



### Cobrimento, Fissuração e Durabilidade

- Artigo do Prof. Yukimasa GOTO - 1971
- Formulações para calcular a abertura das fissuras
- Pesquisas de Phil Moss FERGUSON - 1968

Prof.. Eduardo C.  
S. Thomaz  
Notas de aula

1 - Pioneiras experiências feitas por Y.Goto sobre fissuração e aderência.



Yukimasa GOTO – "Cracks formed in concrete around deformed tension bars. " Journal ACI, Proc. Vol. 68 ( 1971 ) – Nr 4 - pag. 244 – 251

2 - Fissuração é um Antônimo de Durabilidade.

Dez diferentes formulações, aferidas experimentalmente, para calcular a abertura das fissuras em peças fletidas de Concreto Armado. 1960 / 2007

3 - Resultados de ensaios sobre alongamento de fratura na tração do concreto. Feitos por Moersch e Wayss & Freitag em 1903 , Kleinlogel em 1904, e outros feitos por Furnas Centrais Elétricas até 2002. E também os medidos por Y. GOTO em 1971.

4 - Pesquisas de Phil Moss Ferguson sobre Flexural crack width at the bars in reinforced concrete beams. Center for Highway Research - 1968

5 - Diversos fatores que, segundo as formulações, causam maior abertura das fissuras em peças fletidas de Concreto Armado.

6 - Sugestões.

Eduardo Thomaz

## 1971 - Cobrimento, Fissuração e Durabilidade



**Yukimasa GOTO – Cracks formed in concrete around deformed tension bars.** Journal ACI, Proc. Vol. 68 ( 1971) – Nr 4 - pag. 244 – 251

Ensaio de tração em tirantes de concreto armado. Após a fissuração, era feita uma injeção de tinta vermelha nas fissuras. A seguir, o corpo de prova era fendilhado paralelamente à barra.

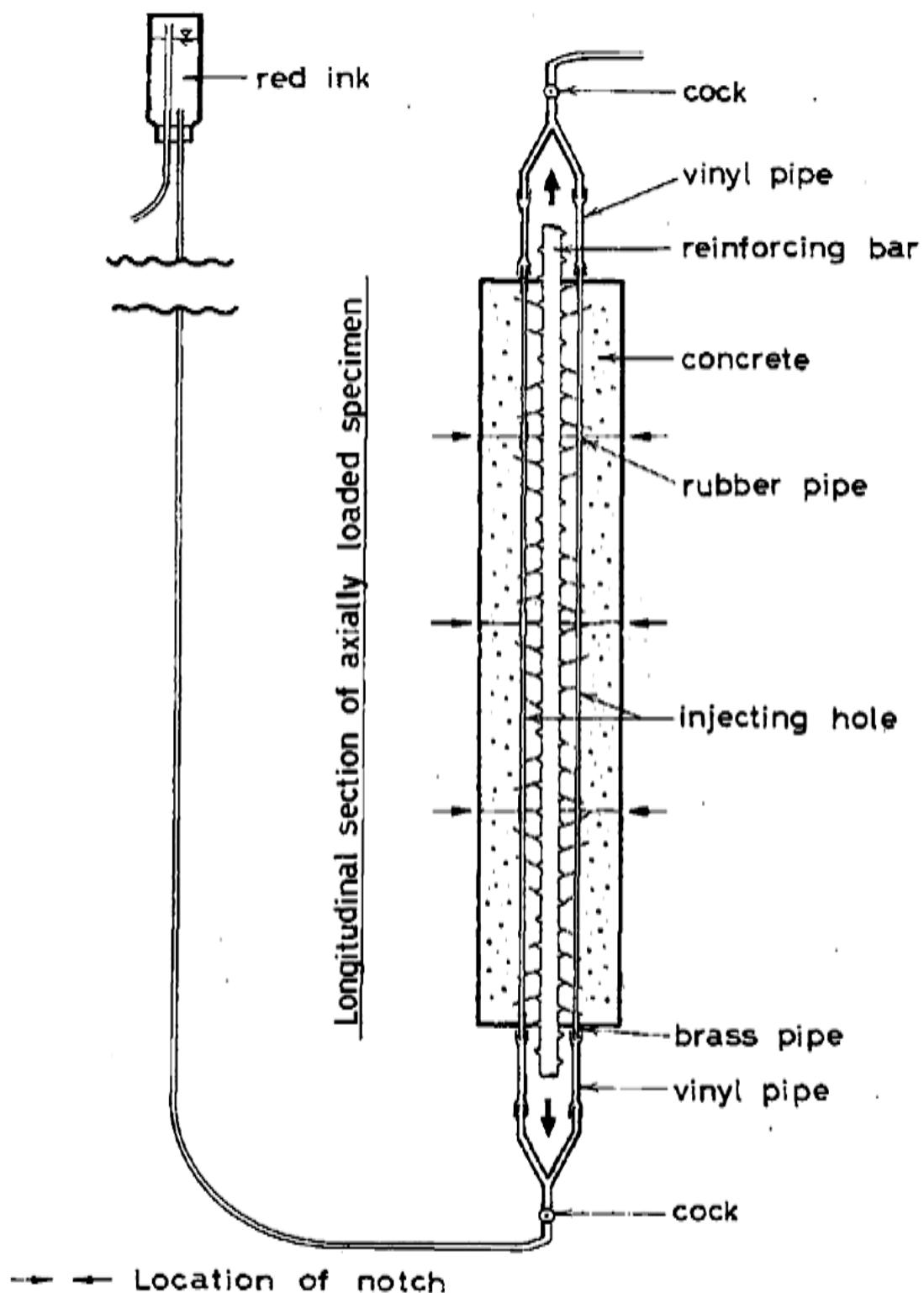
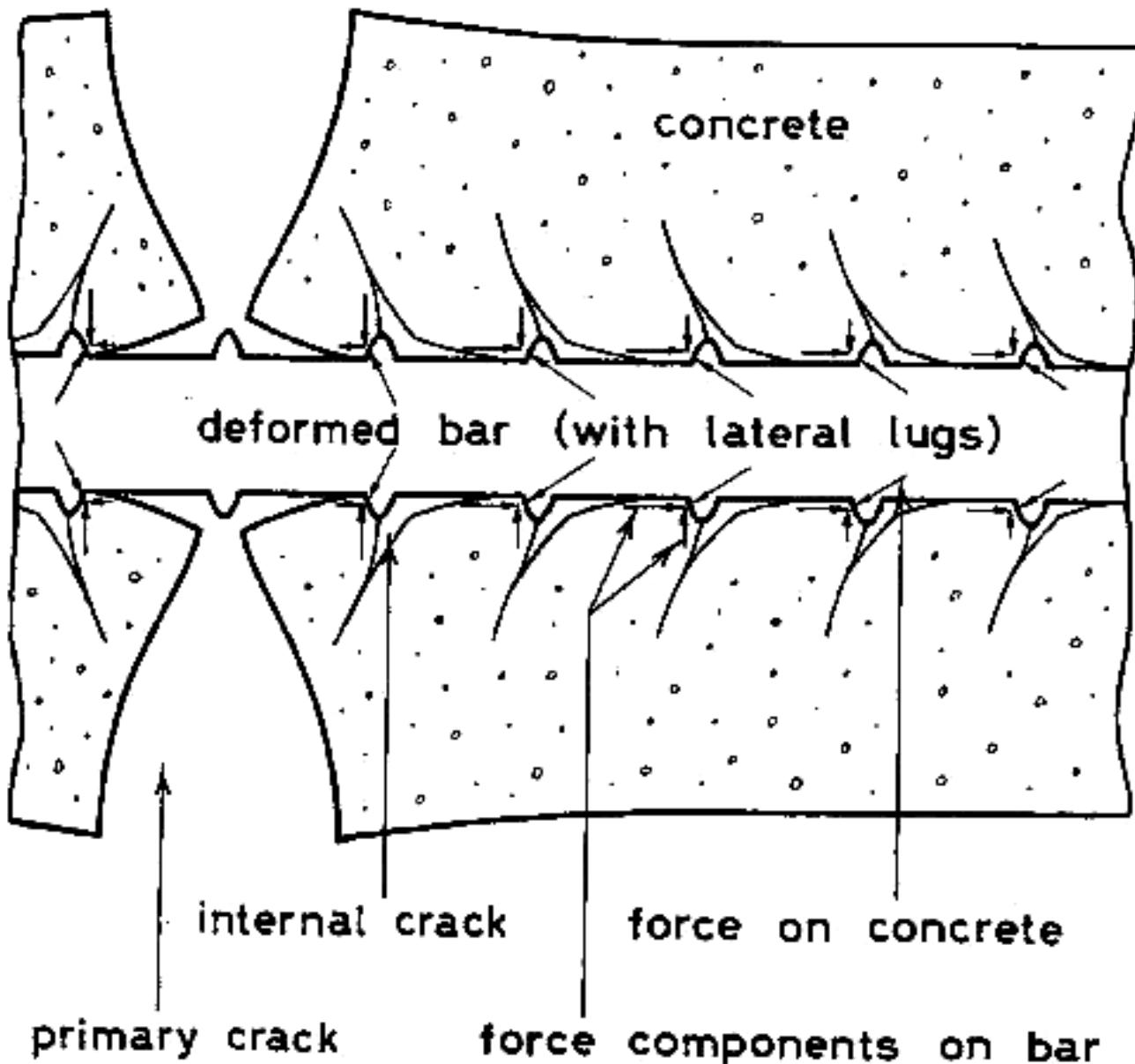


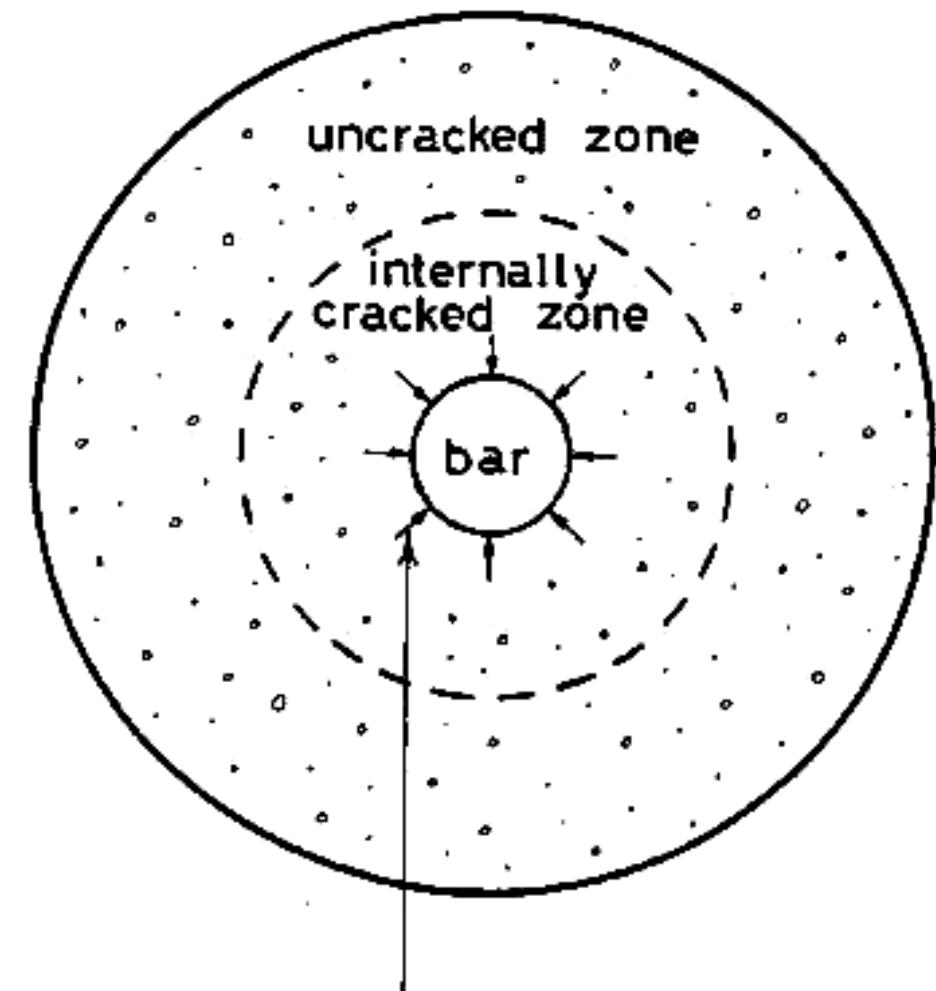
Fig. I—Equipment for injection of ink

## FISSURAÇÃO OBSERVADA

Longitudinal section of axially loaded specimen



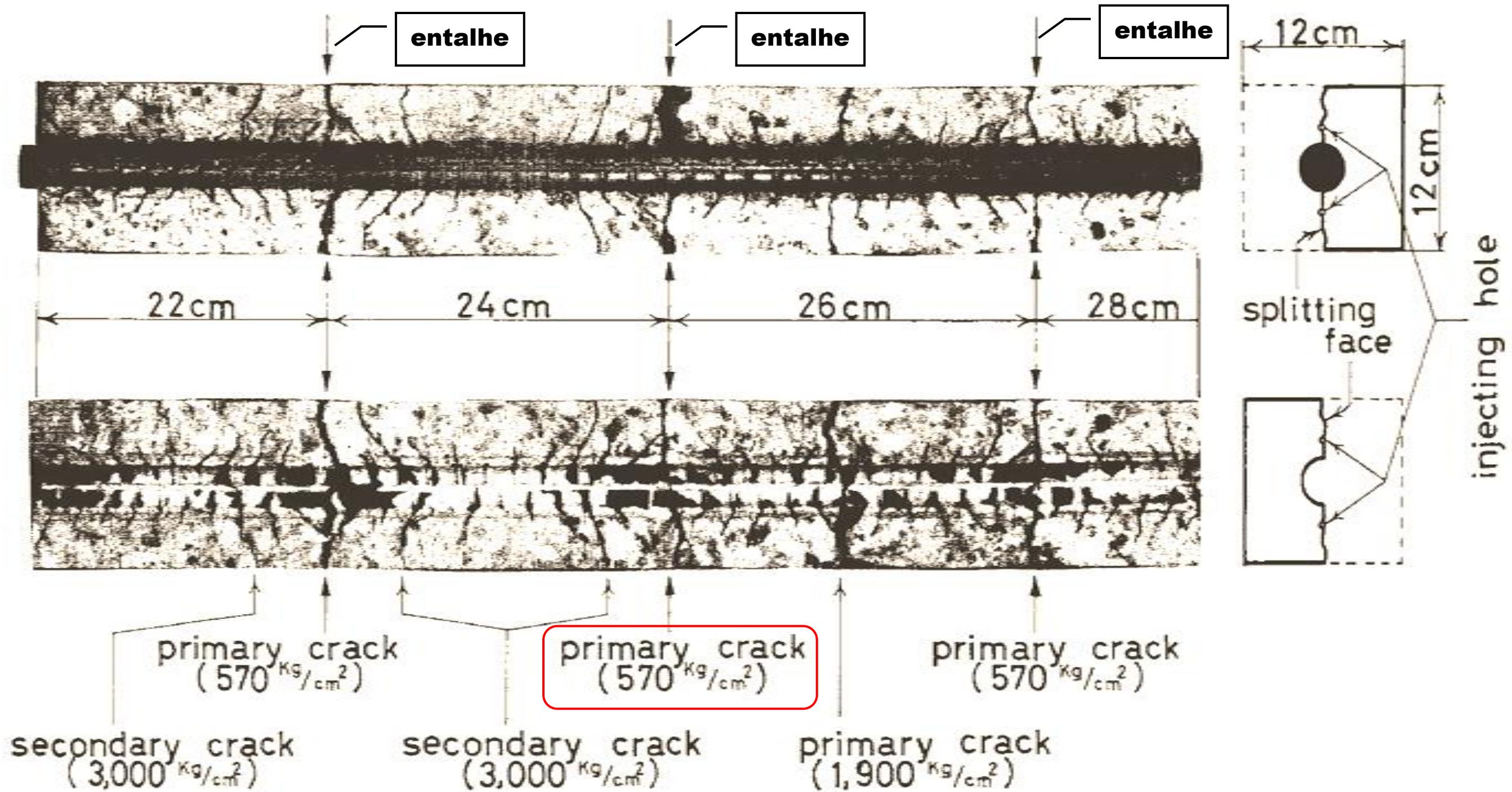
Cross section



tightening force on bar  
(due to wedge action and  
deformation of teeth of  
comb-like concrete)

Fig. 3—Deformation of concrete around reinforcing steel after formation of internal cracks (schematic diagram)

