Everyday fracture mechanics, and generation problems.
Summer schools are needed!

László Tóth*

Trzebnica, 3–6 th September 2013

Everyday Fracture Mechanics, and Generation Problems

SUMMER SCHOOLS ARE NEEDED

Prof. Tóth László
University of Debrecen
University of Miskolc
Bay Zoltán Institute, Miskolc
TVE Engineering Ltd.

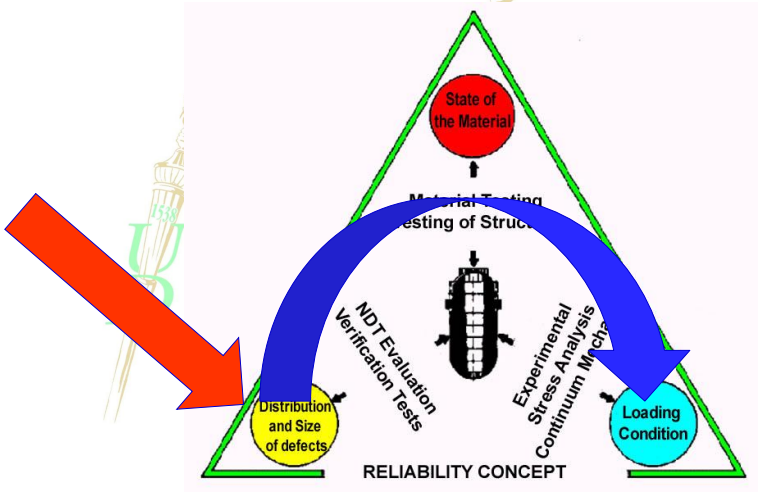
*University of Debrecen, University of Miskolc, Bay Zoltán Institute, Miskolc, TVE Engineering Ltd.

The „basic words" of the ECONOMY

MONEY - PROFIT - COST

- Safety (pure number)
- Reliability (money, investment)
- RISK (money, expenses)

EVERYDAY Fracture Mechanics???



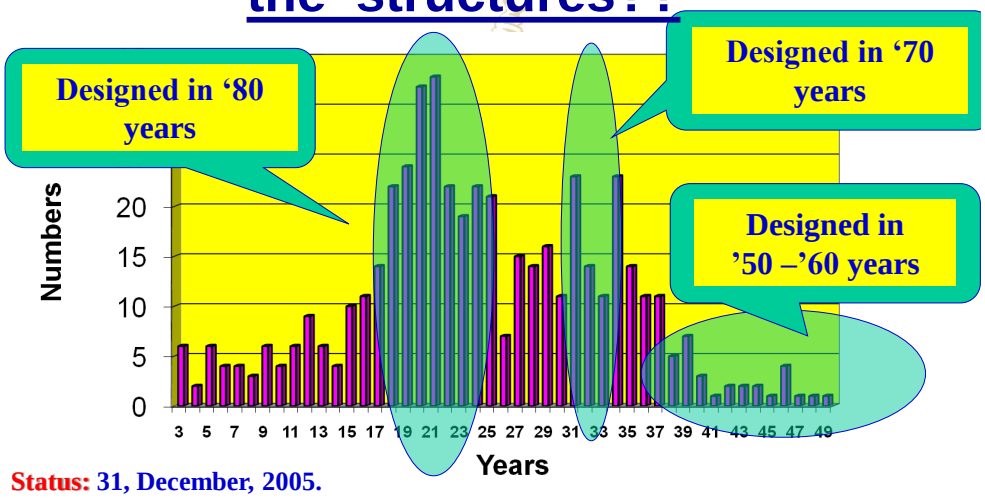
Everyday Fracture Mechanics and Generation Problems – Summer Schools are Needed
Trzebnica, 3-6, September 2013
13th Summer School on Fracture Mechanics

Can be detected the „CRACK-LIKE" defects?

- 1876 Magnetic field testing, A. HERING (USA)
- 1895 X-Ray testing, Wilhelm Conrad RÖNTGEH (D)
- 1925 γ - Ray testing, H. PILON,M.A. LABORDE (F)
- 1927 Magnetic particle testing, A. ROUX (F)
- 1929 Potential-drop, E.A. SPERRY (USA)
- 1933 Penetrate testing, H. REICHERT (D)
- 1936 Eddy current testing, F. FÖRSTER (D)
- 1936 Acoustic-emission testing, F. FÖRSTE[illegible]
- 1942 Ultrasonic testing, Floyd A. FILESTONE (USA)
- 1997 Phase – arrayed UH testing (Tomoscan FOCUS)

YES!! !!!!

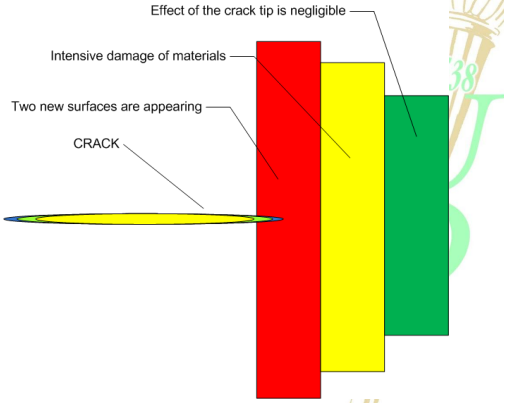
Is there possible the „CRACK-LIKE" in the structures??



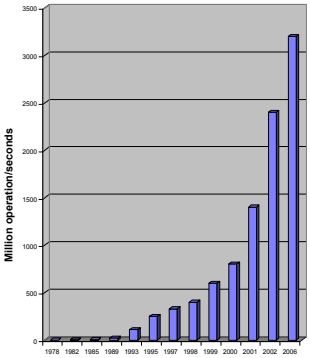
Status: 31, December, 2005.

What are needed to handle the „CRACK-LIKE" defects?

