

# History of large accidents – driving force for developments in materials testing and selection

Motto:

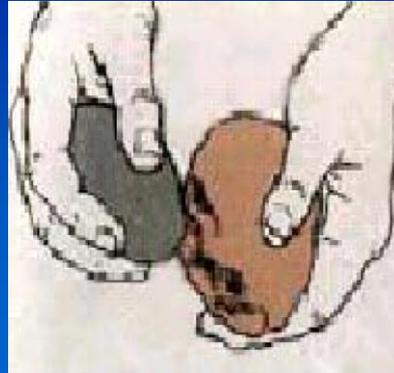
**No man is civilised or mentally adult until he realises that the past, the present, and the future are indivisible.**

# prehistoric man

*Mechanical testing of materials*



flake tool



x

chipping test



- Foot – tools to get and to prepare
- Arms/weapons - winning subjecting the other family, tribe... world
- Transport – railway ways, bridges
- Enhancement of man efficiency, capacity
- Breakdowns, failures and accidents

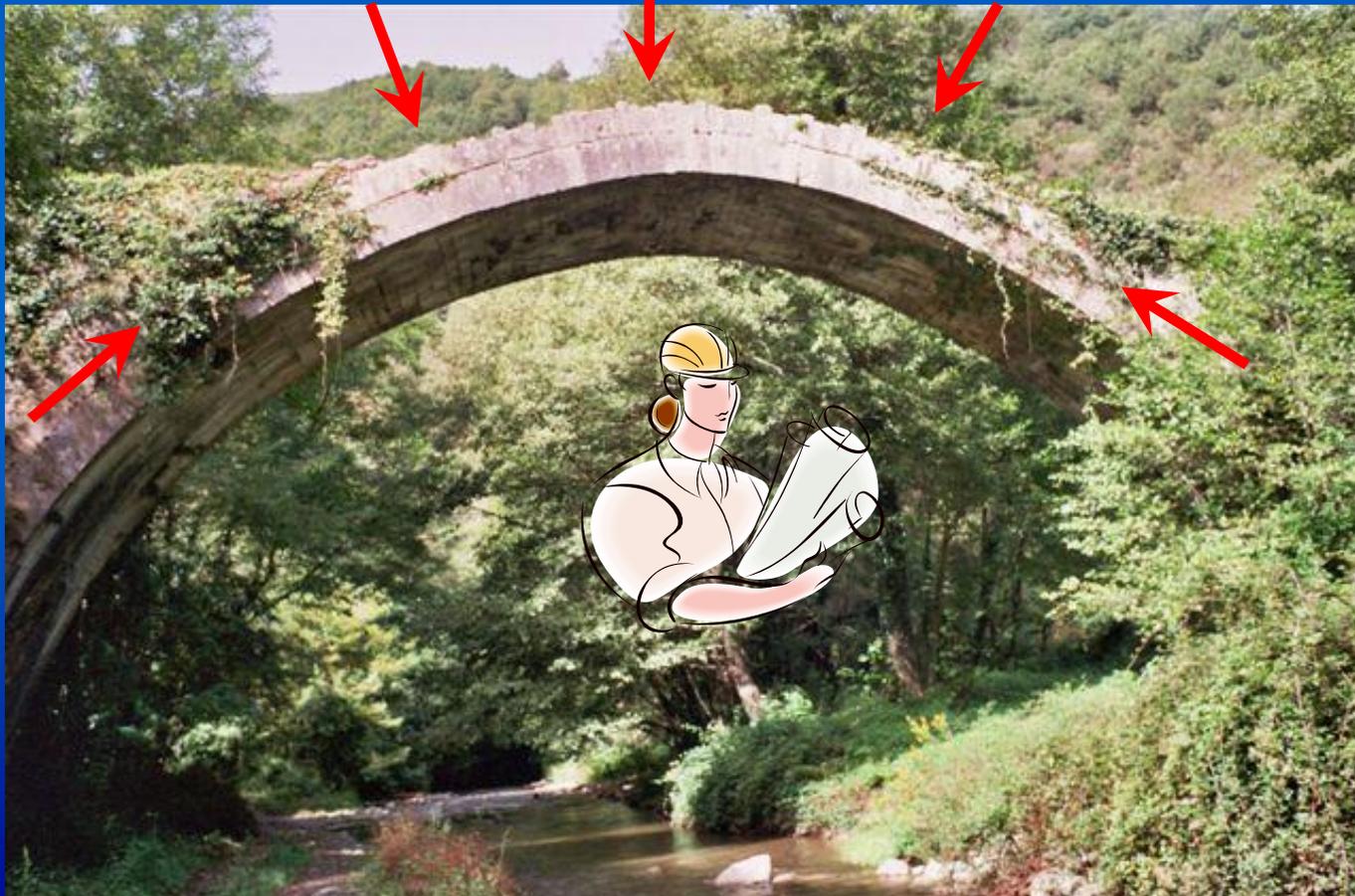
**19. century**

➤ prehistoric Rome

➤ antique Rome

## history

- prehistoric bridge (stone, bricks), designer below the bridge when testing, transposition of the tensile loads to compression loads
- ceramic composites – clay/straw for buildings, shanty





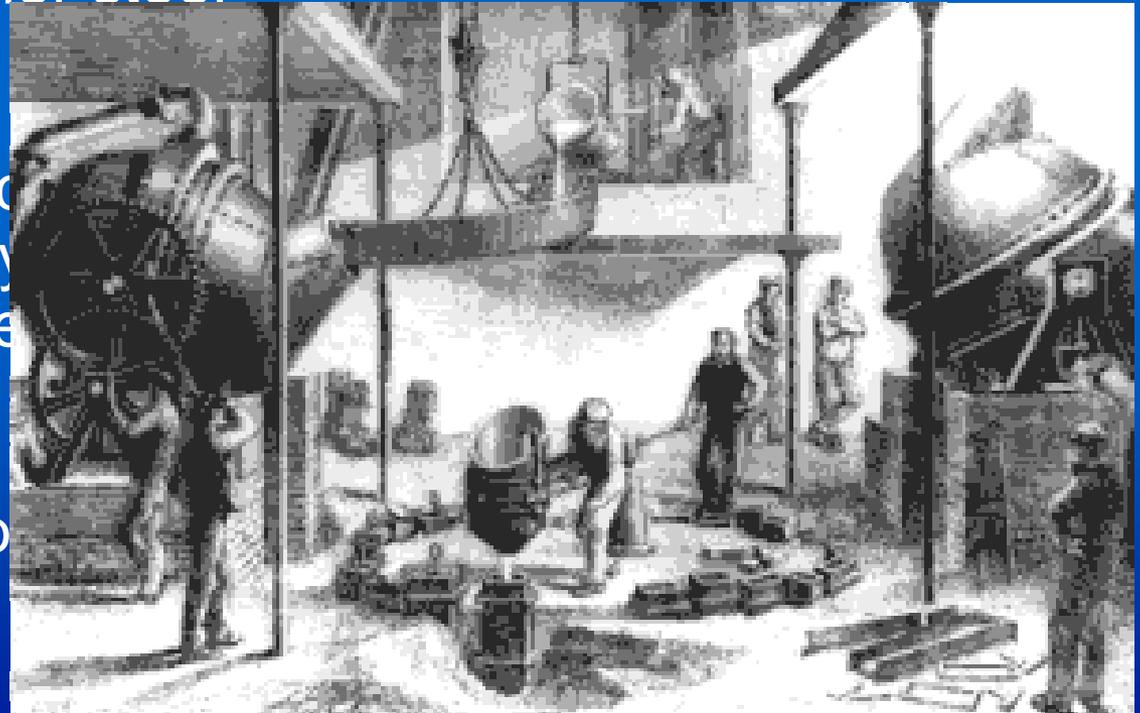
- **technical progress**  
dykes (dams), canals, pumps, refractors
- **newly applied / introduced structural materials**  
stones, bricks, brass, cast irons and weld iron
- **progress in testing**  
tensile tests of wires (Leonardo da Vinci),  
testing of cross beams (buildings) in flexure  
(Galileo Galilei),  
springs testing (Robert Hooke)
- **failures, accidents, crashes**  
??? they are observed, but no outcomes,  
advise, knowledge and/or predictions of such  
behaviour

- **technical progress**  
steam engine, bridges from cast iron
- **newly applied / introduced structural materials**  
ductile cast iron
- **progress in testing**  
tests in torsion, shear tests, strength calculation of the cross beams loaded in flexure - Aug. Columb
- **failures, accidents, crashes**  
??? – they are, but still it is not possible to explain and/or even predict failures

