Modelling philosophy for structural concrete

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Objekttyp: **Article**

Zeitschrift: **IABSE reports = Rapports AIPC = IVBH Berichte**

Band (Jahr): **62 (1991)**

PDF erstellt am: **20.06.2024**

Persistenter Link: https://doi.org/10.5169/seals-47638

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Modelling Philosophy for Structural Concrete

Logique de modélisation du béton structurel

Modelierungsphilosophie für Konstruktionsbeton

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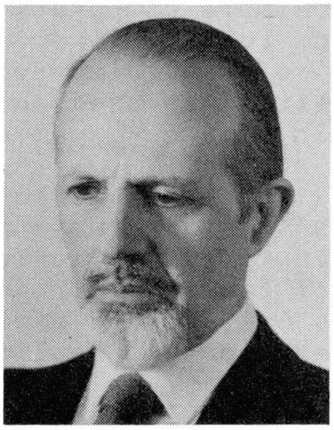

T.P. Tassios, born 1930, is a civil engineer, working in the field of bridge design and of the redesign of reinforced concrete and masonry structures. His research work is on basic modelling under monotonic and cyclic loading. He has served as President of some international Engineering Associations, like CEB, RILEM.

SUMMARY

Firstly, the history of modelling in structural engineering is briefly covered. Subsequently, the basic features of a model are described and used as a guidance in assessing four packages of models: for plain concrete, for bond-related models, for force-transfer models through interfaces and for models depicting failure of compressive fields.

RÉSUMÉ

L'histoire de la modélisation dans le domaine du génie des structures est rappelée. Les propriétés exigées d'un modèle sont décrites et utilisées pour l'évaluation de quatre groupes de modèles influencés par l'adhérence, le transfert d'efforts à travers des interfaces, et des phénomènes de la rupture de zones comprimées.

ZUSAMMENFASSUNG

Die geschichtliche Entwicklung des Modellierens im Konstruktiven Ingenieurbau wird zunächst behandelt. Dann werden die grundlegenden Eigenschaften eines Modells beschrieben und als Richtschnur für die Beurteilung von vier Modellierungsvorschlägen genommen: für unbewehrten Beton, für Verbund, für die Kraftübertragung über Kontaktflächen und für das Versagen von Betondruckfeldern.

1. PREAMBLE

a) Design may be carried out just through experience, i.e. via a trial and error process. This used to be the way of structural engineering in the past; however, the very many of the structures of the past which had fallen down, cannot anymore tell us how risky and uneconomical such a procedure used to be.

The next step in design history, seems to be a hybrid procedure. Much was done by experience, but several structural parts were checked by simple computations. As rudimentary as these checks might have been, for the first time they have made use of "modelling": Instead of building something and just see if it stands, little arithmetics was used on paper, as a substitute of reality; and this is in essence a magic process!

Nowadays, the blend is the same but the second stage is getting stronger: A conceptual design always precedes, and an analytical procedure comes after (only an "apprentice sorcerer" would cancel the first stage, out of fanatism for just arithmetics). However, actual modelling keeps its somehow magic character as an interface between the designer and reality.

b) What, then, is a model: A mathematical tool predicting the structural behaviour of a critical region or of a structural assemblage (*).

And how it functions: As an interface between the designer and reality, making use of an acceptable degree of abstraction and simplification.

Last but not least, how it may be built? Fig. 1 reminds the anatomy of modelling. "Formalistic" models are based on empirical data

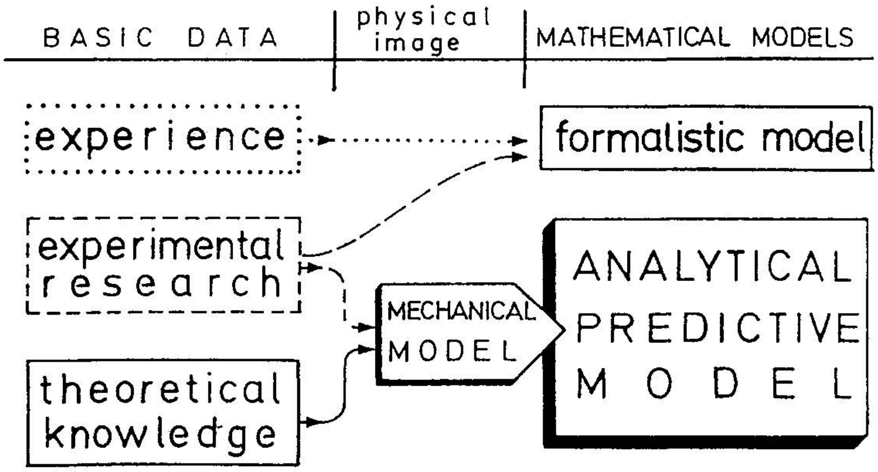

Fig. 1: The anatomy of model building

(*) Within this paper, distinction is made between a particular "analytical model" and a "design philosophy" which includes a system of compatible models; thus, the term "model" here is not used as in [1].