## Yukimasa GOTO – Cracks formed in concrete around deformed tension bars

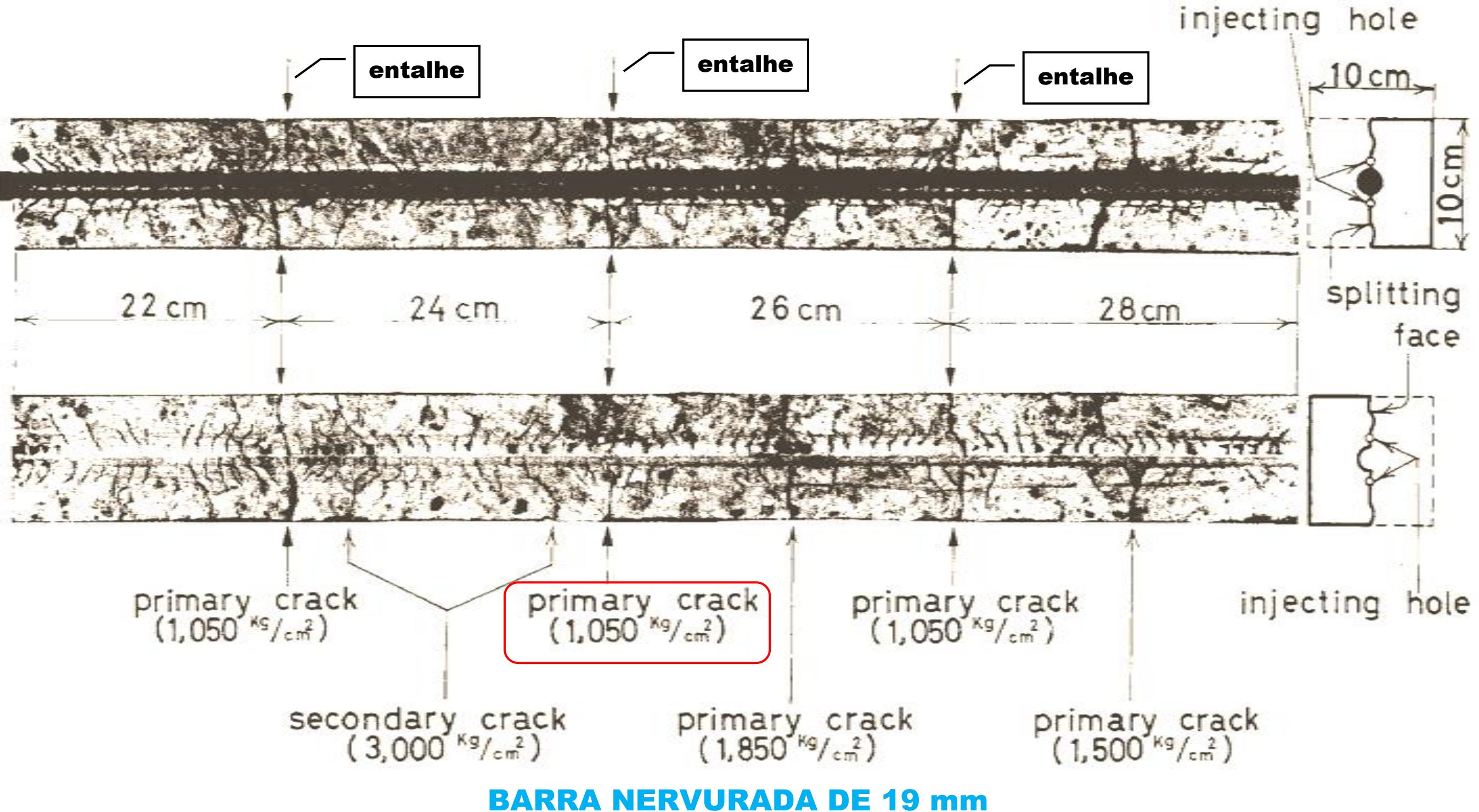


### BARRA NERVURADA DE 32 mm

**1<sup>a</sup> Fissura no concreto com  $\sigma_a = 570 \text{ kgf/cm}^2$ , i.e. alongamento  $\varepsilon = 0,27\text{mm/m}$**

**Aumentando a tensão no aço surgem novas fissuras até  $\sigma_a = 3000 \text{ kgf/cm}^2$**

## Yukimasa GOTO – Cracks formed in concrete around deformed tension bars

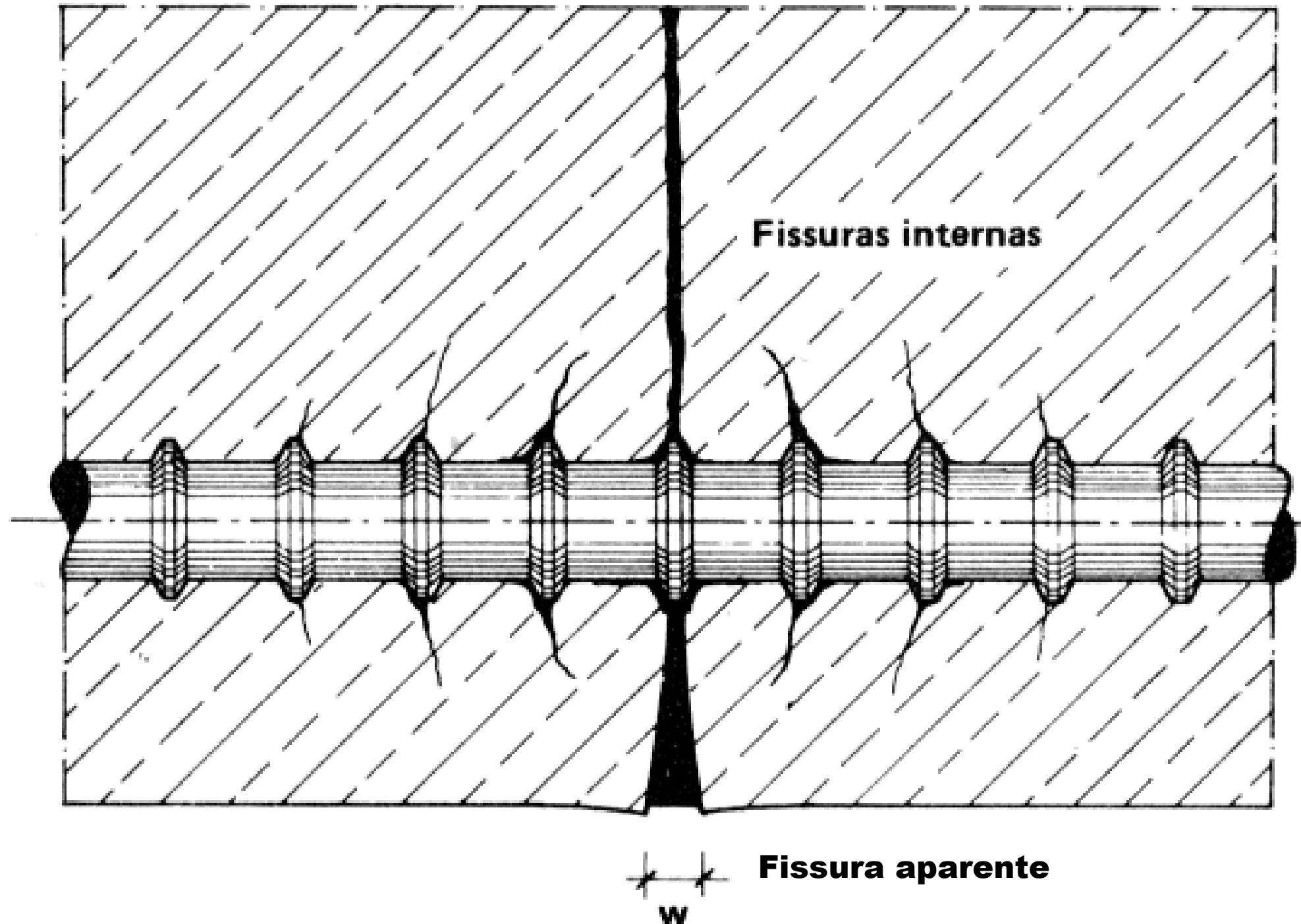


**1<sup>a</sup> Fissura no concreto com  $\sigma_{\text{aço}} = 1050 \text{ kgf/cm}^2$ , i.e. alongamento  $\varepsilon = 0,50 \text{ mm/m}$**

**Aumentando a tensão no aço surgem novas fissuras até  $\sigma_{\text{aço}} = 3000 \text{ kgf/cm}^2$**

**Segundo Yukimasa GOTO a fissura na face da viga é maior do que junto à barra da armadura.**

*" At the surface of the reinforcing bars the primary crack widths are smaller than the widths at the concrete surface, and are especially smaller in the case of deformed bars."*



**1960 / 2007**

**FORMULAÇÕES PARA A ABERTURA DA FISSURA**

# FORMULAÇÕES PARA A ABERTURA DA FISSURA

a médio = espaçamento médio entre fissuras ;  $\varepsilon$  médio = alongamento médio do aço  
 Wmáx = maior abertura de fissura ; Wm = abertura média de fissura ; C = cobrimento ;  
 S = distância entre as barras ;  $\phi$  = diâmetro das barras ;

$\sigma_{\text{SII}}$  = tensão no aço em serviço. estádio 2. ; fct = resistência à tração do concreto ;  
 Es = módulo de elasticidade do aço ;  $\mu = \rho$  = porcentagem de armadura ( ver na coluna "Observação" )

		$\frac{W_{\text{máx.}}}{W_m}$	a médio			$\varepsilon$ médio	Observação
	Geral	K	$K_2 S$	$+ K_1 C$	$+ K_3 \frac{\phi}{\mu}$	$\frac{\sigma_{\text{SII}}}{E_s} \times \left( 1 - \left( \frac{\Delta \sigma_S}{\sigma_S} \right) \right)$	
1960	NB2- 1960 Prof. Lobo Carneiro INT /RJ	1,8	---	3 cm	$+ 0,140 \times \frac{\phi \text{ (cm)}}{\mu}$	$\frac{\sigma_{\text{SII}}}{E_s} \times \left( 1 - 0,375 \times \left( \frac{fct}{\sigma_{\text{SII}}} \right) \times \left( \frac{1}{\rho_{\text{ef}}} \right) \right)$	$\rho = \frac{AS}{b \times [2,0 \times (h-d)]}$
1968	DIN 1045 G. Rehm	2,1	---	4 cm	$+ 0,025 \times \frac{\phi \text{ (cm)}}{\mu}$	$\frac{\sigma_{\text{SII}}}{E_s} \times \left( 1 - \left( \frac{3,0 \left( \text{kgf/cm}^2 \right)}{\sigma_{\text{SII}}} \times \left( \frac{1}{\mu} \right) \right)^2 \right)$	$\left( \mu = \frac{As}{b \times d} \right)$
1970	CEB 70	2,1	----	1,5 C	$+ 0,04 \times \frac{\phi}{\mu}$	$\frac{\sigma_{\text{SII}}}{E_s} \left( 1 - \left( \frac{7,5 \left( \text{kgf/cm}^2 \right)}{\sigma_{\text{SII}}} \times \left( \frac{1}{\mu} \right) \right) \right)$	$\left( \mu = \frac{As}{b \times d} \right)$
1978	CEB 78	1,7	0,2 S	2 C	$+ 0,05 \times \frac{\phi}{\rho_f}$	$\frac{\sigma_{\text{SII}}}{E_s} \times \left( 1 - 0,5 \times \left( \frac{\sigma_{\text{sr}}}{\sigma_{\text{SII}}} \right)^2 \right)$	$\rho_f = \frac{As}{b \times h_{\text{ef}}}$
1978	NB1/78	1,0	---	2 C	$+ 0,045 \times \frac{\phi}{\mu}$	$\frac{\sigma_{\text{SII}}}{E_s} \times [ 1 - (0) ]$	$\left( \mu = \frac{As}{b \times d} \right)$
1988	DIN 1045/1988 Peter Schiessl Eilhard Wölfel	2,1	---	5 (cm)	$+ 0,10 \times \frac{\phi \text{ (cm)}}{\rho_f}$	$\frac{\sigma_{\text{SII}}}{E_s} \times \left( 1 - 0,5 \times \left( \frac{\sigma_{\text{sr}}}{\sigma_{\text{SII}}} \right)^2 \right)$	$\rho_f = \frac{As}{b \times [2,0 \times (h-d)]}$

## CONTINUAÇÃO

		$\frac{W_{\text{máx.}}}{W_m}$	a médio			$\varepsilon_{\text{médio}}$	Observação
	Geral	K	$K_2 S$	$+ K_1 C$	$+ K_3 \frac{\phi}{\mu}$	$\frac{\sigma_{\text{SII}}}{E_s} \times \left( 1 - \left( \frac{\Delta \sigma_s}{\sigma_s} \right) \right)$	
1999 2001	EuroCode 1999 e DIN10452001	<b>1,0</b> <b>Usar 1,7</b>	---	---	$0,278 \times \frac{\phi}{\rho_r}$	$\frac{\sigma_{\text{SII}}}{E_s} \times \left( 1 - 0,40 \times \left( \frac{\text{fct.ef}}{\sigma_{\text{SII}}} \right) \times \left( \frac{1+n \rho_{\text{ef}}}{\rho_{\text{ef}}} \right) \right)$	$\rho_r = \frac{A_s}{b \times [2,5(h-d)]}$ $n = \frac{E_{\text{aço}}}{E_{\text{concreto}}}$
2002	EuroCode 2002	<b>1,0</b> <b>Usar 1,7</b>	---	3,4 C	$+ 0,17 \times \frac{\phi}{\rho_r}$	$\frac{\sigma_{\text{SII}}}{E_s} \times \left( 1 - 0,40 \times \left( \frac{\text{fct.ef}}{\sigma_{\text{SII}}} \right) \times \left( \frac{1+n \rho_{\text{ef}}}{\rho_{\text{ef}}} \right) \right)$	
2002	NBR6118 /2002	<b>1,0</b> <b>usar 2,0</b>			$\left( \frac{\phi}{12,5 \times \eta} \right) \times \left( 45 + \frac{4}{\rho_r} \right)$ <p>com <math>\eta = 2,25</math></p> $\approx \left( 1,6\phi + 0,14 \frac{\phi}{\rho_r} \right)$ <p>como <math>1,6\phi \approx C</math></p>	$\frac{\sigma_{\text{SII}}}{E_s} \times (1 - (0))$	
			---	$\approx C$	$+ 0,14 \times \frac{\phi}{\mu}$	$\frac{\sigma_{\text{SII}}}{E_s} \times (1 - (0))$	

**CONTINUAÇÃO**  
**PROF<sup>a</sup>. MARIA CASCÃO - 2003 / 2007**

		$\frac{W_{\text{máx.}}}{W_m}$	a médio			$\varepsilon_{\text{médio}}$	Observação
	Geral	K	$K_2 S$	$+ K_1 C$	$+ K_3 \frac{\phi}{\mu}$	$\frac{\sigma_{\text{SII}}}{E_s} \times \left( 1 - \left( \frac{\Delta \sigma_S}{\sigma_S} \right) \right)$	
2003 / 2007	MARIA CASCÃO	1,7	0,4 a 2 C	$k_3 \times k_4 \times (\phi / \rho_r)$		$\frac{\sigma_s}{E_s} \left  1 - \beta_1 \beta_2 \left( \frac{\sigma_{sr}}{\sigma_s} \right)^2 \right $	VER ABAIXO

$$W_k = 1,7 \left[ 2 \left( c + \frac{a}{5} \right) + k_3 k_4 \frac{\phi}{\rho_r} \right] \frac{\sigma_s}{E_s} \underbrace{\left[ 1 - \beta_1 \beta_2 \left( \frac{\sigma_{sr}}{\sigma_s} \right)^2 \right]}_{\geq 0,4}$$

onde:

$$\begin{aligned} k_3 &= 1,0 && \text{barras lisas} \\ &= 0,5 && \text{barras nervuradas} \end{aligned} \quad \geq 0,4$$

$$k_4 = -8,9 \xi^3 + 6,4 \xi^2 + 2 \xi + 0,2 \quad \text{sendo } \xi = c/(h-x)$$

$$\rho_r = A_s/A_{cr} \quad \text{sendo } A_s \text{ - área da armadura tracionada}$$

$A_{cr}$  - área de concreto envolvendo a armadura:  $bh$  na tração

$2b(h-d)$  na flexão

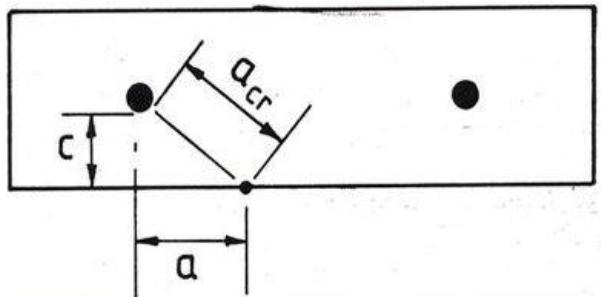
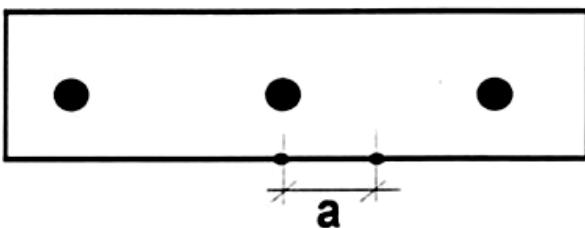
$$fctm = 0,23 f_{ck}^{2/3} \quad \text{resistência do concreto à tração (em MPa)} \quad \leftarrow \text{Almeida (1984)}$$

$$\begin{aligned} \beta_1 &= 0,7 && \text{barras nervuradas} & \beta_2 &= 1,0 && 1^{\circ} \text{ carregamento} \\ &= 0 && \text{barras lisas} & &= 0,5 && \text{carga cíclica} \end{aligned}$$