# Period 1800 - 1900

*Mechanical testing of materials*

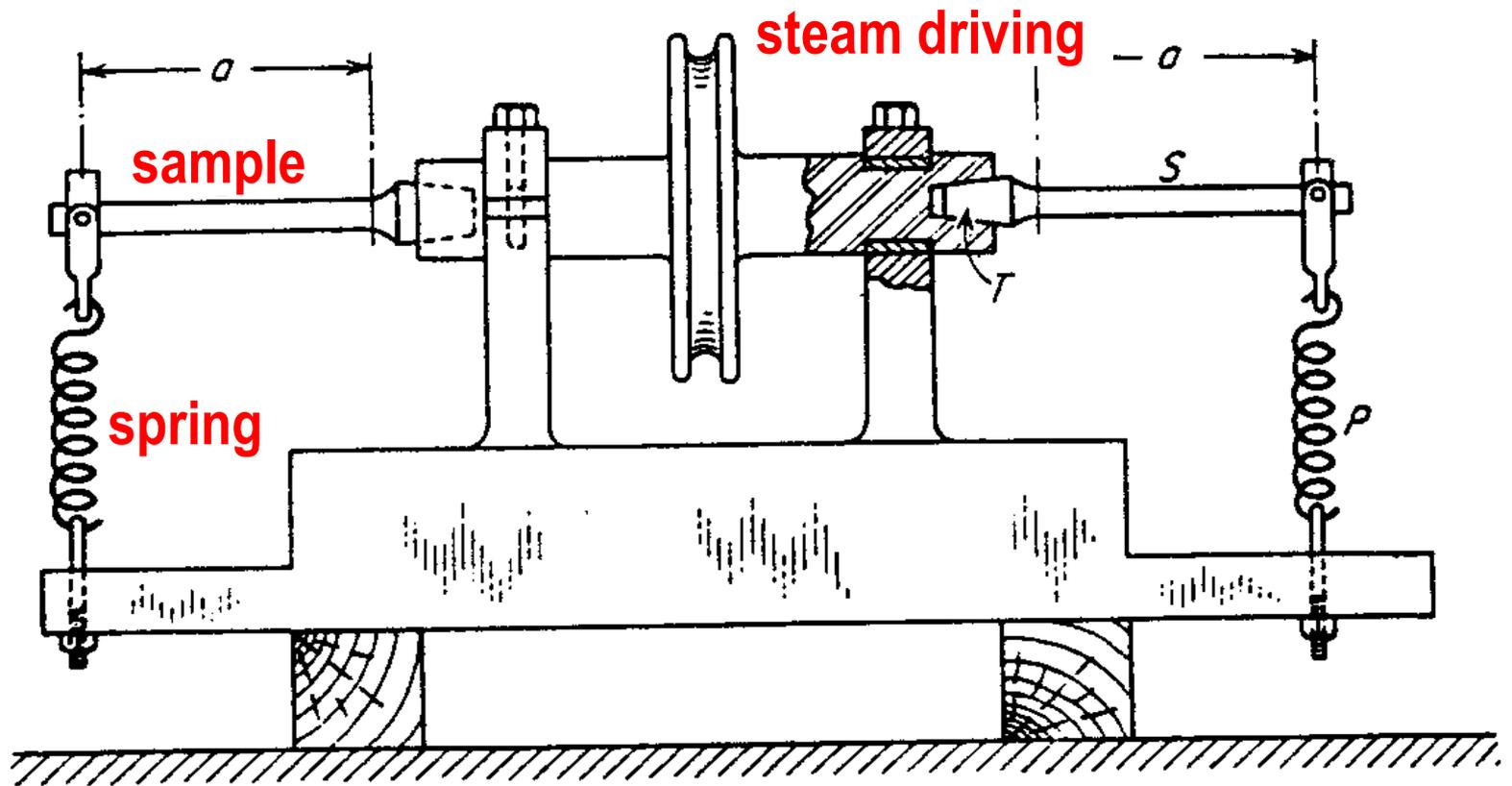
- **technical progress**  
railways, hinged bridges, combustion engine
- **newly applied / introduced structural materials**  
Portland cement, rubber vulcanization,  
Bessemer steel
- **progress in testing**  
fatigue/cyclic loading  
plasticity  
machine
- **failures, accidents**  
steam boiler  
bridges



**The American Society for Testing and Materials, 1898**

# Period 1800 - 1900

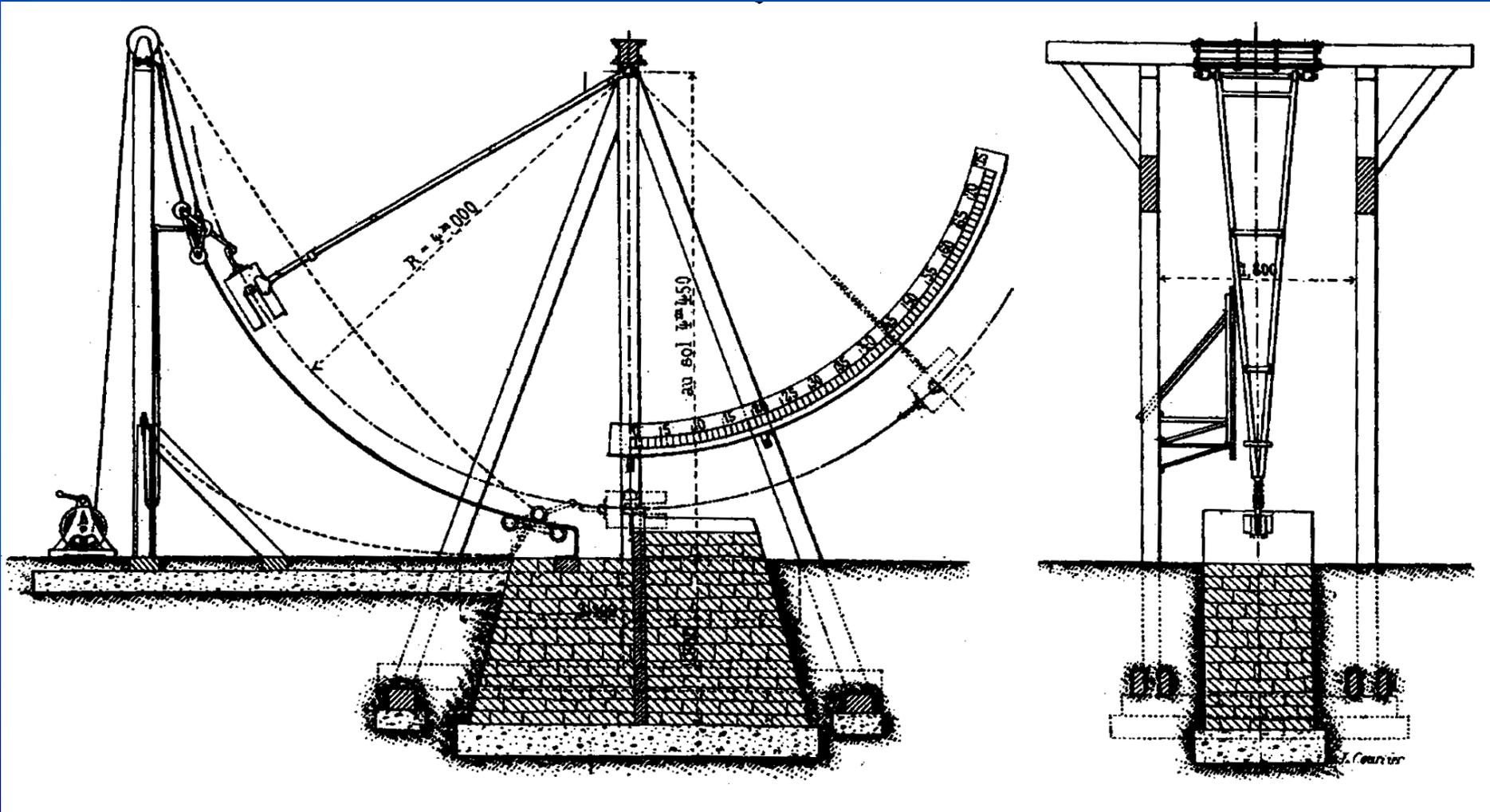
fatigue test –Wöhler, railway axles  
(number of turns/cycles to specimen fracture)



# Period 1800 - 1900

*Mechanical testing of materials*

Impact (notch) toughness – Charpy – unification  
Impact pendulum - hammer on the rotating arm:



# Period 1800 - 1900

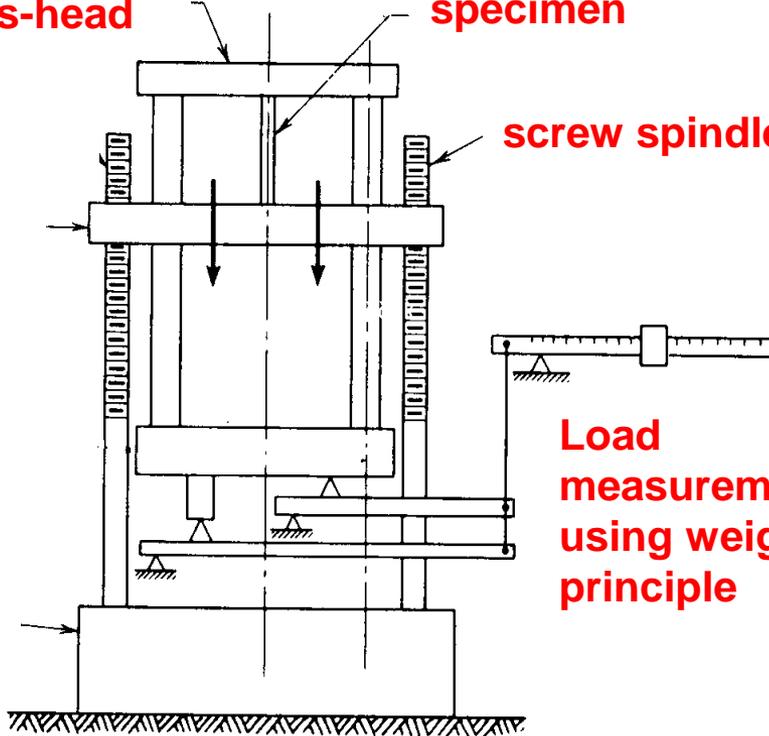
## mechanical test machine (declinable weigh)

