NECESSARY CONCRETE STRENGTH FOR FORM STRIPPING OF IN SITU CAST CONCRETE

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Synopsis

An investigation has been carried out to study the need of early age strength of in situ cast concrete, above all at form stripping. In laboratory has been studied foundation specimens, 2.4 m high wall specimens and 4.2 m floor slabs according to strength, deformation and cracking. Most of the specimens were also studied in regard to mechanical damages at form stripping.

On wall specimens with different strengths the influence of reinforcement on the bearing capacity has been studied at horizontal loads.

Floor slabs were investigated both concerning instantaneous and long-term deflection at different compressive strengths. The influence of the shores on the deflection was also observed.

Keywords: damage, deflection, form stripping, strength.

1. INTRODUCTION

The early strength of concrete is essential both from a technical point of view and from an economical one. There is need of some concrete strength at form stripping to avoid mechanical damage, large deformation and rupture. On the other hand too high demands for the strength cause delayed form stripping and increased costs. Of course it is important to find a strength satisfying both the technical and economical requirements. For this reason Cementa AB has carried out laboratory tests with support from the Swedish Council for Building Research in order to increase the knowledge of such a form stripping strength.

Before the laboratory tests started two background investigations were carried out. The first one dealed with the distribution of the volume of in situ cast concrete among foundations, vertical and horizontal structural elements. The reason for this investigation was that the need of strength at form stripping is unequal for different types of structural parts, for instance walls and floor slabs. This investigation covered 115 building structures of different types and the results are concluded in TABLE 1. A rough statistical estimation indicated somewhat more horizontal elements than the table shows. This is also confirmed by a control investigation.

This marketing analysis also established that the volume of columns and pure beams was very small, only a few per cent of the volume of walls and floor slabs respectively.

TABLE 1 The distribution in per cent of cast in situ concrete among different types of structural elements. The figures put in brackets refer to a limited control investigation based on deliveries from 6 ready mixed concrete plants

	Type of structural element			
	Foundation	Vertical	Horizontal	Total
Main investigation ∿ 200 000 m^3	45	27	28	100
(Control investigation ∿ 20 000 m^3)	(46)	(18)	(36)	100

The second background investigation consisted of about 30 interviews concerning stripping time and strength. In most cases site engineers were interviewed. It was clear that in practice the stripping time was mostly fixed in advance and it was very important not to exceed this time, especially with leased forms. The results are summarized in TABLE 2.

TABLE 2 Normal form stripping times, in days, according to interviews with site engineers. In practice the form stripping time of 1 day means 15-20 hours depending on form cleaning, reinforcement work and so on.

	Buildings*	Civil engineering works**
Foundations	1	1
Walls, columns	1	1 - 7
Floor slabs, beams	2 - 7	3 - 21

The necessary stripping strength is obtained by different measures such as calcium chloride, insulation and heating. The use of calcium chloride is very common when permitted.

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*) Residential, public and industrial buildings.

**) Bridges, power stations, quays, sewage plants etc.

Only exceptionally the form stripping was permitted to be delayed, for instance by very cold weather. On the other hand floor slab forms are sometimes stripped the day after casting. In exceptional cases it also happens that vertical forms are used twice a day. The form stripping time can also be increased deliberately, if other activities are not delayed.

Among other things the interviews showed that columns according to form stripping are treated more carefully than walls, and pure beams more carefully than floor slabs.

Damages in connection with cast-in details, especially loosened electric boxes, seems to be a frequent problem in cold weather. A local building committee questioned if the amount of safety reinforcement in walls to resist wind and impacts during the building period was sufficient in winter.

Finally many engineers wanted a shortened stripping time for floor slabs.

2. THE SCOPE OF THE LABORATORY TESTS

The laboratory test included 29 foundation slabs, 29 walls and 13 floor slabs with measures representative of residential buildings. The foundation slabs were cast as supports for the walls. Still, they were also used for an ocular inspection of mechanical damages in connection with the form stripping (10 slabs) and for a loading test on edges and corners to investigate the resistance against loads at different concrete strength.

The wall specimens were all inspected ocularly concerning mechanical damages at the form stripping. This inspection was supplemented by a nail test according to FIG 1.

