Paper No. 3

SHEAR CAPACITY OF COMPOSITE
PRESTRESSED CONCRETE BEAMS
by K. CEDERWALL & E. SARAN

DISCUSSION

by M.W. BRAESTRUP
Rambøll & Hannemann
M.Sc., Ph.D., Chief Engineer

The writer has studied the above paper with considerable interest, and would like to offer the following comments for the consideration of the authors.

The analysis of the test results is carried out on the basis of the formula:

$$V_u = kb_w d\sqrt{f_c} + V_s + V_p$$

Here V_p and V_s are the contributions from prestress and stirrups, respectively, whereas the first term is the contribution from the concrete, f_c being the compressive strength (in MPa), d the effective depth, b_w the web thickness, and k an empirical factor.

Two stirrups are placed in the shear span, and the authors evaluate V_s on the assumption that only the one closest to the load is active. However, also the stirrup closest to the support will contribute to the shear capacity, if it is not yielding then it is acting as a support, reducing the effective shear span.

The factor k decreases with increasing shear span ratio. Thus if the concrete strength is sufficiently high we would expect both stirrups to yield at failure, increasing the effective shear span. Indeed, this appears to be the case for beam B13 (Fig. 7 of the paper), which had a concrete strength almost triple that of beam B9 (Fig. 6). Consequently, some of the test results might be compared with a third alternative, when the term V_s corresponds to the capacity of two double legged stirrups Ø8.

The above behaviour of beams with weak shear reinforcement is reflected by the plastic solution (cf. e.g. Braestrup & Nielsen /6/), which gives the following expression for the shear capacity V of a rectangular beam with depth h and width b:

$$V = \tfrac{1}{2}b(\sqrt{a^2+h^2} - a)f_c^* + V_s \qquad (8)$$

Here a is the clear shear span, i.e. the projected length of a yield line through the beam, V_s is the combined yield force of the stirrups crossing the yield line, and f_c^* is the effective concrete strength, which is a ratio $f_c^* = \nu f_c$ of the cylinder strength. The solution (8) is valid for beams that are overreinforced, i.e. the yield force T_y of the main reinforcement shall exceed the value $T_y = \tfrac{1}{2}bhf_c^*$, otherwise the term h^2 under the root sign is replaced by $4(h-T_y/bf_c^*)T_y/bf_c^*$.

It is not obvious how the plastic solution (8) could be applied to the composite I-beams considered by the authors. A promising approach would be to consider a yield line composed by three straight sections at different inclinations, corresponding to the top flange, the web, and the bottom flange, which for convenience may be identified with the prefabricated beam section. Such an analysis has been carried out for a sandwich slab element by Jensen & al. /7/.

The above considerations raise the following points of concern for the evaluation of the test results:

- For the beams with high strength concrete both stirrups may be yielding at failure, affecting the contributions from the concrete as well as from the stirrups.
- The beams with high strength concrete may not be over-reinforced, in which case the concrete contribution depends not only on the shear span ratio but also on the main reinforcement strength.

Finally, the authors evaluate the concrete contribution on the basis of the in situ concrete only, irrespective of the - in some cases very different - concrete strength of the precast elements. The writer finds this hard to justify, considering the fact that the precast part constitutes a significant proportion of the composite beam section.

The plasticity approach, outlined above, is unable to evaluate the strength contribution from prestress, indeed the plastic solution predicts no increase in shear capacity due to prestressing. This is apparently unrealistic, as may be seen by comparing beam B2 with B16 and B12 with B8, the only appreciable difference being the level of prestress. The writer agrees with the authors that the code rules are unsatisfactory, and is looking forward to the results of a more sophisticated approach.

REFERENCES

/6/ Braestrup, M.W., Nielsen, M.P.: "Plastic methods of analysis and design". Handbook of Structural Concrete, Ch. 20, 53 pp, Pitman, 1983.

/7/ Jensen, J.F., Bræstrup, M.W., Bach, F., Nielsen, M.P.: "Præfabrikerede sandwichelementer af letbeton. En analyse af forskydningsstyrke of nedbøjninger. (Lightweight concrete prefab sandwich elements. An analysis of shear strength and deflections)". Technical University of Denmark, Department of Structural Engineering, Internal Report I 54, 28 pp, 1977.

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SHEAR CAPACITY OF COMPOSITE
PRESTRESSED CONCRETE BEAMS
by K. CEDERWALL & E. SARAN

Authors reply to comments from
M.W. BRAESTRUP
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M.Sc., Ph.D., Chief Engineer

We greatly appreciate the comments from M.W. Braestrup and should like to start our reply with our own final remarks that the present approach is not a sound basis for the understanding of the behaviour in the ultimate state. We will also admit that the plastic approach originated from M.P. Nielsen and M.W Braestrup is much more appealing and the members of the Division of Concrete Structures at Chalmers University have in many cases tried to use this approach with more or less success. Unfortunately we did not try to use the plastic approach for this case because of the fact that it up till now has not been able to explain the beneficial effect of prestress.

Concerning the question of the contribution of the stirrups to carry the shear force we have studied the effect of the result if we considered just one stirrup or no stirrup at all, because according to existing rules the distance between the stirrups are too large to give any effect. The result was that less spread was obtained if we considered the effect of one stirrup and we decided to use this result. For some of the prestressed beams it could be that even more than one stirrup was engaged because of a less inclination of the compressive struts but we treated all the test beams as a homogeneous sample which certainly can be questioned.