fixed cross-head

specimen

screw spindle

moving  
cross-head

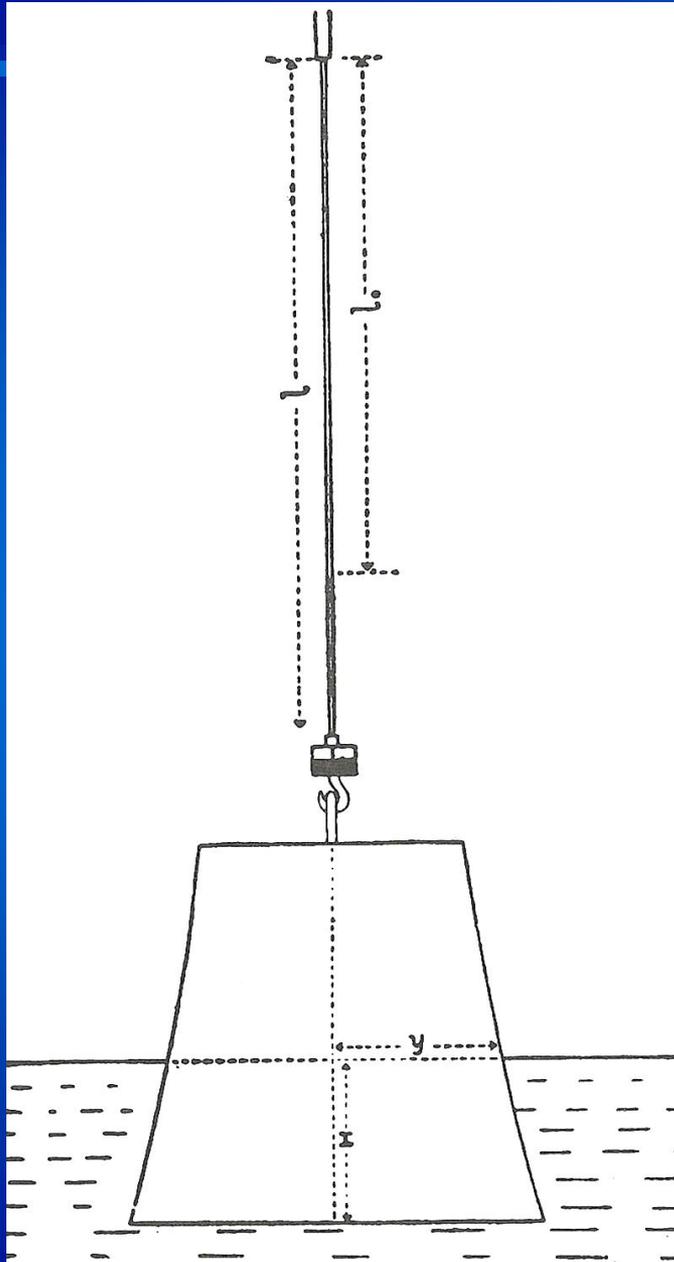


engine,  
gear box

Load  
measurement  
using weight  
principle

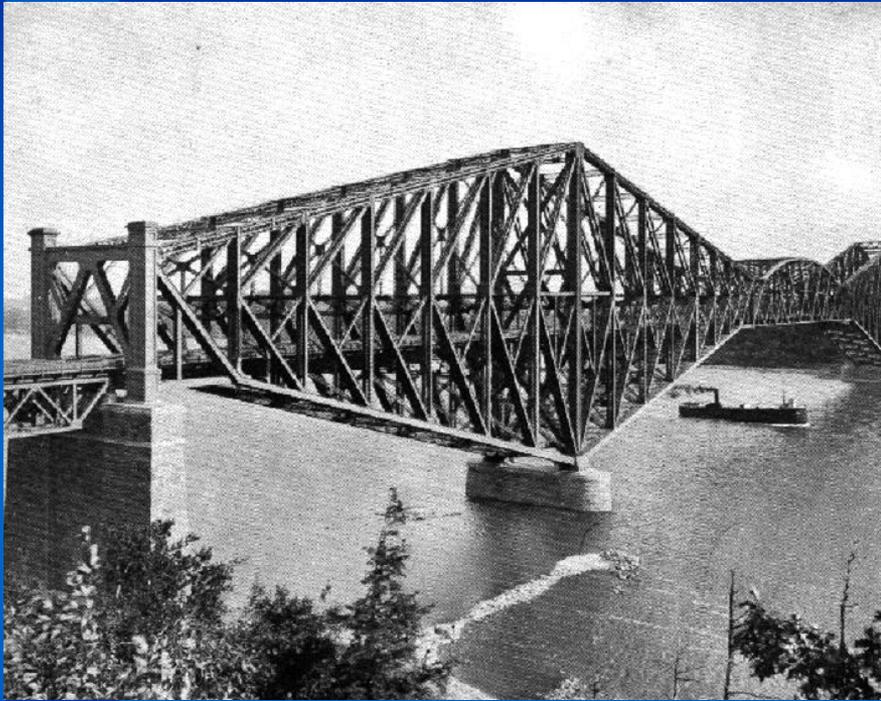


- **technical progress**  
electricity, engine airplane, electron tube
- **newly applied / introduced structural materials**  
alloying / alloyed steels, aluminium alloys, synthetic plastics (bakelite)
- **progress in testing**  
hardness testing - Brinell, impact tests - Charpy, creep tests – Andrade
- **failures, accidents, crashes**  
bridge in Quebec, reservoir (silo) for treacle in Boston,.....  
they are !! with bigger and bigger impacts onto human life and economic implications, still problems with explanations of causes

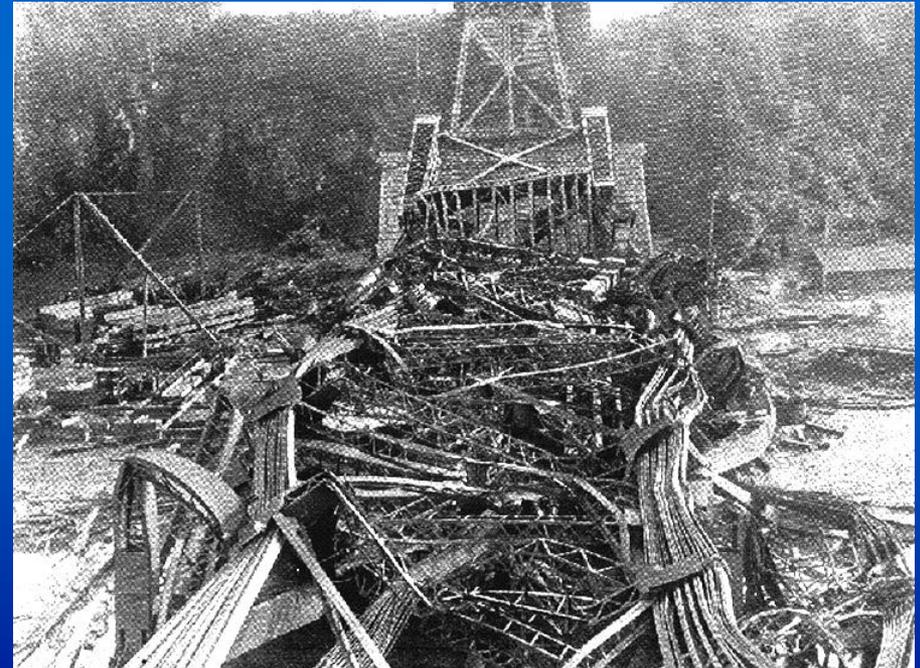


Andrade creep test - at constant true-stress during uniform deformation of test sample

weight submerged into liquid



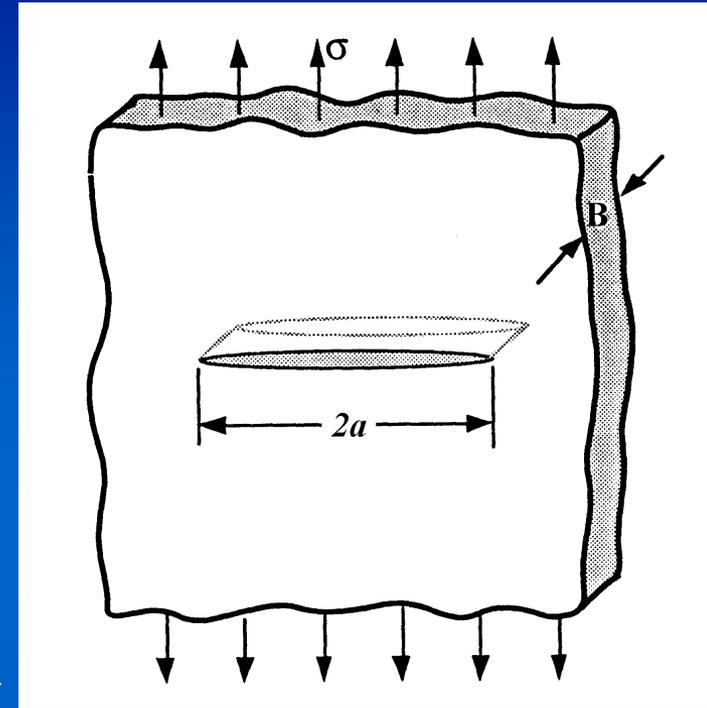
bridge in Quebec  
– bar construction



- **technical progress**  
gas turbine, strain transducers (strain gauges)
- **newly applied / introduced structural materials**  
stainless steel, tungsten carbide (cutting tools)
- **progress in testing**  
understanding to fracture – Griffith
- **failures, accidents, crashes**  
railway wheels, rails  
they are, some of them explained but still catastrophic, low predictability

## Griffith

- Energy balance (energy conservation law)
- Infinitely large plate loaded by constant stress, internal crack, thickness B
- Work associated with new fracture surface increment (crack propagation) “covered” by elastic energy released in surrounding of the growing crack



