GRUPPO ITALIANO FRATTURA
IGF

I° CONVEGNO NAZIONALE

MILANO 4 MAGGIO 1983
ENEL-CRIS, VIA ORNATO 90/14 - 20162 MILANO

A. DI TOMMASO - Istituto di Scienza delle Costruzioni
Università di Bologna

APPLICAZIONI DELLA M.F. ALLO STUDIO DEL DANNEGGIAMENTO E DELLA FESSURAZIONE DEI CALCESTRUZZI.

Lo studio del danneggiamento meccanico dei calcestruzzi sottoposti a stati di sforzo monotoni e ciclici può essere descritto in termini di M.F. Infatti l'effetto principale del danneggiamento consiste in microfessure di scollamento fra le due "fasi", aggregato a pasta di cemento, che costituiscono il calcestruzzo.
Relazioni empiriche possono anche essere istituite fra comportamento meccanico macroscopico e stati di danneggiamento. Un accenno viene anche fatto alle tecniche di osservazione in grado di descrivere tale danneggiamento.
Un secondo punto nel quale i concetti di M.F. risultano utili è quello della fessurazione, valutato su materiale "omogeneo", data la scala di indagine. In questo caso la M.F. lineare e la M.F. elastoplastica non sembrano direttamente applicabili per le caratteristiche di elevato "softening" che presenta questo materiale. In questo caso vengono esaminati particolari aspetti oggetto di indagini in corso.

1) RICERCHE SUL CALCESTRUZZO

LIVELLI DI INDAGINE

OGGETTO DI INDAGINE

MODELLAZIONE

LIVELLI	OGGETTO	MODELLI	
MICRO-LIVELLO	STRUTTURA CHIM. PASTA DI CEMENTO	"MATERIAL SCIENCE" MODELS	
MESO-LIVELLO	PORI CRACKS INCLUSIONI	"MATERIAL ENGINEERING" MODELS	STRUCTURAL MECHANICS
MACRO-LIVELLO	COMPORTAM. MECC. ELEM STRUTTUR.	"STRUCTURAL ENGINEERING" MODELS	

1.)

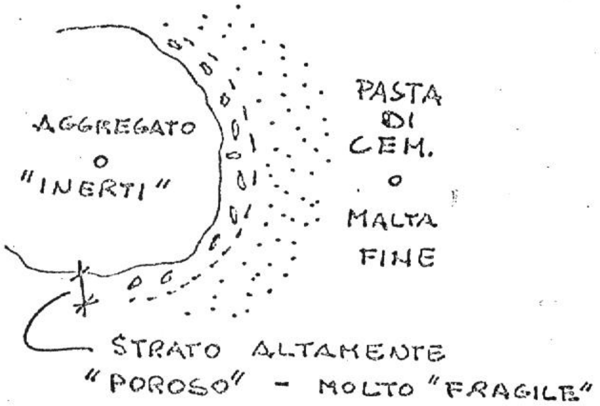
1.1) MICRO-LIVELLO

1.2) MESO-LIVELLO

MATERIAL ENGINEERING MODELS.

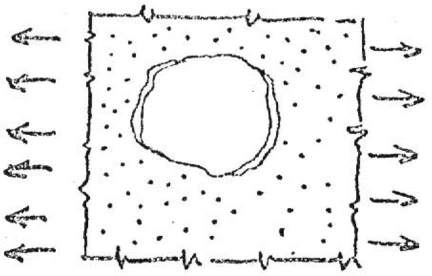
SITUAZIONE

MATERIALI COMPOSTI



FESSURAZIONE IN MATERIALI POROSI

CONSEGUENZA



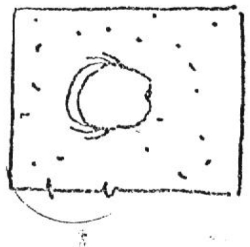
TENSIONI TERMICHE O DA RITIRO ⇒ DEBONDING

CARATTERISTICHE DEL MODELLO

1) NON-LINEARITÀ GLOBALE PER DISSIPAZIONE DI ENERGIA DI FRATTURA.

2) ENERGIA DI FRATTURA ⟷ PERC. AGGREGATO

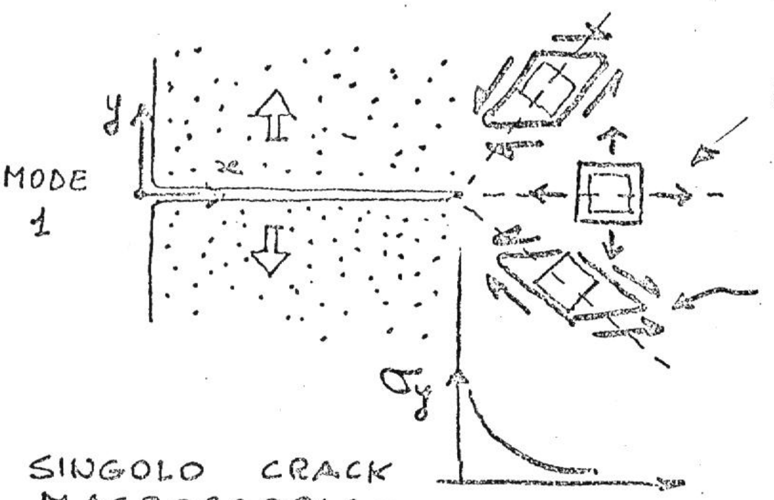
1)



CRACK ARRESTORS !