Of the walls 13 specimens of different compressive strength were vertical loaded, FIG 7, most of them to rupture. A simultaneous registration of the compressive deformation was made to get information on the modulus of elasticity. 13 other wall specimens were loaded to rupture by a horizontal load, FIG 9. These tests were a study of the influence of the reinforcement on the ultimate load at a lower concrete strength than 5 N/mm^2.

All the 13 floor slabs were inspected ocularly concerning mechanical damages on the concrete surface. Load tests to rupture were carried out on 10 slabs immediately after form stripping and on 3 slabs a month after the removal of the form. At form stripping all the shores except those in the middle of the span were first removed and the deflections were measured. Immediately after that the middle shores were taken away and the deflections measured again, FIG 12. The deflections were also registered both during the loading and during the time between the form stripping and the ultimate load test. All the slabs were cast against forms on shores.

3. MECHANICAL DAMAGES AT FORM STRIPPING

3.1 Ocular inspection and nail test

It was clear that the form could often be stripped at a very low concrete strength (< 0.5 N/mm^2) without damages in the shape of scalings, broken edges etc. on the concrete. However, at such a low strength the concrete surface is very easily damaged. It can, for example, be visible scratched by a finger nail and edges can without difficulty be spoiled by a thumb to a depth of about 10 mm. Normally a strength of 2 N/mm^2 seems sufficient for form stripping with a reasonable low risk of mechanical damages. This conclusion based on ocular inspections was supported by measuring the depth of a scratch caused by a nail loaded with 20 N, FIG 1. This figure shows that the depth of a scratch increases rapidly when the compression strength falls below 2 N/mm^2. In regard to scaling the results from the wall tests are summarized in FIG 2. The above-mentioned results seem to be in accordance with the results reported by Harrison /1/.

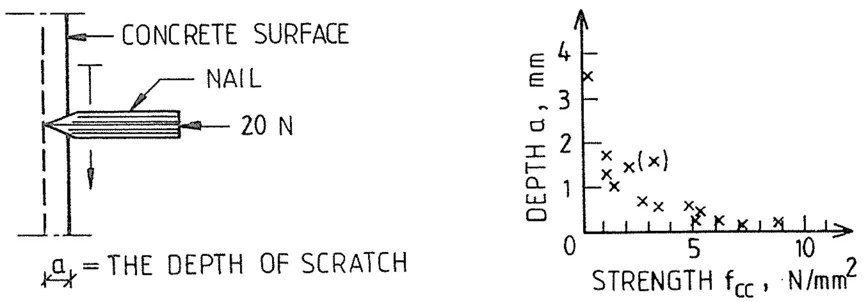


FIG 1. A 20 N spring loaded nail was pulled along the concrete surface (left). The depth a of the scratch was registered for different concrete strength f_{cc} (right).

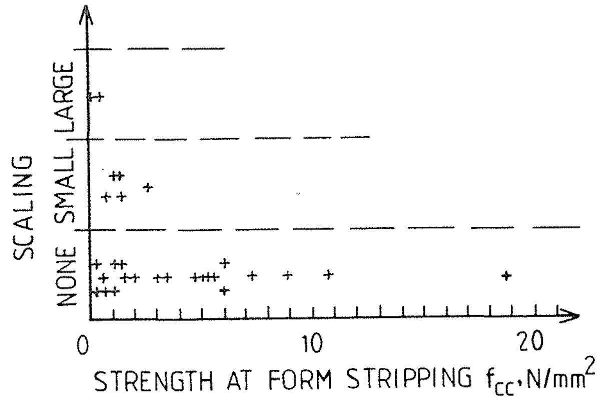


FIG 2. The distribution of damages in the shape of scalings on the concrete surface. The results refer to ocular inspections of the wall specimens.

There were two exceptions from the results above. Surfaces cast against rough sawn timber showed up small scalings up to 3 N/mm^2 and edges with burrs caused by openings in the form could be broken also at a compression strength higher than 10 N/mm^2, FIG 3.

Two edges of every wall specimen were bevelled by a triangular batten, FIG 6. They essentially reduced the amount and size of edge damages.