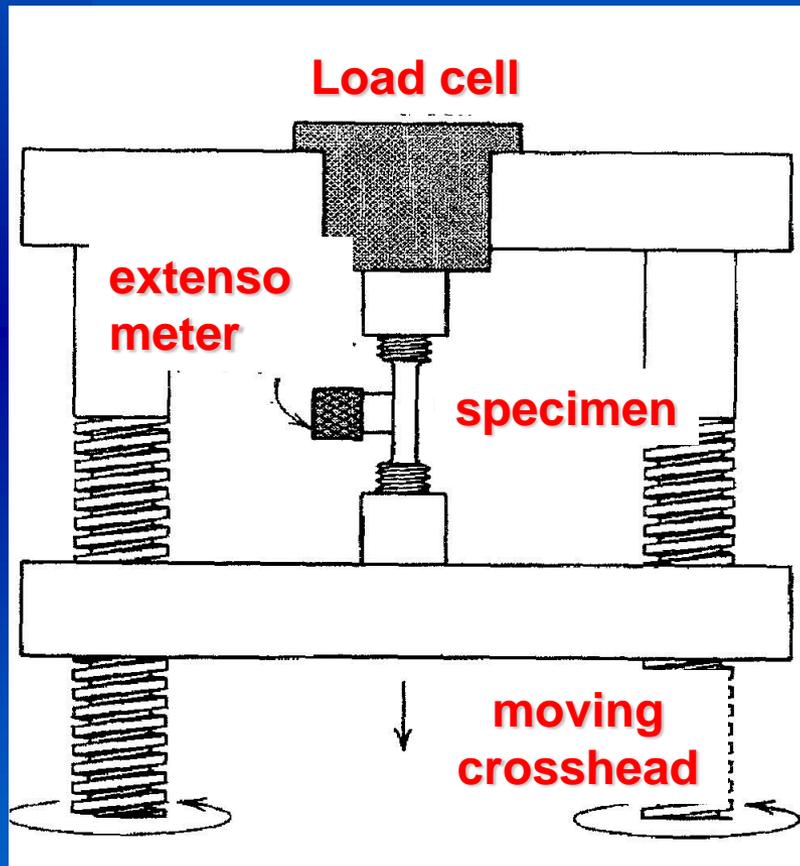
$$-\frac{dW_{el}}{dA} = \frac{dW_s}{dA}$$

$$\sigma_f = \left( \frac{2.E.\gamma_s}{\pi.a} \right)^{1/2}$$

- **technical progress**  
controlled nuclear reaction, jet airplane, transistor, computer, sputnik (satellite)
- **newly applied / introduced structural materials**  
Ni alloys, Ti alloys, glass fibre reinforced plastics
- **progress in testing**  
electronic test machine, low cycle fatigue - Coffin, fracture mechanics – Irwin
- **failures, accidents, crashes**  
Liberty ships, Comet airplanes, steam generators

# Period 1940 - 1960

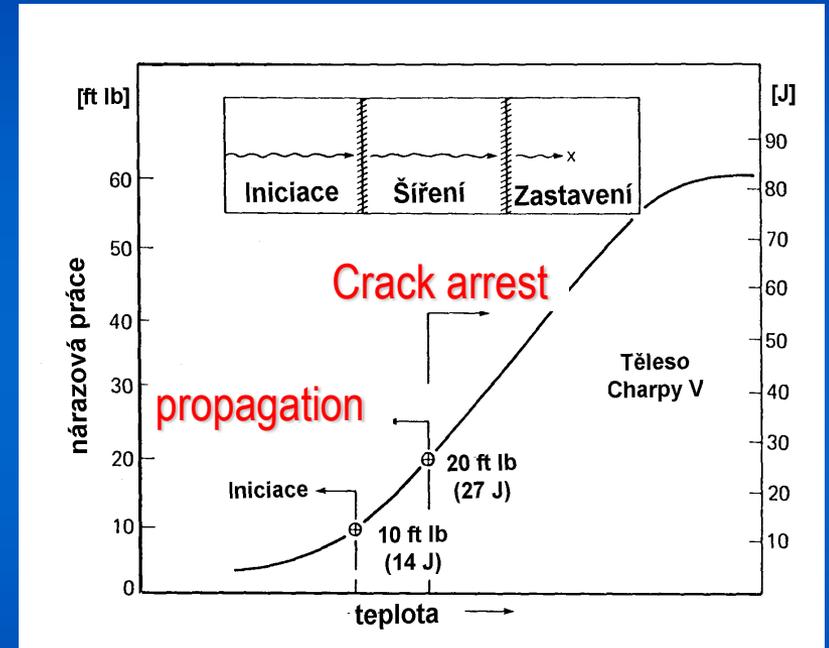
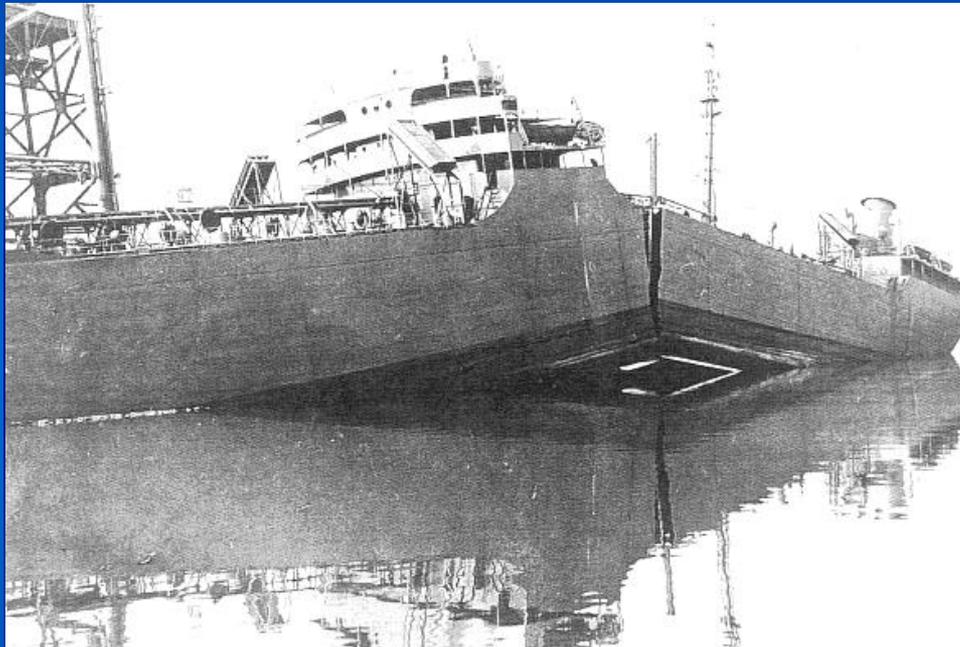
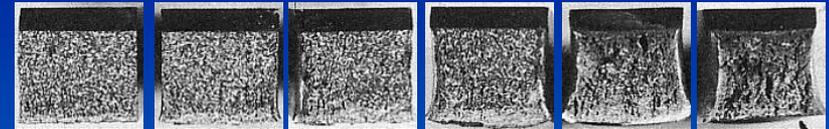
## Electronic test machine



# Period 1940 - 1960

*Mechanical testing of materials*

## Accidents of Liberty ships



**1943 – fully welded ships Liberty**

**In total 2 700 ships - failures, 400 damaged by brittle fracture, 90 very seriously and 20 totally destroyed**

**Naval Research Laboratory in Washington D.C.**

**Period 1940 - 1960**

*Mechanical testing of materials*

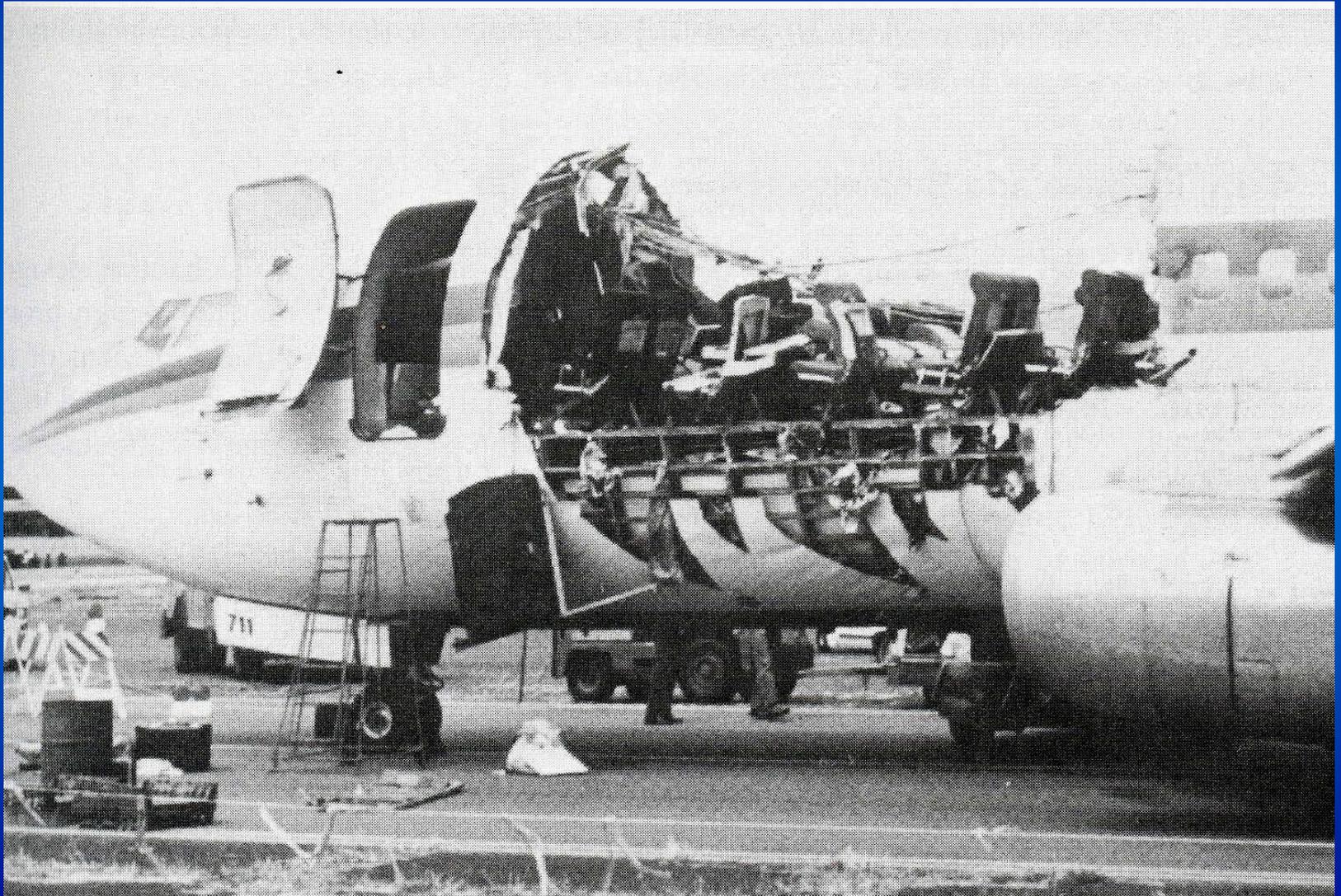
**airplane Comet, 1953-1955, several catastrophic accidents**



