SHEAR FORCE CAPACITY OF THREE-LAYERED COMPOSITE CONCRETE SLABS

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ABSTRACT

A number of prefabricated three-layered composite concrete slabs have been tested to shear failure. The top and bottom layers consists of structural lightweight concrete and the centre layer consist of slurry infiltrated lightweight expanded clay aggregate.

The simply supported slabs were loaded with a point load F to shear failure. Parameters which varied were: the shear span and the thickness of the centre layer. The influence of the shear span effect has been examined and a design approach is proposed.

Key-words: Composite, Concrete, Shear failure, Shear span, Slab.

1 INTRODUCTION

The use of prefabricated composite concrete slab elements has increased and it is therefore essential to understand the failure modes of such structural elements. In particular the shear failure needs to be investigated further.

This kind of three-layered composite concrete elements does not only decrease the dead load of the structure, but also has a better thermal insulation than normal strength concrete and decreases the time for construction which results in cost savings.

The main interest of these tests has been to study how the interaction between bending and shear influences the shear force capacity of three-layered composite concrete slab elements.

2 THEORETICAL MODEL

The failure mode is considered to be a modified Coulomb criterion see /3/. The failure criterion can be written as a relation between the two principal stresses σ_I and σ_{II}

$$k\sigma_I - \sigma_{II} = nf_{cc} \qquad (1)$$

where

$$k = \frac{1+\sin\phi}{1-\sin\phi} \qquad (2)$$

ϕ = angle of friction
n = effectiveness factor for the compressive strength of the concrete.

Test results for concrete /3/ has shown that the parameter k has a value of about 4 which corresponds to an angle of friction, $\phi = 37°$.

Due to the fact that the stress-strain relation for concrete is characterized by strain softening, see FIG. 1., it is not obvious that concrete can be considered as a plastic material. However if the plastic solution is modified by reducing the compressive concrete strength with a factor n, a good correlation with the test results can be obtained. The effectiveness factor, n, is mainly dependent on the compressive strength of the concrete, the loading conditions and how the structure is reinforced.

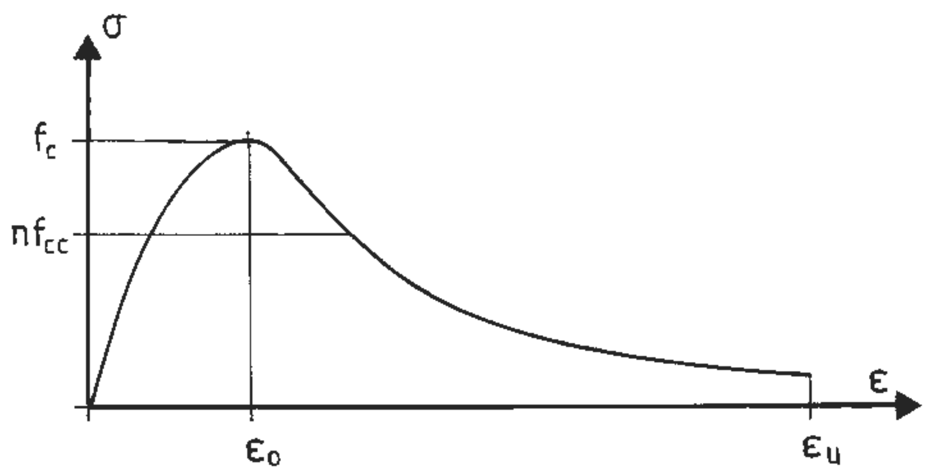

FIG. 1. Stress-strain relation for concrete in compression

For the three-layered composite concrete slabs the compressive zone is well defined to the top layer. If it is assumed that the stresses in the compressive zone are uniformly distributed, the compressive stress and the shear stress can be written

$$\sigma_c = -\frac{V_u a}{btd} \qquad (3)$$

$$\tau_c = \frac{V_u}{bt} \qquad (4)$$

where

a = shear span
b = width of slab
d = internal lever arm (distance between the centres of the top and bottom layers)
t = thickness of the top layer
V_u = ultimate shear force

From Mohr's circle the principal stresses can be written

$$\sigma_{I,II} = \frac{\sigma_c}{2} \pm \sqrt{\frac{\sigma_c^2}{4} + \tau_c^2} \qquad (5)$$