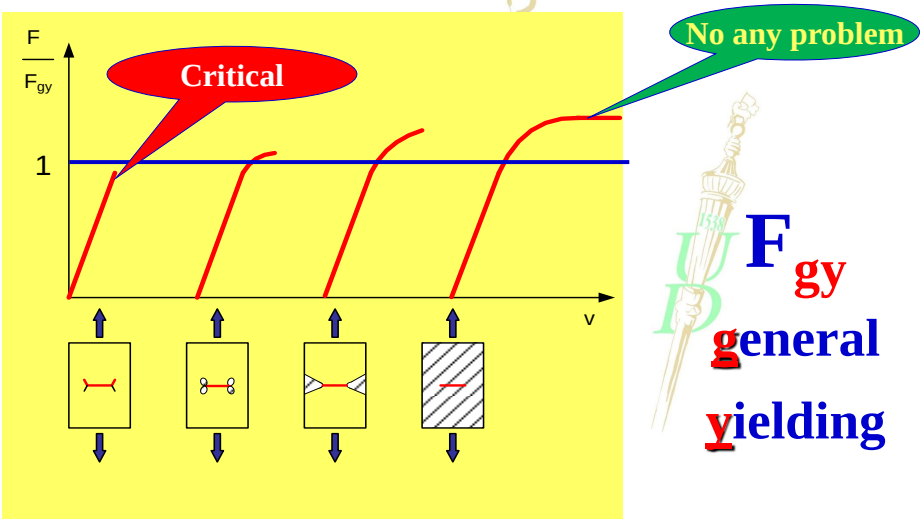
Mechanical models



Tools

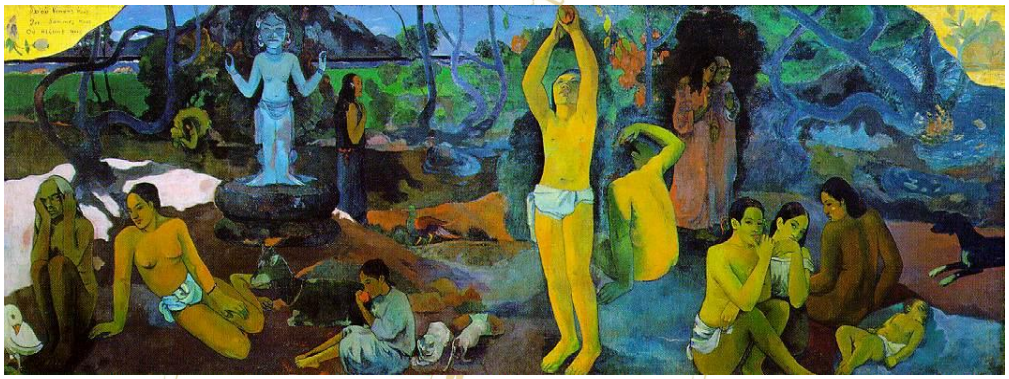


Types of fractures



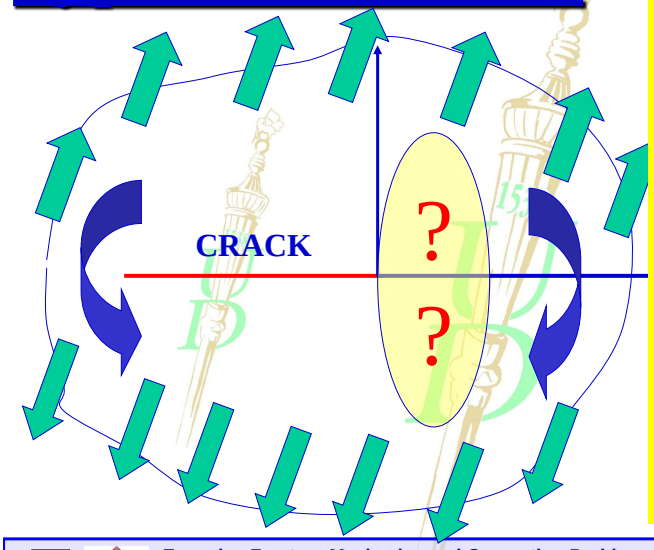
F_{gy}
general
yielding

Where we come from? What we are? Where we going to?



Paul GAUGIN, 1897 (Boston, Museum of Fine Arts, 141x376 cm)
1848. Május 8.- **1903. Június 7.**

Types of Fractures



Goal:

Deteremination of the crack propagation RESISTANCE of materials

What kind of MODEL is needed?

What kind of limit criteria?

What kind of experimental technique?

Mechanical model

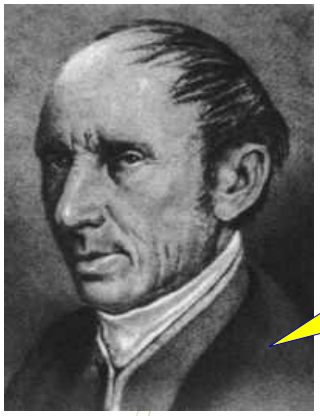
Augustin Louis CAUCHY
1789.08.21. – 1857.05.23.

"Recherces sur l'équilibre et le mouvement intérieur des corps solides ou fluides élastiques ou non-élastiques"

- *30. September1822.*
- Academy of Paris

Royal Society in 1979
"Fracture Mechanics in Design and Service - Living with Defects"

Mechanical model

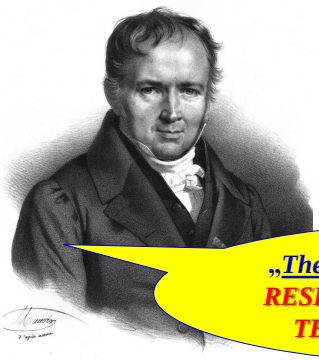


Augustin Louis CAUCHY
1789.08.21. – 1857.05.23.

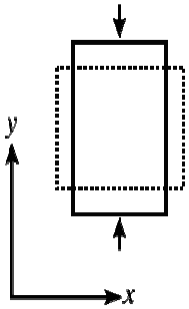
„…Cauchy is crazy guy, and there is nothing to be done against him. But, he is only the person in the word who is the specialist in mathematics…"

- **Elaboration of the ELASTICITY**
- **Two independent ELASTIC PROPERTIES**

Mechanical model



Poisson-ratio



„The life is good only for two things:
***RESEARCHING** of mathematics and*
***TEACHING** of mathematics…”*

$$\nu = -\frac{\varepsilon_x}{\varepsilon_y}$$

Siméon-Denis POISSON
1781.06.21. – 1840.04.25. (59 év)

Mechanical model

- *École Polytechnique*
- I. Sándor vs. XVIII Lajos; St.Pétervár
- Creation of railway-network
- Bridge building
- The FIRST BOOK on Theory of ELASTICITY in 1852

„Leçons sur la théorie mathématique de l'élasticité des corps solides”

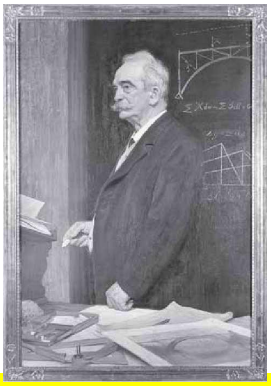
Gabriel LAMÉ
1795.07.22. – 1870.05.01.

Mechanical model

Adhémar Jean Claude Barré de
Saint-Venant
1797.08.23. – 1886.01.02.

