BRITTLE MATTER DUCTILIZATION IN STRUCTURES

by

A.I.CISMIGIU[I] and L.C.DOGARU[II]

INTRODUCTION

Since CONSIDÈRE until nowadays,detailed lab tests show that concrete,which in conditions of "normal" experiments behaves like a relatively brittle body,while put into state of triaxial compression,shows a significant strength growth at compression and shear and high DUCTILITY.On the other hand the few experiments with triaxial tension suggest for the ductile steel a decohesive cleavage excessively brittle under high strengths.The RESPONSE of materials essentially depends on EXPERIENCE CONDITIONS to which they are subjected;DUCTILITY and BRITTLENESS being thus "state properties" and materials division into DUCTILE and BRITTLE is highly conventional.

PASSIVE or ACTIVE exploration of state of stresses in which brittle matter offers high strength and ductility is an act of engineering creation with high technological implications.Some of these technologies are already applied in current practice;others,more promising,are in view for the near future.

INTRINSIC CURVE OF ELASTOPLASTIC DEFORMABILITY

The concept of intrinsic surface and its meridian curve has been introduced by A.CAQUOT for a isotropic and homogeneous milieu in 193o and for an unisotropic milieu with certain symmetries in 1953/through a corective tensor/. The authors associated to the STRENGTH intrinsic curve a curve of elastoplastic DEFORMABILITY/Fig.1/.This association allows for a direct relation between Strength,Ductility and Brittleness as state properties.For the cylindrically compressed brittle body the empirical equation of this curve has suggested in the form of Fig.1.Supplementary tests are however necessary.

METHODS OF BRITTLE MATTER DUCTILIZATION

The main methods for brittle matter ductilization are: /1/The Association with a Ductile Metal according to Composite Materials Principle,/2/Passive Confinement, /3/Active Confinement and/4/Triaxial Precompression.

DUCTILIZATION BY ASSOCIATION IN COMPOSITE MATERIALS

The main composite materials are:Reinforced Concrete,

I Struct.Eng.,Professor of Theory of Structures and Head of Dep.,Institute of Architecture,Bucharest

II Struct.Eng.,Analyst in Problems of Structural Design, The Centre of Organization and Cybernetics in Constructions,Bucharest

Composite Steel RC and Reinforced Web Masonry.The mere moulding of ductile steel into a conglomerate,such as concrete,does not automatically accounts for the ductility; rigurous actions of conforming are necessary according to the dimensions,forms and proportions of elements,prevaling sresses,possible stress combination,etc.

The experience gathered in nature and laboratories makes it possible to point out the main factor determining the response of RC element.These interconected factors define a "RESPONSE FUNCTION" which was suggested in a first form as follows:

$$R = R[\lambda; (M\text{-}N\text{-}Q); \mu_W^{\%}; (n-\Delta); RS]$$

λ = flexibility; $(M\text{-}N\text{-}Q)$=stress combination/bending-axial stress-shear/; $\mu_W^{\%}$=transverse reinforcement; $(n-\Delta)$ number and magnitude of alternate cycles; RS = longitudinal-transv. reinforcement system.

In case that the element has not been initially conformed to earthquake criteria,response function becomes a function of behaviour,of damage.Grouping factors around main INTERNAL INTERACTIONS of function "R" a first opportunity of practical approach may be obtained.These sub-interactions have been suggested in three chains /Fig.2a,b,c/.The first one /Fig.2a/ suggests control by design of energetical processes in terms of element slenderness and prevailing stresses,the second /Fig.2b/ confines the ductility domain to vertical RC elements, the third /Fig.2c/ links strength and cyclic deformability by the reinforcement system,suggesting at the same time an energetical definition of ductility.

Although this treatment has been tested for some RC elements it has a more general applicability.