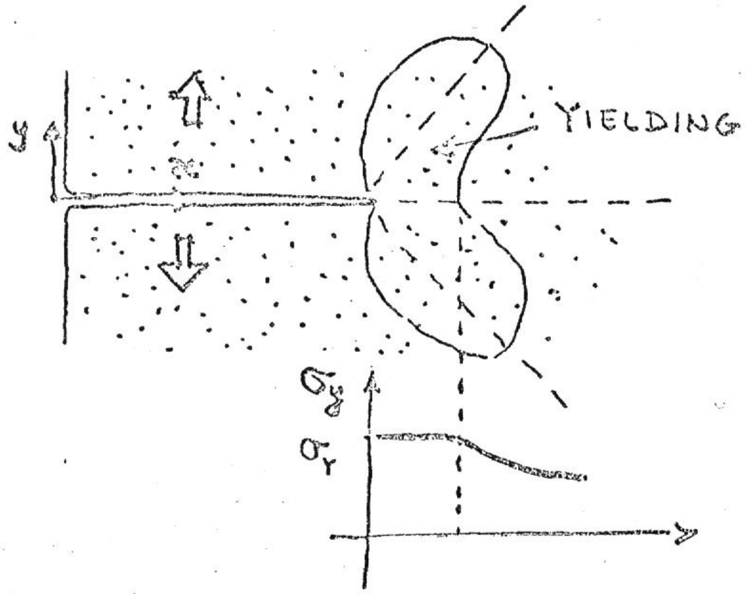
1.3) MACRO-LIVELLO

STRUCTURAL ENGINEERING MODELS

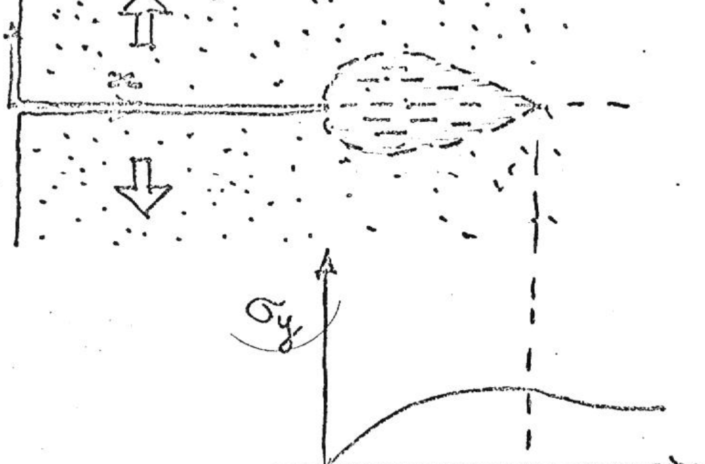


MATERIALE
OMOGENEO
ELASTICO

SINGOLO CRACK
MACROSCOPICO



MATERIALI
ELASTO/PLASTICI

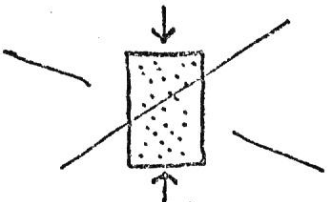


MATERIALI
ELASTO/FRATTURANTI

(*) NEL MACRO-LIVELLO IL CLS. PUO' CONSIDERARSI OMOGENEO.

2) TECNICHE DI OSSERVAZIONE DEL DANNEGGIAMENTO

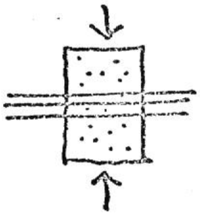
2.1) ESPOSIZIONE AI RAGGI-X



Anche sotto carico. Osservazioni eseguite contemporaneamente in più direzioni.

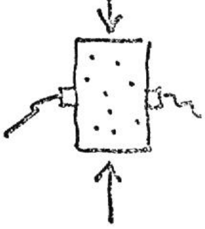
S.R. ROBINSON (1965); F.O. SLATE - S. OLSEFSKI (1974)

2.2) OSSERVAZIONI OTTICHE



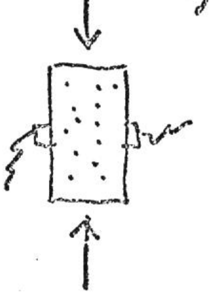
Sezioni a vari livelli di carico.
trattamento con inchiostri
osservazioni col microscopio ottico
R.H. DHIR - M. SANGHA (1974)

2.3) MISURE DI VELOCITÀ DI ATTRAVERSAM. ULTRASUONI



Descrizione, sotto carico, di un parametro di "densità" di micro-cracks in correlazione con la velocità di attraversam. degli ultrasuoni.