- **Correction of the CAUCHY „stress-definition”**
- **Introduction the Poisson-ratio into the theory of elasticity**
- **TORSION of rectangular bars**
- **Principe of LOCAL EFFECT’s: The Principe of Saint Venant**

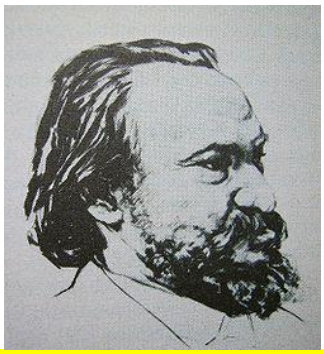
Plastic deformation – plasticity



Christian Otto MOHR
1835.10.08. – 1918.10.02.

- **Scientific adviser at the Royal Railway Company in Hannover (Bridges, railway network, etc.)**
- **Professor at**
  - The Technical High School in Stuttgart
  - The Technical High School in Dresden
- **Mohr-circle, the plastic-limit definition (1882) (in soil-mechanics)**

Material behaviour – plastic deformation



Johann BAUSCHINGER
1834.06.11. – 1893.11.25.

- Mathematics
- Professor at the Technical University of Munich
- Bauschinger - effect
- Experimental determination of material properties - STANDARDISATION

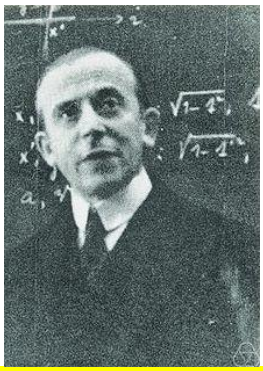
Bauschinger conferences: 1884, 1886, 1890 and 1893

Plastic Deformation

Maximillian Titusz HUBER
1872.01.04.– 1950. 12.09.
Lviv-Boston

- Civil engineer
- Teacher of the University of Lemberg
- Formulation of the circumstances of plastic deformation (in the thesis – 1904- Centenary in 2004, distortion energy)

Plastic deformation



Richard von MIESES
1883.04.19.– 1953. 07.14.
Lviv-Boston

- Mathematician, Physicist, Engineer
- Prof. at the Technical High School of Dresden, University f Berlin Theory of the distortion energy
- Yielding criteria on the basis of distortion energy (1913)

Plastic Peformation

Henrich HENCKY
1885.11.12.– 1951. 07.06.

- Mechanical Engineer (Darmstadt)
- Elzasz-Lotharingia Railway Company, Ukraine (Harkov)
- Delft, MIT, Harkov, State University Moscow, Iljusin Institute,
- Yielding criteria on the basis of distortion energy (1923)

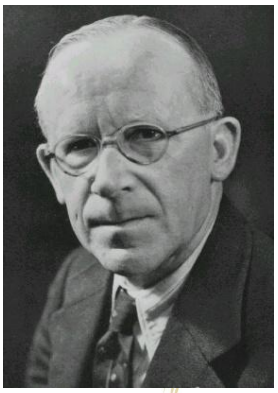
HUBER-MIESES-HENCKY

Stresses at the sharp notches

Karl WIEGHARD
1874.06.21.– 1824. 06.10.

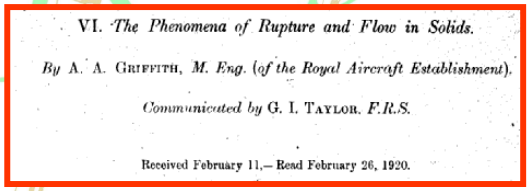
- **Herzogliche Technische Hochschule, than Hannover,**
- **University of Vienna (than Dresden)**
- **Split (cleave) of elastic body, 1907**
- **The singularity problem at the vicinity of sharp notches $1/\sqrt{\rho}$** (ρ-distances measured from the notch tip)

Fracture Mechanics- CRACK problems



Alan Arnold GRIFFITH
1893.06.13.– 1960. 10.13.

- **Mechanical Engineer (London, BSc és Liverpool University MSc)**
- **Aerodynamics**
- **Royal Aircraft Establishment**
- **Rolls-Royce**
- **Founder of FRACTURE MECHNICS**



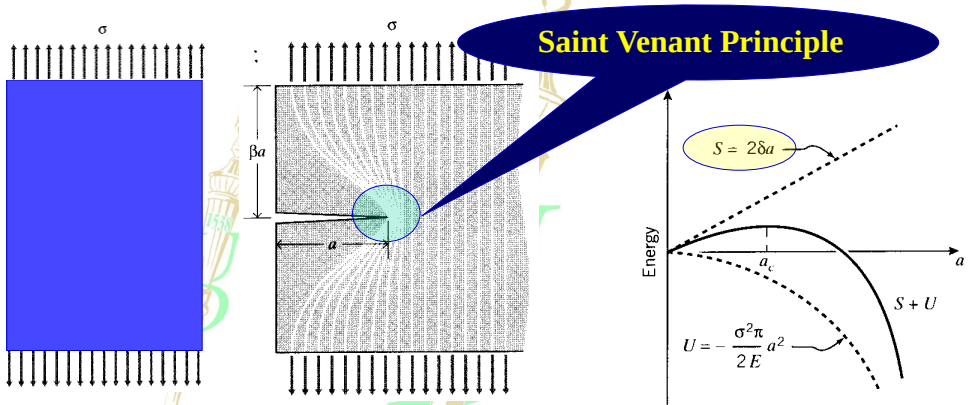
VI. *The Phenomena of Rupture and Flow in Solids.*

By A. A. Griffith, *M. Eng. (of the Royal Aircraft Establishment).*

Communicated by G. I. Taylor, *F.R.S.*

Received February 11,— Read February 26, 1920.

Fracture Mechanics - CRACK



$U=E\varepsilon^2/2=\sigma^2/2E$

$$U = -\frac{\sigma^2}{2E} \cdot \pi a^2$$

$$S = 2\gamma a$$

Fracture Mechanics - CRACK

$$\frac{\partial(S+U)}{\partial a} = 2\gamma - \frac{\sigma_f^2}{E}\pi a = 0$$

$$\sigma_f = \sqrt{\frac{2E\gamma}{\pi a}}$$

$$\sigma_f = \sqrt{\frac{E\mathcal{G}_c}{\pi a}}$$

Later in the'50th: G. IRWIN

Solution of the plain problems (ΔΔF=0)

Sir George Biddel AIRY
1801.07.27.– 1892. 01.02.

- Trinity College
- Director of the Observatory in Cambridge
- Royal Astronomer
- Airy - function (1863)

$$\sigma_x = \frac{\partial^2 F}{\partial y^2},\ \sigma_y = \frac{\partial^2 F}{\partial x^2},\ \tau_{xy} = -\frac{\partial^2 F}{\partial x \partial y}.$$

Where F-function (algebratic or trigonometric) in progression form which is fulfilling the boundary conditions. The parameters of the progression are determined from this condition.