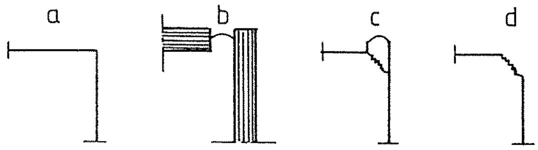


FIG 3. The origin of a damage at an edge caused by a burr in consequence of an opening in the form work.

a) Wanted shape.
b) A burr is formed.
c) The burr is spoilt by forces at form stripping.
d) The final result.

3.2 Loading tests on corners and edges

The load tests were carried out on the upper side of the foundation slabs as shown in FIG 4. The results according to FIG 5 indicate a decreasing ultimate load with decreasing compressive strength and load area. For that reason placing of a triangular batten in the form seems to be an appropriate step in order to protect edges and corners of concrete at an early age. The curving lines close to the origin in FIG 5 show that sharp edges are easily damaged also by small forces. This is in accordance with the results from the ocular inspection above.

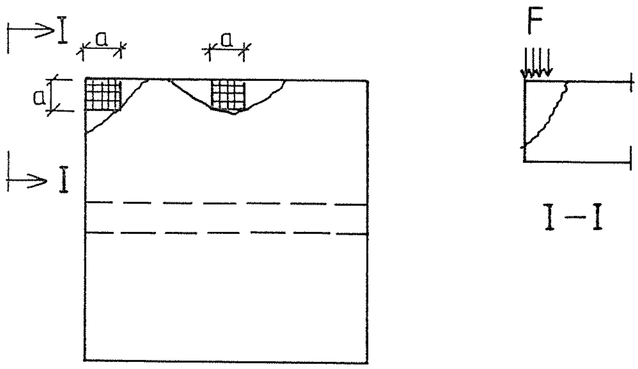


FIG 4. Load tests of a corner and of an edge carried out on a foundation slab.

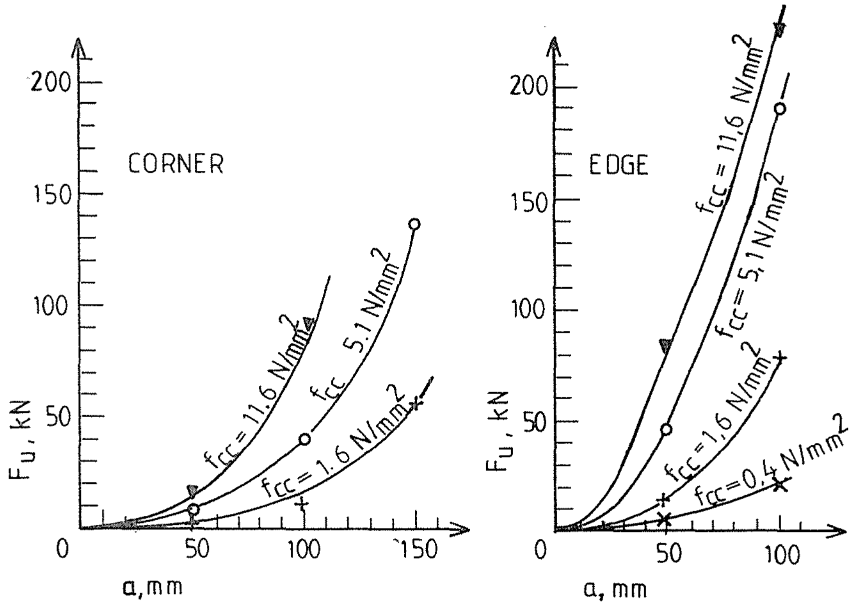


FIG 5. The ultimate load F_u as a function of the size of the loaded area (a x a in FIG 4) at loading on a corner (left) and on an edge (right).