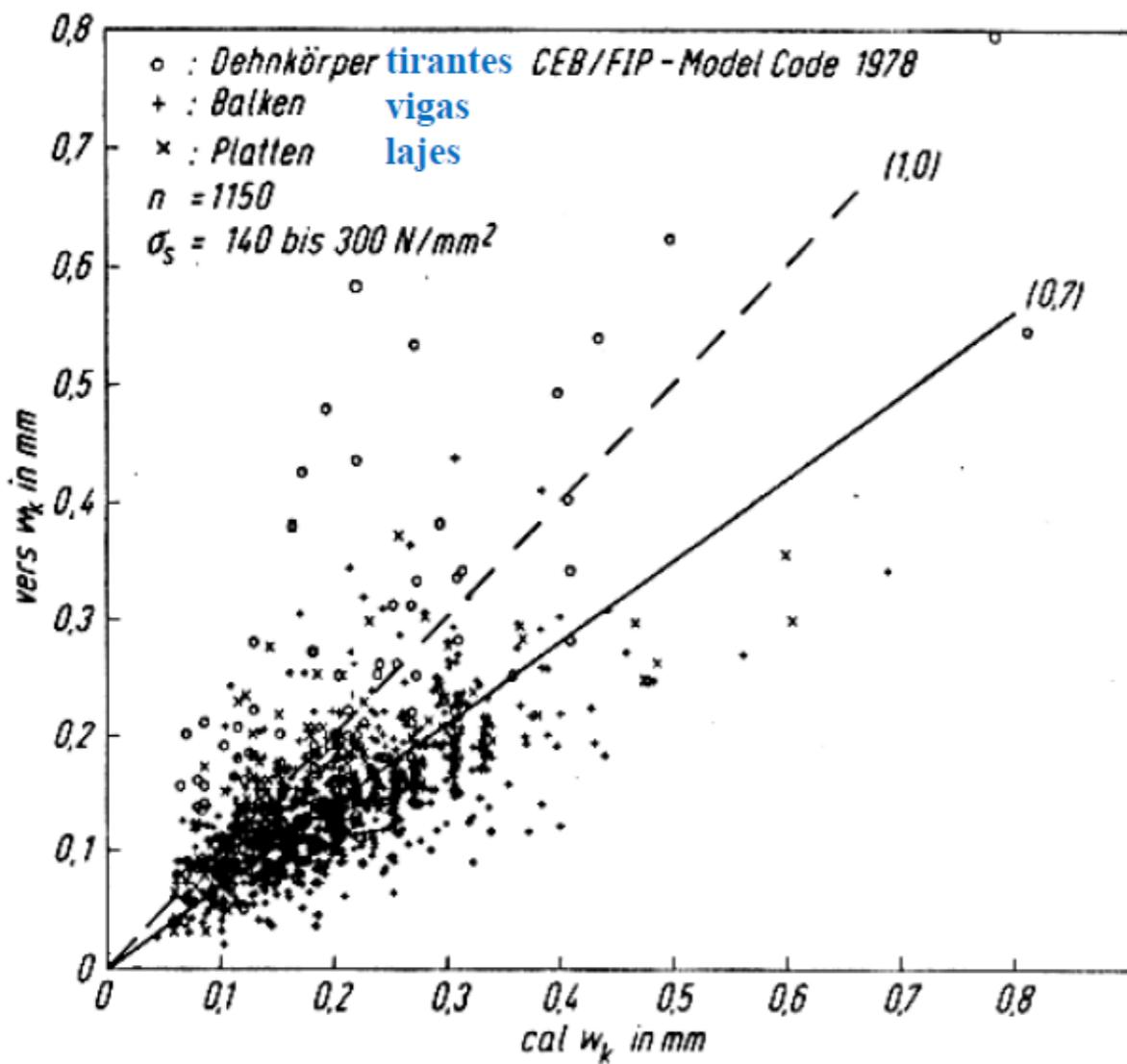
**PROF<sup>a</sup> MARIA CASCÃO - 2003 / 2007**

- |  |         |
|--|---------|
| → cobrimento                               | c       |
| → área de concreto envolvida na fissuração | A c,ef  |
| → diâmetro das barras                      | ϕ       |
| → qualidade de aderência das barras        | η       |
| → curvatura                                | c/(h-x) |
| → distância                                | a       |
| → espaçamento entre barras da armadura     | s       |

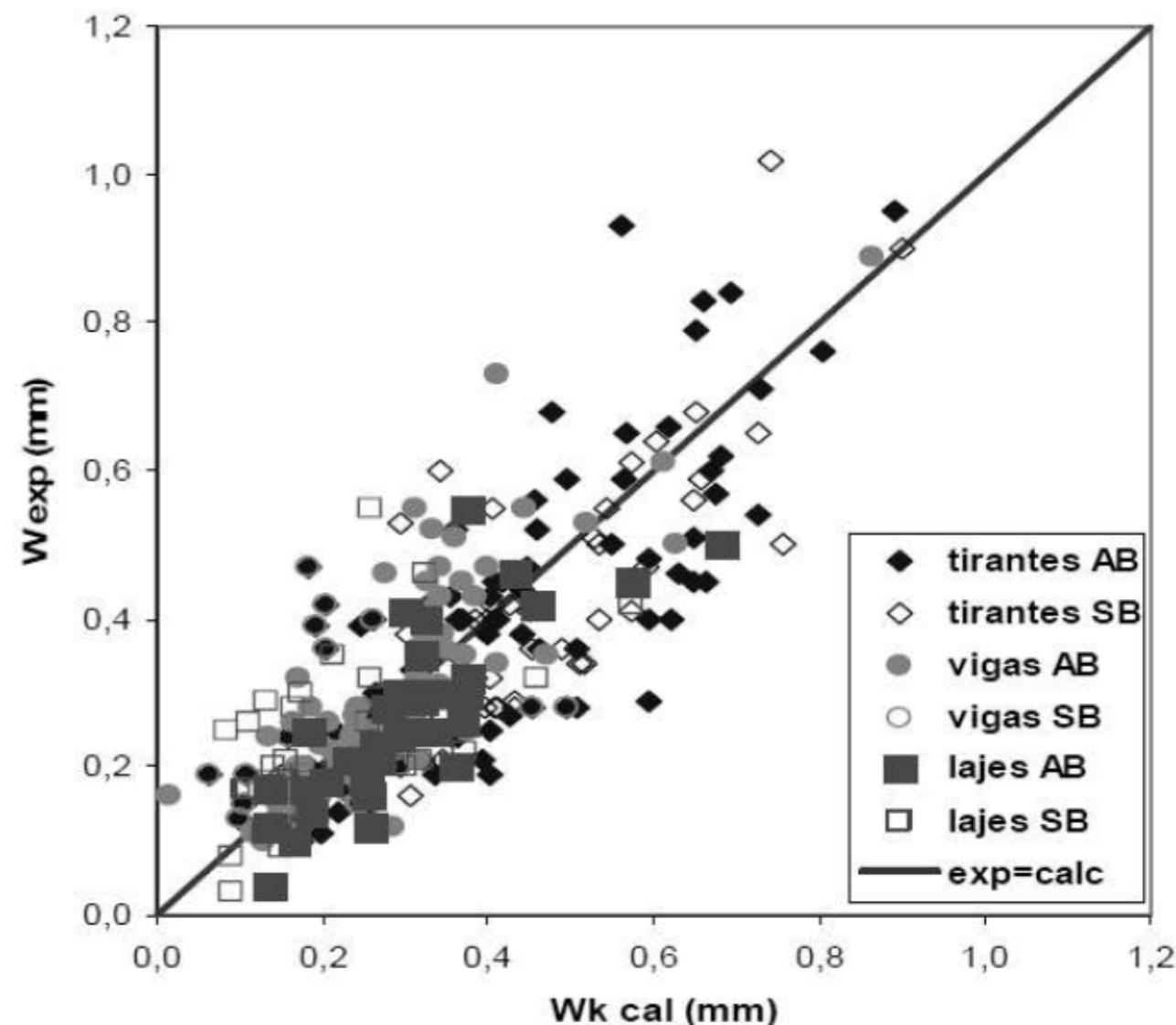


## AFERIÇÃO DAS FÓRMULAS CEB 78 E MARIA CASCÃO

**CEB 1978**



**MARIA CASCÃO 2003**



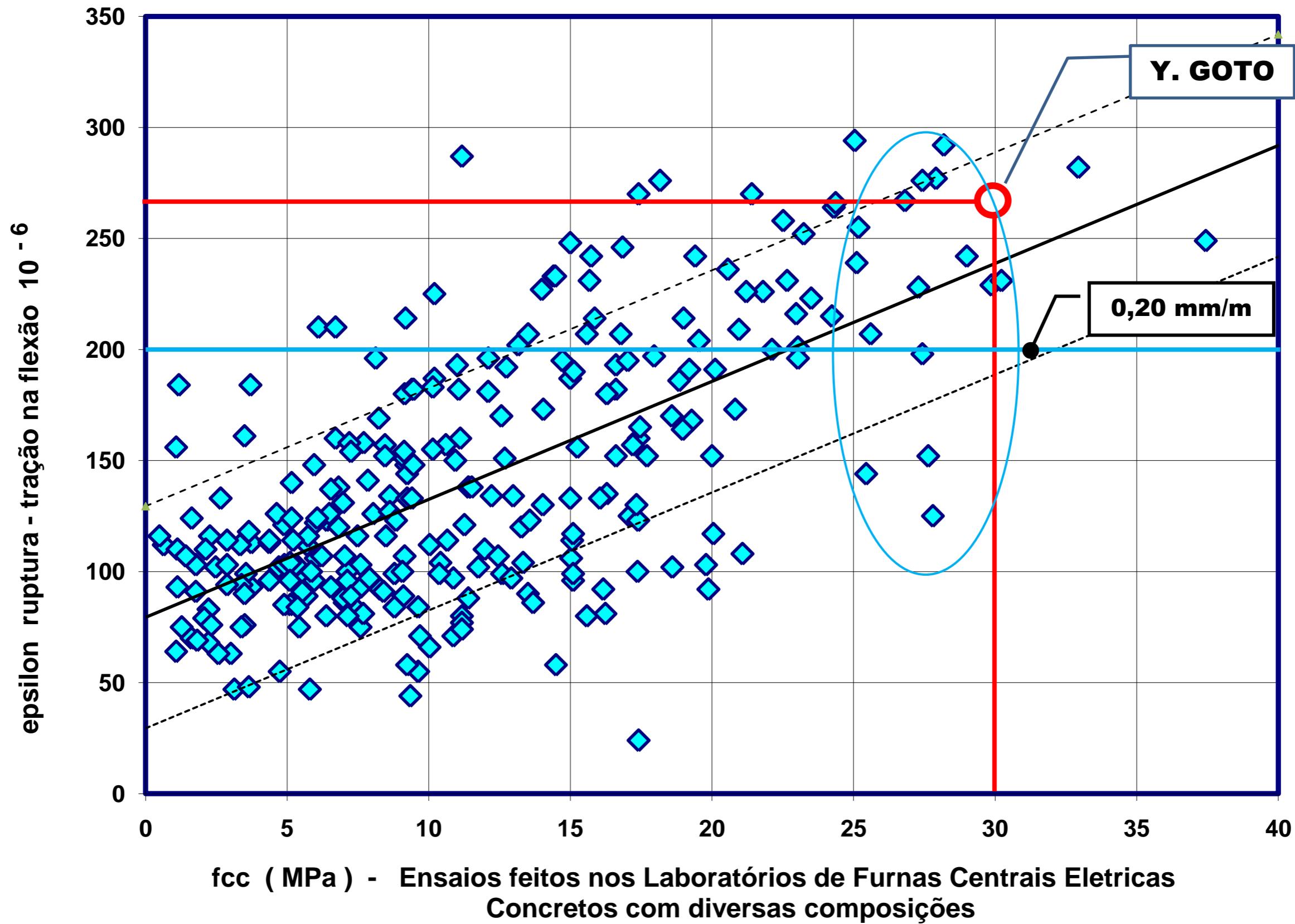
- 1 – Todas as fórmulas tem uma configuração similar.
- 2 – Todas as formulações mostram uma grande dispersão.
- 3 – Há décadas tenho usado a fórmula do CEB -78 para analisar fissuras observadas em obras reais.  
O cálculo segundo o CEB-78 compara bem com as fissuras reais observadas nas obras.
- 4 – A NBR 6118 poderia adotar a formulação deduzida e aferida pela Enga. Maria Cascão.

**1903 / 2002**

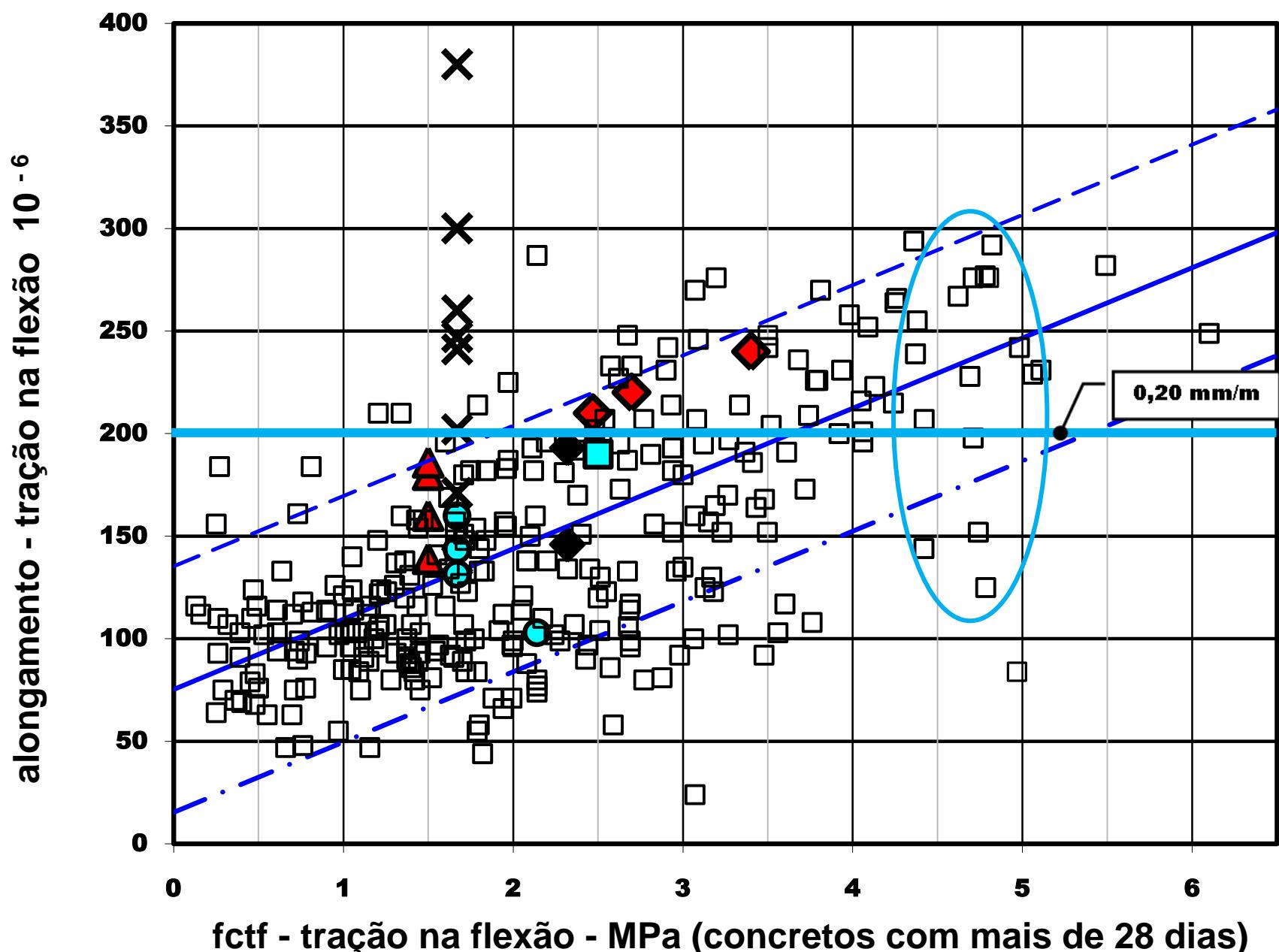
**ALONGAMENTO DE RUPTURA À TRAÇÃO DO CONCRETO**

# ALONGAMENTO DE RUPTURA À TRAÇÃO DO CONCRETO

Alongamento epsilon de fratura de tração na flexão  
Furnas - Concreto



## Alongamento epsilon de fratura de tração na flexão



- Van Vliet - Concreto simples - Tração Axial - 2000
- ◆ Moersch - Concreto Simples - Tração Axial - 1903
- ✗ Wayss & Freitag - Concreto Armado - Flexão - 1903
- ▲ Comissão Alemã de Concreto Armado - Flexão - 1917
- Furnas - Concreto Simples - Flexão - 2002
- ◆ Kleinlogel - Concreto Simples - Flexão - 1904
- Furnas - Alongamento de tração na flexão - média
- Furnas - Alongamento de tração na flexão 10%
- Furnas - Alongamento de tração na flexão 90%
- Wayss & Freitag - Concreto Simples - Flexão - 1903
- FURNAS

Segundo Furnas :  $fctf \text{ (MPa)} = 0,165 fcc + 0,20 \text{ (MPa)}$

$fcc = 25 \text{ MPa} > fctf = 4,3 \text{ MPa} ; fcc = 30 \text{ MPa} > fctf = 5,1 \text{ MPa}$

**1968**

**FLEXURAL CRACK WIDTH AT THE BARS IN  
REINFORCED CONCRETE BEAMS**

**Phil Moss Ferguson**

THE UNIVERSITY OF TEXAS AT AUSTIN

# **1968 - FLEXURAL CRACK WIDTH AT THE BARS IN REINFORCED CONCRETE BEAMS**

FLEXURAL CRACK WIDTH AT THE BARS IN  
REINFORCED CONCRETE BEAMS

by

Syed I. Husain

and

Phil M. Ferguson

Research Report Number 102-1F

Research Project Number 3-5-66-102  
Crack Width Study

Conducted for

The Texas Highway Department

In Cooperation with the  
U. S. Department of Transportation  
Federal Highway Administration  
Bureau of Public Roads

by

CENTER FOR HIGHWAY RESEARCH  
THE UNIVERSITY OF TEXAS AT AUSTIN

June 1968



**Phil Moss Ferguson**

THE UNIVERSITY OF TEXAS AT AUSTIN

**Syed I. Husain**

<http://behruyan.com/wp-content/uploads/2016/10/crack-1.pdf>

<https://library.ctr.utexas.edu/digitized/summaries/102-1-f-s.pdf>

**Research Project Number 3-5-66-102**  
**Crack Width Study**

**The Texas Highway Department**  
by

**CENTER FOR HIGHWAY RESEARCH**  
THE UNIVERSITY OF TEXAS AT AUSTIN

**JUNE 1968**

A total of 32 reinforced concrete beams were tested, although 9 of these were only modestly effective because they were used in developing the basic technique.

The 9 preliminary beams were 24 in. deep and 16 of the other 23 were the same depth. In addition 7 members 7 in. deep were tested.

Steel stresses ranging from 20 ksi ( 140 MPa) to 40 ksi (180 MPa) and covers from 0.75 in. to 3 in. clear were used.

Bars were largely #11 ( 36mm ) , but a few specimens with #8 (25mm), or #6 (19mm) bars were compared.

The injection itself was made with Epoxy 530 and Hardener 9816, colored with carbon black dye and mixed in proportions which were varied with the temperature. The beam was left under load for at least a day after injection to cure the epoxy. Then it was unloaded and moved into position for sawing.

The objective of the test was to measure internal crack widths. To get inside the beam, diamond point saw cuts were made to form the channels indicated by the solid lines in Fig. 4.