DUCTILIZATION BY PASSIVE CONFINEMENT

a.CONSIDÈRE interaction.Confinement by mild steel.
b.CAQUOT interaction.Conf.by highly resistant steel[1]
c.TOMII interaction.Confinement by steel tubes [2]
d.Confinement by FILAMENTS or FELTS.
e.Confinement by FILAMENTS under PRESSURE.In granular conglomerate,mortars with metallic/or synthetic/ filaments are injected under high pressures after a previous vacuum /tests under performance:CISMIGIU-PIETRIS/.

DUCTILIZATION BY ACTIVE CONFINEMENT

a.LOSSIER-MIHAILOV interaction.The natural tendency of some materials expansion is barred in the period of hardenning.
b.Electrical-Thermic Confinement.
c.Conf.by PRESSURE and VIBRATIONS.MANEY Interaction.
d.Conf.with prestressed wires.BEN-ZVI Interaction [3]
It is a particular case of triaxially cylindrical precompression.

DUCTILIZATION BY TRIAXIAL PRECOMPRESSION

According to the general principle of presressing,in each point of solid medium an initial tensor T_o,artificial and permanent,is deliberately introduced,so that by its superimposing on variable tensors of mechanical and climatic milieu T_{MMC},a compression tensor $T_o+T_{MMC}=T_C$ should result in any conditions.It is the most complex form of brittle media exploitation.Forces dosing on 3 directions is in the engineer's hand and it depends on the dimensions, forms and destinatiom of the massive:forges,high capacity presses,special foundations,reactors,etc.[4]

THE INFLUENCE OF CROSS-SECTIONS.OTHER INTERACTIONS

Cross-sections of structural elements can appear in two essentially different forms:CONCENTRATED or LAMELLAR/Fig.3/ in the first case the introduction of transverse sresses according to the principles and technologies mentioned above is possible;Mohr's cercle is"freed"by the origin of axes and progresses into the divergent zone of intrinsic curve /surface/,offering strength and ductility.In the second case this is not possible and the advantages of the divergent zone cannot be exploited.In this latter case other interactions have been imagined highly based on the ELEMENT FRAMING.The main interactions tested in laboratories or checked by practice are:

a.POLEAKOV-SMITH Interaction.Frames with "active" masonry panels.

b.MIODRAG VELKOV Interaction.Masonry panels with reinforced web/core/ monolithically linked by RC frames.

c.LATERAL framing.Lamellar slender shearwalls bordered by confined columns/American Conception/

d.COMPLETE framing.Story RC panels bordered along the whole contur by columns and beams/Classical Japan.Concept./

e.Modern Japanesse Interactions:/1/Frames associated with Slit Panels of Dr.K.MUTO/2/Ductile Panels with embedded plates or bars/3/Panels with flexible shear connectors.

INSTEAD OF CONCLUSIONS

1.Exploitation of TRIAXIALITY.Toward New Interactions. Concrete elements ductilization can be treated in following successions:/1/first the yield in longitud.reinforcements is reached,then concrete is crushed.This is the case of composite material structures stressed at bending or at bending and compression,eventually confined in strongly compressed zones/2/longitudinal reinforcements can not reach limit values but concrete is intense ductilized by passive or active methods.

New interactions must be tought in the 2nd succession. The compression of gravity,overturning and eventually axial precompression must be changed from a factor of brittleness into a factor of ductility.This may be the case of high capacity columns or boundary elements of strong shearwalls transformed in heavily confined milieux.Panels framed into so resistant and ductile structures will be treated as shear energy absorbers in the first stage of postelastic work.

2. Introduction of Viscous Deformations. Elasto-Visco-Plastic Devices. The idea is to design devices with a large visco-elastic hysteretic loop for wind deflections which could move parallel with the displacement axis by plastic deformations for strong earthquakes/Fig.4/

3. Degradations. Energy. Ductility. Any energy absorbtion implies the existance of some inner changes and a predisposition for DEGRADATIONS. The energy consumed for degradations is wholly absorbed by the body and cannot be restored. Ductility is the property of the matter to absorb energy during a process of alternate stress. The energetical definition of ductility is rendered by the relation:

$\delta = W_{AC} / W_{AC} - W_{AB}$ W_{AC} = Accum. energy. W_{AB} = Absorb. energy.