4. LOADING TESTS ON WALLS

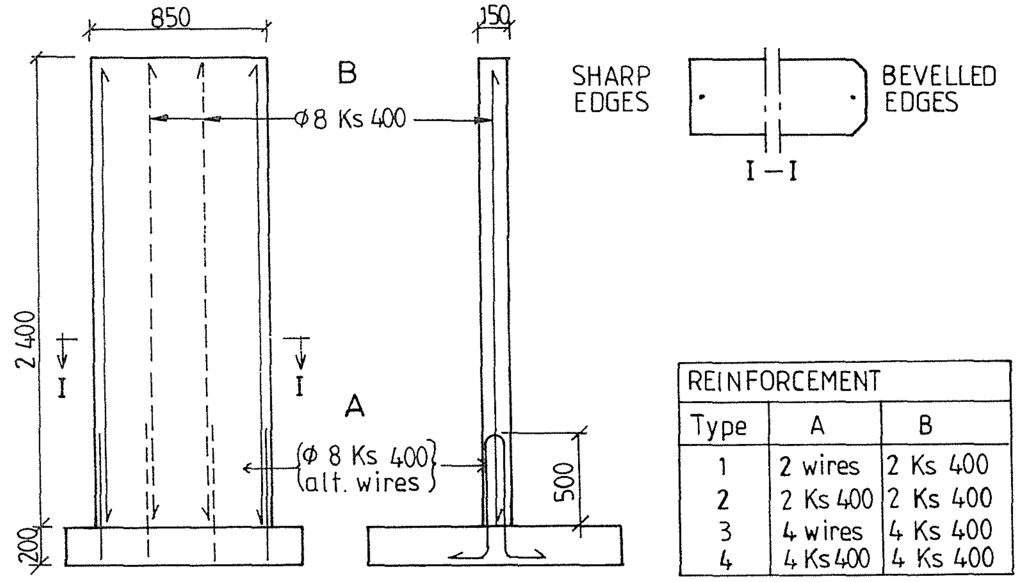
4.1 Vertical centric load

The 13 wall specimens of different compressive strength and with measures and reinforcement according to FIG 6 were loaded during contemporaneous registration of the compressive deformation. The concrete strength was controlled by 150 mm cubes, stored and insulated to have the same curing conditions as the walls. The relationship between the strength of cubes and the strength of the walls is given in FIG 7 and seems to be linear in the investigated interval. In all the walls loaded to the ultimate strength the rupture was developed in the upper part by spalling or crushing. This was to be expected since the concrete strength normally has its lowest value in the top of a wall. In practice the bottom of a wall can be the weakest part during the winter when casting against a cold floor slab. This was confirmed in the interviews with the site engineers.

Using the results from the deformation measurements the modulus of elasticity, E_{cc}, was estimated. It was found that the E_{cc} of the wall tolerably good corresponded to E_{cc} from the more careful laboratory tests on small specimens by Byfors /2/, FIG 8.

4.2 Horizontal load

As a precaution there is in Sweden a demand for some reinforcement (for 150 mm thick walls ø8 c100 mm Ks400 with a yield point of 400 N/mm^2) in walls which are free-standing during any phase of the building process. The concrete compression strength is supposed to be at least 5 N/mm^2. In order to study the influence of reinforcement on the ultimate load at a lower concrete strength than 5 N/mm^2 13 wall specimens were loaded to rupture by a



REINFORCEMENT		
Type	A	B
1	2 wires	2 Ks 400
2	2 Ks 400	2 Ks 400
3	4 wires	4 Ks 400
4	4 Ks 400	4 Ks 400

FIG 6. Wall specimens. The form surface consisted of steel, impermeable plastic coated plywood or rough sawn timber.

Reinforcement:
At vertical loading, FIG 7, type 1-2
At horizontal loading, FIG 9, type 1-4

The yield limit of the hot-rolled Ks 400 was 485 N/mm^2 and the corresponding value (0.2-limit) of the cold-rolled wires (effective area 25 mm^2) was ∿ 1 200 N/mm^2.