The soulion of the PLAIN problems

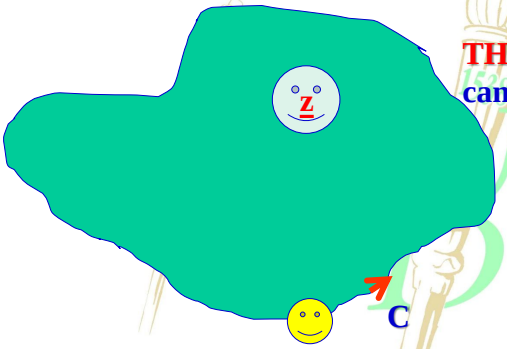
Jurij Vasziljevics KOLOSOV
1867.08.25.– 1936.11.07.

- Mathematician, engineer
- University of St. Petersburg. Mat-Phys. Faculty, Estonia, St. Petersburg
- „Application of the COMPLEX-Function for the solution of the [illegible]N problem of the elasticity”

Two functions are needed

$$\sigma_y + \sigma_y = 2\left\{\varphi'(z) + \overline{\varphi'(z)}\right\} = 4\,\mathrm{Re}\left\{\varphi'(z)\right\},$$
$$\sigma_y - \sigma_x + 2i\,\tau_{xy} = 2\left\{\bar{z}\,\varphi''(z) + \psi'(z)\right\},$$
$$2\mu(u+iv) = \kappa\varphi(z) - z\,\overline{\varphi'(z)} - \overline{\psi(z)}.$$

The importance of the COMPLEX FUNCTIONS (Cauchy)



THAN: in any z point the value of f(z) can be determined

$$f(z) = \frac{1}{\pi i} \oint_C \frac{f(\xi)}{\xi - z}$$

If: f(ξ) is known in ξ

The solution of the PLAIN problem

Niko MUSZHELISVILI
1891.02.16.– 1976.07.16.

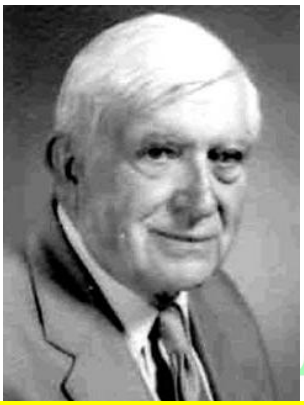
- Mathematician, engineer
- University of St. Petersburg. Mat-Phys. Faculty, St. Petersburg
- State University of Tbiliszi, Department for Mathematics
- Founder of the Georgian Academy of Sciences
- *„Some basic problems of mathematical theory of elasticity"*
- *Solution of the singular problems of elasticity by* ***CONFORM TRANSFORMATIONS***

The solution of the PLAIN problem

Harald Malcom WESTERGAARD
1888 Copenhagen -1950 Harvard University

- Student at the Universities of Gottingen, Munich
- Teacher at University of Illinois,
- Dean at Harvard University Engineering Faculty (1936-50)
- Axi-symmetrical problems
- Only ONE F-function is needed!

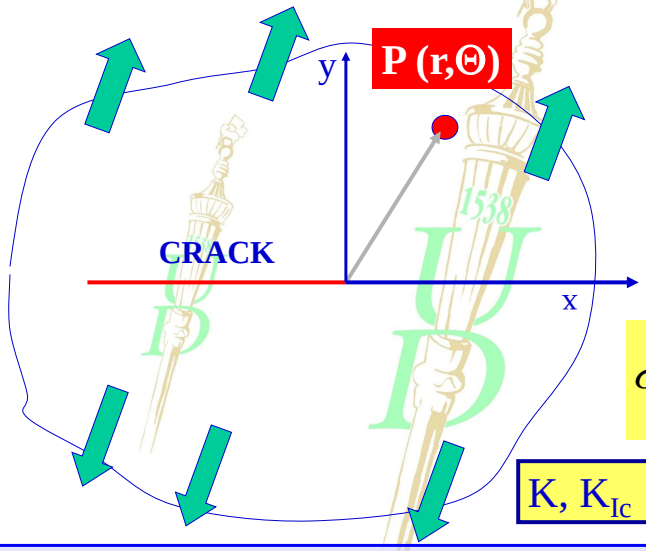
The solution of the PLAIN problem



Ian Naismith SNEDDON
1919.12.08. – 200.11.04.

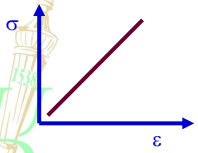
- Scottish Mathematicians, Glasgow
- Invited professor in Poland, Soviet union
- Member of Polish Academy of Sciences
- Musician at professional level
- ***1969*** ***”Crack problems in the classical theory of elasticity”***

Linear Elastic Fracture Mechanics



What kind of model?

Linear elastic



$$\sigma_{ij} = \frac{K}{\sqrt{2\pi r}} f_{ij}(\Theta)$$

$K, K_{Ic} \Rightarrow MPa\sqrt{m}$

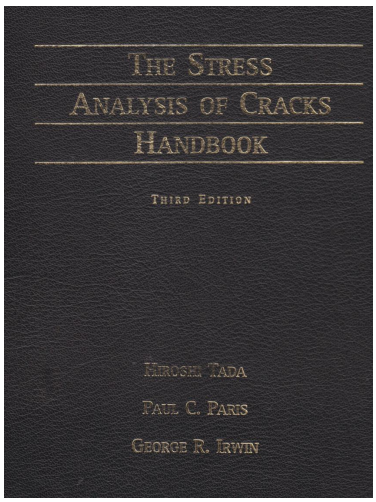
What are the consequences of the model??

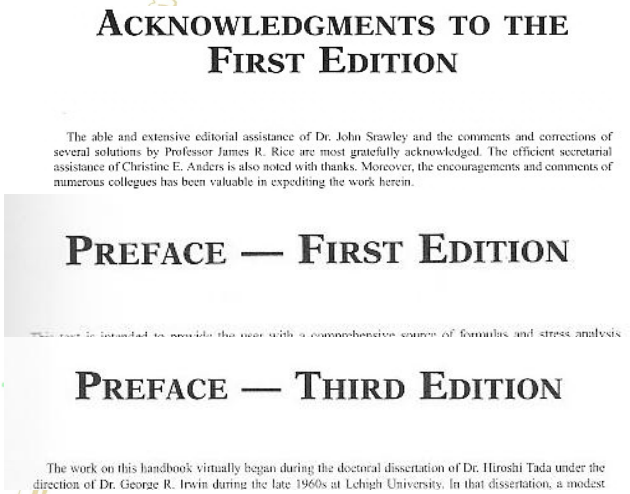
- Singularity of the stresses at the crack tip
- Invariant quantity of the K values (the same condition can be produced in any structures)
- K_{crit}=material property, ie. Crack propagation resistance, TRANSFERABILITY for structures
- Additivity (K_I, K_{II} és K_{III} can be summarised)
- Definition of the FRACTURE CRITERIA at any loading conditions $K_c=f(K_{Ic},K_{IIc},K_{IIIc})$