By means of (2) and (5) the following expression can be derived from (1)

$$3\frac{\sigma_c}{2} + 5\sqrt{\left(\frac{\sigma_c}{2}\right)^2 + \tau_c^2} = nf_{cc} \qquad (6)$$

Under the assumption of a compressive failure in the top concrete layer the formal maximum shear capacity of the compressive zone can be expressed

$$V_\tau = nf_{cc}bt \qquad (7)$$

By means of (3), (4) and (7) the following expression can be derived from (6)

$$\frac{V_u}{V_\tau} = \frac{3\frac{a}{d} + 5\sqrt{\left(\frac{a}{d}\right)^2 + 4}}{2\left[4\left(\frac{a}{d}\right)^2 + 25\right]} \qquad (8)$$

The solution to equation (8) is shown in FIG. 2.

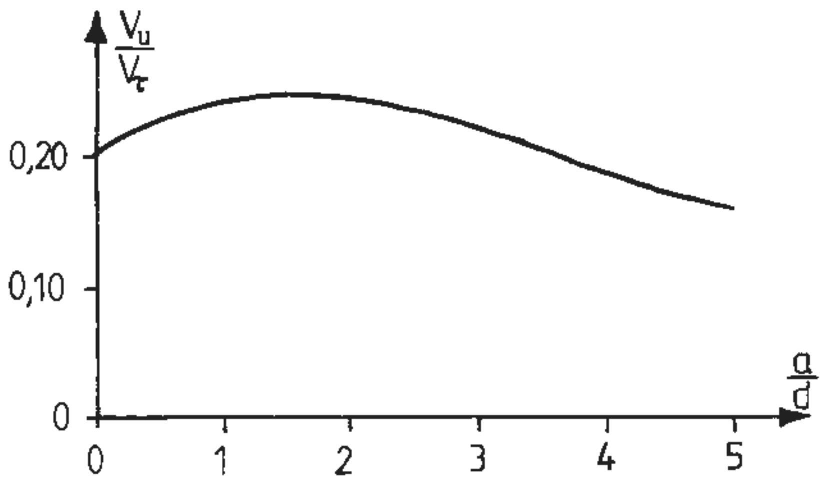

FIG. 2. The relation between the shear capacity and the shear span

The shear span effect shown in FIG. 2. is due to interaction between bending and shear.

3 SHEAR TESTS

3.1 Test program

In this research project ten shear tests have been carried out to evaluate the influence of the shear span effect on the ultimate shear force capacity. All slabs which were tested had a width of 600 mm and the thicknesses of the top and bottom layers were 20 and 40 mm respectively, see FIG. 3. The slab elements were reinforced with three reinforcement bars with a diameter of 10 mm in the bottom layer and 2 bars with a diameter of 7 mm in the top layer.

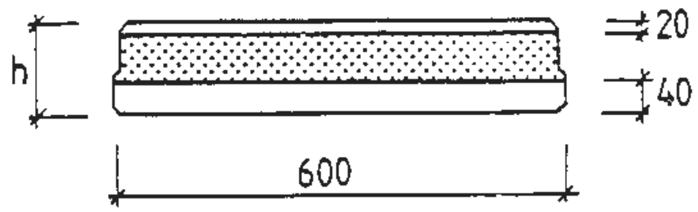

FIG. 3. Cross section of slabs

Five slabs were loaded to shear failure with a point load F at a distance a, the shear span, from the support. As the shear span, a, was short compared to the length of the elements, both ends of the slab elements were tested see FIG. 4. and TABLE 1.

The slabs were numbered according to their total thickness, h. For example slab 101 was the first slab tested with a thickness of 100 mm and slab 123 was the third slab tested with a thickness of 120 mm.

As can be seen in TABLE 1. slabs 101 and 104 were identical and tested under the same conditions and also slabs 122 and 124.