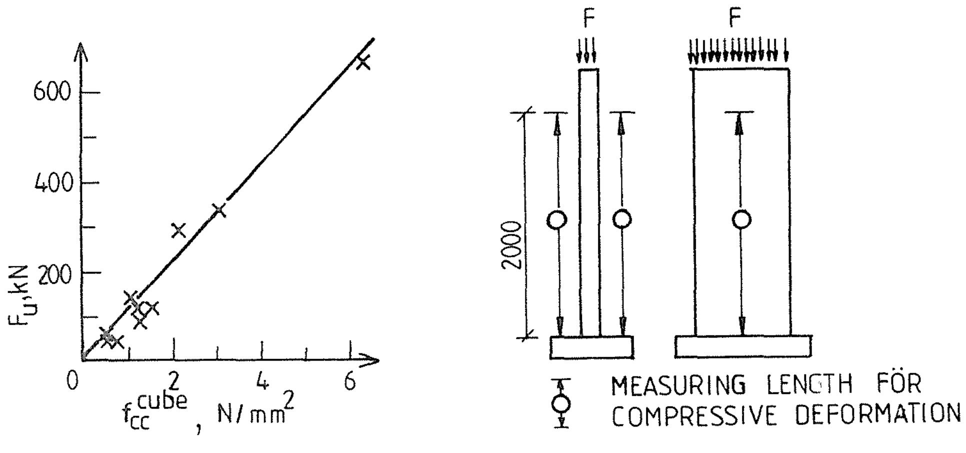


FIG 7. The ultimate load F_u of the vertical centric loaded wall specimens as a function of the concrete strength f_{cc}^{cube}. This one was measured on 150 mm cubes cured in the same way as the wall specimens. Experimental arrangement to the right.

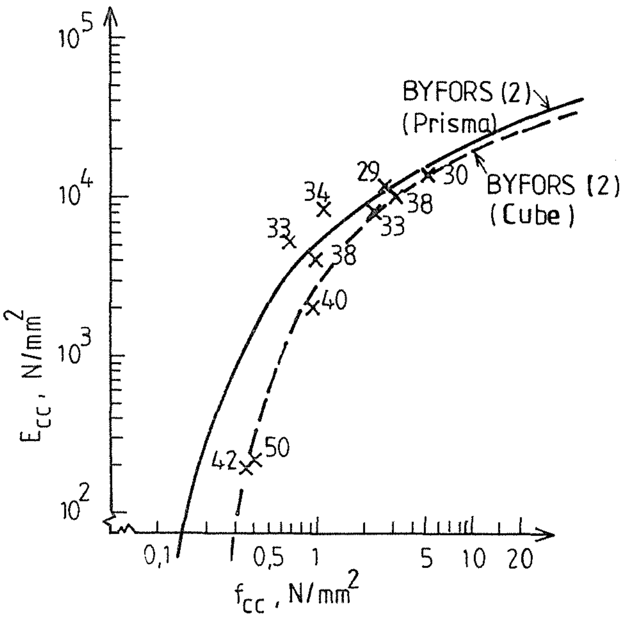


FIG 8. The modulus of elasticity in the walls as a function of the compressive strength F_{cc}, FIG 7. The figures up to the measurement test results state the compressive strength in per cent of the concrete strength at which the modulus has been calculated.

horizontal load, FIG 9. The reinforcement consisted in the walls of straight centric bars B and of stirrups A, FIG 6 and 9.

The test results are summarized in FIG 9 and TABLE 3. It can be stated that for a certain amount of reinforcement the ultimate load increases very slowly if the concrete strength exceeds a definite value. In this case the value is about 5 N/mm^2. For a concrete strength $f_{cc} < 2$ N/mm^2 the ultimate load decreases rapidly with decreasing concrete strength. Another conclusion from FIG 9 is that the ultimate load can essentially be raised by an increased reinforcement. Thus, it is possible to strip the form at a lower strength than 5 N/mm^2 with preserved ultimate load. Still, independent of the quantity of reinforcement $f_{cc} = 2$ N/mm^2 seems to be the absolute lowest limit for the form stripping of walls. One reason for this is the need of a sufficient saftety against mechanical damages. Another reason appears in the fact that a correct estimation of the ultimate wall load for such a low strength ($f_{cc} < 2$ N/mm^2) is difficult to do depending on the steep gradient of the first part of the load-strength curve, FIG 9.

The walls seemed to have two weak points, I and II in FIG 9, and all the ruptures seemed to appear in one of these two positions. However, calculations pointed out that the real cause of the rupture ought to be in position I due to the small efficient height. If the rupture appeared in position II which only happened with wire reinforcement it might have been a secondary effect, probably due to insufficient bond to the stirrups A. In