K-solution Handbooks

- **Sih: Hanbook of Stress Intensity Factor (1973)**
- **Tada -Paris-Irwin: The Stress Analyis of Cracks Handbook (1973)**
- **Rooke-Cartwrigth: Compendium of Stress Intensity Factors (1976)**
- **Murakami: Stress Intensity Factors (Continously from 1987)**

Handbooks





ACKNOWLEDGMENTS TO THE FIRST EDITION

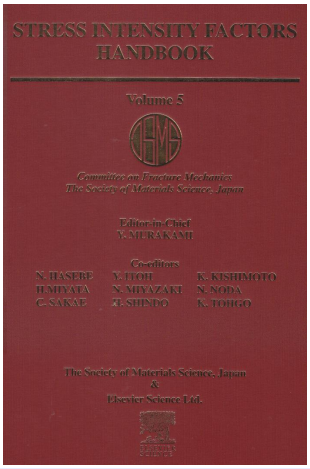
The able and extensive editorial assistance of Dr. John Srawley and the comments and corrections of several solutions by Professor James R. Rice are most gratefully acknowledged. The efficient secretarial assistance of Christine E. Anders is also noted with thanks. Moreover, the encouragements and comments of numerous collegues has been valuable in expediting the work herein.

PREFACE — FIRST EDITION

PREFACE — THIRD EDITION

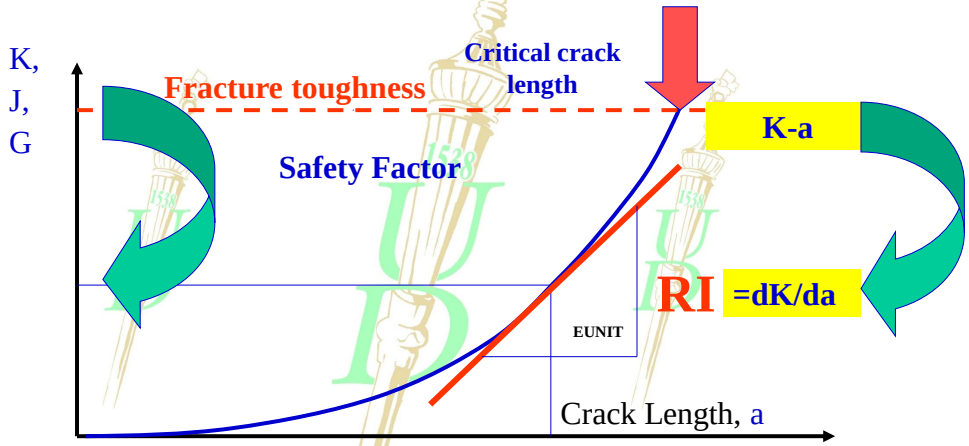
The work on this handbook virtually began during the doctoral dissertation of Dr. Hiroshi Tada under the direction of Dr. George R. Irwin during the late 1960s at Lehigh University. In that dissertation, a modest

Handbooks

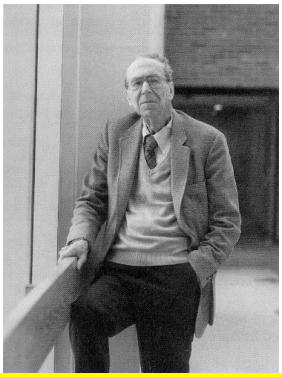


- Murakami Yukitaka
- 1-2 Volumes:1986 12.01.
- 3. Volume 1992
- 4. Volume 2001
- 5. Volume
- Electronic Handbooks

Crack Propagation Sensitivity Index, RI= dK/da



Mathematicans v.s. Engineers, USA

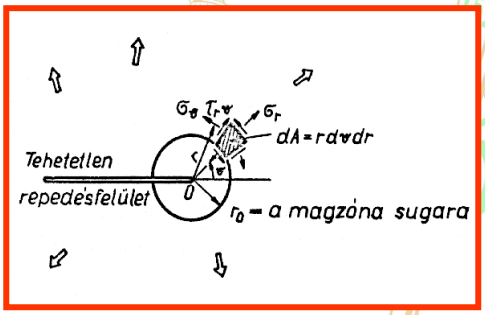


George Rankin IRWIN
1907.02.26. – 1998.10.09.

- Physicist
- USA, Naval Research Laboratory
- Leigh Egyetem (1967-1972)
  Paul C.Paris, G. Sih, teaching aids
- University of Maryland (1972-)
- http://mek.oszk.hu/01100/01191/

G. SIH- 1973, Strain energy density

$$S = f(\vartheta) = K_I^2 + 2a_{12}K_I K_{II} + a_{22}K_{II}^2$$



Crack extension direction

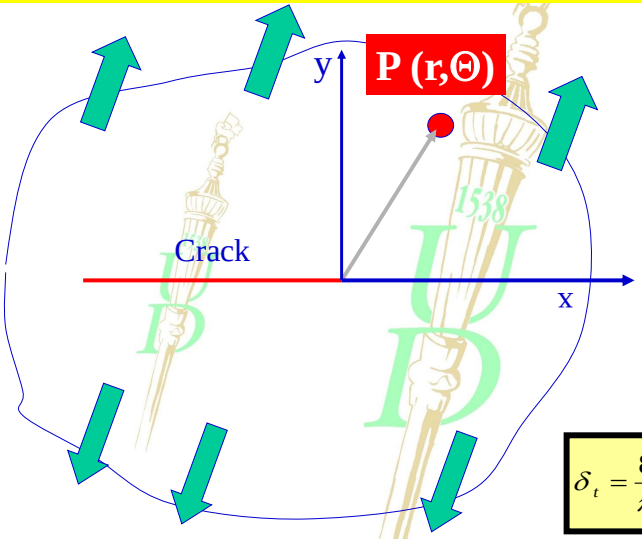
$$\frac{dS}{d\upsilon} = 0$$

Mathematicians v.s. Engineers, Europe

Alan Arthur WELLS
1924.05.01. – 2005.11.08.