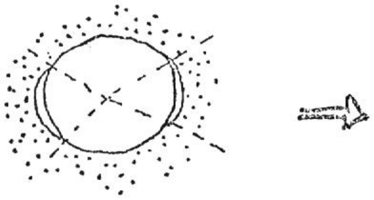
2.4) ANALISI DELLA "EMISSIONE ACUSTICA"



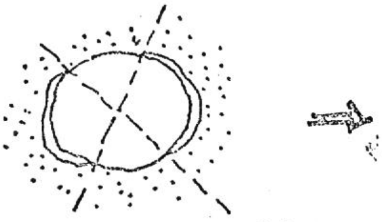
Registrazione dei segnali durante la evoluzione del fenomeno di fessurazione.

3) MECCANISMI DI DANNEGGIAMENTO

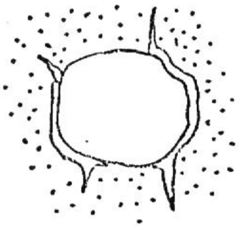
— MESO-LIVELLO —



SCOLLAMENTO PRIMITIVO

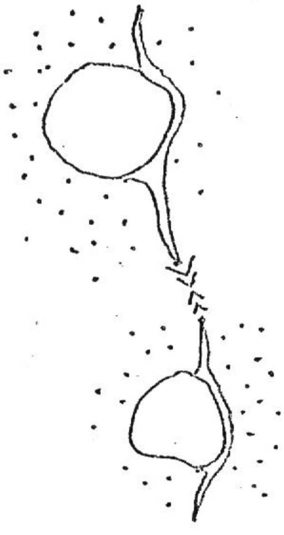


AUMENTO DI SCOLLAMENTO

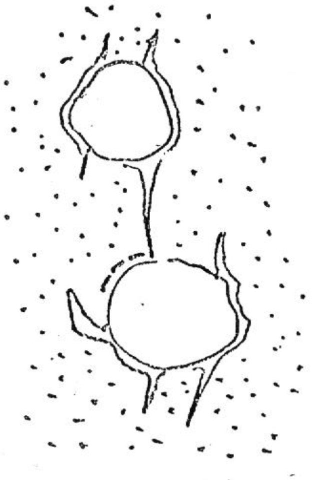


DIRAMAZIONE DEL CRACK

CRACKS DI COLLEGAM. DEI PORI

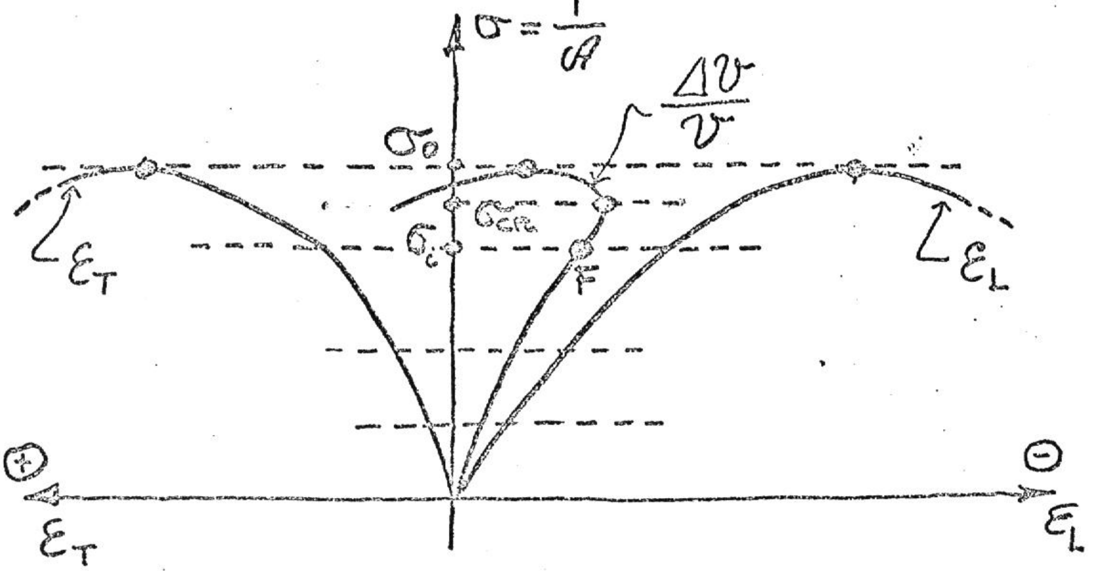


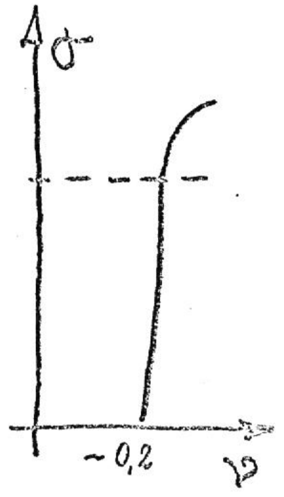
EFFETTO "PONTE"