only, whereas "analytical-predictive" models are making use of physical knowledge on the function of the system considered. Despite the progress made, structural concrete may still be studied by means of formalistic models, especially in new fields; but the related lack of global understanding and the risk of possible gross-errors cannot be overemphasised.

Thus, every effort is justified towards rational modelling. And this Symposium is one of the best opportunities to enhance developments to this end.

2. REQUIRED FEATURES OF A MODEL

a) In Table 1 an attempt is made to inventorise the required features of a structural model in general. It is not within the scope of this lecture to elaborate on them; however, the same Table 1 offers a short justification of each requirement, as well as a description of the ways towards their achievement.

No	FEATURE	WHAT FOR?		HOW?
1	Rationality	▪ Adaptability to broader fields or to future developments ▪ To enchance communication and consciousness		a) Non-equivocalness b) Based on Mechanics c) Sound constitutive law
2	Accuracy	▪ Predictiveness		a)Sufficient number of basic variables along the life-time b)Sensitivity analysis c)Checking through experiments d)Calibration through practice (model "maturity")
3	Reliability vs. uncertainties	▪ Uniformity of safety level		a) Probabilistic analysis b) Experimental parametric study
4	Simplicity	▪ Applicability	per se	a) Selection of main variables b) Acceptance of a level of inaccuracy
5	Compatibility with other models		within the system	(Through rationality)

Table 1: Required features of a model and how to get them.

It is apparent that some of these desired characteristics of a model are **contradictory** with each other. The main contradiction is related with the understandable claim for simplicity, which seemingly may be opposed to accuracy, compatibility and eventually to rationality. Thus a certain optimisation is needed: The concept of **efficiency** of a model emerges here, with the following qualitative definition:

$$E_f = \frac{P_r}{G} \qquad (1)$$

where E_f = the efficiency of the model
P_r = its predictive capacity, with however $P_r \nless P_{ro}$
(i.e. a minimum of necessary predictiveness required)
C = the complexity (or the application costs) of the model.

b) Within the preceding short analysis, no distinction was made between "research" models and "design" models (see [2] §2): Depending on

- the importance of the structure,
- the complexity of expected actions, and
- the stage of design,

several accuracy and sophistication levels of models may be used in design. Schlaich [2] rightly points out that "review is the play ground of sophisticated modelling techniques, and even research models may be applied". To say the same thing in terms of Equ. 1, for a given efficiency level, higher complexity is tolerated if higher predictiveness in needed.
It is hoped that these introductory comments may be of some value in assessing the suitability of models of structural concrete to be used now or in the future.

c) We should not end this section without a clear statement regarding design "by testing". In fact, there is sometimes a tendency to skip-over modelling and go back to the rather ancient situation (§1.a) when design was based on "build and see" (in our case "test and see"). That is why I maintain that such a tendency is rather retrograde, despite its seemingly "pragmatic" appearance: Out of the nine prerequisites to achieve Rationality, Accuracy and Reliability (Table 1), only a couple of possibilities are offered by just direct testing....

But even if the intercession of a model is recognised, modelling by testing runs considerable risks, as i.a.:

- Several actions or influences expected during the intended lifetime, might be overlooked.
- The in-time variation of basic variables, may not be accounted for in laboratory testing (e.g. concrete tensile or compressive strength degradations, or cyclic nature of loading or hygrothermal conditions).

That is why, a "prior calculation model" should always be sought (if unknown) by means of physical knowledge and appropriate parametric experimental investigations.

Last but not least, the reliability handling of the deterministic test-results should be appropriately carried out; and, of course, in-life uncertainties are not represented by the in-lab scattering!

3. COMPATIBLE PACKAGES OF STRUCTURAL CONCRETE MODELS

In what follows, examples of some relatively rational and compatible models are discussed. Independently of their apparent complexity, these models are amenable to further simplifications, precisely because they are rational: From a rational and complicated model, we may easily get a simplified one; whereas from a set of rules of thumb we could never produce a rational model with a broader field of applications.

