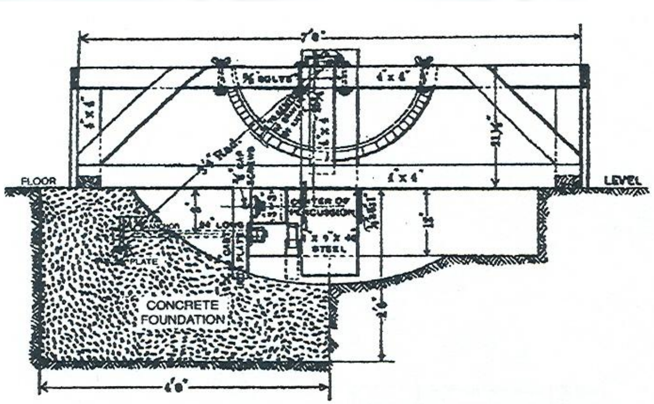
Early International Developments - 1895 to 1910 -

- The International Association for Testing of Materials (IATM) was founded in 1895, during the first international conference on material testing
- The American Society for Testing and Materials (ASTM) was established in 1898
- 1902 saw the publication of an ASTM bibliography on impact testing, listing more than 100 papers from US, France, and Germany
- By 1905, developing consistent impact testing procedures was deemed so important inside IATM that a new Committee 26 on Impact Testing was formed
- In 1906, George Augustin Albert Charpy became the chair of the IATM impact testing activity
- The pivotal publications on (pendulum) impact testing were:
  - S. Bent Russell, American Society of Civil Engineers (1898)
  - G. A. A. Charpy, 7th IATM Congress, Budapest Hungary (1901)

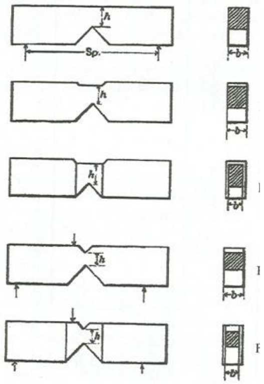
S. Bent Russell, 1898

Experiments with a New Machine for Testing Material by Impact

- **Resilience**: “(…) *work absorbed in the deformation of a material.*”
- The Impact Testing Machine*: “In designing it the main idea was to make a machine which would **measure the energy actually absorbed** in breaking the test bar.”*
- *“This was to be done by using a hammer **in the form of a pendulum**.”*
- *“The **difference between the height … before striking and … after striking** would measure the energy absorbed in breaking the bar.”*



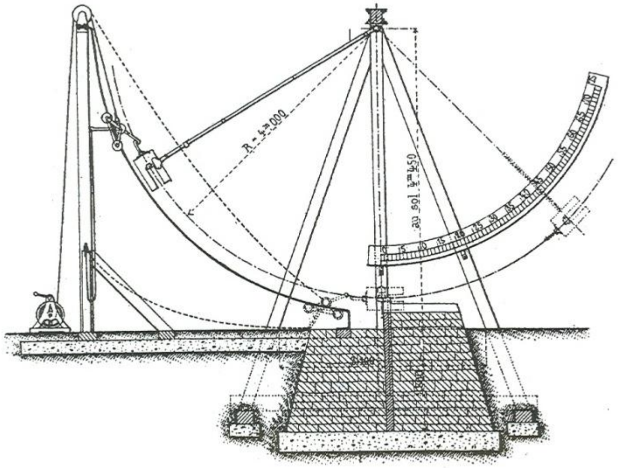
- Tests of Tough Materials*: “To break such a bar (wrought iron) successfully, it must first be **nicked**.”*
- Materials Tested: cast iron, paving brick (brittle); wood, bronze, plow-steel, aluminum, wrought iron, steel (tough)



George A. A. Charpy, 1901

Essay on the Metals Impact Bend Test of Notched Bars

- *"If (…) the tests on notched bars have not been widely adopted, this is undoubtedly due to the drawbacks of any testing method whose peculiarities **cannot be defined in a rigorous way**."*
- *"It is therefore extremely important to **standardise in a rigorous way** shape and dimensions of the notch."*
- *"The bar is subjected to **a series of impacts** from a constant height and we count the **number of impacts needed to provoke rupture**, as well as the **angle at which rupture takes place**. These two data allow a very clear ranking of the different metals."*
- *"The loss due to **passive resistances** can be easily evaluated by performing a **free swing** and following the reduction of the freely swinging pendulum."*