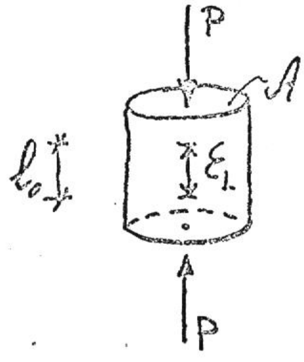


ARRESTO O DEVIAZIONE DEI CRACKS

1)
2.3) COMPORTAMENTO A COMPRESSIONE MONOTONA



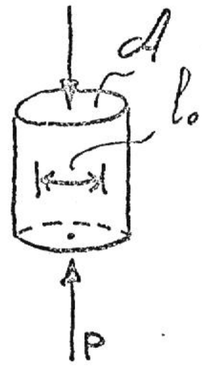




deform. longitudinale

$\varepsilon_L = \dfrac{l - l_0}{l_0}$

negativo



deform. trasvers.

$\varepsilon_T = \dfrac{l - l_0}{l_0}$

positivo

Variazione specifica di volume $\dfrac{\Delta V}{V} = \varepsilon_L + 2\,\varepsilon_T$

Coefficiente di Poisson $\nu = \left| \dfrac{\varepsilon_T}{\varepsilon_L} \right|$

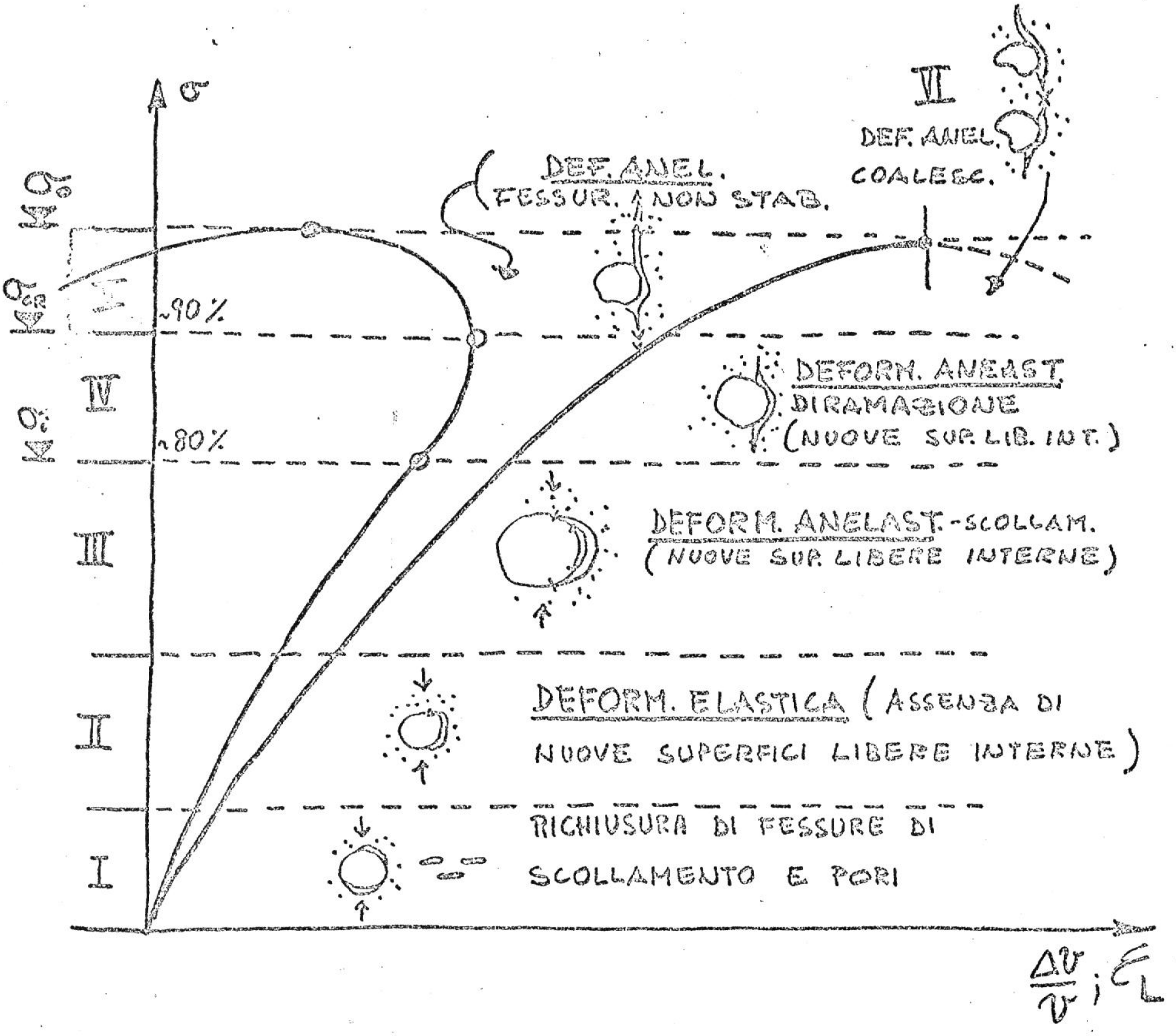
Livelli di Tens. caratteristici :