3.1. Modelling of concrete

It was too simple to be true what was hoped in the past, i.e. to produce R.C. models in which the behaviour of concrete itself was oversimplified. We now understand that fracture mechanics' considerations for concrete under tension and even under compression (see i.a. [3]), confined concrete constitutive laws (see i.a. [4]), as well as local compression of concrete end-faces, are sine qua non for physical understanding and for subsequent rational modelling. Time-dependent effects should also be realistically modelled (see i.a. [5]).

3.2. Bond related models

A performance oriented Code (see i.a. [6]) should address the following issues within the serviceability limit-state design:

- Crack width control (be it for aesthetics or for durability reasons under severe environments, or for tightness)
- Deflections' control (for functional reasons).

Similarly, ultimate limit-state considerations include:
- Anchorage checkings, and
- Rotational capacity control in case ductility is governing.

Besides, in every analysis, the value of stiffness (or, better, a knowledge of hysteretic behaviour) is needed.

Inspite of the fact that all these phenomena are strongly bond-dependent, a **fragmentaristic** modelling is normally followed: In each of these **five** areas, loosely related or totally unrelated models are used. It is said that this is dictated by "practical" necessity, which may be true. But this violates the 5th principle of model-making (s. Table 1), i.e. compatibility, and it may lead to inconsistencies or indeed to gross-errors.

An optimisation between compatibility and simplicity could be sought by adopting a basic model governing all these areas ("local bond vs. local slip" constitutive law, as I will maintain), and subsequently coming down to practical simplifications. Even simple formalistic rules may be derived, which however will keep track of the input data of the same initial model.

As a matter of fact, it has been proved that, despite its large variability, a "local bond stress versus local slip" constitutive law, via appropriate algorithms, is able to rationally produce complete information on the following issues (see i.a. [7], Fig. 2):

- Tension stiffening effects
- Cracks' widths prediction
- Force/elongation diagrammes of a tie under both monotonic and cyclic actions.
- Pullout (anchorage) force-slip diagrammes.

Of course, flexural behaviour is also influenced by compressive behaviour, but the modelling of compression is relatively simpler, both under unconfined and confined conditions.

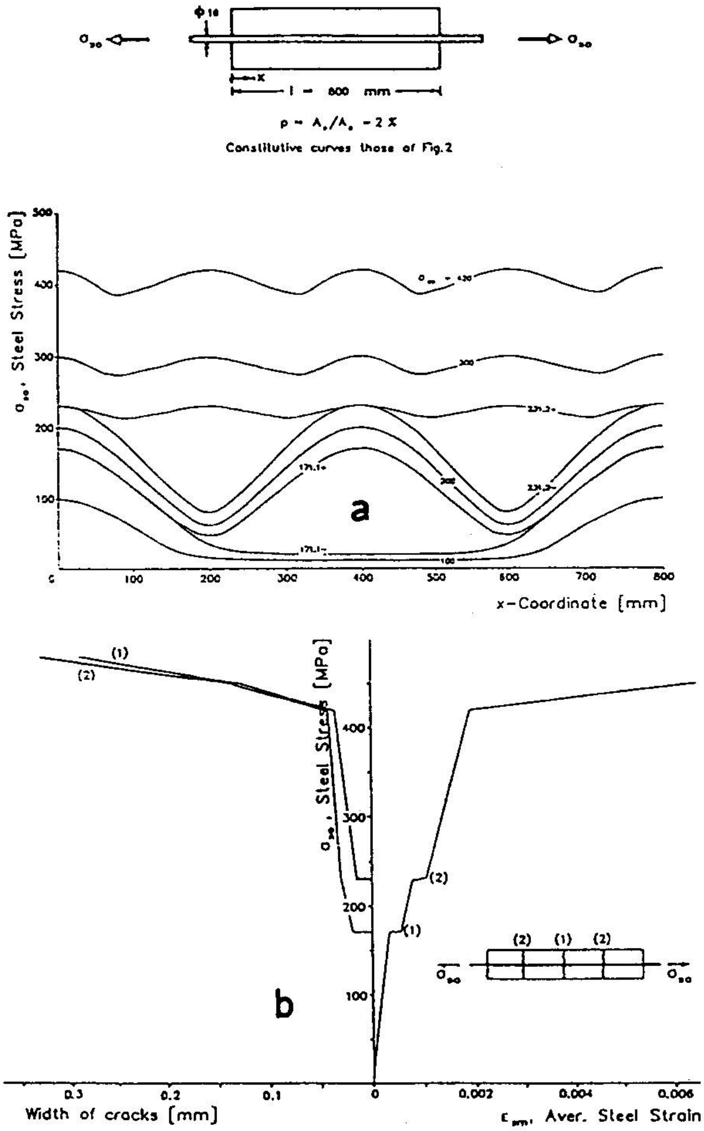

Fig. 2: Steel stress (a), and crack-widths (b) development during gradual loading of R.C. tie, up to post-yield levels