Standardization/harmonization efforts - 1910 to 1922 -

- **Standardization efforts** were being pursued within individual countries and at machine manufacturers
- Impact machines of **three major types** were available to customers: Drop-Weight, Pendulum and Flywheel
- **Two specimen configurations** were most popular:
  - Smaller specimen: 10 mm × 10 mm cross section; 53 mm length; 40 mm span; notch depth 2 mm to 5 mm; notch root radius 1 mm
  - Larger specimen: scaled up by 3X in all dimensions
- The **smaller specimen type eventually prevailed** because it allowed the use of more compact and cheaper machines and because not all structures could accommodate 30 mm thick specimens
- At the 6^{th} Congress of IATM (New York, 1912), a steel producer presented a report stating that improved impact test procedures had allowed him to **reduce by a factor of 20** the number of production parts rejected due to brittle performance

(After a long pregnancy) ASTM E23 is born
- 1922 to 1933 -

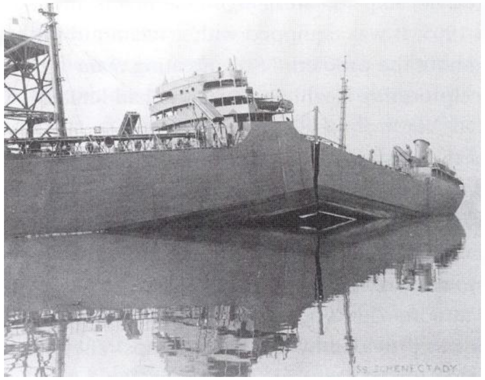
- After World War I, serious work resumed on **standardizing impact test procedures**
- In 1922, ASTM E-1 (Methods for Testing) sponsored a **Symposium on Impact Testing of Materials** in Atlantic City, NJ
- A **survey of 64 US testing laboratories** was presented, showing considerable support for the development of an ASTM test standard
- An ASTM subcommittee was formed in 1923 to prepare a standard test method for pendulum impact testing
- After 10 years of work, **ASTM E23-33T** “Tentative Method of Impact Testing of Metallic Materials” was published:
  - Machines of pendulum type were to be used
  - Both Charpy and Izod tests were covered
  - Only V-notch was considered for Charpy specimens
  - No geometry was specified for the striking edge
  - Units: English preferred, metric optional

Multiple E23 revisions
- 1934 to 1941 -

- First E23 revision was issued in 1934 and retained the **"Tentative"** designation
- In 1939 and 1940, the Impact Subcommittee of E1 started discussing the **tup radius** and a survey was conducted of the geometries used in the UK (0.57 mm) and France (2 mm)
- For reasons that were not recorded (☹), subcommittee members decided at the 1940 meeting on the use of an **8 mm striking edge radius**
- ASTM E23 was reissued in 1941 (**E23-41T**) with the following changes:
  - 8 mm radius for the edge of the striker
  - Preferred units became metric (English optional)
  - Keyhole and U-notches were added for Charpy specimens
- Similar discussions occurred inside **other standardization bodies** around the world

The (in)famous Liberty ships!
- 1941 to 1948 -

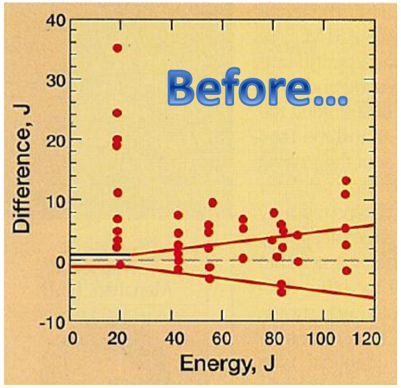
- Impact testing was still not commonly included in material specifications and construction standards until impact tests were used to effectively detect **ductile-to-brittle transition behavior**
- The greatest impetus came from the large number of **failures in Liberty ships** (over 20 % from February 1942 to March 1946)
- In 1948, the National Bureau of Standards (today NIST) released a **report on the investigation of fractured plates** removed from some of the ships