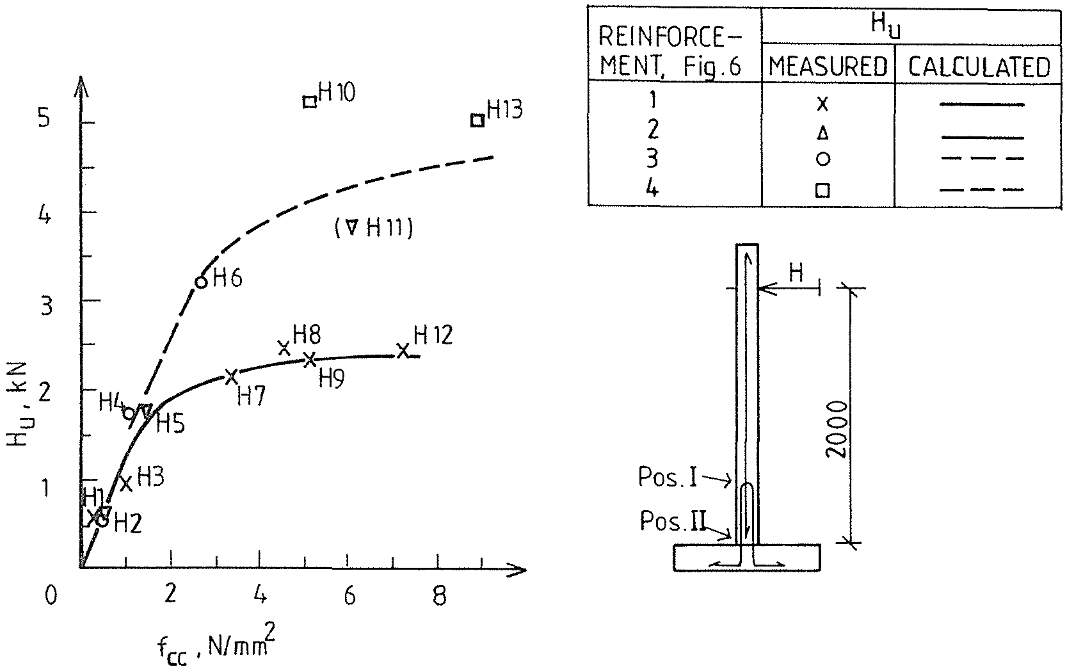


FIG 9. The ultimate load H_u as a function of the concrete strength f_{cc}. Both measured and calculated values are shown. The latter refer to position I.

TABLE 3 The compressive concrete strength, f_{cc}, the ultimate load, H_u, and the position of rupture of the horizontal loaded wall specimens according to the load tests.

Wall No.	Reinforcement, FIG 6	f_{cc}* N/mm^2	H_u kN	The visible position** of the rupture
H 1	1	0.4	0.60	I
H 3	1	1.1	1.00	II
H 7	1	3.5	2.20	II
H 8	1	4.7	2.50	II
H 9	1	5.1	2.40	II
H 12	1	7.3	2.50	II (I)
H 4	2	1.1	1.80	I
H 6	2	2.7	3.25	I
H 2	3	0.4	0.60	I
H 5	3	1.5	1.75	I
H 11	3	6.1	3.90	I
H 10	4	5.2	5.25	I
H 13	4	8.9	5.10	I

*) The concrete strength was measured on 150 mm cubes, insulated to get the same curing conditions as the corresponding wall.

**) Position I and II refer to FIG 9.

some tests the reinforcement could be exploited over the yield limit, No. H 10 and H 13.

It must be emphasized that form stripping of walls at a lower strength than $F_{cc} = 5\ N/mm^2$ must be approved by the designer who also has to decide upon increased reinforcement etc. A careful control of the necessary concrete strength before the form stripping is also of great importance. The reason for all this is that a collapsing wall means a real danger of life.

5. LOADING TESTS ON FLOOR SLABS

5.1 Deflection at form stripping

The principal measures and reinforcement of the specimens are given in FIG 10-11. The interval of the compressive strength of the concrete was at form stripping $f_{cc} = 2\text{-}19\ N/mm^2$ and after 28 days $f_{cc}^{28} = 16\text{-}45\ N/mm^2$.