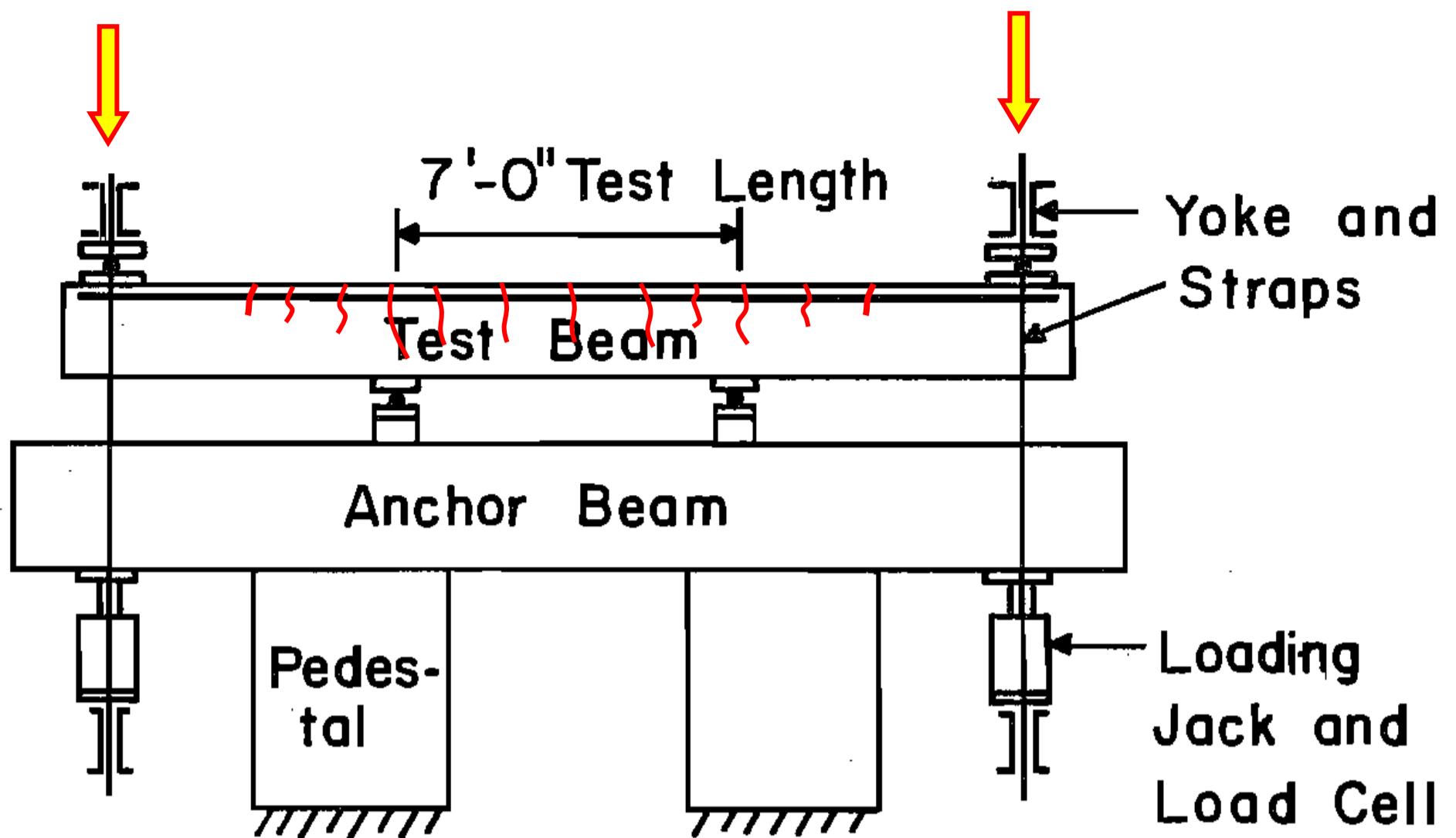
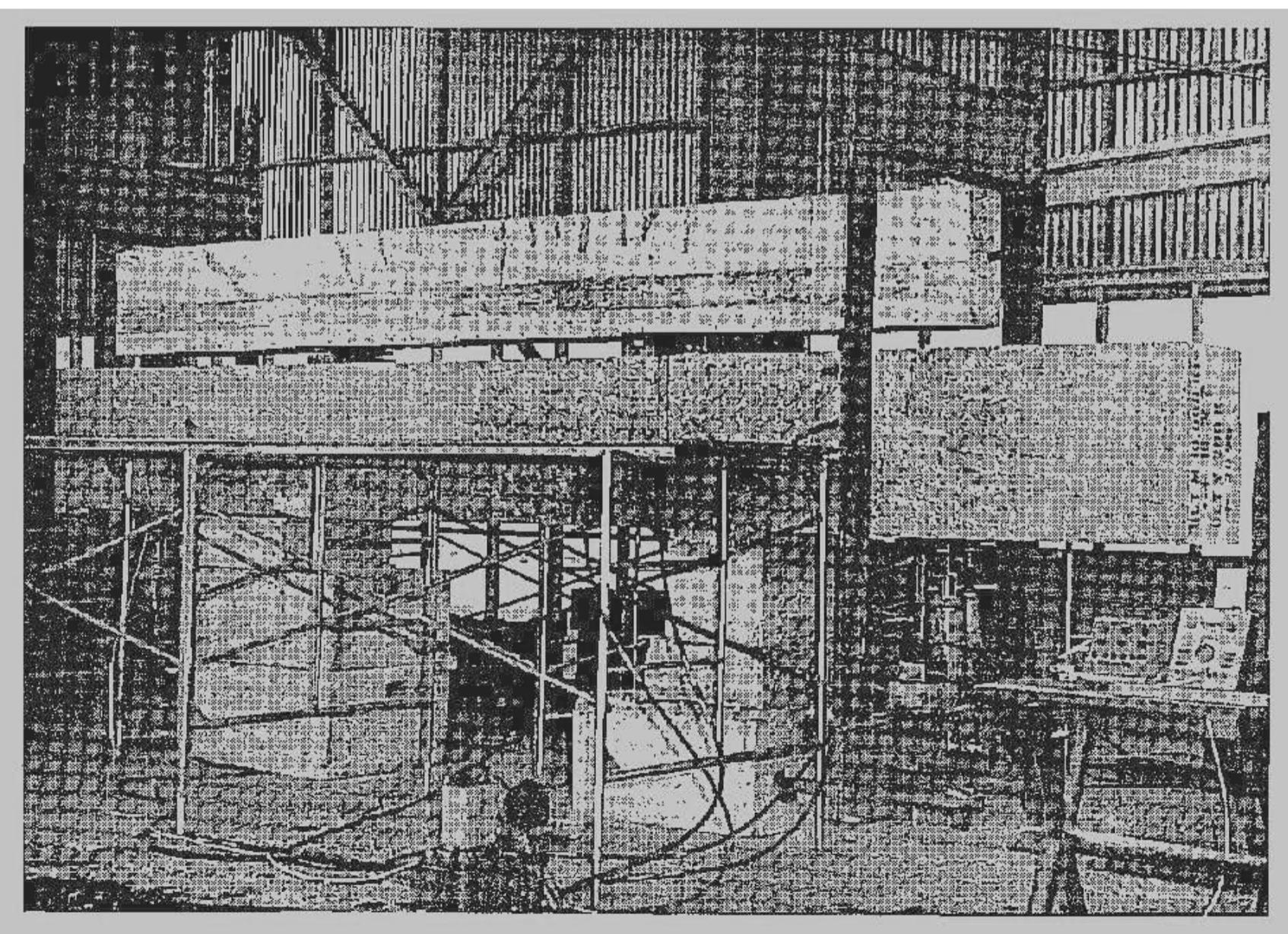


Fig. 1. Arrangement of loading rig.



The objective of the test was to measure internal crack widths. To get inside the beam, diamond point saw cuts were made to form the channels indicated by the solid lines in Fig. 4.

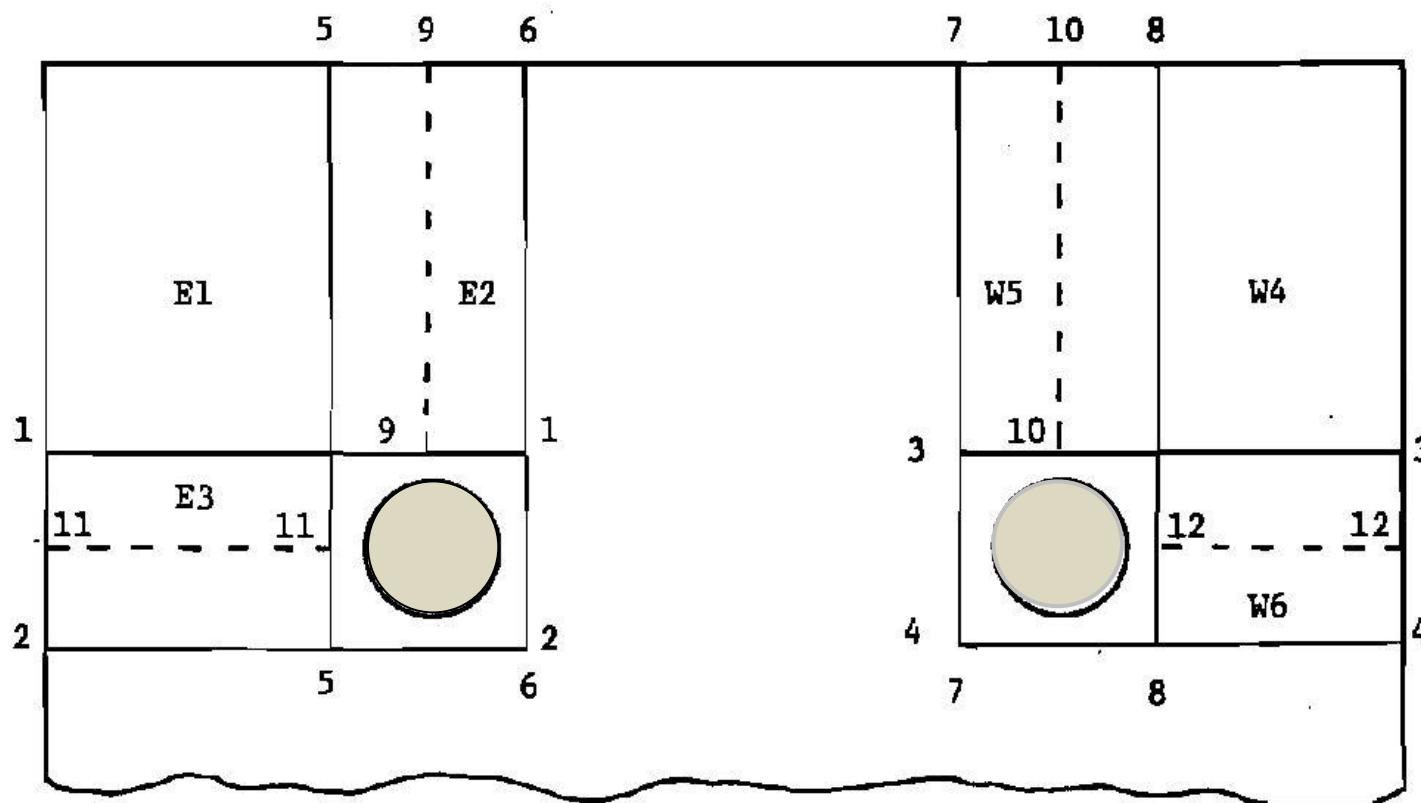
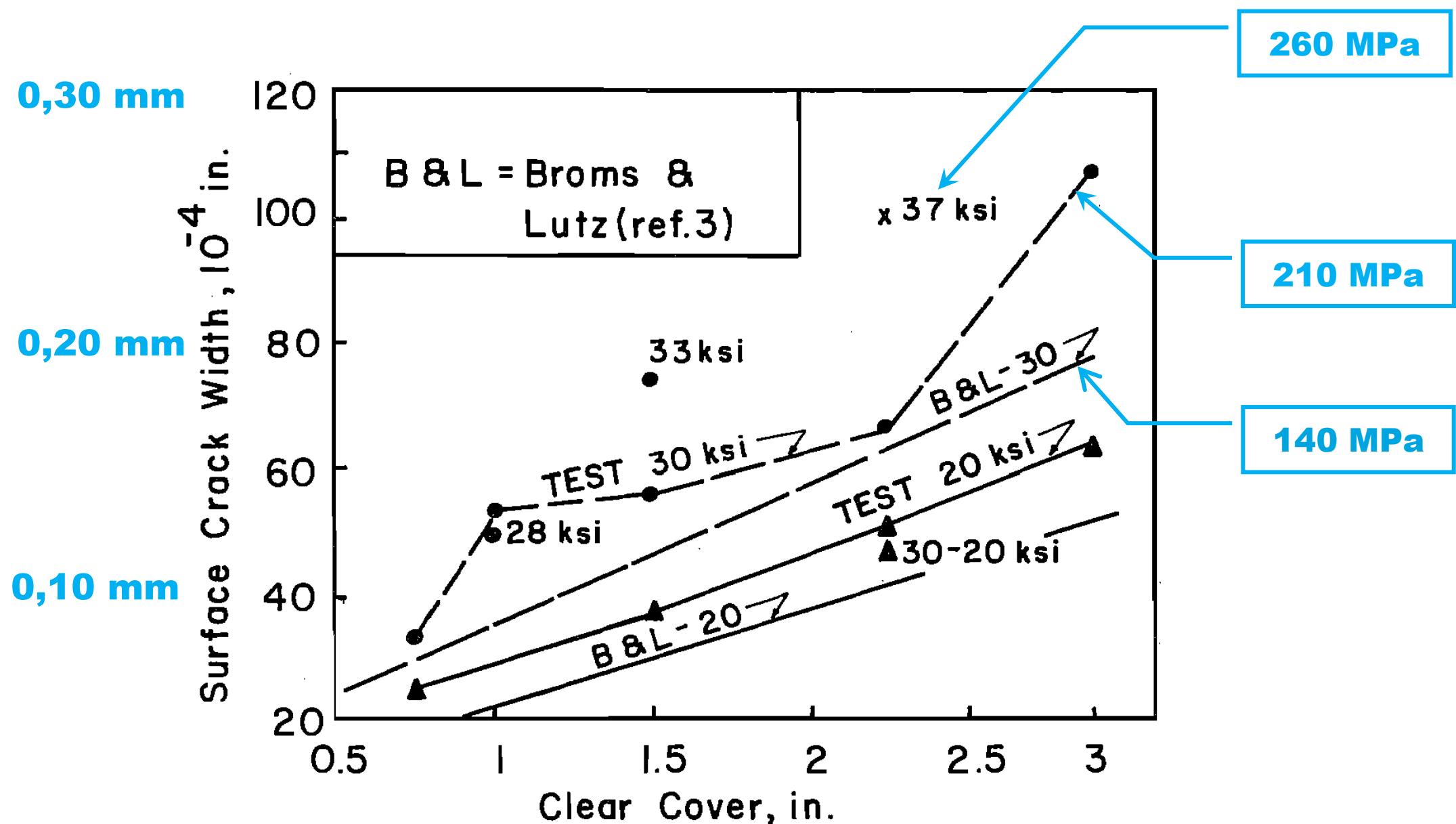


Fig. 4. Primary pattern of saw cuts. The cuts along the dotted lines were made later.



A ABERTURA DA FISSURA AUMENTA COM A TENSÃO NO AÇO E  
COM A ESPESSURA DO COBRIMENTO.