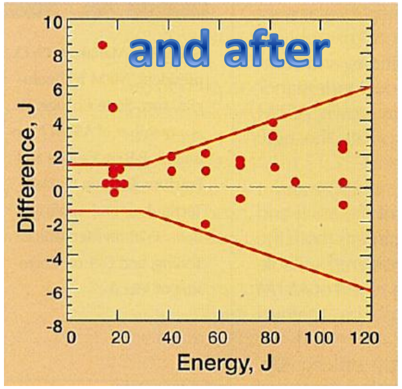
- The report established a **correlation** between the impact properties and the transition temperature of the plates and the likelihood of fracture propagation or arrest; **no such correlation** was found with tensile properties, chemical composition or microstructure
- The report also established a **minimum toughness requirement** of 15 ft-lb (~ 20 J)

Reducing variability: verification testing - 1948 to present -

- Critics of impact testing always alluded to the **scatter of test results**, claiming it was an apparently inherent characteristic of the test
- Many users of ASTM E23, on the other hand, were convinced that the scatter between individual machines could be **significantly reduced** by addressing and eliminating the primary variables responsible for scatter
- A decisive contribution came by D. E. Driscoll (Watertown Arsenal, NY, 1955), who demonstrated that much of the scatter could be eliminated by **rigorous testing** and **accurate maintenance** of the testing machine

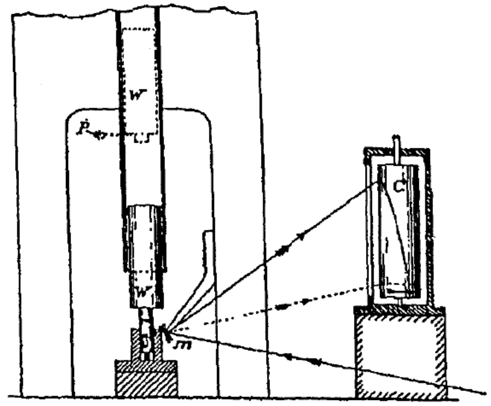


- Limits of 1 ft-lb (**1.4 J**) and **5 %** were set for individual machines (expected to be met by 90 % of the machines)
- In 1964, ASTM E23 was revised to require **indirect verification testing**

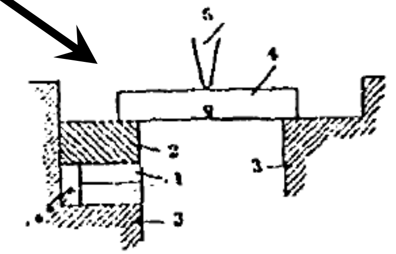


Instrumented Impact Testing

- The **earliest paper** on measuring incremental forces during impact loading: B. W. Dunn, *J. Franklin Inst.*, 1897 (Russell's paper is from 1898!)
- Dunn's technique for measuring deflection data: **light projection onto a revolving film** →



- **Simultaneous recording** of force and deflection: A. Gagarin, 1912
- Use of a **piezoelectric load cell** for measuring force: R. Yamada (1929) and S. Watanabe (1930)



- **Strain-gage technology** developed between 1930 and 1961: first instrumenting the back of the hammer, then the supports and finally the striker (S. Sakui, 1961)
- More recent developments are due to advances in data acquisition and analysis
- First commercial instrumented pendulum: PSWO, Germany 1958