The main results are summed up in FIG 12. This indicates that the deflection with all the shores removed decreases rapidly at increasing concrete strength up to $f_{cc} = 10\ N/mm^2$. After that the deflection decreases very slowly. On the other hand, with the middle shores left the instantaneous deflection was essentially reduced and smaller than 1 mm. This is in accordance with calculations with regard to the halving of the span and to the support conditions. The lowest strength at form stripping seems to be about 10 N/mm^2 in order to get a sufficient safety against too much deflection. Regarding the steep part of the curve in FIG 12 a careful control of the form stripping strength is necessary. However, if the surface form could be stripped with the middle shores left for some days a still lower stripping strength could be possible. In such a case the actual conditions must be considered carefully before deciding the form stripping strength.

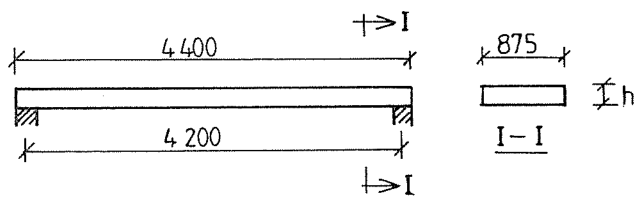


FIG 10. The measures of the floor slabs.
Type 1: h = 160 mm. Type 2: h = 200 mm.

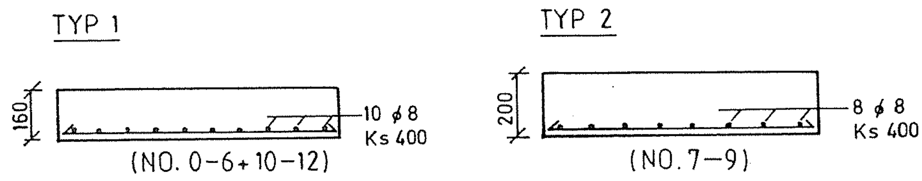


FIG 11. The reinforcement of the floor slabs.

In FIG 13 calculated deflections (E_{cc} from FIG 8) are compared to the measured ones. For the partly cracked concrete the calculation is done according to Wilson /3/. The accordance seems to be acceptable.