**A FISSURA É ESTREITA JUNTO À BARRA DE AÇO E LARGA NA FACE DA VIGA.**

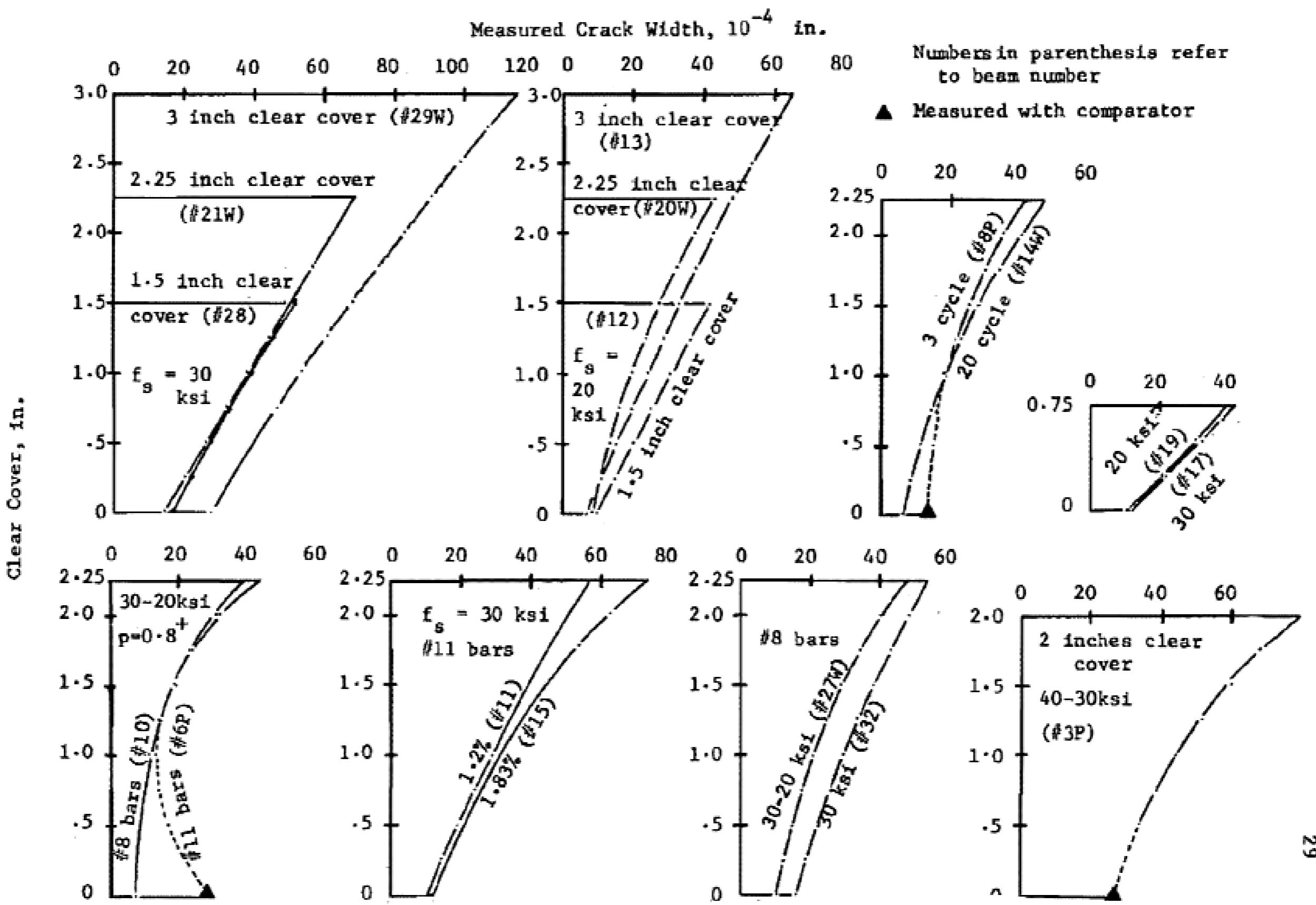
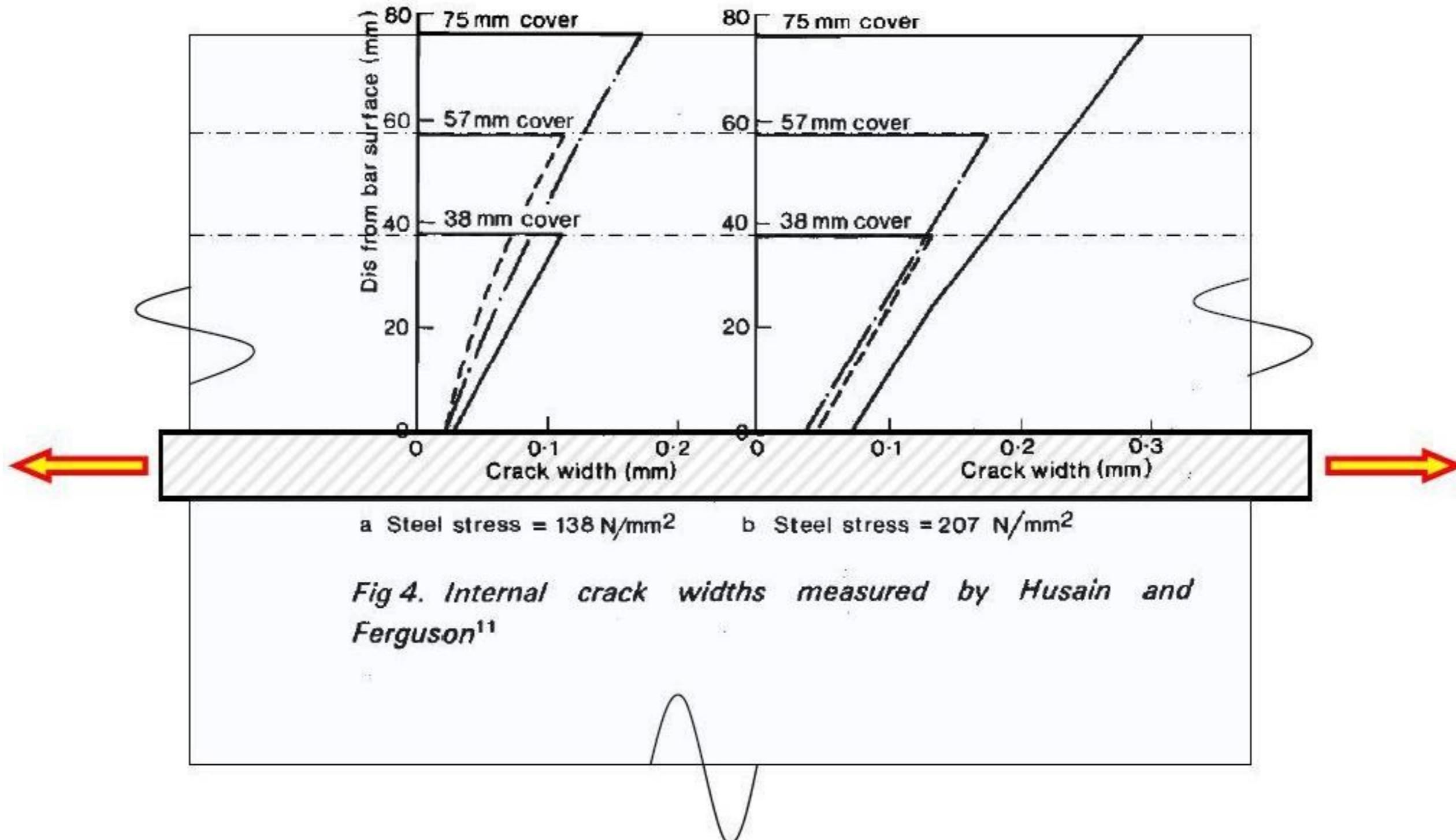


Fig. 18. Best fit curves for crack profiles



*Fig 4. Internal crack widths measured by Husain and Ferguson<sup>11</sup>*

*Internal crack widths measured by Husain and Ferguson  
(figura editada)*

## RESUMO : FISSURA JUNTO À BARRA X FISSURA NA FACE DA VIGA.

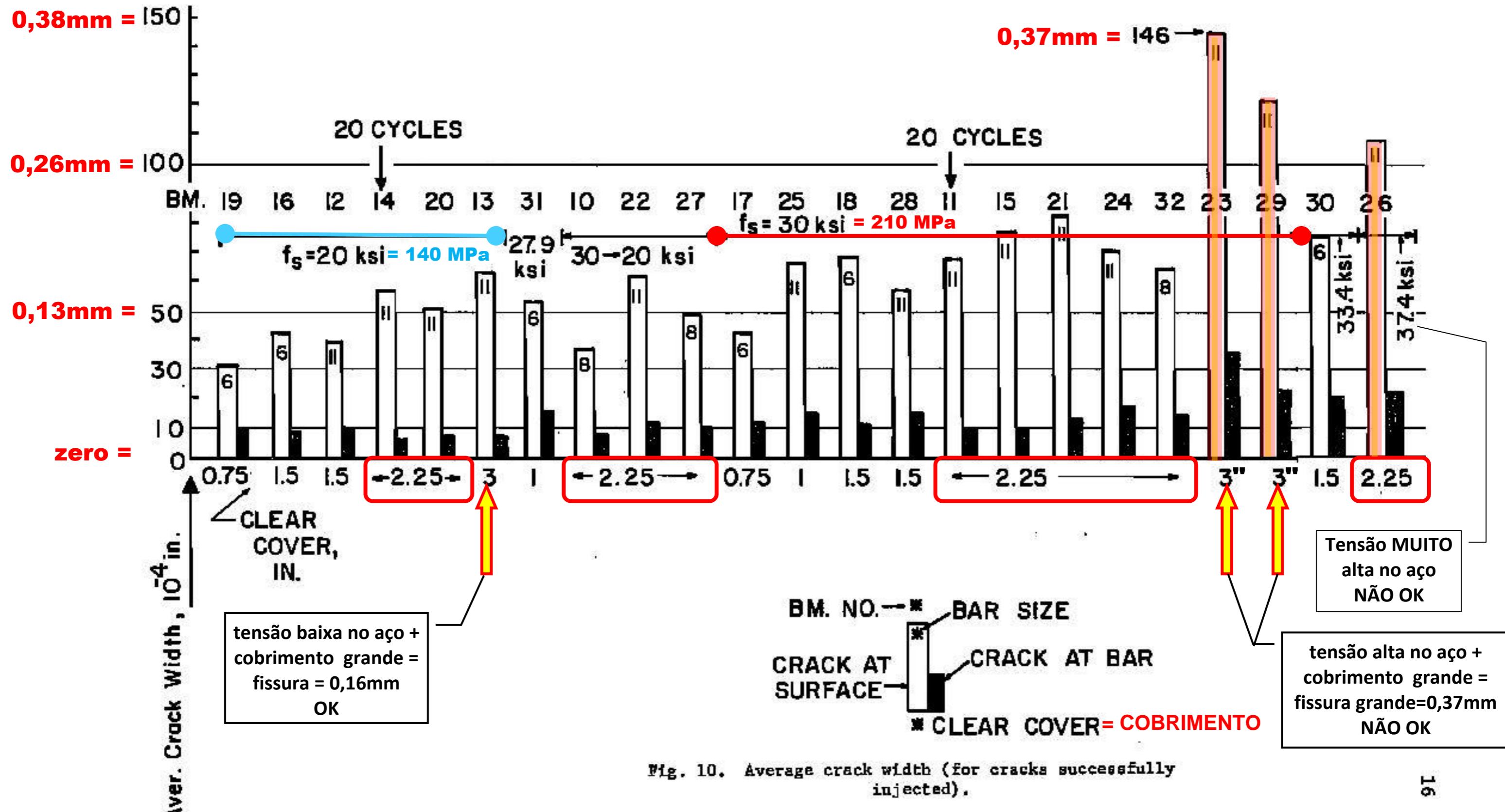


Fig. 10. Average crack width (for cracks successfully injected).

**TENSÃO ALTA NO AÇO + COBRIMENTO GRANDE = FISSURA GRANDE = NÃO OK**

## Conclusions

A new technique has been developed for measuring the width of cracks within the concrete covering the bars. The tests have clarified the relation between crack width at the bar and at the surface and have given some measure of the width variation within the cover.

With this technique the following crack characteristics have been noted.

1. The crack spacing and the crack width at any level vary from average values by at least  $\pm 50\%$ . Average widths are used here for comparisons between cases.

2. Steel stress was the most important variable influencing crack width at the bar.

(a) Average crack widths at the bar surface at 20 ksi steel stress range downward from 0.0010 in., the smaller values being associated with thicker bar cover.

(b) At 30 ksi the average crack width at the bar is about 50 percent greater than at 20 ksi, except that at a cover of 3 in. the average jumps suddenly to 0.0029 in.

Since no such increase occurs at a cover of 2.25 in. (where the average is only 0.0013 in.), it appears that the extra heavy cover is not actually helpful insofar as cracking is concerned.

3. For other conditions equal, crack width at the beam tension face varied almost linearly with the cover.

However, at 30 ksi and 3 in. cover the width was greater than this ratio would suggest.

4. Surface crack width at 30 ksi was (very roughly) 50 percent greater than at 20 ksi, except at 3 in. cover it was more than doubled.

5. The ratio of crack width at the bar to that at the surface varied from 0.10 to 0.31, being largest in a shallow member with clear cover of 0.75 in.

6. The crack thickness from bar to surface plotted approximately as a trapezoid, except that shallow members had relatively greater widths at middepth of the cover. A similar nearly linear variation in crack width existed laterally from the bar to the edge of the beam, with slightly smaller crack widths (possibly because nearer the beam neutral axis).

7. Repetitions of load for 20 cycles had no noticeable influence on measured crack dimensions

**1972**

CORROSION OF REINFORCING STEEL EMBEDDED IN STRUCTURAL CONCRETE

by

James T. Houston  
Ergin Atimtay  
and  
Phil M. Ferguson

Research Report No. 112-1F

Research Project Number 3-5-68-112  
Crack Width-Corrosion Study

Conducted for

The Texas Highway Department

In Cooperation with the  
U. S. Department of Transportation  
Federal Highway Administration

by

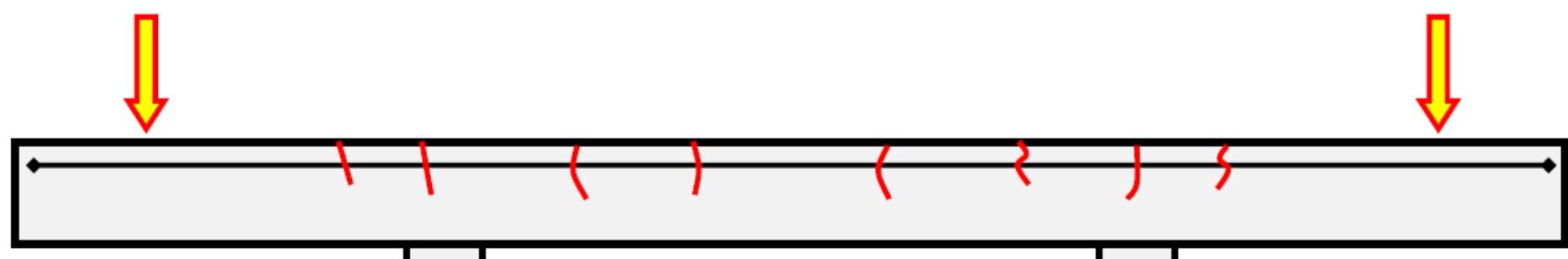
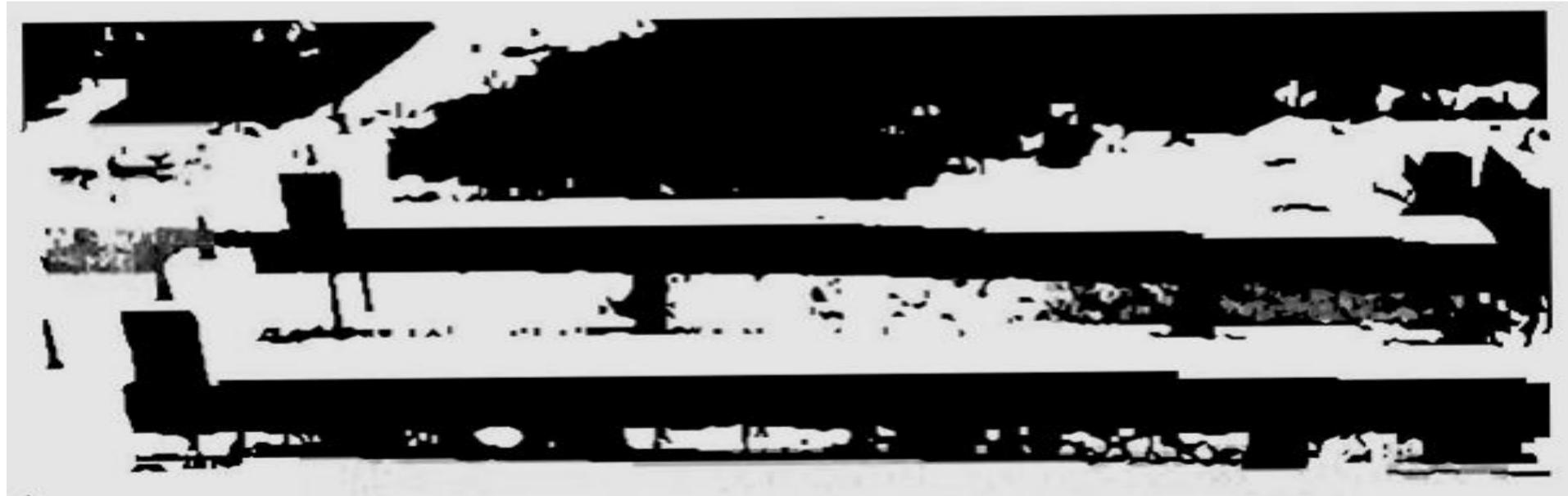
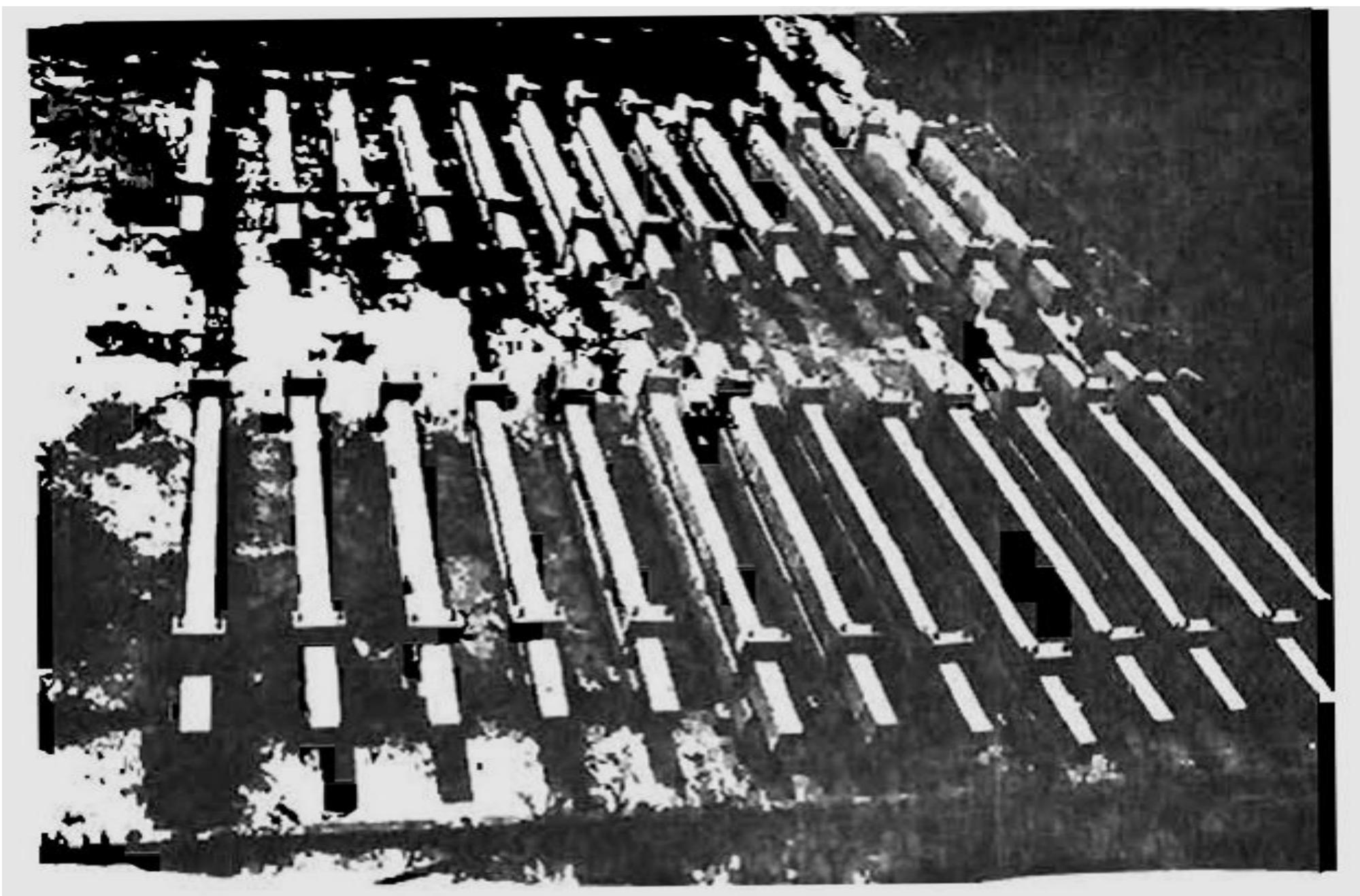
CENTER FOR HIGHWAY RESEARCH  
THE UNIVERSITY OF TEXAS AT AUSTIN

March 1972

<https://library ctr.utexas.edu/digitized/texasarchive/phase1/112-1f-chr.pdf>

The program undertaken spanned four years and involved 82 structural elements. They included 34 normal weight and 6 lightweight loaded beams. Also included were 36 normal weight and 6 lightweight slab specimens. These specimens were subjected to daily spraying with a 3 percent salt solution for various periods of time, ranging up to 34 months. Two views of the testing area where the specimens were sprayed are given in Fig. 1.2.1.