## Period 1940 - 1960

*Mechanical testing of materials*

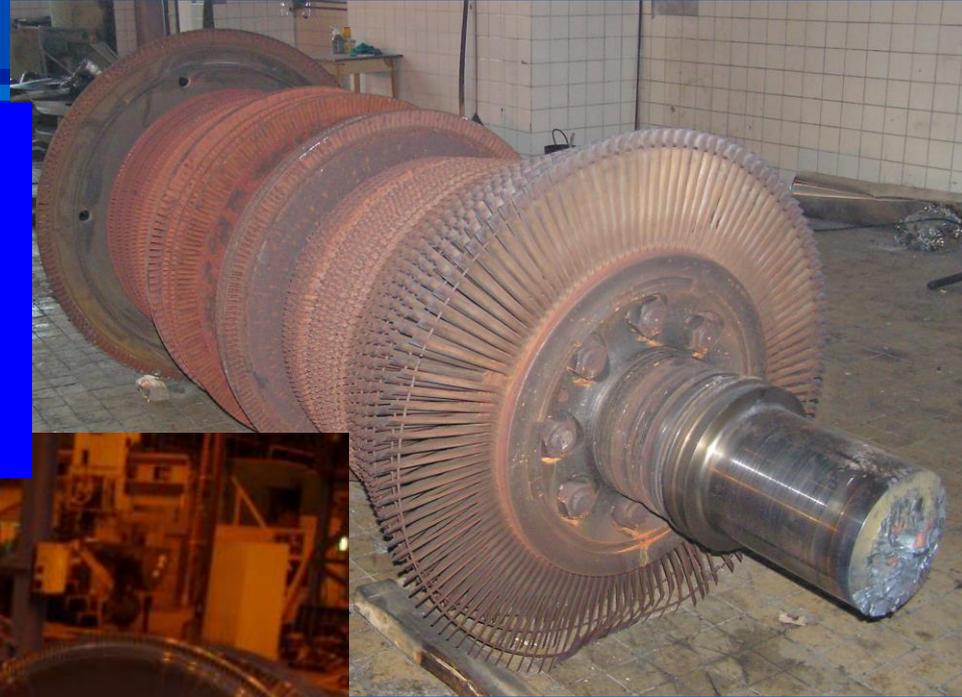
airplane Comet, 1953-1955, landed after crash



## Period 1940 - 1960

steam generator – after 55 years  
of operation and .....

after first several hundreds of  
speed of operational life



Human error > idiocy

# Period 1940 - 1960

Irwin – beginning of fracture mechanics

$$k \sqrt{2\pi} = K_I$$

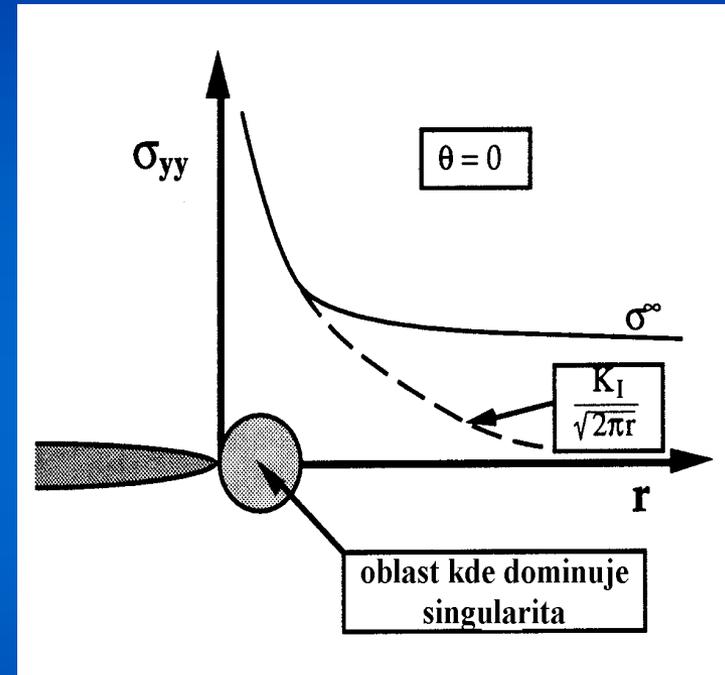
notions:

