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Artikel: Summary of general discussion

Autor: Rostam, S.

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SUMMARY OF GENERAL DISCUSSION

1. Plastic Analysis in Structural Design

During the previous sessions it had been demonstrated that plastic analysis of concrete structures has achieved broad acceptance among concrete researchers.

The impression could therefore be had that all problems have been solved and that the theory was ready to be applied as a general basis, and not just as a yield line theory for slabs as it has been so successfully applied for decades. This conclusion could not be drawn from the Colloquium, nor was it the aim of the participants.

On the contrary, the final discussion showed that the theory was maturing, and that its successful application to numerous well-defined problems had given confidence to its coming role as a rational means of designing concrete structures in the ultimate limit state.

However, the discussions had also focused on assumptions and basic problems needing further consideration.

2. Properties of Plain Concrete

The general discussion concentrated to a large extent on whether concrete does in fact comply with the basic assumptions of plasticity.

K.H. Gerstle concentrated on the actual properties of plain concrete. He referred to a cooperative research project involving several US research institutes exploring multiaxial concrete behaviour. This investigation has been under way for several years and the following main results were presented by way of slides of three-dimensional models of the obtained stress-strain relationships.

- Six sets of σ-ε curves of biaxial tests with $\sigma_1/\sigma_2 = 1/3$ showed wide scatter though they were obtained from supposedly identical tests. So large was the scatter that it, according to Gerstle, appears that probabilistic methods would have to be used to reach a rational prediction.
- Similar tests, but from different laboratories and using different test methods, showed so large a scatter that it was of dubious value to assign a single curve to describe the behaviour of the concrete in the actual structure.
- Experimentally determined biaxial and triaxial strength envelopes exhibited so large a scatter that they, according to Gerstle, provide food for thought, and should be kept in mind when evaluating the results of analyses and tests.

The fact that reinforced concrete is a composite material led several participants to view its behaviour as an interaction between the constituent materials only to be fully understood when the behaviour of the individual materials is understood.

M.D. Kotsovos was in agreement with K.H. Gerstle when seeking to study the behaviour of reinforced concrete using a realistic representation of the properties of plain concrete. No successful attempt to do so has been made to date which, according to Kotsovos, was the most important reason why various proposed theories may only predict the behaviour of certain structural members under certain types of stress conditions. In this respect, he could see no link between the contents of session 1 on constitutive equations and the application of the theory of plasticity presented in the rest of the sessions.

He based this conclusion on the following comments on the various assumptions presented, describing the basic properties of concrete:

- Failure mode of concrete.
  Various types of modes of failure (fracture) have been considered, e.g. crushing under compression, cleavage under tension, shear, punching shear etc. However, it has been established by experiments that fracture is caused by crack propagation in the direction of the maximum principal compressive stress, and this is valid under any state of stress.
- Strength properties of concrete.
  A Coulomb-Mohr failure criterion has been assumed to describe adequately the strength properties of concrete under triaxial stress states. However, this representation is not correct since the criterion does not describe the effect of the intermediate stress, which has been found by experiment to be significant.Furthermore it is rather doubtful whether this criterion can realistically predict the strength under relatively high triaxial states of stress.

  Under plane stress conditions, the square failure envelope with zero tensile strength seems to be generally acceptable. However, in practice there is always some stress, though debatably minimal, in the third direction. If this stress is tensile, the proposed envelope is unsafe, even under relatively small compressive stresses on the plane of loading. In this case concrete will crack on a plane parallel to the plane of loading.
- Stress-strain relationships of concrete.
  Typical stress-strain relationships for concrete likely to be encountered in practice are shown in Figure 8 of the paper by Kotsovos in Session 1. Similar is the shape of the relationships under biaxial compression, whereas under tension the descending portion is non-existant.

  In view of this evidence, elastic (or rigid) - plastic idealization is hardly justified according to Kotsovos. It may be justified under high biaxial states of stress, as shown in Figure 6 of the above-mentioned paper, but it would be difficult, if not impossible, to define any yield line under such states of stress.

The remark by Kotsovos on the stress-strain relationships of concrete in tension, as having no falling branch, should be compared with the comments by M.P. Nielsen during the discussion of Session 2. M.P. Nielsen feels that the successful ability of plastic analysis to describe phenomena dependent on the tensile strength of concrete, indicates the presence of a falling branch in tension.

This focuses on a difference of opinion on a matter of apparently considerable importance in the understanding and further development of the rational theory of plasticity to treat reinforced concrete structures. In view of this, further well-considered tests on the stress-strain relationship of concrete in tension should be carried out, and the application of the results in the theory should be considered further.

3. Restraints

C.T. Morley presented an engineering approach to the same problems by discussing the restraints necessary to achieve a sufficient load carrying capacity. Also S.M. Uzumeri concentrated on the beneficial effect of confined concrete.

Shear strength can, as indicated by C.T. Morley, derive from inclined forces, provided sufficient restraint is available, as in a clamped beam. This is equivalent to the tension field theory valid for steel plate girders, where the restraint is provided by the flanges, and for masonry structures, where the foundation can provide the necessary restraint.