## VIGAS ENSAIADAS



A significant finding of this study showed that although corrosion protection was directly related to depth of cover over reinforcement, a more meaningful parameter in this regard was the ratio of the clear cover to bar diameter (C/D). Greater corrosion protection was provided by beams and slabs having high values of C/D with good protection resulting for C/D values greater than about 3.0. This finding is of importance since normal design practice calls for specific minimum concrete cover regardless of bar size whereas this study shows that a given cover may provide adequate protection for a small bar but may be totally inadequate for a relatively large bar. In addition to C/D effects, it was determined that the initial rate of corrosion of reinforcement was very dependent upon concrete cover. For example, the decrease of a 2 in. cover down to 1 in. resulted in a four fold increase in the initial rate of corrosion.

Although flexural cracking of concrete was found to promote corrosion of the reinforcement at the crack location, the severity of the long term corrosion damage to the bars was primarily dependent on the depth of concrete cover. Large cracks usually found in conjunction with large cover promoted early corrosion at the crack locations, but further development of the corrosion as well as longitudinal cracking of the cover over the bars were inhibited for the larger covers. Narrower cracks generally associated with shallow covers had little influence on the overall corrosion. In that instance the bars were rather uniformly rusted with extensive longitudinal splitting of the concrete cover over the bars.

Only a slight increase in corrosion resulted as a consequence of stressing the beam reinforcement through flexural loading. These observations indicate that the existence of stresses in the reinforcing bars (up to 36 ksi) and the flexural cracks produced by these stresses were of less importance as corrosion accelerating hazards than had been expected.

TABLE 4.2.2  
CONCRETE MIX PROPERTIES

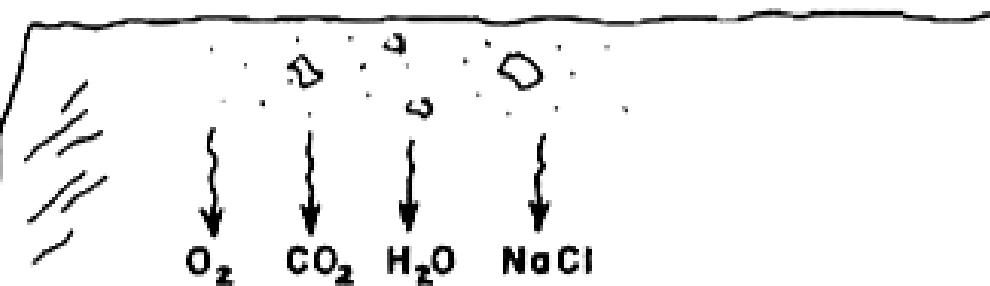
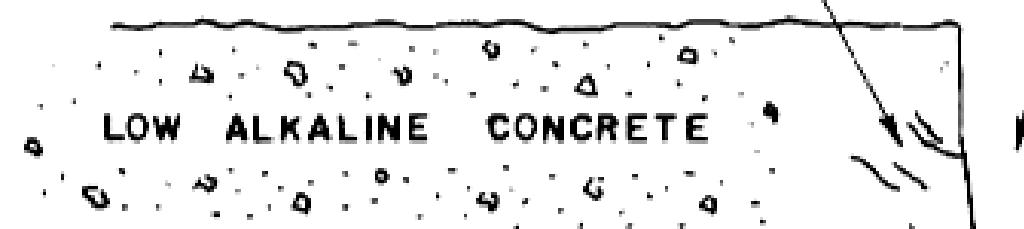
SPECIMEN NO.	MIX. PROPORTIONS BY WEIGHT* (Water:cement:sand:gravel)	SLUMP (in.)	AIR (%)	CEMENT FACTOR (Sacks/or yd.)
1	0.54: 1 :3.14: 4.08	5	---	5.0
2	0.60: 1 :3.14: 4.08	5	---	5.0
2B	0.54: 1 :3.14: 4.08	4 1/2	4.6	---
2BL	0.55: 1 :2.32: 2.38	4 1/2	5.0	5.5
3	0.60 1 :3.65: 4.06	3	6.0	5.0
4	0.60: 1 :3.65: 4.06	3	6.0	5.0
5A	0.51: 1 :3.15: 4.08	3 1/2	5.5	5.0
6	0.49: 1 :3.15: 4.08	3 1/2	7.0	5.0
7A	0.52: 1 :3.15: 4.08	4 1/2	4.5	5.0
8	0.49: 1 :3.15: 4.08	3	6.25	5.0
9	0.53: 1 :3.15: 4.08	2 3/4	4.25	5.0
9BL	0.55: 1 :2.32: 2.38	4 1/2	5.0	5.5
10	0.53: 1 :3.15: 4.08	2 3/4	4.25	5.0
11	0.52: 1 :3.15: 4.08	3	5.0	5.0
12	0.52: 1 :3.15: 4.08	3	5.0	5.0
13	0.49: 1 :3.15: 4.08	3	6.0	5.0
14	0.49: 1 :3.15: 4.08	3	6.5	5.0
14B	0.49: 1 :3.15: 4.08	3	7.0	---
14BL	0.55: 1 :2.32: 2.38	4 1/2	4.5	5.5
15	0.49: 1 :3.15: 4.08	3	5.0	5.0
15B	0.49: 1 :3.15: 4.08	3	7.0	---

\* Actual batch weights not adjusted to SSD condition by moisture corrections.

Salt crystal growth and alternate freeze and thaw cycles promote the formation of cracks.

Longitudinal Crack: Path for easy penetration of corrosive agents.

## FISSURA LONGITUDINAL

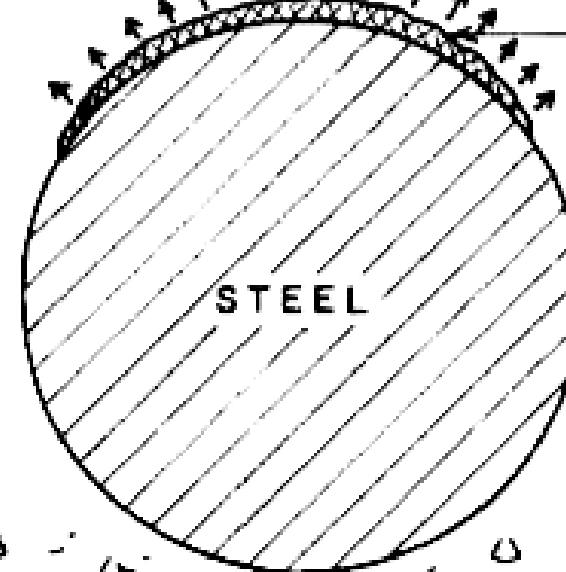


Rate of penetration depends on permeability of concrete. Penetration of CO<sub>2</sub> causes carbonization of concrete, lowering the pH.

O<sub>2</sub>, H<sub>2</sub>O, NaCl inhibit the possibility of self-limiting corrosion

Expansive forces created by the corrosion product promote the cracking and spalling of concrete.

End View of Embedded Bar



HIGH ALKALINE CONCRETE

Initially rust scale forms at transverse cracks. The expansive forces created promote longitudinal cracking if C/D ratio is small.

Fig. 4.1.3. General mechanism for the corrosion of reinforcing steel in concrete.

## **FISSURA LONGITUDINAL**



**ATERRO DO FLAMENGO / RJ**

## FISSURA LONGITUDINAL



## COBRIMENTO / DIÂMETRO DA BARRA

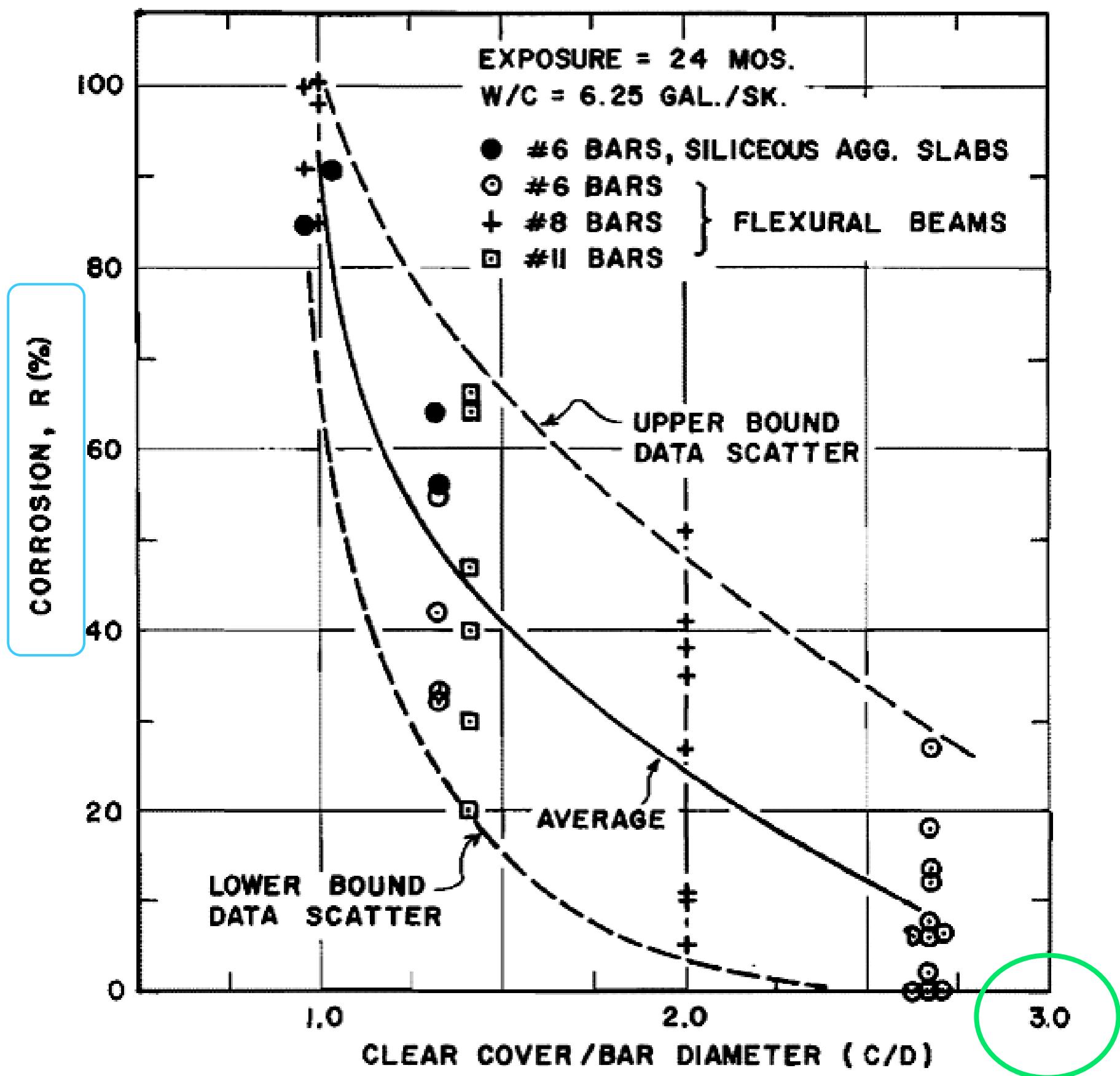


Fig. 3.4.5 Effect of C/D ratio upon corrosion of unstressed reinforcing bars in beams and slabs.

# Agregado Calcário

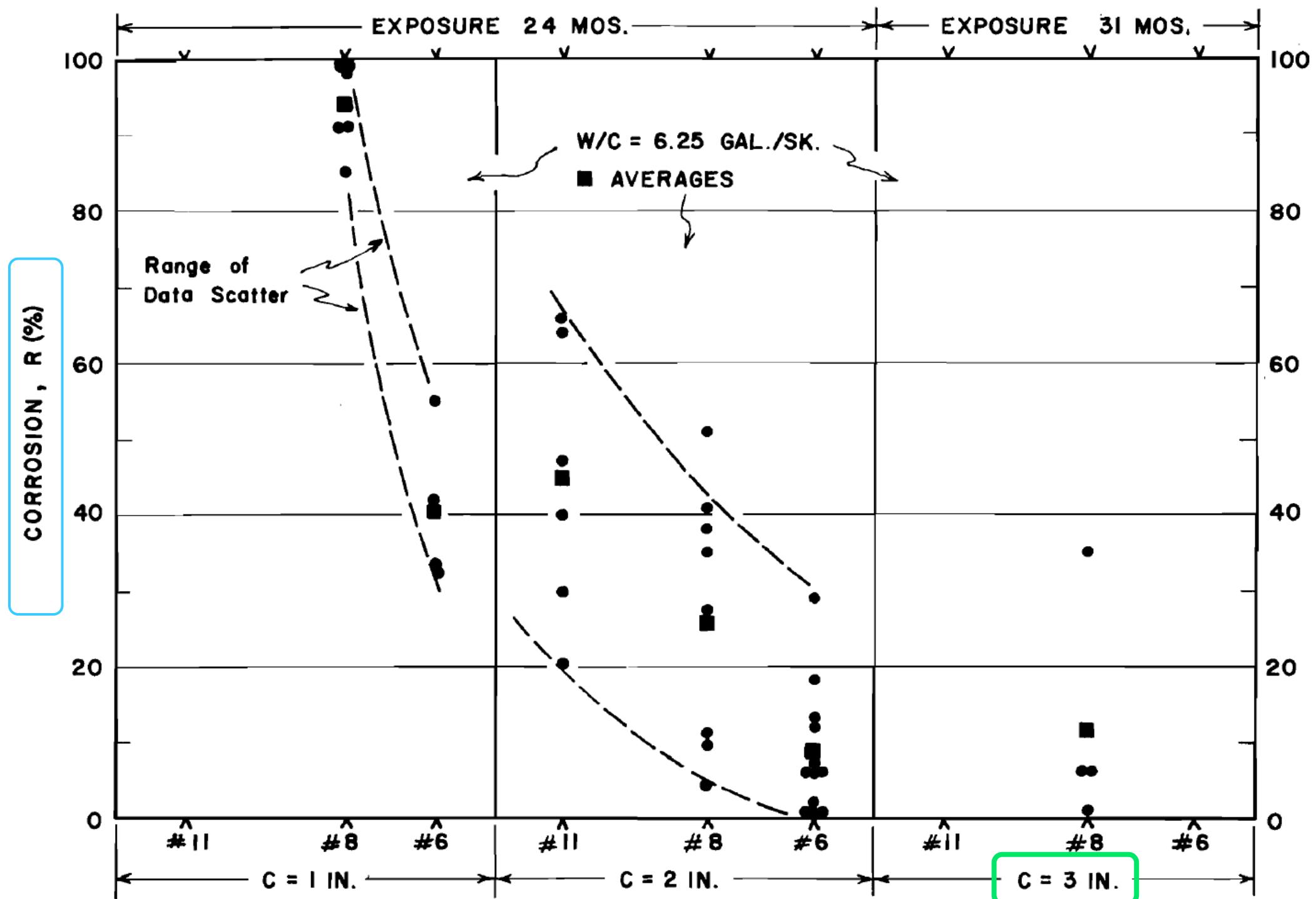


Fig. 3.4.2 Effect of clear cover and bar diameter upon corrosion of unstressed bars in beams of 1-1/2 in. crushed limestone aggregate concrete.