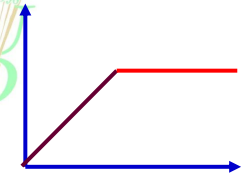
- **Engineer, Nottingham University**
- **Cambridge PostDoc**
- **1951-BWRA applicant**
- **1961 Deputy Director**
- **1964 Queen's University, Belfast**
- **1977- BWRA Director to 1989**
- ***COD, material property measure techniques - 1961***

General Yielding Fracture Mechanics



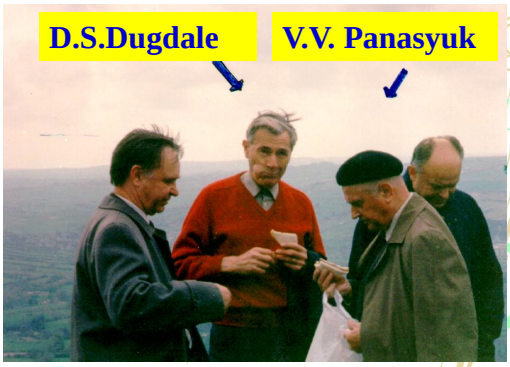
What kind of model ?

Elastic – ideal plastic



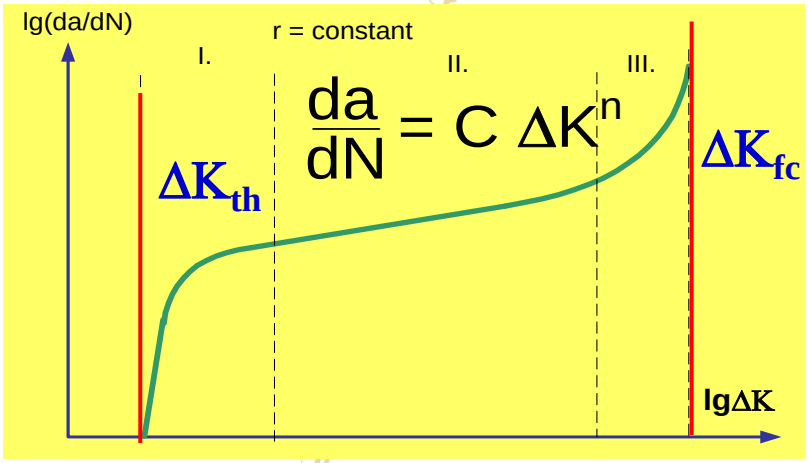
$$\delta_t = \frac{8}{\pi}\frac{R_{eH}}{E} a \ln\left[\sec\left(\frac{\pi\sigma}{2R_{eH}}\right)\right]$$

Crack-tip models

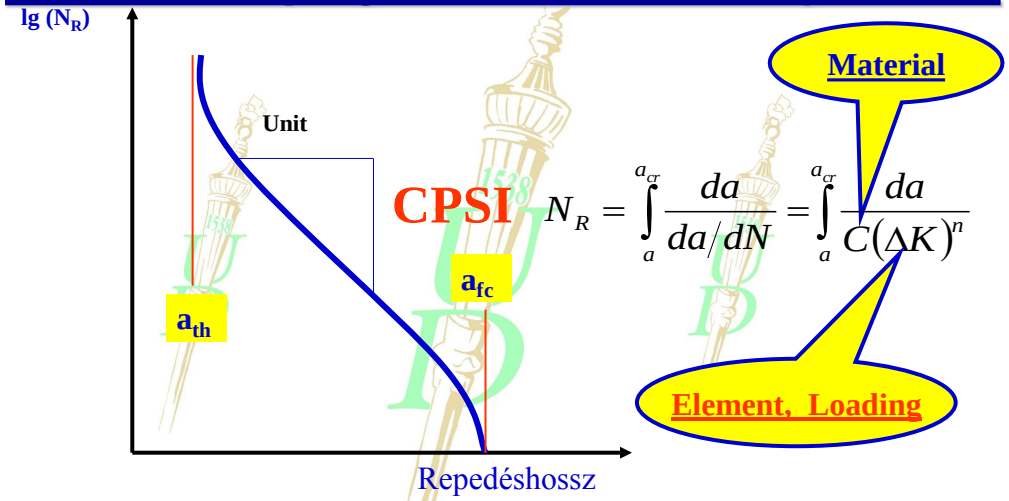


- **Dugdale - 1960**
  - „Plastic wedge"
  - At the crack tip max. yield strength
- **Panasyuk - Leonov 1959**
  - For BRITTLE material
  - Material property can be measured

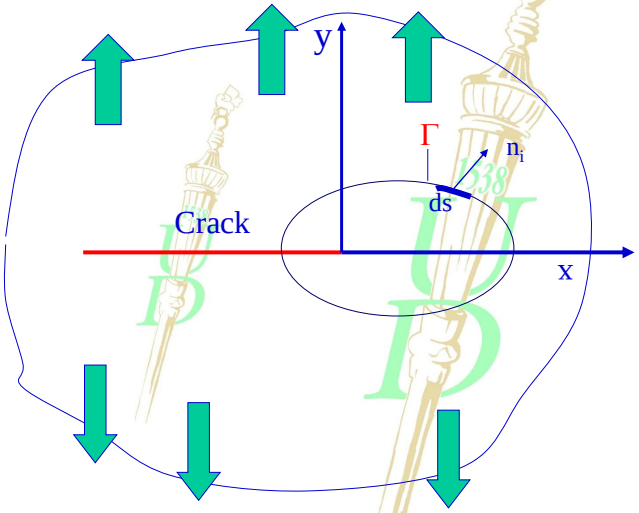
Crack growth under cyclic loading



Crack Propagation Sensitivity Index

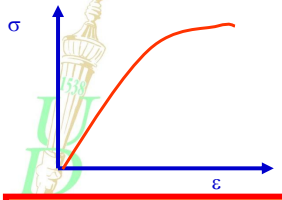


J-integral (Cherepanov 1967, Rice – 1968)



What kind of model?

Non-linear elastic!!



$$J = \oint_{\Gamma} W dy - \oint_{\Gamma} P_i \frac{du_i}{dx} ds,$$

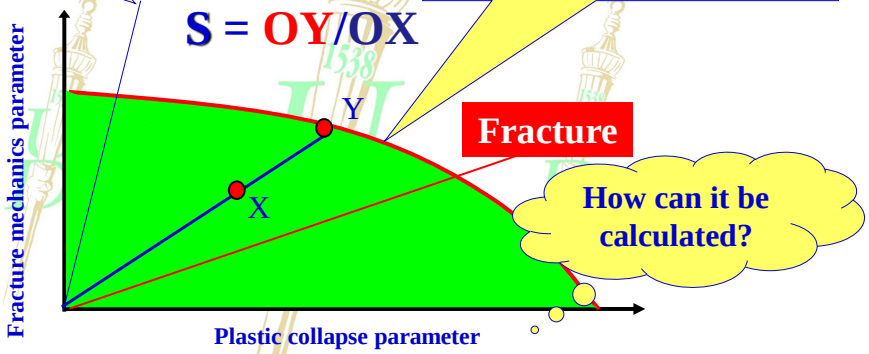
$$W = \int_0^{\varepsilon} \sigma_{ij} d\varepsilon_{ij},$$

$$\varepsilon_{ij} = 0{,}5\left(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j} \right)$$

"Safety diagrams" (from 2000)

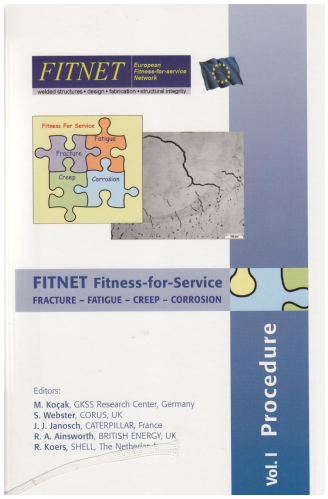
Application limit??