σ_i σ_0

σ_{CR}

4)

2.3) COMPORTAM. A COMPRESSIONE MONOTONA



MECCANISMI DI DANNEGGIAMENTO PREVALENTI AI VARI LIVELLI DI TENSIONE.

FRACTURE MECHANICS AT MACROSCOPICAL LEVEL

ENERGETIC CRITICAL PARAMETER $\mathcal{G}_{IC}$

« Crack extension force » IRWIN -1957.

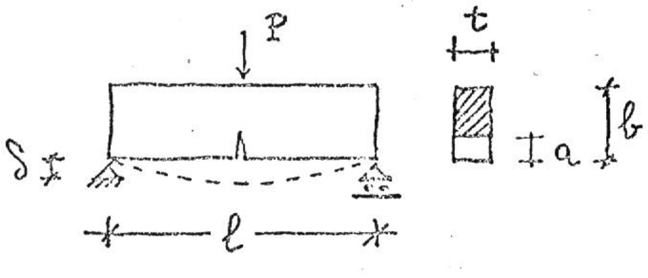
$\mathcal{G}_{IC} \leftrightarrow 2\gamma$

(SURFACE ENERGY γ

" thermodinamic energy necessary to produce a unit free surface " GRIFFITH - 1920.)

ANALOGOUSLY THE « Crack extension force $\mathcal{G}_{IC}$ » was defined as the energy absorbed in a unit crack extension.

THE PARAMETER $\mathcal{G}_I$ IS DEFINED AS THE "ELASTIC ENERGY RELEASED IN A "UNIT" VIRTUAL CRACK EXTENSION". IF $\mathcal{G}_I$ IS EQUAL TO $\mathcal{G}_{IC}$ THE ENERGY RELEASED IS SUFFICIENT TO PRODUCE THE NEW FRACTURE SURFACE AND SO CRACK PROPAGATION REALLY OCCURS. (MODE I)



$C = \frac{\delta}{P}$ (compliance)

$$\mathcal{G}_I = -\frac{1}{2}\frac{P^2}{t}\frac{dC}{da} \quad (*)$$

IF WE CONSIDER AN ACTUAL CRACK EXTENSION, THE (*) PROVIDES AN EXPERIMENTAL METHOD, NAMED DIRECT METH. BY KAPLAN (1961), WHICH ALLOWS $\mathcal{G}_{IC}$ TO BE EVALUATED.

LINEAR ELASTIC FIELD $\longrightarrow$ $\mathcal{G}_{IC} = \frac{K_{IC}^2}{E}$

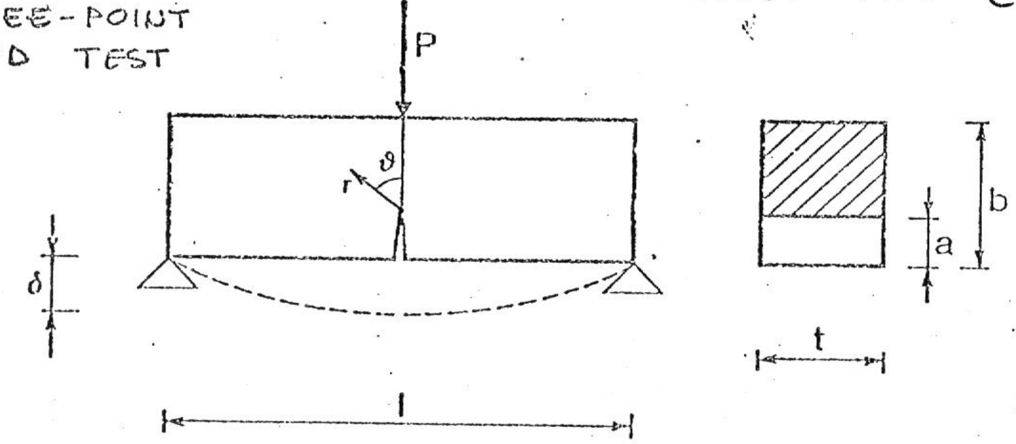
$\longrightarrow$ $\mathcal{G}_{IC} = 2\gamma$