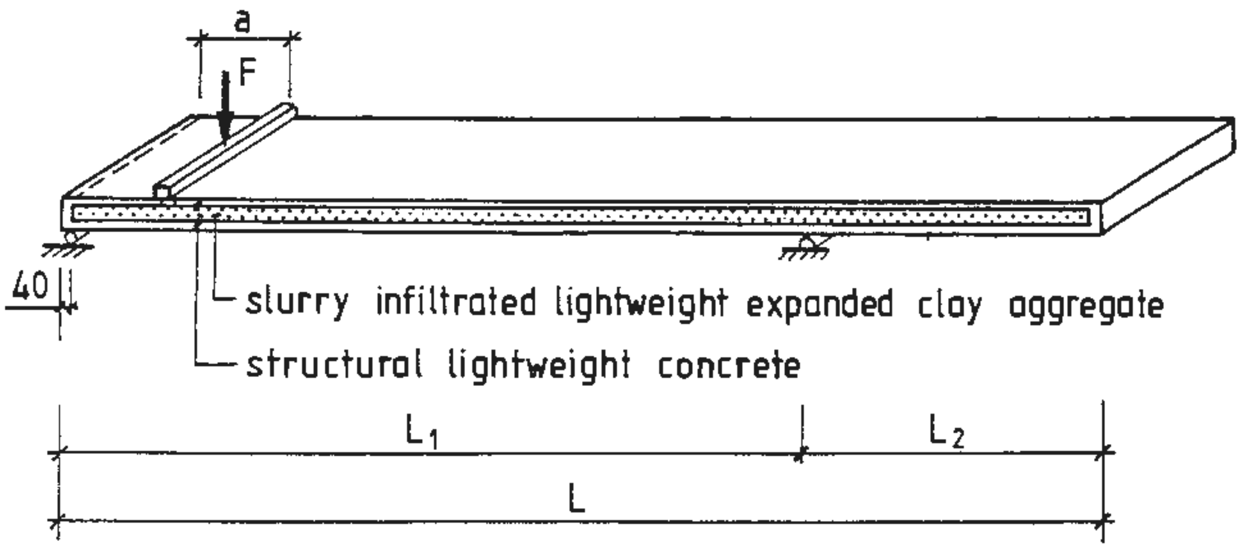

FIG. 4. Test set-up for the shear tests

TABLE 1. The test program

Slab no	L [mm]	L_1 [mm]	L_2 [mm]	h [mm]	a [mm]	d [mm]
101	3200	2300	900	100	425	70
102	3200	2300	900	100	225	70
103	3200	2300	900	100	325	70
104	3200	2300	900	100	425	70
121	4200	3000	1200	120	225	90
122	4200	3000	1200	120	425	90
123	4200	3000	1200	120	325	90
124	4200	3000	1200	120	425	90
143	4200	3000	1200	140	275	110
144	4200	3000	1200	140	425	110

The prefabricated slab elements which were tested consisted of a top and bottom layer of structural lightweight concrete and a centre layer of slurry infiltrated lightweight expanded clay aggregate see FIG. 4.

3.2 Test results

For all slabs tested bending cracks were observed under the load in the bottom concrete layer before the ultimate shear failure occurred. In FIG. 5. a typical shear crack is shown.

FIG. 5. Shear crack in slab 101 with a long shear span

The comparison between the theoretical model and the test results is shown in FIG. 6. and TABLE 2. The theoretical values of (V_u/V_τ), $(V_u/V_\tau)_{cal}$, are calculated with equation (8) and the values observed from the tests, $(V_u/V_\tau)_{obs}$, are obtained by using equation (7) and measured values of f_{cc}, b, t and F.

The effectiveness factor, n, is estimated at 0.70 by using figure 2.23 in reference /3/. f_{cc} is measured to the value f_{cc} = 15 MPa from compressive tests of small cubes taken from one of the slabs. The shear force V_u is calculated from the measured ultimate load, F, considering the dead weight of the slab.