## Agregado Silicoso

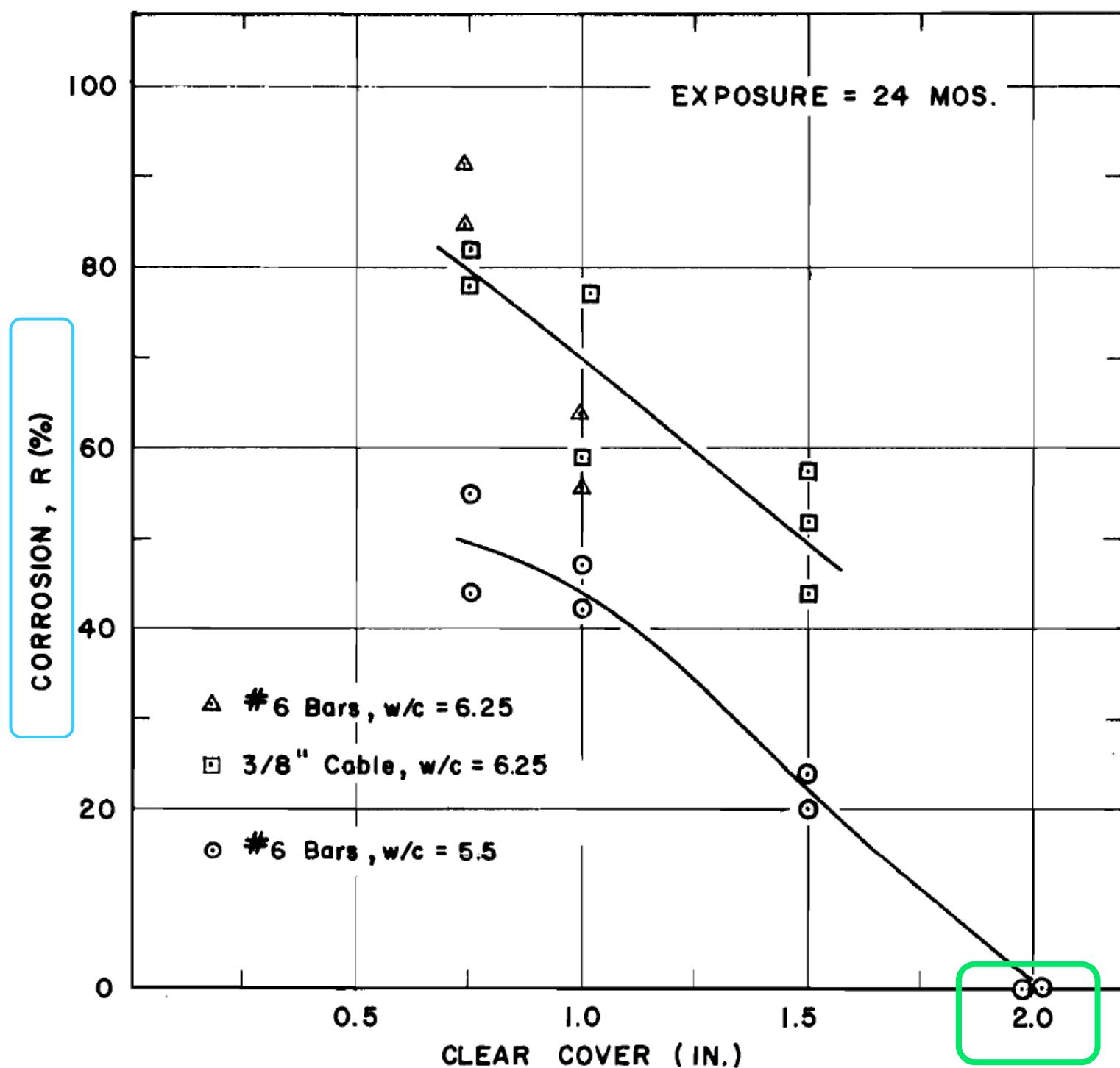


Fig. 3.4.1 Corrosion of reinforcing bars and prestress cables in slabs made of 3/8-in. siliceous aggregate.

1978

**Corrosion of reinforcing steel in  
concrete and its relation to cracking**

**Andrew W. Beeby**

# 1978 - CORROSION OF REINFORCING STEEL IN CONCRETE



## Corrosion of reinforcing steel in concrete and its relation to cracking

**A. W. Beeby**, PhD, CEng, MInstuctE, MICE

*Cement and Concrete Association*

The Structural Engineer/March 1978/No. 3/Volume 56A

<https://trid.trb.org/view/78946>

## COMENTÁRIOS DE **Andrew W. Beeby** :

### **Corrosion damage in practice ( Fotos adicionadas por Eduardo Thomaz, para ilustrar o texto )**

When reinforcement rusts, the corrosion products generally occupy considerably more volume than that of the steel destroyed.

The magnitude of this increase in volume varies somewhat from situation to situation, but a value in the region of 2 to 3 times the volume of metal removed would not be unreasonable.

As a result, the corrosion products from quite small reductions in the cross-sectional area of a bar will produce internal stresses sufficient to disrupt the surrounding concrete.

The typical indications of corrosion in reinforced concrete structures are wide cracks along the line of bars, spalled-off corners or substantial spalled areas on slabs. ( VER FOTOS ADIANTE )

In most practical circumstances this spalling occurs well before the reinforcement has become significantly weakened.

Once the cover has been spalled off, rapid corrosion of the exposed steel will take place. ( VER FOTOS ADIANTE )

The indications are that corrosion of exposed bars may occur at about 10 times the rate at which it occurs at cracks, sufficient to cause significant weakening of the bars in a short time relative to the design life of a structure.

The primary objective of design against corrosion is thus design against spalling rather than design against unacceptable loss of reinforcement area.

**EXEMPLO DE CORROSÃO EM ARMADURA DE LAJE EM ANTIGA PONTE NA RESTINGA DA MARAMBAIA / RJ**  
Construção de 1943, desativada.

**SPALLING = DESPLACAMENTO DO FUNDO DA LAJE**



**EXEMPLO DE CORROSÃO EM ARMADURA DE LAJE EM ANTIGA PONTE NA RESTINGA DA MARAMBAIA / RJ**  
**Construção de 1943, desativada.**

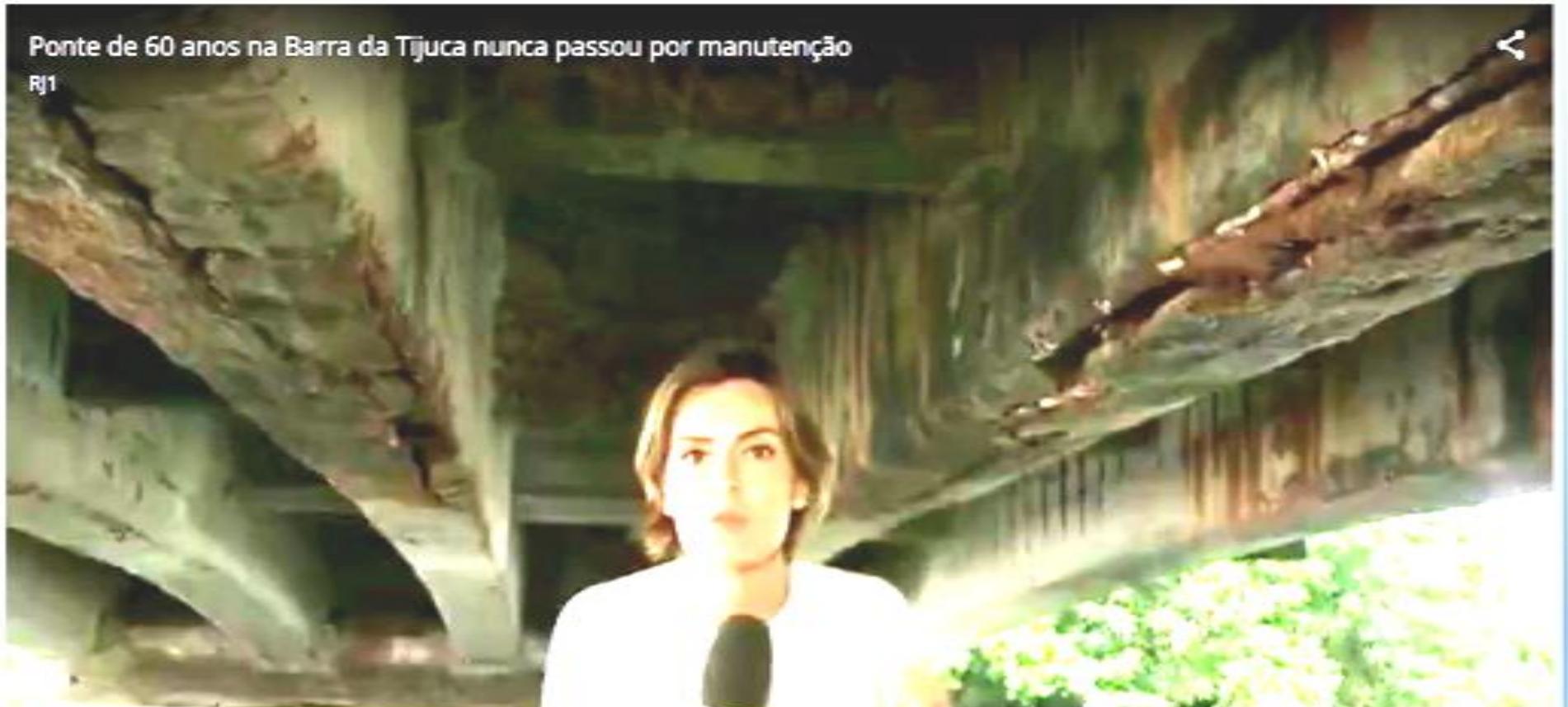
**SPALLING = DESPLACAMENTO DO FUNDO DA LAJE**



**The parameters that are likely to influence spalling of the concrete can be derived very simply.**

The internal forces generated by corrosion will depend on the depth of corrosion, the corroded length and the bar diameter. The ability of the concrete to resist these forces will depend on the location of the bar (a corner bar will be weaker than one in the centre of a slab), the tensile capacity of the concrete and the cover.

## **SPALLING = DESPLACAMENTO DO FUNDO DA VIGA**



<https://globoplay.globo.com/v/7255759/>

Houston, Atimtay and Ferguson, who carried out tests on 82 beam specimens sprayed daily with 3% salt solution, concluded that the ratio of bar diameter  $\phi$  to cover  $c$  was a major parameter and that little significant corrosion damage occurred if this ratio exceeded 3.

Most of the specimens had values of the ratios  $c/\phi$  in the range 1-3, which must cover the likely practical range of this parameter.

It is interesting to note that the specimens used in the Munich tests had values of  $c/\phi$  of 3 or 4, 5, and that very few workers other than Houston, Atimtay and Ferguson have tested values lower than these.

None of the researchers working with large values of  $c/\phi$  reported any spalling from corrosion in their tests. Thus a major part of the exposure test data refers to situations that are unlikely to lead to the type of corrosion damage met with in practice.

**Exemplo : Armadura da Viga de uma Ponte na Barra da Tijuca / RJ**

**SPALLING = DESPLACAMENTO DO FUNDO DA VIGA**



<https://globoplay.globo.com/v/7627738/>



**SPALLING = DESPLACAMENTO DO FUNDO DA VIGA**



**Construção de 1939 ainda em uso, sendo reparada.**

**BARRAS DE 32 mm e COBRIMENTO = 3cm → → c/φ =1**

Another variable mentioned above as being likely to critically affect the possibility of spalling is the length of bar over which corrosion occurs.

In situations where the initiating source of corrosion is a crack perpendicular to the line of the bar, the corroded length is likely to be small, typically up to about 3 bar diameters.

Far larger corroded lengths will occur where a crack follows the line of a bar. In such a situation, the corroded length will be roughly equal to the length of the crack.

Furthermore, the crack will reduce the resistance of the surrounding concrete to spalling.

Longitudinal cracks can result from a variety of sources, e.g. in a beam many of the cracks perpendicular to the main bars will form along the line of stirrups. Similar cracking in slabs often at least partially follows the lines of reinforcement.

On this question of longitudinal cracking, it is worth a brief consideration of some studies that have been carried out on actual structures.

In a contribution to a discussion at the 1957 Stockholm Conference on Bond and Crack Formation, Carpentier reported a survey of reinforced concrete structures associated with the French railway system (these include some 3000 reinforced concrete bridges).

He stated that, of these bridges, about 5% could be considered to be more than superficially cracked.

While this survey had not enabled definite quantitative conclusions to be reached, the following general points had emerged.

The general effect on corrosion of cracks that were not parallel to the direction of the reinforcement was negligible.

It could be stated categorically that 90% of the situations where repair to corrosion damage had been required were the consequences of longitudinal cracks causing corrosion over long lengths of bar and resulting in bursting.

This corrosion often occurred on stirrups (estribos) surrounding the main steel and was possibly initiated by cracks that formed perpendicular to the main bars following the line of stirrups.

**AS DUAS FOTOS ABAIXO MOSTRAM A CORROSÃO NOS ESTRIBOS EM UMA ANTIGA PONTE NA RESTINGA DA MARAMBAIA NO RIO DE JANEIRO**

**Construção de 1943, desativada e em recuperação.**

**BARRAS DE 32 mm e COBRIMENTO = 3cm → → → c/ϕ = 1**



**Similarly, Dechamps et al., who carried out a programme of coring of actual structures to investigate corrosion at cracks, found that very little corrosion occurred where cracks crossed bars but the transverse bars (ESTRIBOS) were considerably more heavily attacked.**

There is a fundamental difficulty associated with the evaluation of data from actual structures; this is that since corrosion causes longitudinal cracking, it is not really possible to tell whether a particular crack caused the corrosion or whether the corrosion caused the crack.

Nevertheless it does seem clear that a crack perpendicular to the line of the bar does not constitute a corrosion risk in practice, while the existence of longitudinal crack may.

**2010**

**Crack width variation within the concrete cover of  
reinforced concrete members.**

**ADORJÁN BOROSNYÓI**

## 2010 - Crack width variation within the concrete cover of reinforced concrete members



ADORJÁN BOROSNYÓI - BME Dept. of Construction Materials and Engineering Geology -  
adorjan.borosnyoi@gmail.com

IVÁN SNÓBLI - BME Dept. of Construction Materials and Engineering Geology - Received: 31.07.2010.

*Fig. 1. gives experimental result of Beeby ( 1978 ) indicating considerable differences between surface crack width and crack width close to the steel reinforcement*

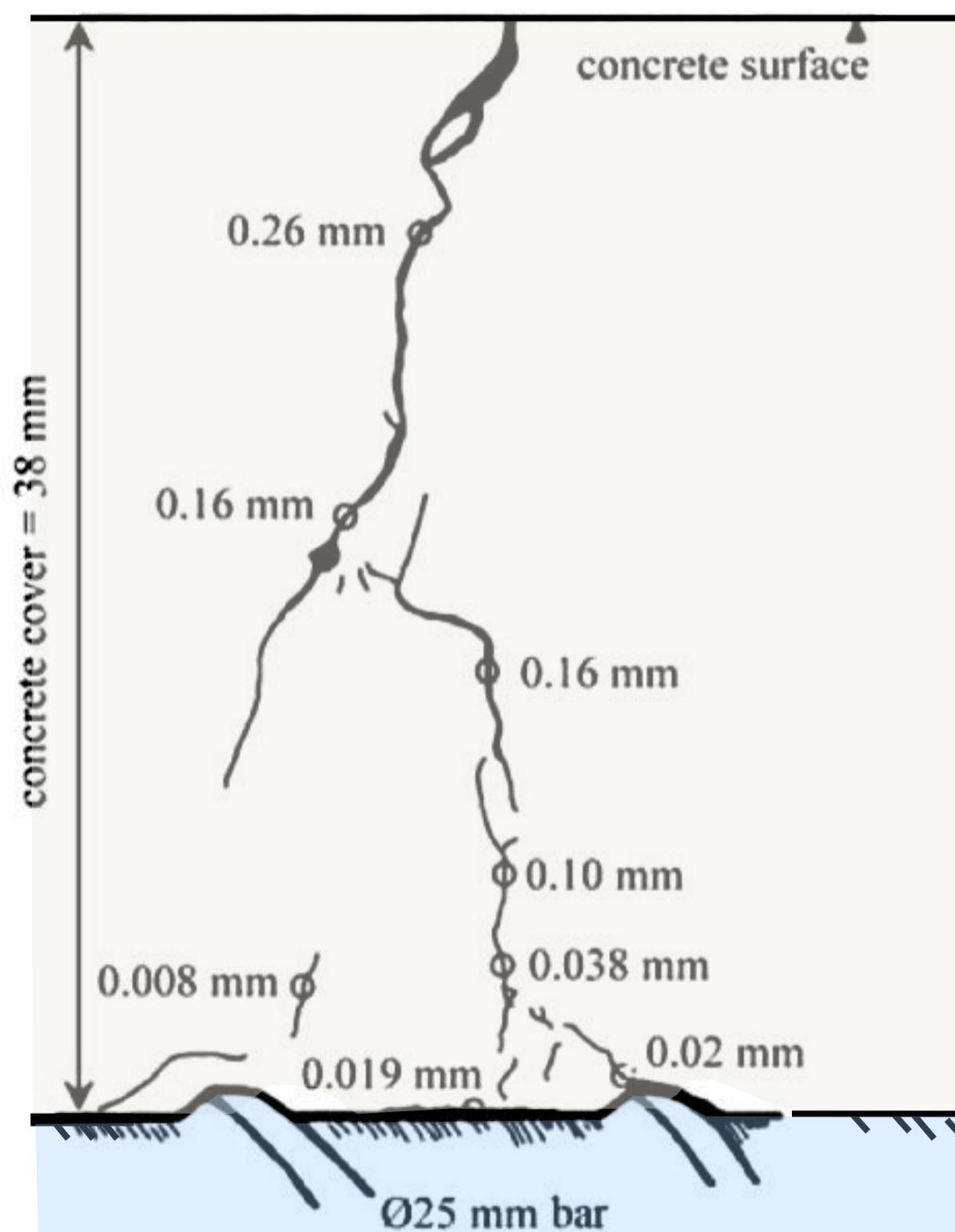


Fig. 1. Variation of crack width within a concrete cover of 38 mm [2]  
1. ábra Repedéstágasság változása 38 mm-es betonfedésen belül [2]