MEASUREMENT OF K_{IC} OR $\mathcal{G}_{IC}$
(MACRO-LEVEL)

FIRST EXP. WORK:

KAPLAN (1961)

THREE-POINT BEND TEST

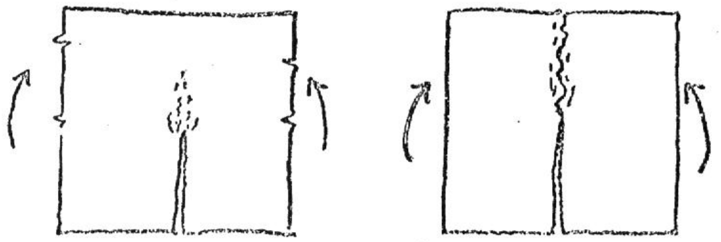


KAPLAN CONCLUSION : 1) $\mathcal{G}_{IC} \geq 2\gamma$

2) LARGER BEAMS $\rightsquigarrow$ HIGHER $\mathcal{G}_{IC}$

GLUCKLICH (1963-68)

CONCLUSIONS : FRACTURE OF CONCRETE IS NOT LIMITED TO THE PROPAGATION OF A SINGLE CRACK BUT A MULTITUDE OF MICRO-CRACKS FORMED IN HIGHLY STRESSED ZONE (PROCESS ZONE) SO THE TRUE FRACTURE SURFACE AREA WAS MUCH GREATER THAN THE APPARENT ONE



$\mathcal{G}_{IC} \gg 2\gamma$

CONCLUSIONS BY SEVERAL AUTHORS:

$G_{Ic} \gg 2\gamma$

G_{Ic} INCREASES WITH INCREASING AGGREGATE VOLUME

INCREASE AS THE ANGULARITY FACTOR OF AGGREG. INCREASES

AGGREGATES "CRACK ARRESTORS"

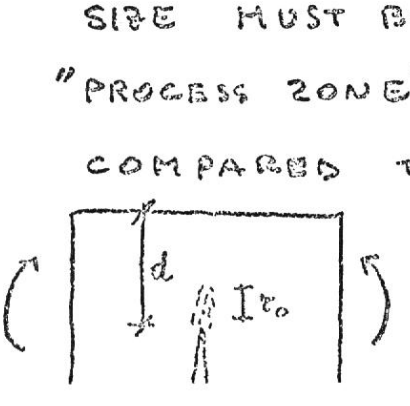
- SEVERAL INCONSISTENCIES BEGAN TO APPEAR IN G_{Ic} EVALUATION REGARDING THE FOLLOWING EFFECTS:

1) <u>SPECIMEN SIZE</u>
2) NOTCH DEPTH
3) <u>SPECIMEN TYPE</u>

MAIN PROBLEMS:

SPECIMEN SIZE LARGE ENOUGH TO PROVIDE <u>A VALID F. M. TEST</u>

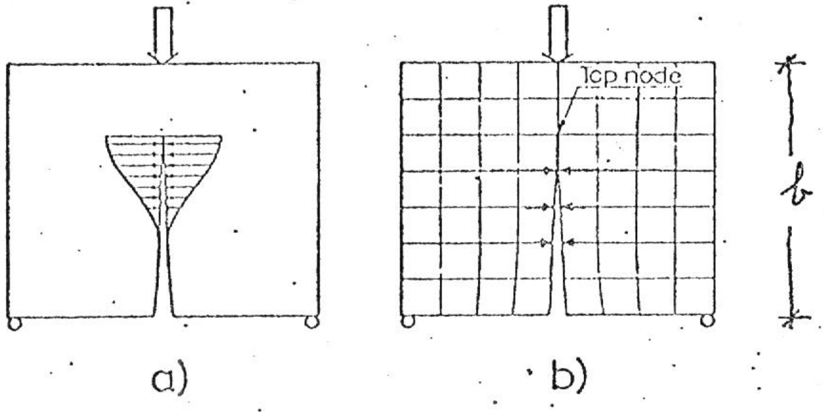
<u>WALSH</u> (1972) SUGGESTED THAT THE SPECIMEN SIZE MUST BE LARGE ENOUGH SO THAT THE "PROCESS ZONE" AT CRACK TIP IS "SMALL" COMPARED TO THE "LIGAMENT."