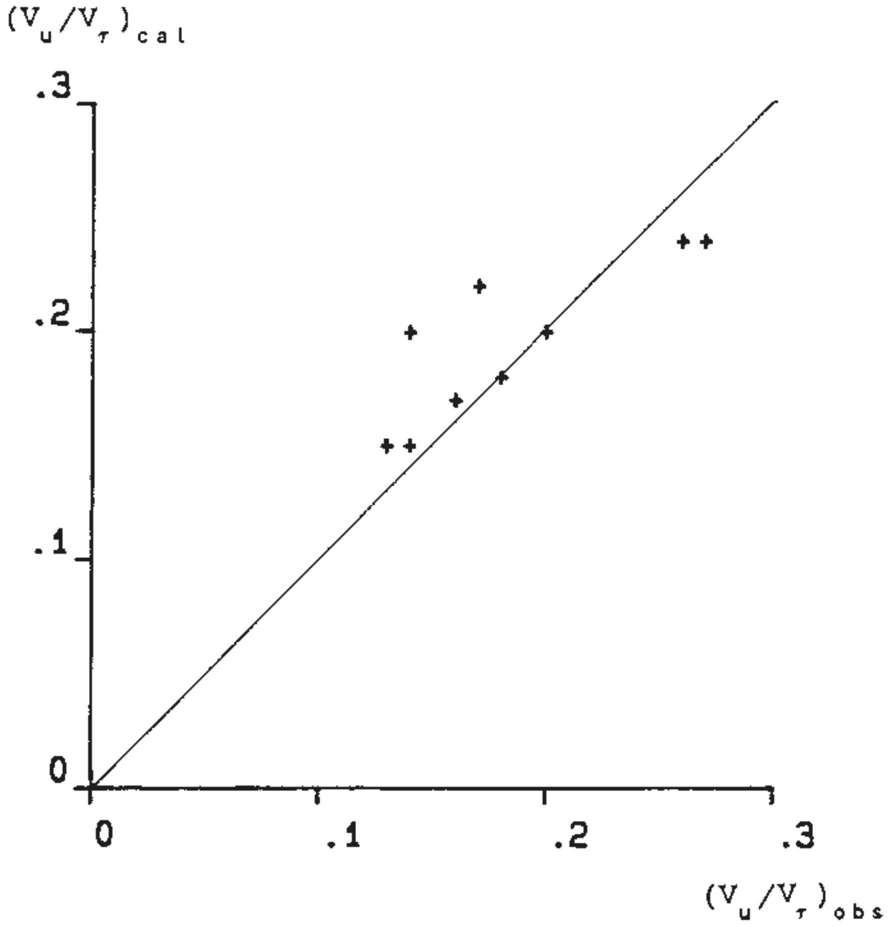

FIG. 7. Comparison between theoretical model and test results

Best correlation between the theoretical and measured values of V_u/V_τ is obtained for long shear spans. This is probably due to the fact that for the short shear spans the failure cannot always be considered as a pure shear failure. Slab 102 and 123 do not correlate well with the theoretical expression in equation 8. For slab 102 this is probably because of the short shear span which results in anchorage failure of the reinforcement in the bottom layer.

TABLE 2. Test results

Slab no.	a [mm]	d [mm]	a/d	F [kN]	$(V_u/V_r)_{cal}$ eq(8)	$(V_u/V_r)_{obs}$
101	425	70	6.07	19.1	0.15	0.14
102	225	70	3.21	21.7	0.22	0.17
103	325	70	4.64	23.7	0.18	0.18
104	425	70	6.07	18.2	0.15	0.13
121	225	90	2.50	32.5	0.24	0.27
122	425	90	4.72	19.1	0.17	0.16
123	325	90	3.61	15.6	0.20	0.14
124	425	90	4.72	18.7	0.17	0.16
143	275	110	2.50	31.4	0.24	0.26
144	425	110	3.86	24.0	0.20	0.20

Measurements of strains on the top layer of the concrete gave low concrete strains which showed that the slabs did not fail in bending.

A more detailed description of the tests and test results can be found in reference /1/ and /4/.

4 CONCLUSIONS

It is obvious from the performed tests that the shear capacity for this type of three-layered slabs can be estimated by using the design approach based on the theory of plasticity. The derived expression takes into account the shear span effect and the interaction between bending moment and shear force.

As the tests were performed with a ratio shear span to the internal lever arm of 2.50 - 6.07 no conclusions can be made for the interval 1.0 - 2.0 when the maximum ultimate shear capacity is obtained according to the theory.

5 NEED FOR FUTHER RESEARCH

Further test series on this type of slab and an investigation of the material properties of the concrete using standardized tests would be interesting.

To complete the investigation tests with a ratio a/d less than 2.5 should be performed if possible.

This investigation ought to be completed with tests of three-layered slabs which have shear reinforcement between the layers to see if it is possible to use the same expression (8), maybe with the modification of some parameters, to calculate the ultimate shear capacity.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

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/3/ Nielsen, M., P., "Limit Analysis and Concrete Plasticity, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, USA, 1984.

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8 NOTATIONS

a	shear span
b	width of the top concrete layer
d	internal lever arm (distance between the centers of the top and bottom layers)
t	thickness of the top layer
V_u	ultimate shear force capacity
V_τ	compressive capacity of the top layer
σ_c	compressive stress in the slab
τ_c	shear stress in the top layer