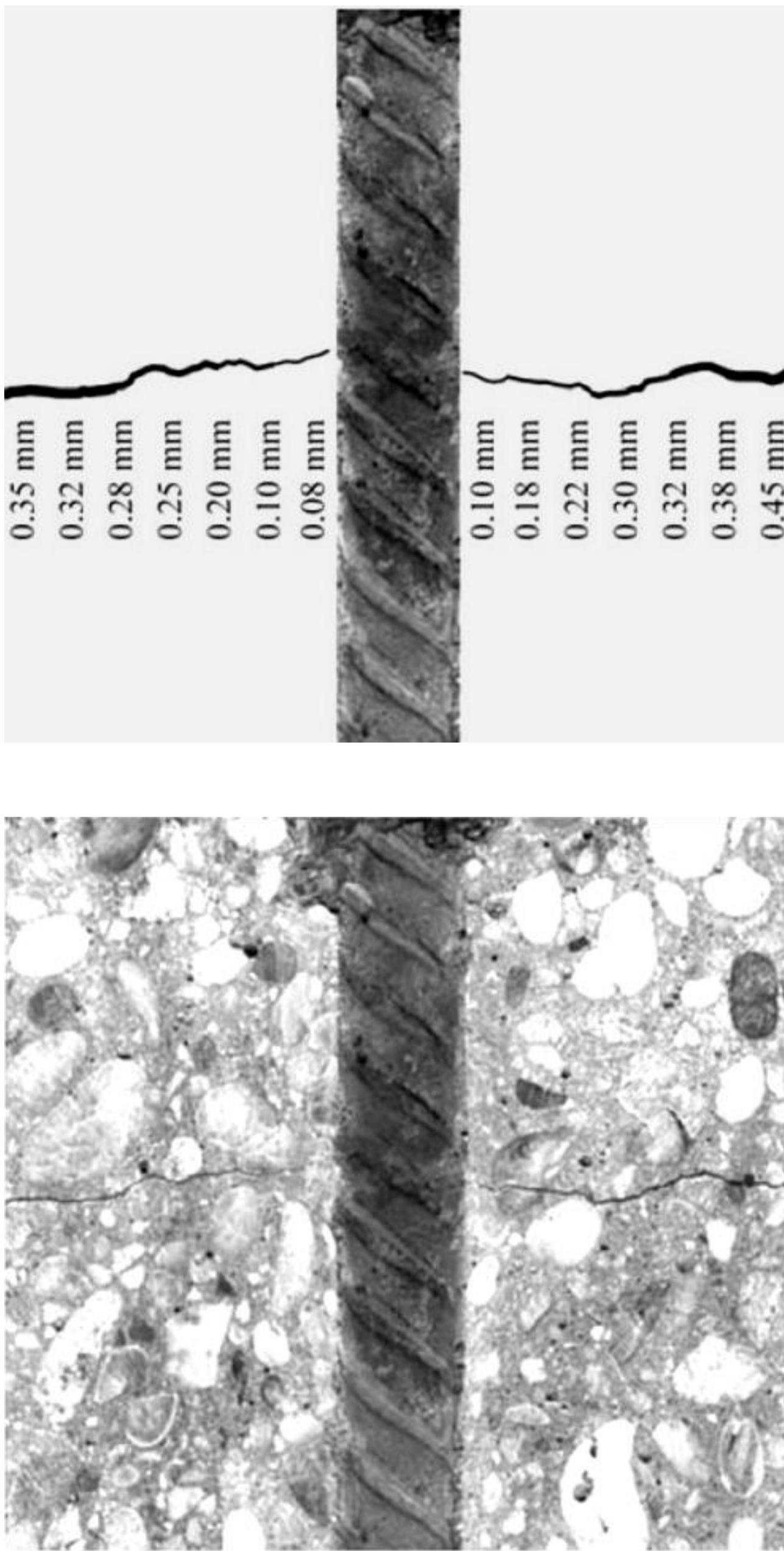
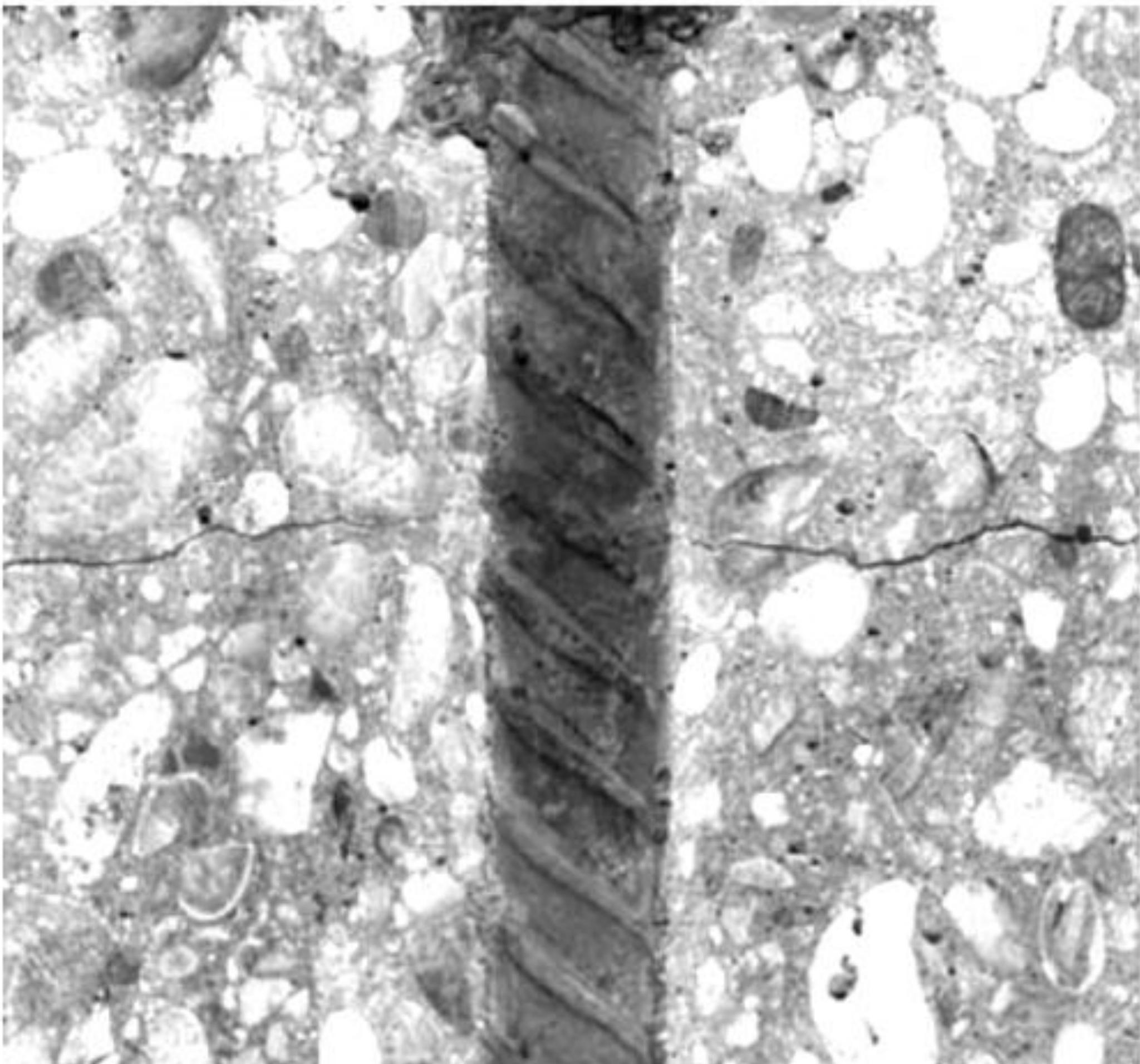


Fig. 4. Variation of crack width for specimen with concentric steel reinforcement (concrete cover of 50 mm)  
4. ábra. Repedéstágasság változása központosan elhelyezett acélbetét mellett (50 mm betonfedés)



*Fig. 4. Variation of crack width for specimen with concentric steel reinforcement (concrete cover of 50 mm)*

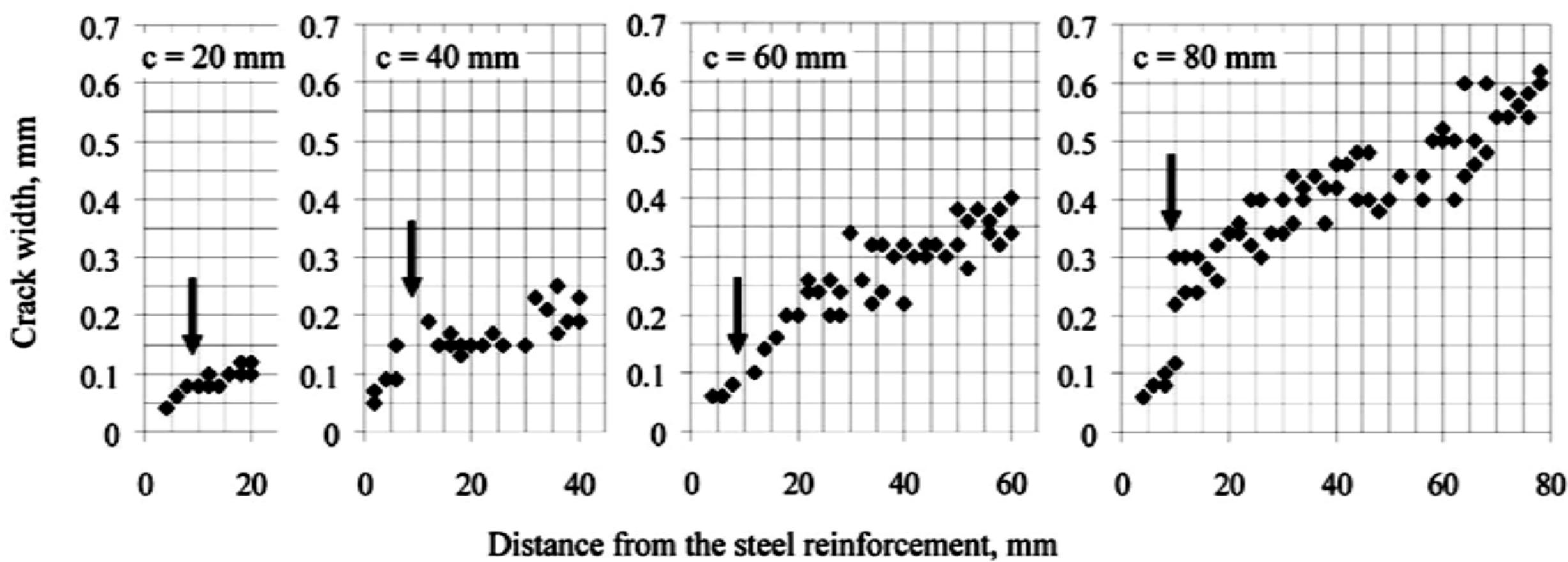


Fig. 5. Variation of crack width for specimens with eccentric steel reinforcement (concrete covers of 20, 40, 60, 80 mm)

5. ábra Repedéstágasság változása különlegesen elhelyezett acélbetét mellett (20, 40, 60, 80 mm betonfedés)

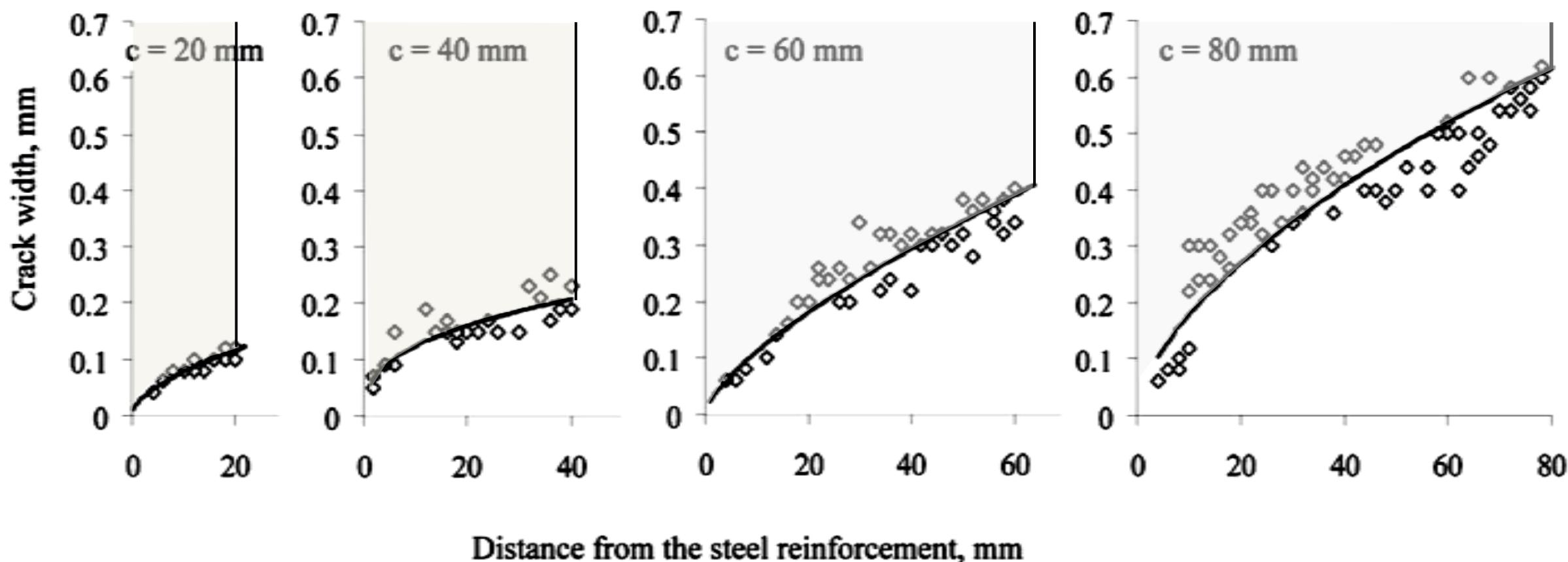


Fig. 7. Regression power function curves for the variation of crack width for specimens with eccentric steel reinforcement (concrete covers of 20, 40, 60, 80 mm)

7. ábra Repedéstágasság betonfedésen belüli változásának ábrázolása hatványfüggvény alakjában; különlegesen elhelyezett acélbetét (20, 40, 60, 80 mm betonfedés)

**2019 - COMENTÁRIOS**

**EDUARDO THOMAZ**

## COMENTÁRIOS de Eduardo Thomaz

1 - Para ter uma boa durabilidade, 5cm de um bom concreto, bem lançado, bem vibrado e bem curado, são suficientes, desde que se dimensione a armadura de modo a limitar a abertura de eventuais fissuras a valores pequenos, por exemplo w≤0,15mm,

2 - OBS. : Os itens sublinhados nem sempre estão presentes nas obras e projetos

3 - Ter pequenas aberturas de fissuras, significa, em vigas e em lajes, usar tensões baixas nas armaduras, o que sempre acontecia no antigo aço 37CA (= atual CA24) , pois o aço tinha tensões máximas em serviço de  $\sigma = 1200 \text{ kgf/cm}^2$ . O elongamento médio do aço era  $\epsilon = 0,6\text{mm/m}$  .

Os ensaios de Yukimasa GOTO mostram o alongamento na fissuração  $\epsilon = 0,27\text{mm/m}$

Y.GOTO - "*Internal cracks usually start at a steel stress less than 14 ksi ( 1000 kg/cm<sup>2</sup>), shortly after primary cracks are formed. They first develop around lugs (nervuras) near the primary cracks, then with increase in steel stress or with repetition of load at lugs progressively farther from the primary cracks.*"

4 - Hoje, o aço CA50 trabalha, em serviço, com cerca de  $\sigma_{\text{máx.}} = 3000 \text{ kgf/cm}^2$ , embora com melhor aderência, devido às nervuras, mas o alongamento do aço é bem maior.

O elongamento médio do aço, em serviço, é então  $\epsilon = 1,4\text{mm/m}$ .

5 - O elongamento de ruptura na tração do concreto é cerca de  $\epsilon = 0,20\text{mm /m}$  ( 0,15 mm/m a 0,25mm)

Os ensaios de Yukimasa GOTO mostram alongamento na fissuração  $\epsilon = 0,27\text{mm/m}$

Ver também : [http://aquarius.ime.eb.br/~webde2/prof/ethomaz/fissuracao/flexao\\_01.pdf](http://aquarius.ime.eb.br/~webde2/prof/ethomaz/fissuracao/flexao_01.pdf)

Por esse motivo em blocos de fundação recomenda-se usar tensões no aço, em serviço, 175 MPa, o que corresponde a uma abertura de fissura de 0,1mm, segundo as medições feitas por Blérot. Em especial em solos com água contendo substâncias agressivas.

Ver : [http://aquarius.ime.eb.br/~webde2/prof/ethomaz/bloco\\_sobre\\_estacas/bloco\\_sobre\\_estacas\\_02.pdf](http://aquarius.ime.eb.br/~webde2/prof/ethomaz/bloco_sobre_estacas/bloco_sobre_estacas_02.pdf)

## COMENTÁRIOS, CONTINUAÇÃO.

**6 - Todas as formulações aferidas por ensaios de diversos autores mostram que :**

**A abertura das fissuras nas lajes e nas vigas fletidas aumenta com :**

- **tensão elevada no aço da armadura** > usar mais armadura , de modo a ter tensões baixas no aço
- **cobrimento grande** > adotar os cobrimentos recomendados pela NBR6118, para a classe de agressividade ambiental, sem aumentá-los.
- **uso de barras de grande diâmetro** > para ter fissuras menores, projetar com maior número de barras de pequeno diâmetro. Porém. as barras finas são mais sensíveis ( geometricamente) à corrosão, pois, por exemplo, uma corrosão de 0,5mm ao redor de uma barra de 8mm reduz sua área em 23% ao passo que em uma barra de 20mm a redução é de 10%. Por isso, em fundações, sapatas e blocos, usar barras grossas.
- **porcentagem baixa de armadura** > usar mais armadura , de modo a ter tensões baixas no aço
- **espaçamento grande entre barras** > com muitas barras o espaçamento diminui.
- **concreto de baixa resistência** > segundo Prof. Paulo Helene "em caso de receio com cobrimentos exagerados, deve-se melhorar o concreto (mil e uma possibilidades com redução de a/c, adições de Metacaulim ou Silica ativa, substituir o tipo de cimento, usar fibras plásticas, usar cristalizantes, escolher agregados adequados, etc.),"
- **barras lisas ao invés de barras nervuradas** > "The spacing of primary cracks in the case of deformed bars (nervuradas ) is closer than with plain bars ( lisas) under similar surroundings, whether measured as an average, a maximum, or a minimum." Menor espaçamento entre fissuras=menor abertura de fissura. Usar sempre barras nervuradas.
- **repetição cíclica das cargas :**

**Y.GOTO** - "In the cases shown in the photographs, the penetration of ink is seen only at the bar surface near the primary cracks, but after about 10,000 cycles of load repetition between steel stresses of 28 and 7 ksi (2000 and 500 kg/cm<sup>2</sup>) ink is seen to penetrate along almost the entire surface of the bar.

After repeated cycles of load, it appears that adhesion has been almost completely broken. The bond between deformed bars and concrete must then depend on the mechanical resistance of lugs(nervuras) and the frictional resistance between concrete and steel at the bar surfaces between lugs."

> Não há como evitar a oscilação das cargas. Em obras com grande carga móvel em relação à carga permanente, como nas pontes ferroviárias com pequeno vão, além da fadiga do aço, existe também a fadiga da aderência como mostra Y. GOTO. Usar mais armadura para reduzir as tensões no aço, aumentar os comprimentos de ancoragem das barras.

- Eduardo Thomaz