In local punching shear problems the necessary restraint is provided by the surrounding slab, and the assumed failure mode, as presented by M.W. Braestrup, is an upper bound approach.

According to Morley some difficulty does arise in practice, when ensuring that some other failure mechanism does not intervene. This was exemplified with punching tests on cylinders, where, for small punch diameters, the failure load, as expected, fell between the loads predicted by the sphere and the flat slab theories respectively. For larger punch diameters the theoretical beneficial effect of shell curvature seemed, however, not to appear. Whether this was due to lack of restraint, or whether another failure mechanism was beginning to intervene, could, according to Morley, not be determined.

Finally his opinion was that the problems involved in applying the plastic theory to reinforced concrete were not caused by the neglect of the tensile strength of concrete, but by applying it to brittle, over-reinforced elements, which has led to the frequent discussion of the introduction of the effectiveness factor during these sessions.

4. Effectiveness Factor

B. Thürlimann supplemented the discussion of Session 2 by stating the two different effects covered in a rational way by ν . These were on the one hand the local effects giving rise to local complicated stress distributions, and on the other hand the influence of both the strain history and the softening up of concrete at collapse which enters into the conditions of the kinematics. At present a different ν-factor is presented for shear, for punching, for anchorage etc. and Thürlimann hoped that the Danish research group, as the originators of this factor, would give it some reconsideration.

5. Deformation of Capacity

The deformation capacity of concrete obviously has a decisive effect on the ability of plastic analysis to model the behaviour of reinforced concrete structures at ultimate.

P. Lenkei presented the results of a recent research project aimed at determining the deformation, cracking and redistribution of internal forces in reinforced slabs for loads increasing up to the maximum value. The behaviour of slabs during this transition process is greatly influenced by the level of orthotropy and by the differences in the principal directions of the resistance of the slab and of the external moments. Lenkei showed that the same ultimate load could be reached by going through different values of deflections and different crack patterns. The differences are in some cases not negligible, and should be considered when serviceability considerations are determining.

6. Energy Absorbing Capacity

Until now only static and proportional loading has been considered, but K.J. Pittner recalled that a multitude of structures have to be designed to resist severe loading cases of a dynamic nature such as earthquakes.

In these cases the dynamic design load can be much higher than the static resistance of the structure. Such designs have to rely on the prediction of the energy absorbing capacity of the structure. This requires a means of determining the deformation capacity as the induced energy is to dissipate as much and as locally as possible.

According to Pittner, a prediction of the energy absorbing capacity requires knowledge of:

- how much reinforcement can be plastified,
- which plastic strains can be accepted, and
- how bonding between concrete and reinforcement can be avoided in order to achieve maximum elongation of the reinforcing bars and thus reach a maximum of deformation capacity.

He thus questions whether the limit state design has to achieve an extreme resistance force of the structure or an extreme capacity to dissipate energy. The latter would thus lead to a basically different definition of structural safety and to revised design principles.

Plastic analysis seems to be only part of the means of designing structures subjected to dynamic or impulsive loading. The presentation by Pittner is therefore a reminder that a supplementary plastic design criterion treating the influence of such loading should be presented.

7. Structural Safety

The interaction between plastic analysis and structural safety was discussed by J. Schneider, who presented a summary of a recommendable paper by W. Bosshard entitled "Structural Safety - a Matter of Decision and Control", published in the IABSE Periodica 2/1979, Surveys S-9/79. The final recommendation by J. Schneider was that scientific models should not be directly pushed into the codes, but should go through a proper filter, e.g. a code writing committee. This could have special interest when viewing the subjects treated at this Colloquium.

8. Secondary Effects in Shear

Possible contributions to the shear carrying capacity represented by secondary effects such as aggregate interlock or dowel effect are often discussed. In this connection T. Brøndum-Nielsen pointed out that shear force which can be transferred across a crack by dowel action is negligible, unless a stirrup happens to be located in the immediate vicinity of the crack, thus preventing the axial reinforcement from being pulled down ("zipper action"). He illustrated this with a photo of a statically indeterminate bridge slab, test loaded to failure. Immediately after a bending compression failure had occurred at mid-span, the axial reinforcement was pulled down over a length of several metres under the sole action of the shear force corresponding to dead load.

9. Notations

Finally A. Holmberg pointed out that only in rare cases were the notations in the numerous presentations equal to those given by CEB and FIP on the basis of ISO 3898.

A further unification in this respect would undoubtedly facilitate a rapid communication with the audience and with the readers of the papers.

10. Complete Design Basis for Concrete Structures

This Colloquium has demonstrated that plastic analysis is developing into an operational method of treating reinforced and prestressed concrete structures in the ultimate limit states.

In a report on the future activities of the IABSE, A.L. Bouma announced a Colloquium planned to take place in Delft in 1981. The subjects to be treated would cover serviceability conditions of concrete structures.

This promises to be a most valuable supplement to the present Colloquium, with the IABSE thus having fulfilled its commitment to cover the two integrated fields in modern concrete design, the one being the ultimate limit state conditions and the other being the serviceability limit state requirements.

S. ROSTAM