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SUMMARY OF DISCUSSION - SESSION 3

Ch. Massonnet opened the discussion by questioning the validity of the square yield locus used by M.P. Nielsen for moments (Introductory Lecture, Fig. 3.3.2). He cited test results pointing to the effect of reinforcement kinking, leading to a concave yield locus with sharp corners.

M.P. Nielsen replied that he had never been convinced by the Liège tests, the reinforcement arrangement being rather complicated. He would study some of the other tests cited, which he had not previously come across. He pointed out that numerous Danish tests on slabs in pure torsion (upper left hand corner of Fig. 3.3.2) showed no increase in strength compared with biaxial bending. In the case of isotropic bending (upper right hand corner) there might be some strength enhancement due to biaxial compression of the concrete, but this is believed to be an effect of secondary importance.

Ch. Massonnet further remarked to D.H. Clyde that he found it hard to believe in the statical equivalence of twisting moments and shear forces.

D.H. Clyde pointed out that the sandhill analogy for pure torsion also predicts forces at the edges of the slabs.

Z. Sobotka presented a method of controlling the yield line pattern by varying the ratio between top and bottom reinforcement in such a way that excessive cracking in the service state is avoided.

P. Marti commented on D.H. Clyde's paper by citing a recent investigation of pure torsion in slabs and beams, using the modified contours criterion with zero tensile strength and an angle of friction of 37°. Lower bound solutions corresponding to statically admissible stress fields were derived, and matching kinematically admissible velocity fields found except for small corner regions. The analysis shows that:
- the concrete crushes in a compressed shell around the periphery of the cross-section
- the compressed shell separates from the stress-free control region
- if there are twisting moments at an edge of a slab, a vertical reinforcement is necessary to connect the top and bottom reinforcement along the edge.

A. Sawczuk asked M.P. Nielsen about needed research in connexion with membrane effects, and commented with regard to K. Sonoda's contribution that it was difficult for the computer to distinguish between elastic unloading and the falling branch of the stress-strain curve. He further requested more information from D.H. Jiang concerning the interaction between slab and subgrade.

M.P. Nielsen replied that he had mentioned the membrane effect mainly to stress its importance in practical applications, but that a theory is still lacking.

Da Hua Jiang explained that the response of the subgrade was measured by load cells, and the pressure subsequently idealized to a conical distribution, as indicated. In answer to a question from A.Losberg, Da Hua Jiang stressed that only unreinforced slabs were considered.

Most of the second discussion period was devoted to problems concerning punching shear.

R.P. Johnson mentioned that we would expect the punching strength to be considerably reduced in the presence of membrane forces, especially in the case of biaxial tension. However, tests carried out had shown no such effect. From the audience it was remarked that similar results had been obtained at Ithaca.

A. Losbey was surprised that the analyses presented by M.W. Braestrup did not take account of the main reinforcement, and he wanted to know if the dowel effect had been investigated.

M.W. Braestrup explained that the analysis only considered the strength in a proper punching failure, which is independent of any membrane forces or main reinforcement. Another point is that the likelihood of such a failure will be strongly affected by these factors. He did not believe there was any significant dowel effect; the reinforcement is of itself very flexible so the only source of dowel action is the tensile concrete strength, which is too small to measure.

M. Reiss remarked that in practical cases of punching, the load is often applied by a column, monolithically connected to the slabs. The boundary conditions at the edge of the column would then be different from those considered by M.W. Braestrup, the shear force being transferred at the tip of a wedge (cf. Fig. 4 of the Introductory Lecture). Therefore tests show that the failure surface generatrix starts perpendicularly in the slab and is not inclined as shown in Fig. 1.

H. Aschl claimed that we all know that tensile concrete stresses are necessary to carry shear loads. On the other hand, the paper presented on plastic analysis showed that good agreement with test results is only obtained assuming zero tensile strength. How do we reconcile these facts?

M.W. Braestrup replied that in most cases the shear failure is constrained by main reinforcement or by the surrounding structure, in such a way that failure cannot occur by separation only. Thus the deformation must include some sliding, in which case the compressive strength of the concrete is mobilised and a tensile strength is not necessary.

M.P. Nielsen showed how shear in beams and slabs may be carried by inclined compression without any need for tensile stresses.

M.W. BRAESTRUP