3.3. Force transfer through R.C. interfaces

Along predetermined interfaces (e.g. precast joints or repaired surfaces, etc) but above all along posteriorly cracked reinforced concrete areas, force transfer is secured by somehow complex mechanisms of:

- pull-out/push-in of steel bars,
- dowel actions,
- re-compression of precracked concrete, and
- concrete to concrete friction.

Modelling of the overall force (N, V) transfer across and along such discontinuous interfaces is of a paramount importance, since as a discrete crack approach (despite its seemingly complexity) offers considerable fundamental insight; and it is also amenable to further simplifications such as smear crack and the like. Among other problems elucidated by such a model development, the bearing capacity of biaxially loaded and cracked R.C. plate, may be better understood.

Based on appropriate input constitutive laws, such global modelling was described in [8], (Fig. 3).

Promising developments are expected along these lines, both for better insight and for more justified practical simplifications.

3.4. Failure of R.C. cracked compressive stress-fields

With the increasing tendency of using truss or struts and ties models in practical design, and with the tremendous development of non-linear finite elements method, the assessment of the bearing capacity of obliquely cracked R.C. region has become a crucial point in modelling.

Directly or indirectly, it has been repeatedly made clear that the bearing capacity of such compressive areas, both in the case of a web of beam or in a plate-element, is conditioned by essentially biaxial effects; one of the possible meso-levels interpretations, inspired by the model discussed in §3.3, is illustrated in Fig. 4. Actually, one of the most practical ways to account for these effects is to consider the transversal tensile strain, and reduce the longitudinal compressive strength accordingly [9].

However, it has to be admitted that for such an important issue, the actual state of knowledge and the level of rationality achieved is not the best we could hope. That is why, several solutions are offered and a continuously better insight is gained (see i.a. [10]).

It seems that all goes as if a macro-level constitutive law of concrete under compression were applicable, with modifications as suggested in [11], (see Fig. 5), which may lead to considerable reductions of both strength and ductility, However, the computational determination of an average transversal stress or strain (for different cases of crack angles, different patterns of reinforcement and different loading histories), remains a challenge.