$r_0 \ll d$

VALID F.M. TEST FOR CONCRETE

HILLERBORG APPROACH



$$l_{ch} = \frac{G_{Ic}\,E}{\sigma_t^2} = \frac{K_{Ic}^2}{\sigma_t^2}$$ « material characteristich length »

σ_t = tensile strength. FOR VALID TEST $b \geq 10\, l_{ch}$ (*)

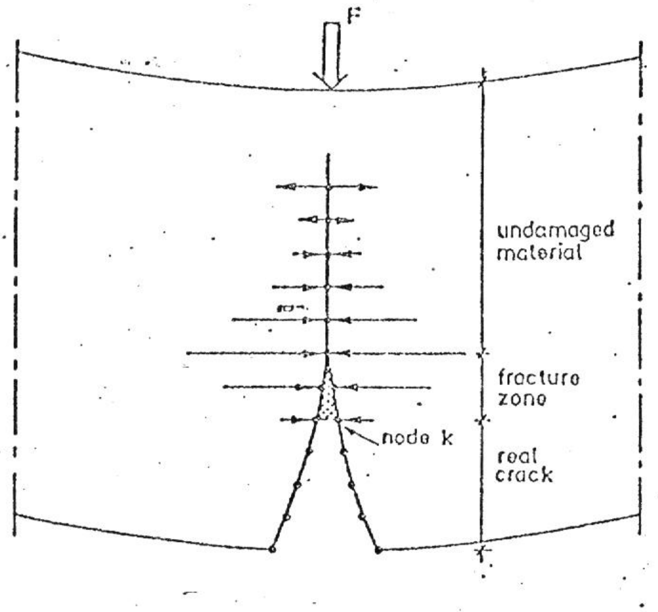


FIG.22- A numerical model (fictitious crack) to simulate crack propagation by F.E. (by HILLERBORG).

THIS (*) CONDITION REQUIRES $b \cong 2 \div 3$ meters !

VALID F.M. TEST FOR CONCRETE

CARPINTERI APPROACH (1981)

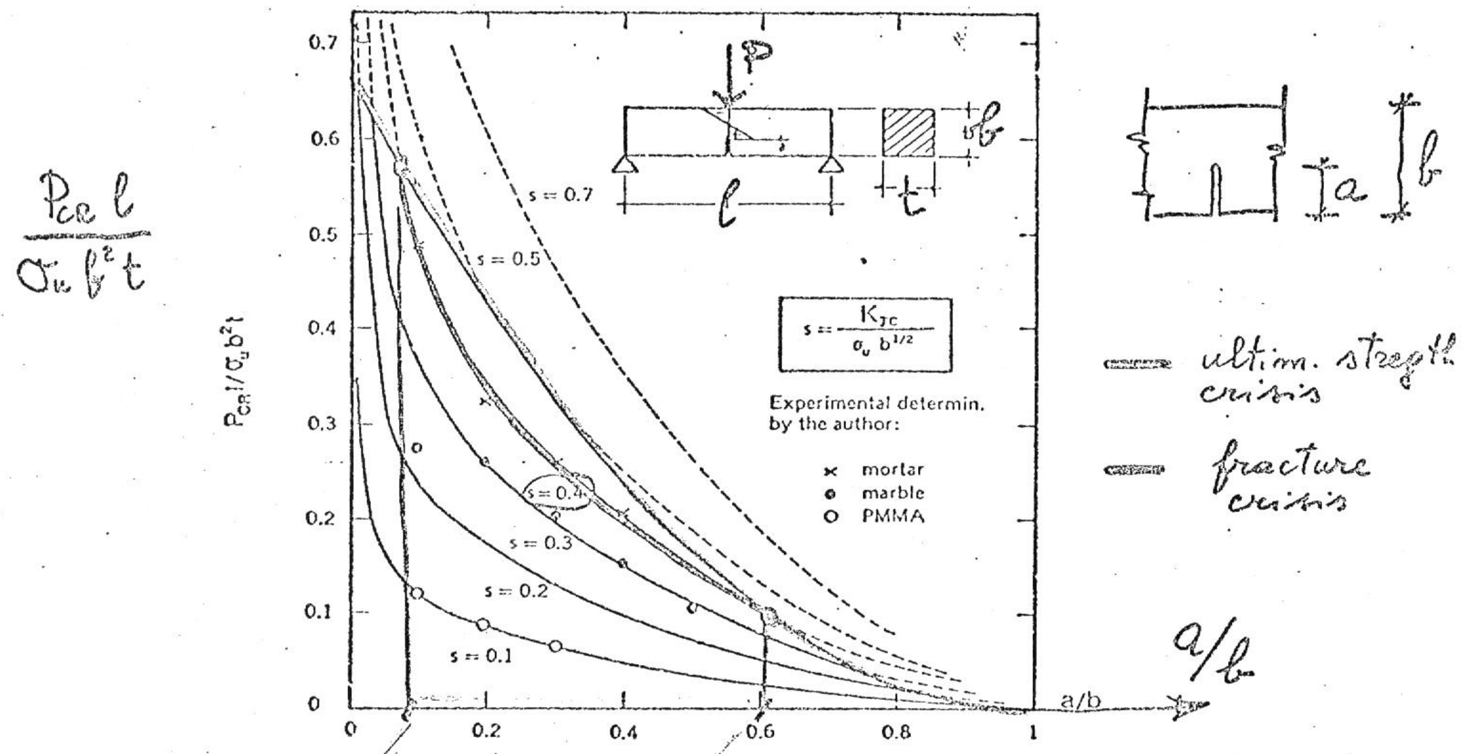


Fig. 5. Crack extension force (varying the brittleness number s) and force of collapse at ultimate strength, against relative crack depth (TPB).