This general form allows for a quantitative comparison of this property irrespective of the analysed body/column, panel, story, structure, etc./. The capacity of ductility can be ensured and controled by design.

All kinds of behaviour to alternate stress can be modelled by simultaneous behaviour of degrading hysteretic elementary components/Fig.5/. Between collapse limits, a component cycles energy as a perfect elastoplastic system. When reaching a collapse limit, a degradation of component is obtained i.e. the restorable energy changes into absorbed and the component becomes unable to cycle energy.

A rather complex behaviour that of concrete/unconfined or confined/can be rendered quite well by means of lo elementary components/Fig.6/. Starting from these premises a mathematical model for the degradable hysteretic structures like these discussed in this paper was conceived and applied.

INSTEAD OF REFERENCES

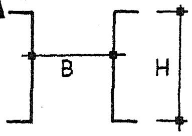
/1/ A.CAQUOT......."Ainsi l'association de deux corps fragiles comme le BÉTON et l'ACIER à HAUTE RÉSISTANCE conduit à un matériau extrêmement DUCTILE"

/2/ M.TOMII........"The fact that the CONCRETE FILLED STEEL TUBE behaves in different manner from the individual components means that lateral interaction EXISTS"

/3/ E.BEN ZVI......"Triaxially prestressed concrete is being advocated by structural engineers as the building material of the FUTURE"

/4/ E.FREYSSINET..."Une autre propriété surprenante est propre aux associations comportant une étreinte triple. On peut réaliser des masses de béton COMPRIMÉ EN TROIS directions et jouissant à la fois des qualités des corps durs: frottement internes très eleves, d'où résistance énorme a la pénétration et des qualités des corps mous: grande déformabilité, absence de fragilité, impossibilité de toute propagation des fisures".

2A $\lambda \rightarrow$ (M-N-Q) INTERACTION



$$\lambda = \frac{H}{B}$$

classification

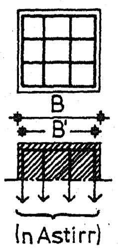
LONG	$\lambda > 5$
MEDIUM	$2{,}5 < \lambda < 5$
SHORT	$\lambda < 2{,}5$

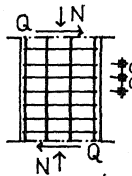
CONTROL OF DUCTILE RESPONSE

	beams	columns
LONG	PH from M	PH from (M+N)
MEDIUM	PH from M accompanied by ductile inclined cracks	PH from (M+N) accompanied by ductile inclined cracks
SHORT	inclined ductile cracks	inclined ductile cracks

PH: plastic hinge at the ends of beams or columns.

2B $\mu_w\% \rightarrow$ (N-Q) INTERACTION



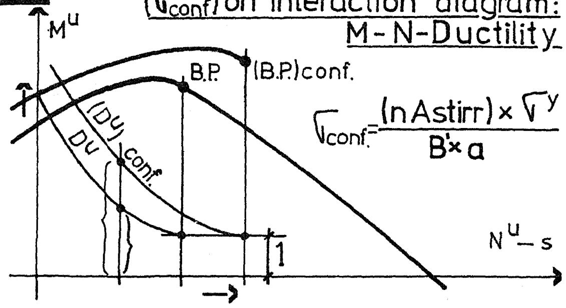


$$\sigma_o = \frac{N}{Ac}$$

$$s = \frac{\sigma_o}{Rcyl.}$$

$$\mu_w\% = \frac{(n\,Astirr) \times 100}{B \times a}$$

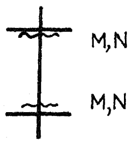
effects of concrete confining (σ_{conf}) on interaction diagram: M-N-Ductility