stress intensity factor

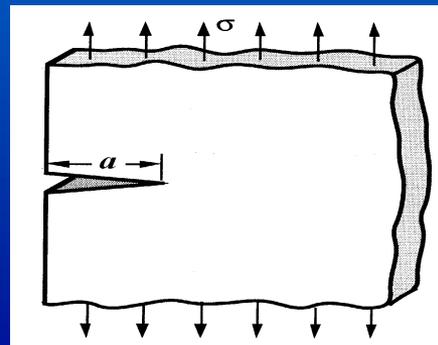
fracture toughness

crack driving force

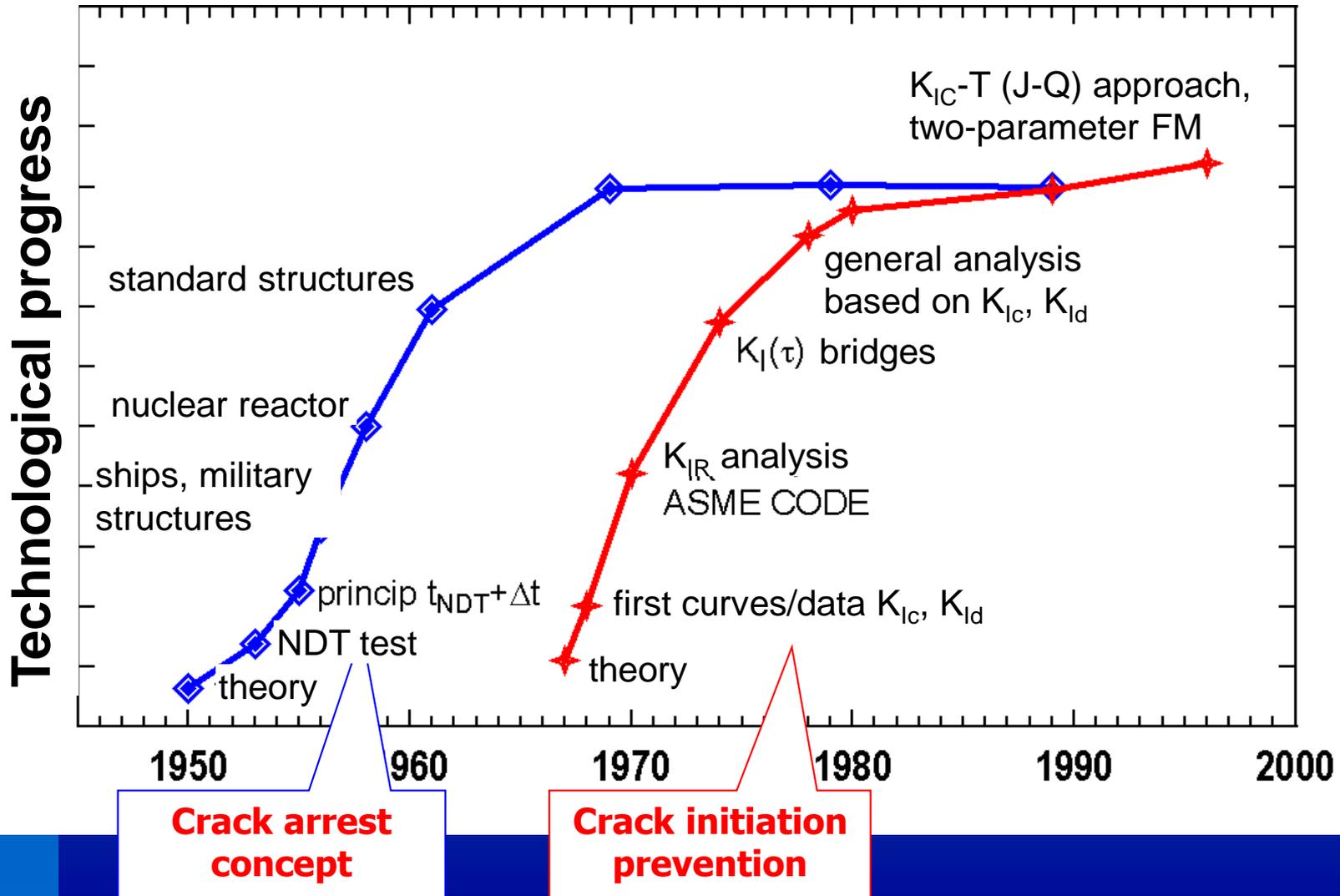
crack propagation resistance



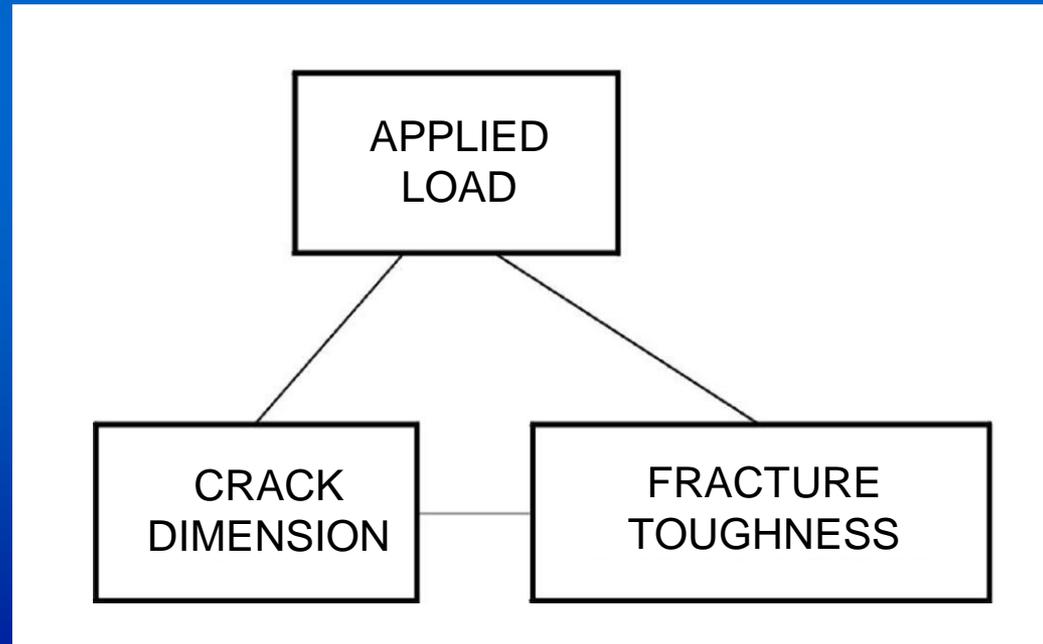
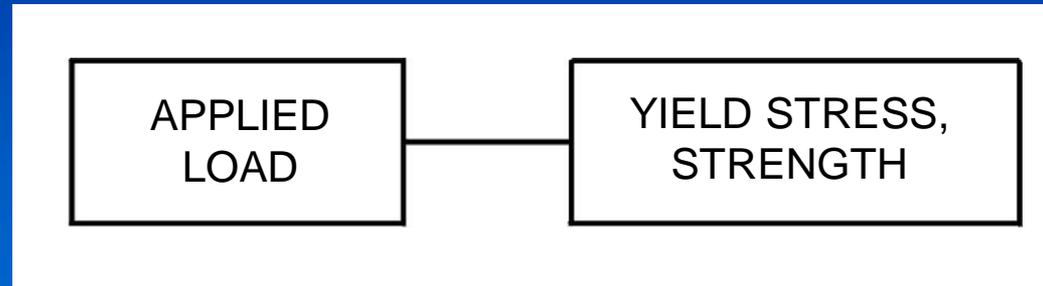
$$K_I = \sigma \sqrt{\pi \cdot a}$$



## Irwin – beginning of fracture mechanics

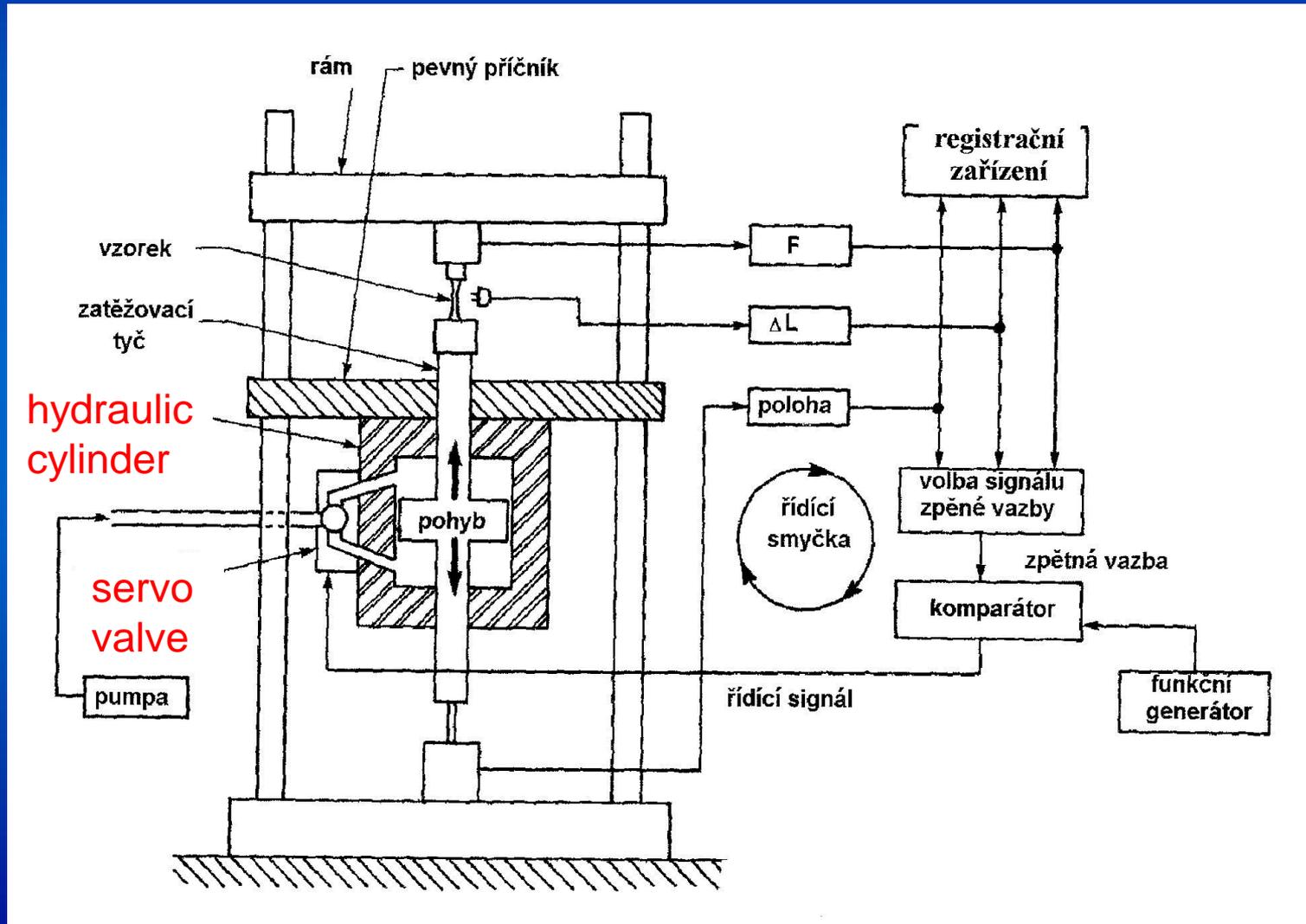


## Irwin – beginning of fracture mechanics



- **technical progress**  
laser, microprocessor, man on moon
- **newly applied / introduced structural materials**  
HSLA steels, composites
- **progress in testing**  
test machine controlled using feed back,  
computer controlled test machine, fatigue crack  
propagation law
- **failures, accidents**  
airplanes F-111, high-way bridges, nuclear  
power stations, large constructions, complex  
effects, better predictability, **human error**

# hydraulic test machine with feed back controlled regime



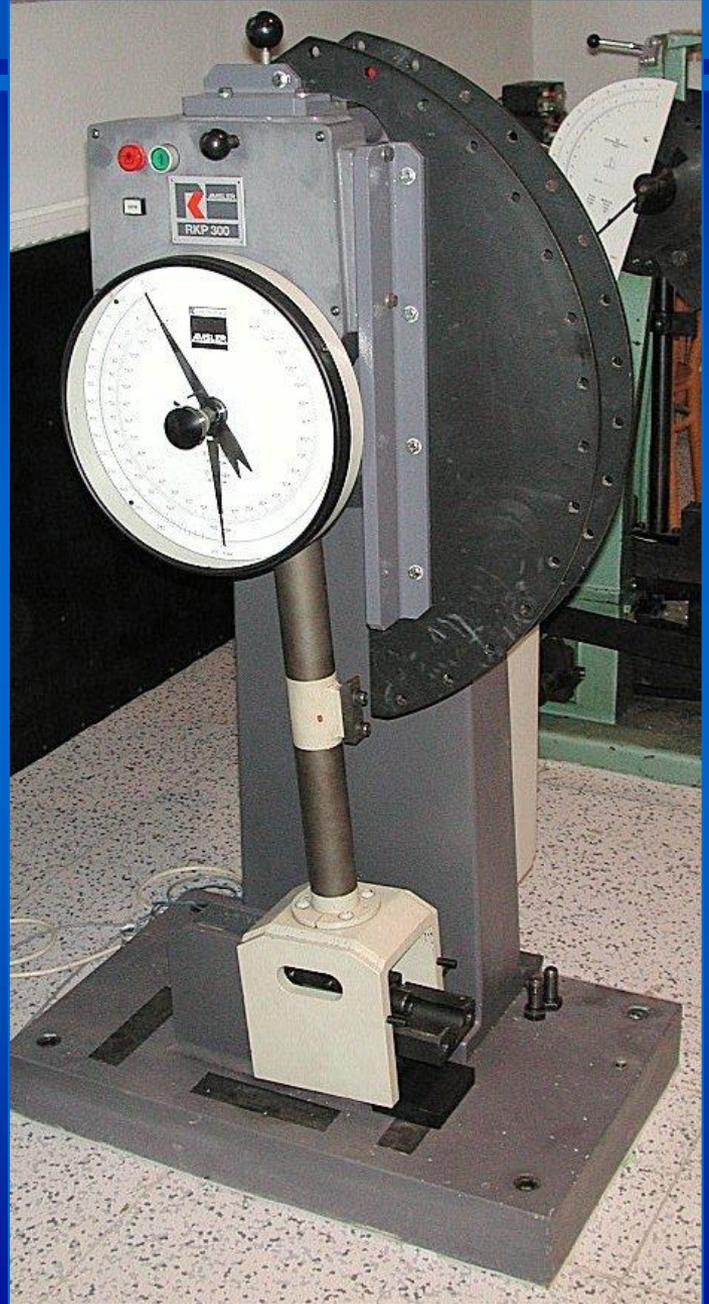
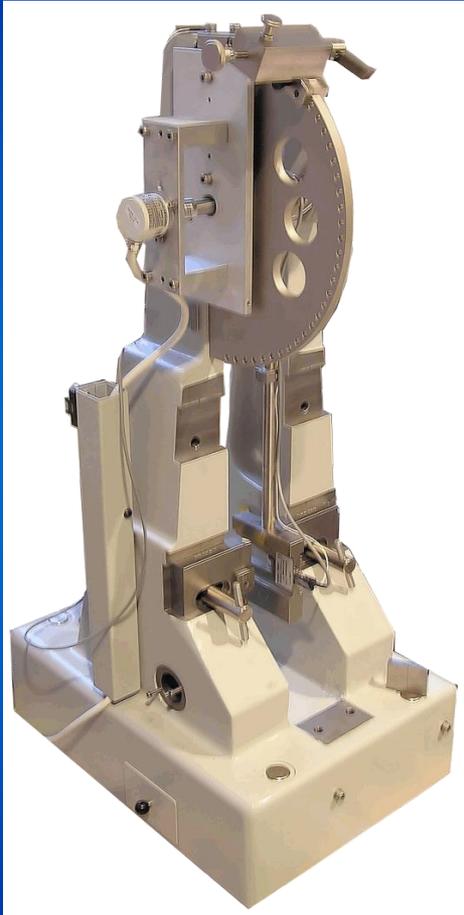