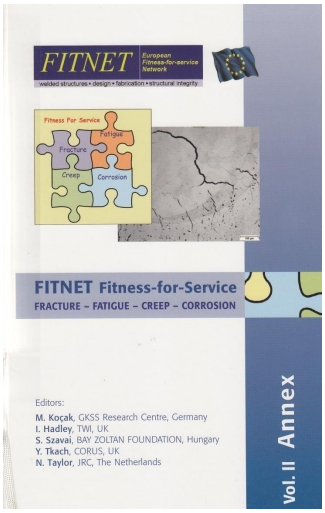
What is the form of the boundary? What is the effect of degradation of material?



How can it be calculated?

The up-to-date methods (SINTAP, FITNET)





FFS procedures (non – nuclear field)

Method	Structure	Country	Introduced
BS 7910	Metal structures	GB	2005
SINTAP	Metal structures	EU	2004
FITNET	Metal structures	EU	2008
R5	Operating at high temperatures	GB	1994
API 579	Oil and Refinary industry	USA	2000
WES 2805	Kötőhegesztések	JPN	1997

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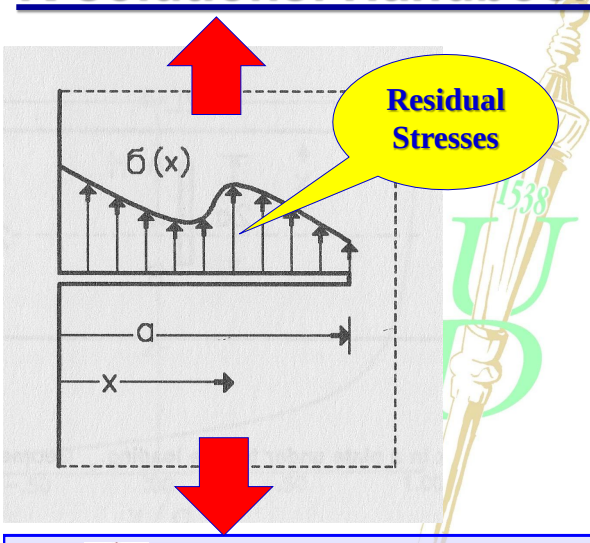
FFS procedures (nuclear field)

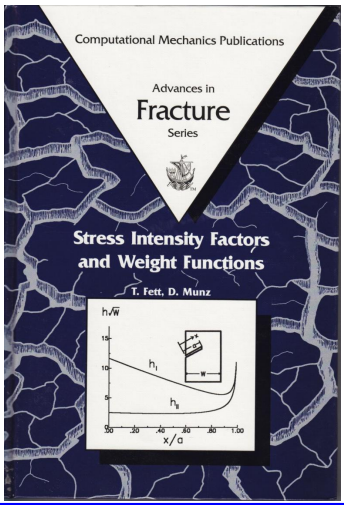
Method	Structural element	Country	Introduced
ASME Sec.XI.	NC	USA	2004
RSE-M	NC	FR	1997
A16 (RCC-MR)	NC	FR	2002
SKIFS	NC	SWE	1996
KTA 3201.4	NC	EU	1999
JSME S NAI	NC	JPN	2004
R6	NC	GB	2001

What kind method suggested to use??

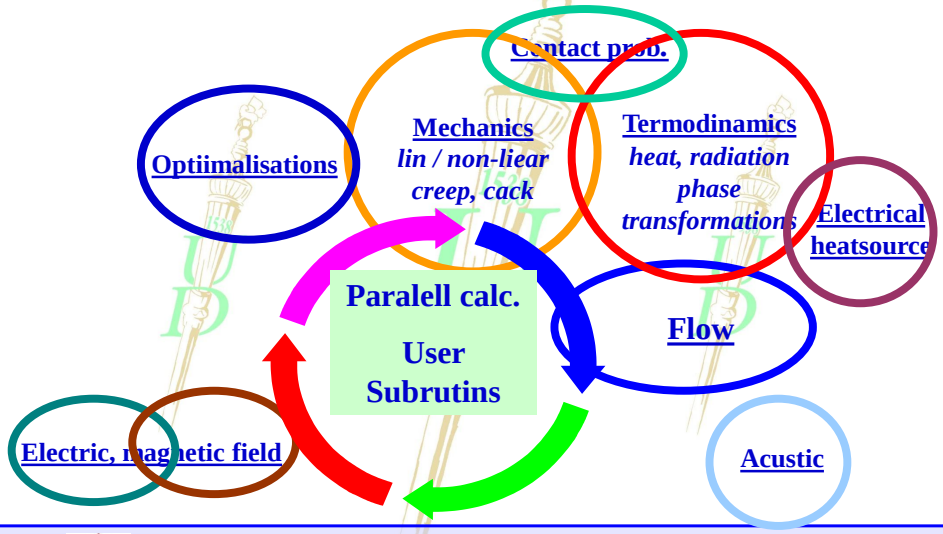
- To start with the MOST CONSERVATIVE one!!!!
- Existence of the NDT procedure for detection the crack POSITION and SIZE!!
- Existence of the K-SOLUTION procedure for any crack positions and loading conditions
- Existence of the STANDARDISED method for determination of CRACK PROPAGATION resistance of material.

K-solutions: Handbooks + Weight funct.