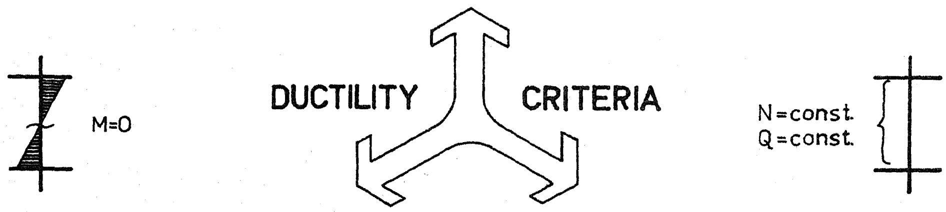
$$\sigma_{conf} = \frac{(n\,Astirr) \times \sigma^y}{B' \times a}$$

MINIMUM ROTATIONAL DUCTILITY IN JOINTS $(D^u)_{min} > 2$

note: In case of current symmetrically reinforced cross-section



- $s < 0{,}3$ ..... $\mu_w\% > s\ \%$ *
- $0{,}3 < s < s_{BP}$ ..... $\mu_w\% > (s + 0{,}1)\%$ *
- $s > s_{BP}$ ..... $\mu_w\% > (s + 0{,}2)\%$ *



CONCRETE STRESS LESSENING IN ZONES WITH M ≅ 0.

- shear (direct) ..... $\left|\frac{\tau_{max}}{Rsh.}\right| \leq 1$
- tension (inclined) ... $\left|\frac{\sigma_1}{Rt.}\right| \leq 0{,}8$
- compression (inclined) .. $\left|\frac{\sigma_2}{Rc.}\right| \leq 0{,}8$

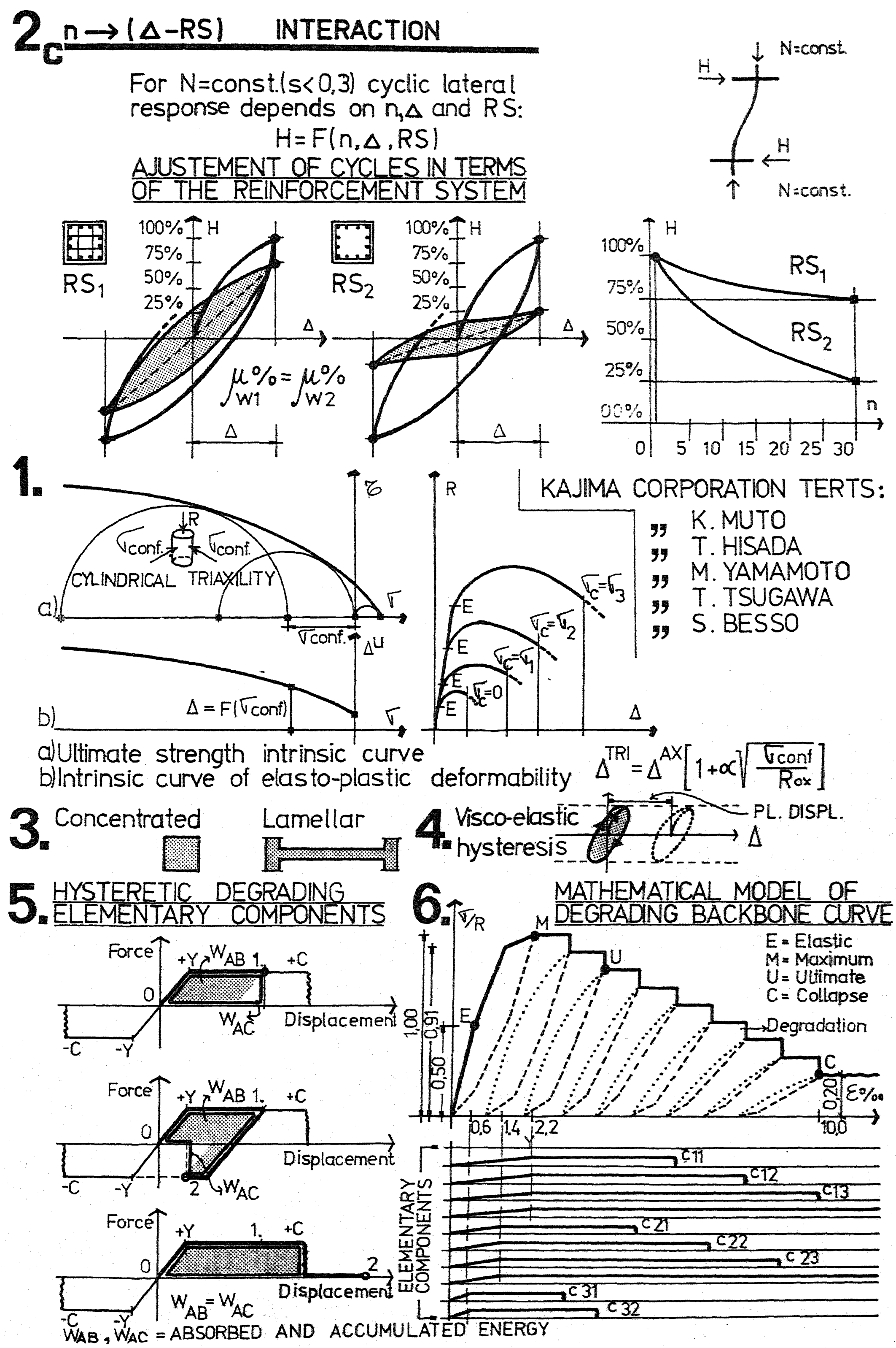
Rc, Rt, Rsh : compression, tension and shear strength.