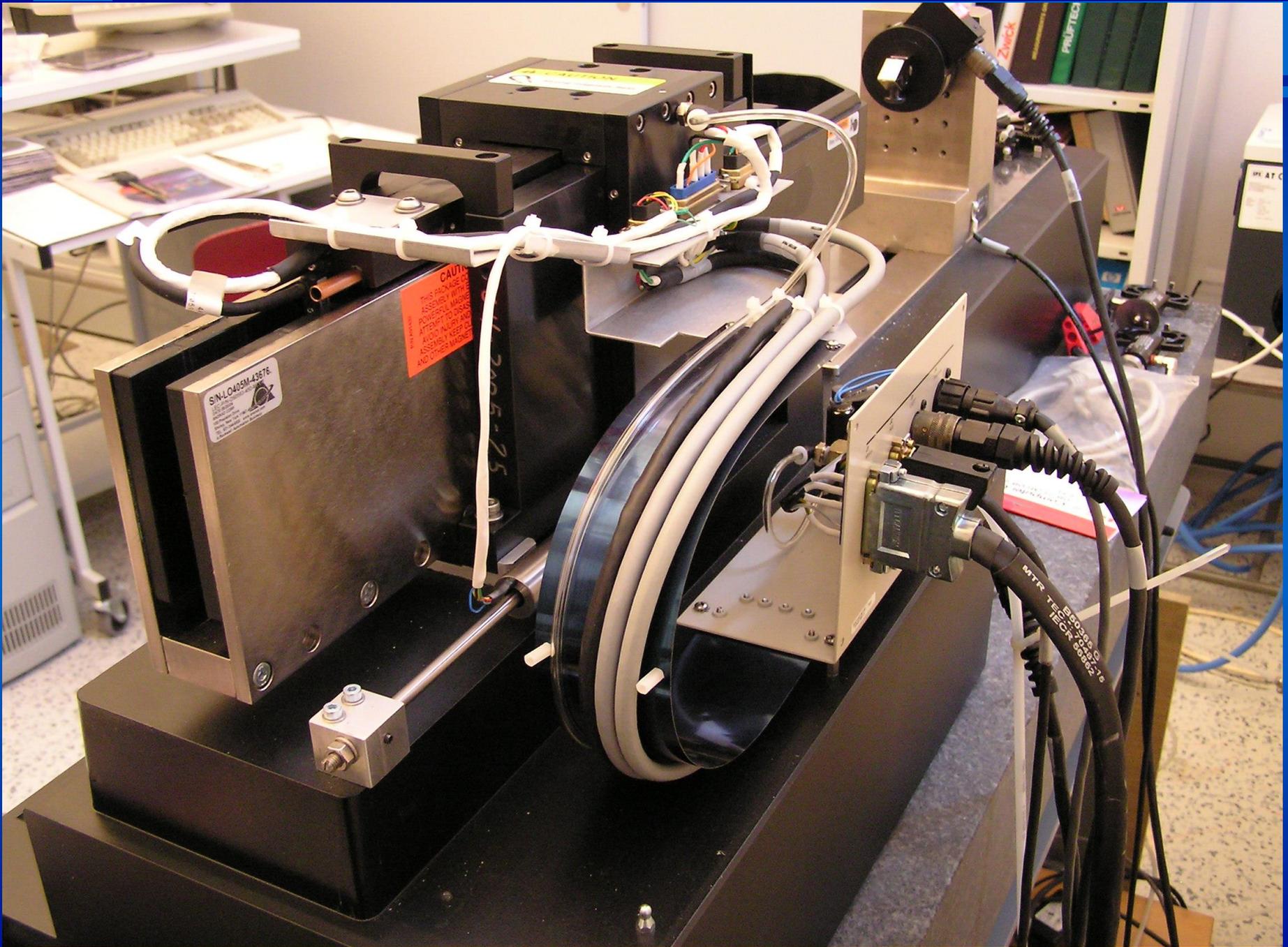
# Period 1980 until today

*Mechanical testing of materials*

- **technical progress**  
space labs, space shuttle
- **newly applied / introduced structural materials**  
duplex steel, structural ceramics
- **progress in testing**  
multiaxial testing, direct digital control of test machines
- **failures, accidents**  
orthopaedic/surgical implants







- human inattention and lack of education
- application of new advanced material not tested under given condition of use

## Pressure vessel for pascalisation of food vegetable, softs etc.



**Martensitic stainless steels**

**Strength design with high safety factors**

**High pressure tests before operations (auto-fretage)**

**State after third high pressure test**

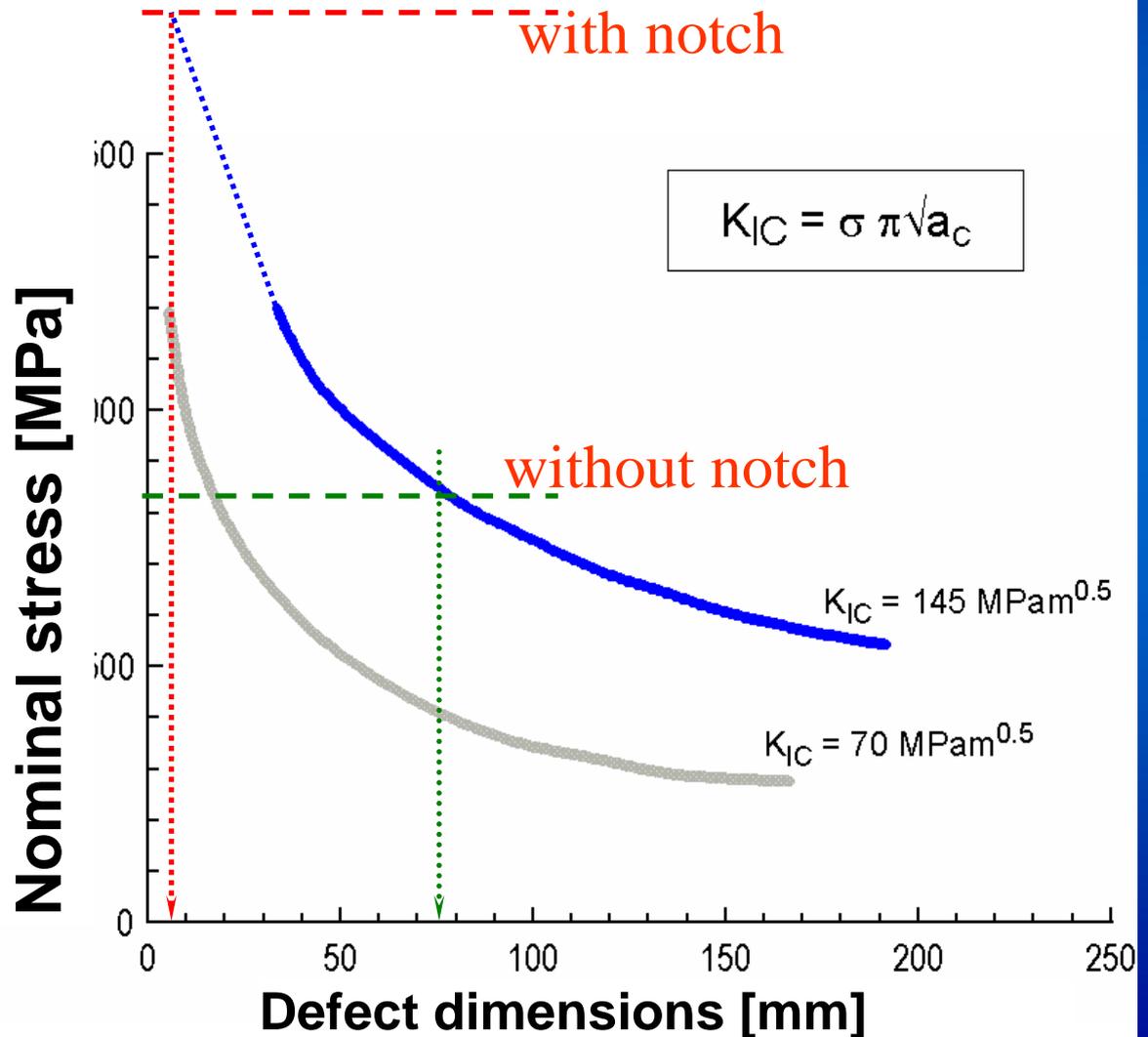
# Causes of accidents in present time

*Mechanical testing of materials*

- human inattention and lack of education



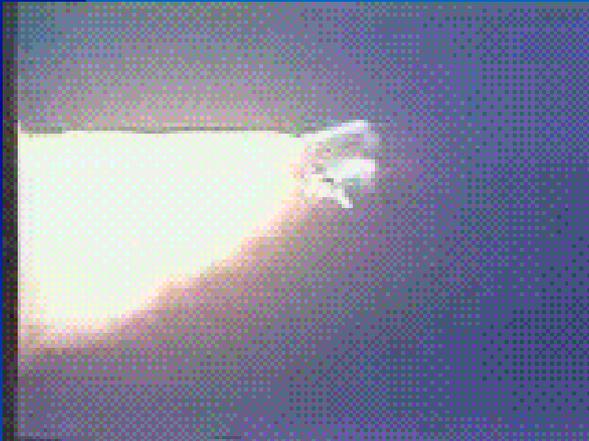
- human inattention and lack of education