Concerning the remarks about the effect of the high strength concrete in the prefabricated bottom flange we have tried to consider that by the following approach which is not described in our paper. The contribution V_c has thus been evaluated as:

$$V_c = b_w \cdot d[k_u \cdot \sqrt{f_{cu}} + k_l \cdot \sqrt{f_{cl}}]$$

where index u refers to the upper part of the beam and index l to the lower part. We did not, however, succeed to get any reasonable result from this approach. If this is due to a too small sample or if the approach is too crude cannot be answered for the moment.

Paper No. 7

FROST RESISTANCE AND
AIR-VOID CHARACTERISTICS
IN HARDENED CONCRETE
by O. E. GJØRV ET AL

DISCUSSION

by L-O NILSSON, professor
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Technology, Göteborg

To relate the service-life of a concrete, subjected to frost attack, to the characteristics of the air-void system is an important task. However limited, the data supplied by the authors is interesting.

It is a pity, however, that the authors are forced to conclude that the air-void characteristics are difficult to relate to the frost resistance in their measurements. Instead the "frost resistance number" is introduced as a pure empirical parameter that includes a number of parameters like strength etc. By using four parameters they manage to find an empirical relation to the frost resistance for 8 data points, five of which have a frost resistance of zero.

The conclusion is based on very few observations. Instead, by not using the total air-void system but a portion of it, a reasonable relationship <u>may</u> be found between the frost resistance and the air-void system smaller than 200 μm, see Figure 1.

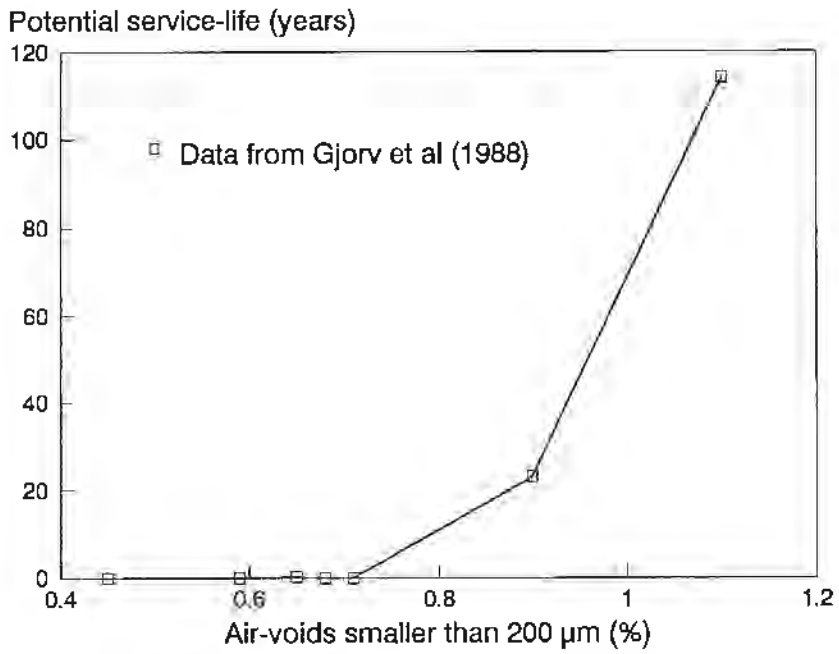

Fig 1 Potential service-life vs air-voids smaller than 200 μm

Due to the limited data Figure 1 is of course far from convincing but it is at least a relationship that has a theoretical meaning. All of the volume of the larger air-voids is not available for the escaping water at freezing. It may be even better to exclude some of the smallest air-voids that become water-filled very early, say those smaller than 50 μm, but that data is lacking.

Consequently the "frost resistance number" is not needed to explain the authors' results. Much more data is required for such a drastic step.

Paper No. 7

FROST RESISTANCE AND AIR-VOID CHARACTERISTICS IN HARDENED CONCRETE

By O.E. GJØRV ET AL

REPLY TO DISCUSSION BY THE AUTHORS

First we would like to thank Dr. Nilsson for his interest in our paper. We agree that the extent of our data is very limited with respect to introducing a new general term for evaluation of the potential frost resistance of concrete. As appears from the paper, however, the concept of the frost-resistance number was originally introduced by Schäfer who based this expression on a comprehensive amount of observations and data.

Both from a theoretical and practical point of view there are many other parameters which affect the frost resistance of concrete in addition to the air-void characteristics. The frost-resistance number is a simplified and empirical expression for evaluation of the potential frost resistance based on some of the most important parameters affecting the frost resistance such as:

- Space capacity of small air voids per unit volume of paste

- Space capacity of capillary voids (volume which can be filled with freezable water)

- Strength level of the material

Although information about the content of small air voids is certainly more valuable than the total air content, information on this single parameter is probably not enough as a general basis for evaluation of the frost resistance.

Recent investigations have shown that also the moisture history of the concrete is an important factor to the frost resistance. Although it may be difficult to provide a general expression taking into account all important parameters, the concept of the frost-resistance number can certainly still be elaborated and improved.