WEB SEWING TRANSVERSAL REINFORCEMENT IN TERMS OF $c = \frac{Q^u}{N_{min}}$ AND λ.

- $c < 1$ .. $(\mu_w\%)_{min} > \frac{1}{200} \times \frac{Q^u}{Ac} \times c$
- $c > 1$ .. $(\mu_w\%)_{min} > \frac{1}{200} \times \frac{Q^u}{Ac}$

$(\mu_w\%) > \frac{10}{\lambda^2}$ (max 1,5%) *

* Values are given for intensely seismic zones.



2c n → (Δ-RS) INTERACTION
For N=const.(s<0,3) cyclic lateral response depends on n,Δ and RS:
H=F(n,Δ,RS)
AJUSTEMENT OF CYCLES IN TERMS OF THE REINFORCEMENT SYSTEM
N=const.
H
RS1
RS2
100%
75%
50%
25%
μ%W1 = μ%W2
Δ
n
0 5 10 15 20 25 30
1.
CYLINDRICAL TRIAXILITY
R
σconf.
a)
b)
Δ = F(σconf)
Δu
E
σc=0
σc=σ1
σc=σ2
σc=σ3
KAJIMA CORPORATION TERTS:
" K. MUTO
" T. HISADA
" M. YAMAMOTO
" T. TSUGAWA
" S. BESSO
a) Ultimate strength intrinsic curve
b) Intrinsic curve of elasto-plastic deformability
Δ^TRI = Δ^AX [1+α √(σconf / Rax)]
3. Concentrated
Lamellar
4. Visco-elastic hysteresis
PL. DISPL.
5. HYSTERETIC DEGRADING ELEMENTARY COMPONENTS
Force
Displacement
+Y
WAB
1.
+C
0
WAC
-C
-Y
2
WAB = WAC
WAB, WAC = ABSORBED AND ACCUMULATED ENERGY
6. MATHEMATICAL MODEL OF DEGRADING BACKBONE CURVE
σ/R
E = Elastic
M = Maximum
U = Ultimate
C = Collapse
Degradation
1,00
0,91
0,50
0,20
ε‰
0,6 1,4 2,2
10,0
ELEMENTARY COMPONENTS
c11
c12
c13
c21
c22
c23
c31
c32