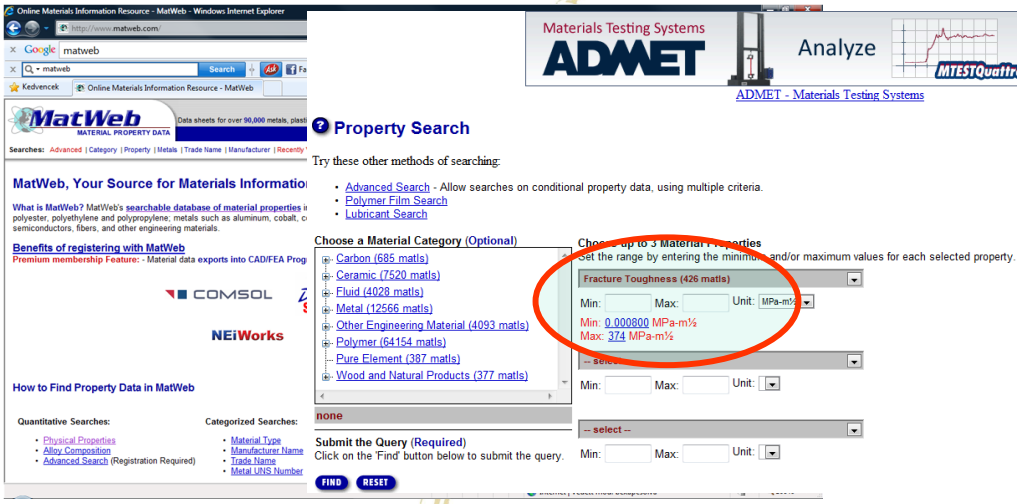
K- solution: Handbooks – Numerical methods



ASTM-Standards

- ASTM E399 - 09e2 Standard Test Method for Linear-Elastic Plane-Strain Fracture Toughness K_{Ic} of Metallic Materials
- ASTM E1820 - 11 Standard Test Method for Measurement of Fracture Toughness
- ASTM D5045 - 99(2007)e1 Standard Test Methods for Plane-Strain Fracture Toughness and Strain Energy Release Rate of Plastic Materials
- STM E2472 - 06e1 Standard Test Method for Determination of Resistance to Stable Crack Extension under Low-Constraint Conditions
- ASTM E1457 - 07e4 Standard Test Method for Measurement of Creep Crack Growth Times in Metals
- ASTM E2760 - 10e1 Standard Test Method for Creep-Fatigue Crack Growth Testing
- ASTM E1290 - 08e1 Standard Test Method for Crack-Tip Opening Displacement (CTOD) Fracture Toughness Measurement
- ASTM D6068 - 10 Standard Test Method for Determining J-R Curves of Plastic Materials
- ASTM E647 - 11e1 Standard Test Method for Measurement of Fatigue Crack Growth Rates

If you don't have measured material data?



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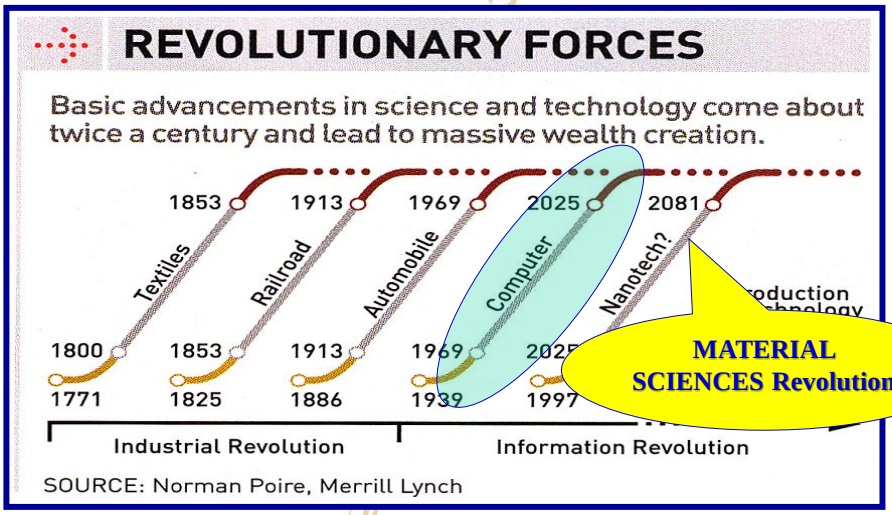
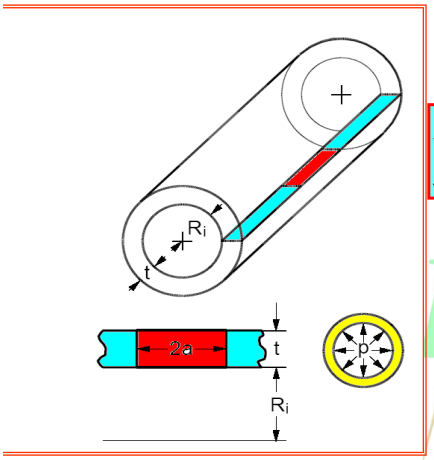
GENERATION Problem: IN GENERAL



Generation Problems

- In the FAMILY
- To find the K-solutions in somewhere (INTERNET)
- To plot the K-a function for a GIVEN structure element
- To prepare the K-a derivate function (for sensitivity analysis)
- To plot the derivative function for a GIVEN structural element
- To perform integration between two crack length ranges
- To plot the N_R vs. Crack length function

GENERATION Problem: in Fracture Mechanics



$$K = F\frac{pR}{t}\sqrt{\pi a}$$

$$F = 1 + 0.072449\lambda + 0.64856\lambda^2 - \\ -0.2327\lambda^3 + 0.038154\lambda^4 - 0.0023478\lambda^5$$

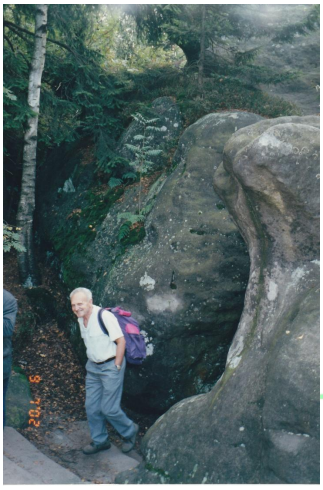
$$\lambda = \frac{a}{\sqrt{Rt}}$$

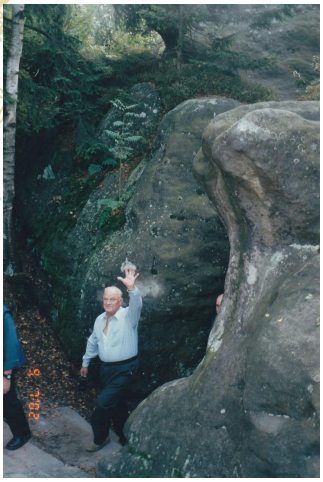
dK/da=????

Concluding remarks

- Fracture mechanics is a well elaborated tool for handling of crack like defects
- Exists NDT method(s) for detecting and sizing the crack like defects
- Assessing the crack-like defects on reliability (or safety conditions) of structures need to be started with the **MOST CONSERVATIVE** procedures, i.e. using **LEFM** procedure.
- All the tools which are using in assessment, are CLEAR.
- In every-day application of FRACTURE MECHANICS we have to consider the GENERATION problem!!! (Summer courses need to be organized!!)

Many thanks to two great PERSONS





Thank you very much for your kind attention!

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