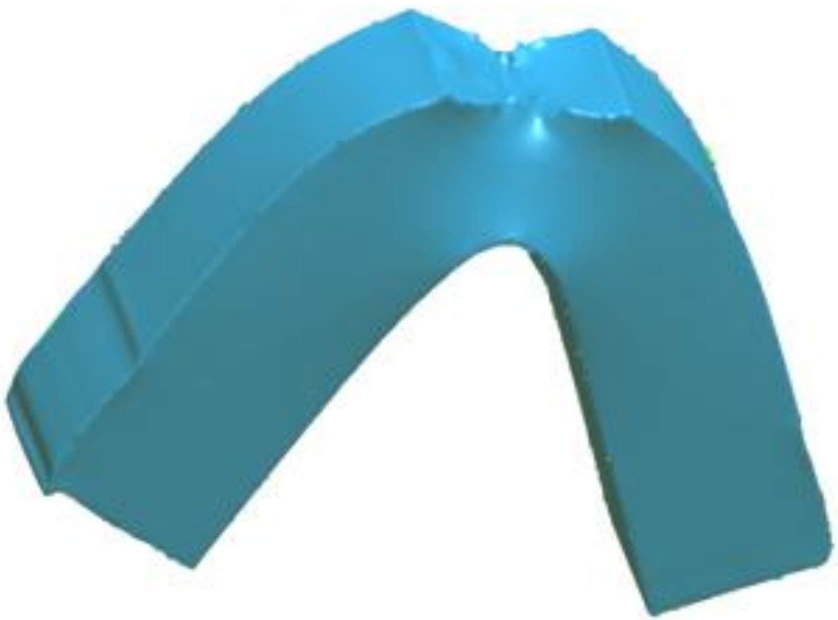
…and Today

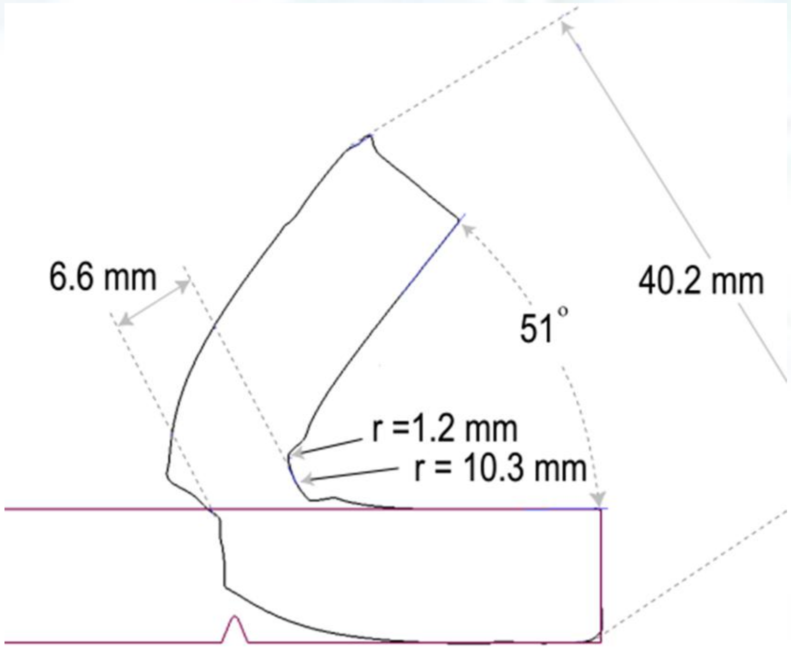
New challenges for an old test

- Plate steels having **high impact toughness** (i.e. absorbed energy > 300 J) are nowadays common
  - e.g., pipeline steels (X-70, X-80, X-100…), high Ni alloys
  - Charpy specimens from those steels typically **do not fracture** in two pieces but bend and are pushed by the striker through the anvils
- The $1,000,000 question: what is the true meaning (value, usefulness, sense…) of the good old Charpy test when the measured impact energy does not correspond to complete fracture of the specimen?
- The classical interpretation of the Charpy test is based on the measurement of the energy required to **break** a notched and supported bar when impacted by a moving mass
- Is it legitimate to compare USE (Upper Shelf Energy) values based on **partially fractured** and **fully fractured** specimens?

A significant example

Ni-Cr-Mo-W alloy (UNS N06022), $KV_{RT} \approx 450$ J





S. Bent Russell wrote in his 1898 essay:

"Having now dealt more or less effectively with the brittle materials, a class that presents greater difficulties must be considered. ... If an attempt is made to break a rectangular bar of soft iron, it will only be bent. To break such a bar successfully, it must first be nicked."

What would S. Bent Russell say in 2011?

- He would possibly say that the conventional, old-fashioned Charpy impact test needs to be somehow **rejuvenated**
- Or, in other words, the specimen needs to be **"nicked" a little more effectively**, in order to promote fracture even in very high toughness and extremely ductile materials
- Ideas (i.e., the 21st century equivalent of "nicking")
  - **deeper notches** (nothing new there – remember M. Charpy?)
  - **sharper notches** (root radius ≤ 0.1 mm)
  - fatigue **precracked** specimens (dynamic toughness tests)
  - **side-grooved** specimens
  - **reducing the specimen cross section** in the notch plane
  - making more effective use of the information extracted from **instrumented tests** (e.g. partitioning absorbed energy, trying to infer fracture initiation from the force-displacement test record, etc.)

And in conclusion…