$$\text{FOR} \begin{cases} s = 0.4 \\ a/b = 0{,}1 \div 0{,}6 \end{cases}$$

CARPINTERI

test brittleness number

$$s = \frac{K_c}{\sigma_u \sqrt{b}}$$

Ⓢ IS OBTAINED BY APPLYING BUCKINGAM TEOR. FOR PHISICAL SIMILITUDE

$s < 0{,}5$

$$\boxed{b > 4 \frac{K_c^2}{\sigma_u^2}}$$

ENGINEERING FRACTURE MECHANICS

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NOTCH SENSITIVITY IN FRACTURE TESTING OF AGGREGATIVE MATERIALS

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G_F = FRACTURE ENERGY

- HILLERBORG - 1978

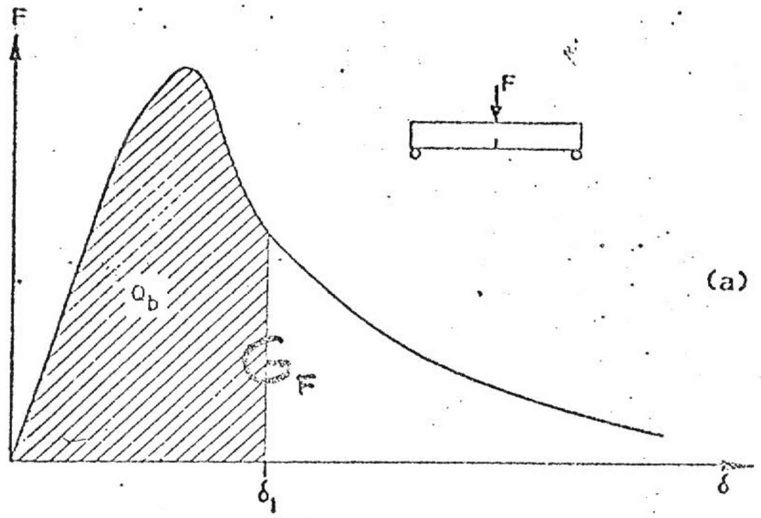
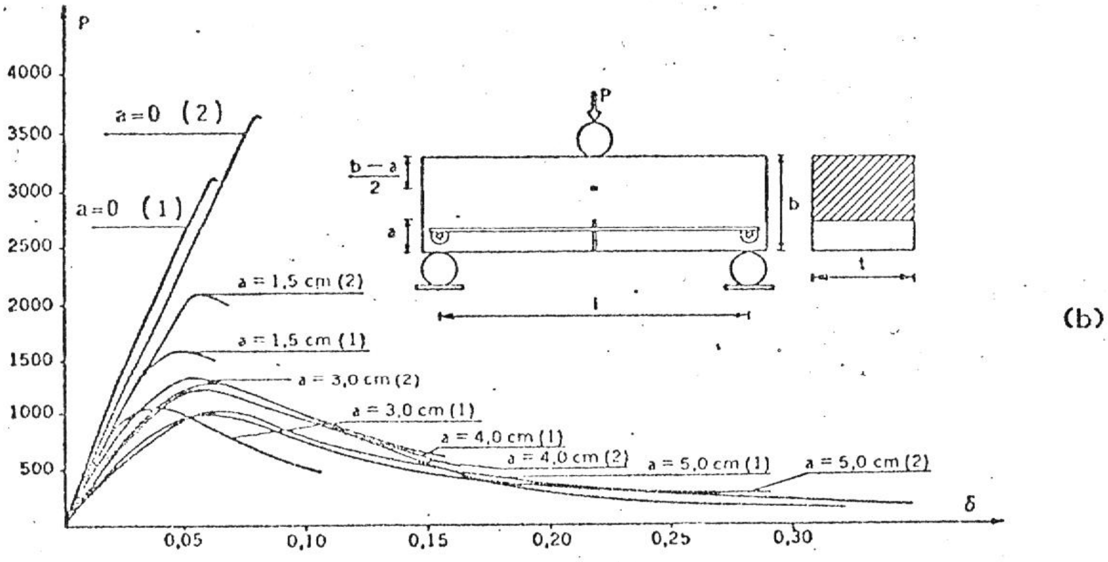


FIG.23 a,b- Three-point bend test. Fracture energy (G_F) evaluation in stable test (t x b x l = 150x150x450 mm).



- DI LEO - 1981