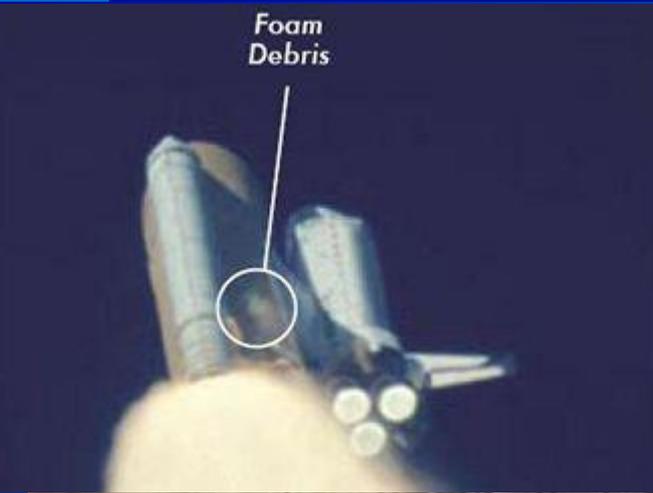
# Příčiny havárií v dnešní době

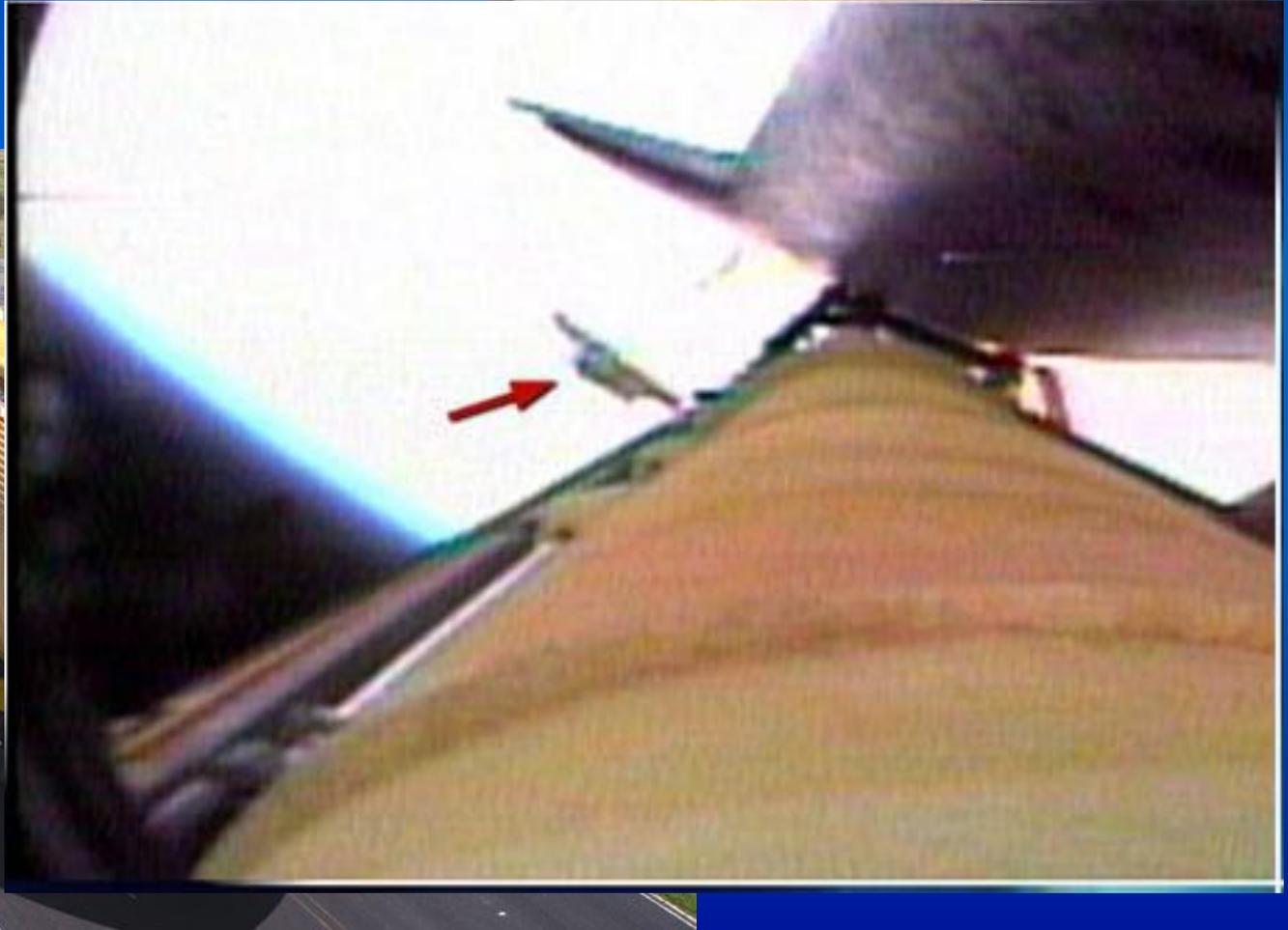
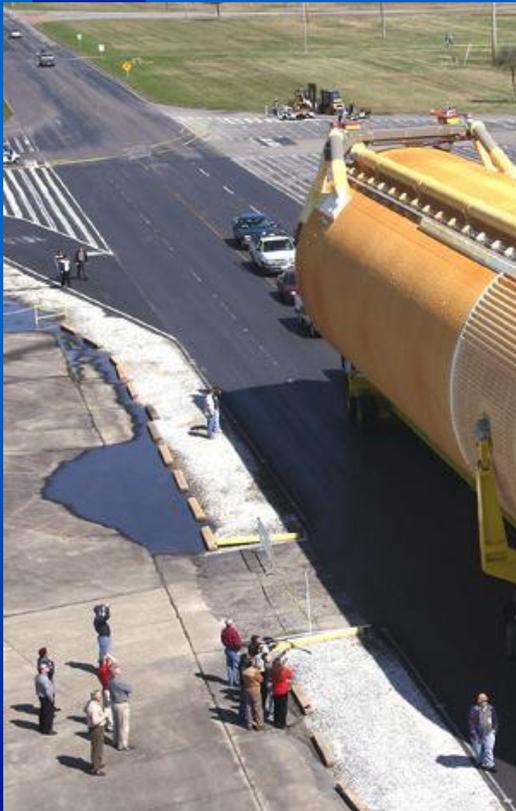
*Mechanical testing of materials*

- human inattention and lack of education  
space shuttle  
28. 1. 1986 1 minute after start, and  
1. 2. 2003 during landing



Foam  
Debris





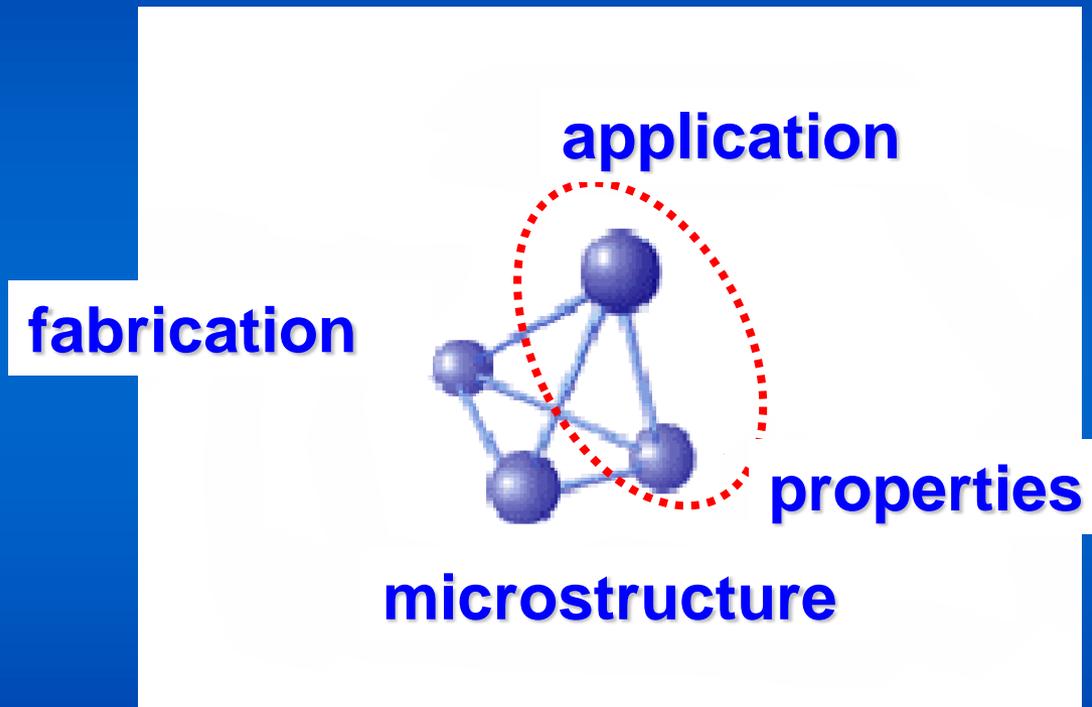


*Mechanical testing of materials*



# Materials design

(knowledge about material based on its use)



(use of the material based on its understanding)