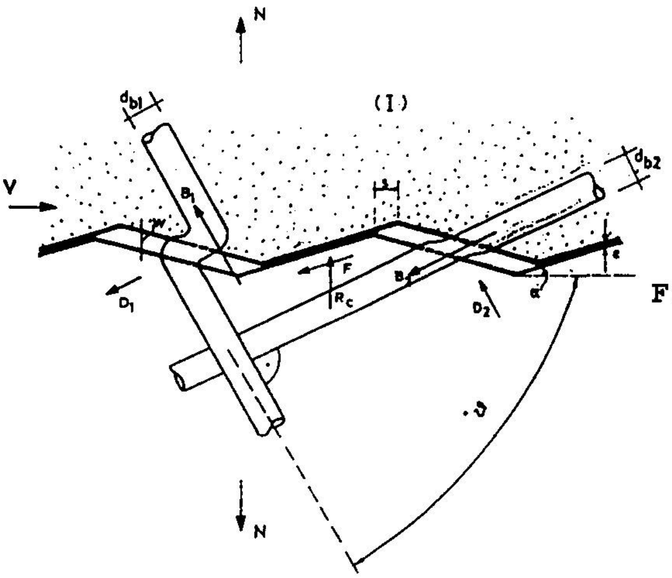

Fig. 3: Topology (a) and force-displacement output (b) of an interface model

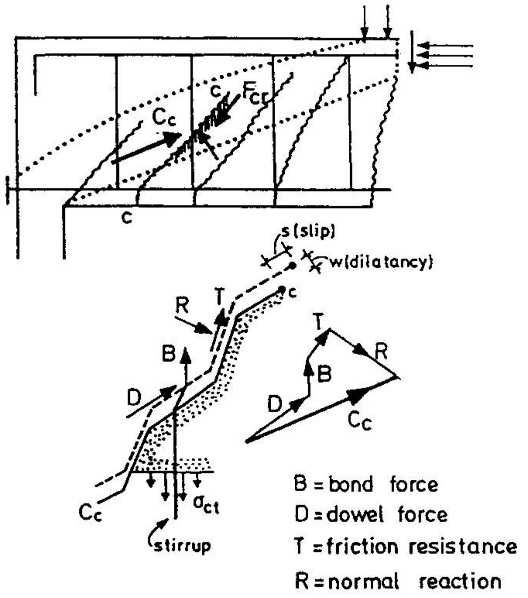

Fig. 4: The pseudo-uniaxial compressive capacity C_c of the strut, is governed by the ultimate shear-transfer capacity F_{cr} along the initial crack c–c (and, consequently, by the angular distortion of concrete)

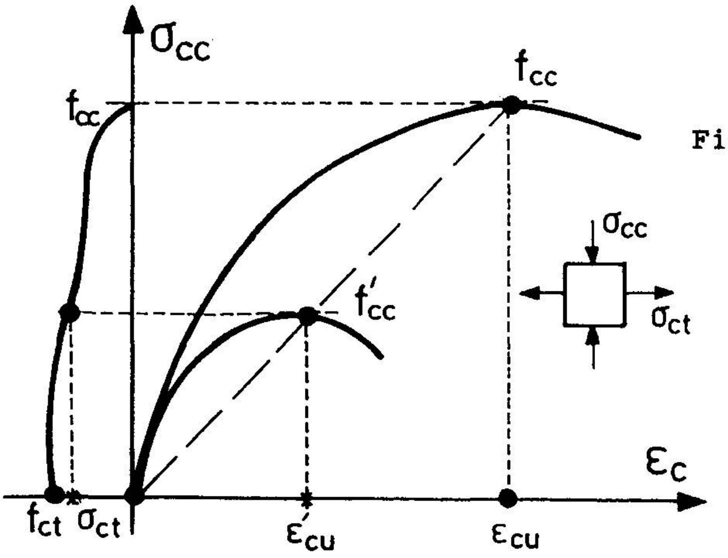

Fig. 5: Transversal tensile stresses, σ_{ct}, modify the constitutive law of plain concrete under longitudinal compression

In the meantime, some design applications are based on rather rough approximations (e.g. $f_c = 0{,}6.f_c$, etc). True, they are covered by calibrations against global experimental results of shear strength of R.C. beams. But the modelling needs definitely a further insight, especially in D-regions where compatibility cannot always be disregarded.

4. INSTEAD OF EPILOG

Modelling of structural concrete is now becoming a Science. But it has to fulfil so many, partly contradictory, requirements (s. Table 1) that it is not far from being an Art.

And that is precisely what makes modelling so attractive and so doubtful.

REFERENCES

1.- BRUGGELING A.S.G.: "An engineering model of Structural Concrete", Introductory report, IABSE Colloquium "Structural Concrete", Stuttgart, 1991.

2.- SCHLAICH J.: "Modelling", Introductory report, IABSE Colloquium "Structural Concrete", Stuttgart, 1991.

3.- HILLERBORG A.: "The compression stress-strain curves for design of R.C. beams", Fracture Mechanics: Application to concrete, ACI SP-118, 1989.

4.- TASSIOS T.P. "Confined Concrete constitutive law", Justification Note No 13, Background Documents for EC8, Vol. 2, Brussels, 1988.

5.- HILLSDORF H.K.: "Evaluation of the time-dependent behaviour of concrete", CEB, GTG 9, Bull. 199, 1990.

6.- TASSIOS T.P.: "Performance oriented rational Codes of practice", Invited lecture, IABSE Colloquium "Structural Concrete", Stuttgart, 1991.

7.- YANNOPOULOS P., TASSIOS T.P.: "R.C. axial elements analysed under monotonic and cyclic actions", ACI, Structural Journal, Jan-Febr. 1991.

8.- TASSIOS T.P., SCARPAS A.: "A model for local crack behaviour", IABSE Colloquium, Delft 1987.

9.- VECCHIO F.J., COLLINS M.P.: "Predicting the response of r.c. beams subjected to shear, using the modified compression field theory", ACI, Structural Journal, No 4, 1988.

10.-REINECK K.H.: "Theoretical considerations and experimental evidence on web comperssion failures of high strength concrete beams", CEB Bulletin, 193, 1988.

11.-KATSARAGAKIS E.: "Plain concrete strength under heterosemous plane stresses", Dr Thesis, (in greek), NTUA, 1988.

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