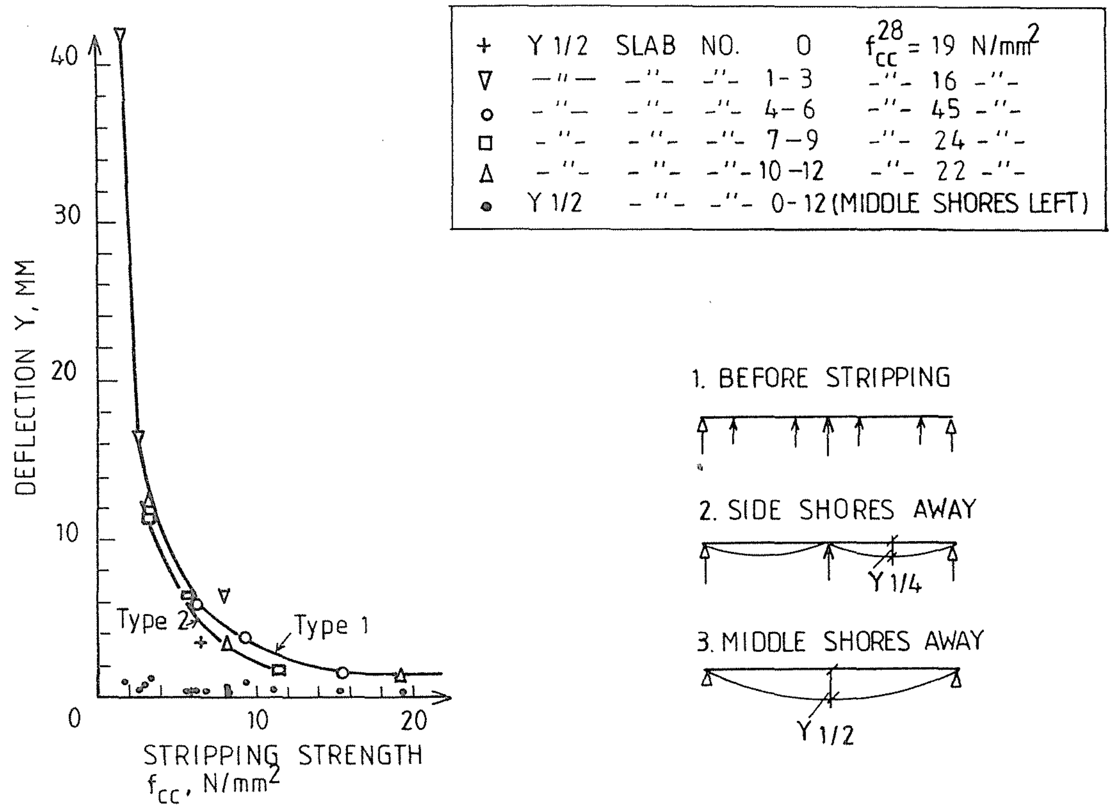


FIG 12. The instantaneous deflection of the floor slabs as a function of the form stripping strength f_{cc}. The slabs No. 7-9 (type 2) had an increased thickness and a reduced reinforcement compared with the other slabs (type 1), FIG 10-11. However, the bearing capacity was intended to be the same one.

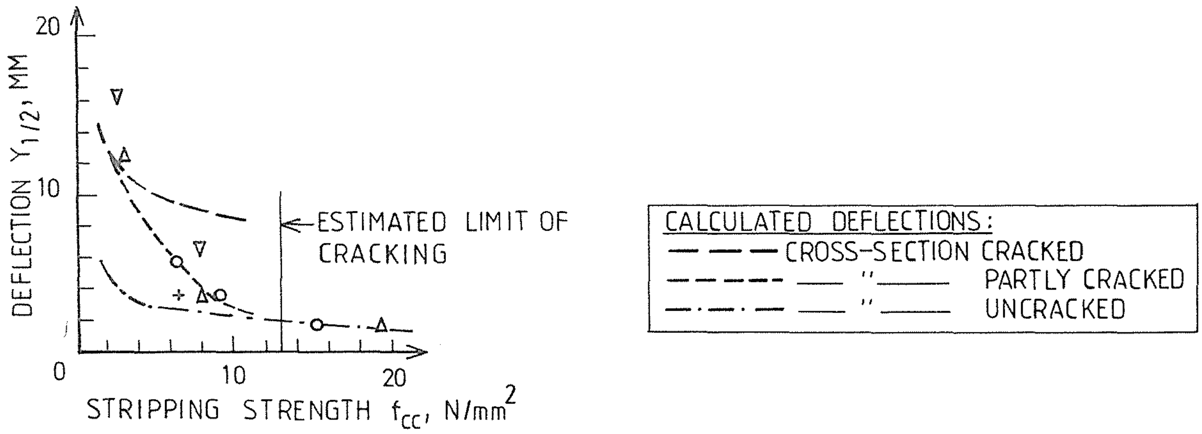


FIG 13. Calculated instantaneous deflections compared to the measured ones for the 160 mm thick slabs.

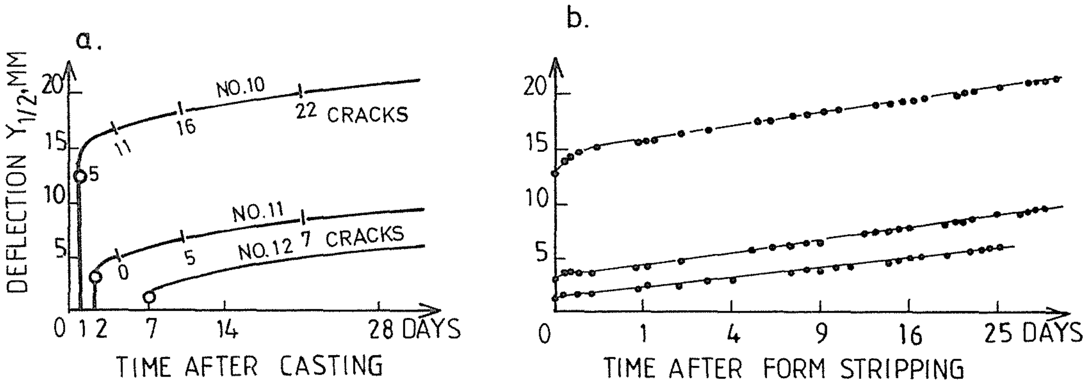


FIG 14. The time graphs of the deflection $Y_{1/2}$ in the middle of the span of the three slabs No. 10-12. The form was removed after 1, 2 and 7 days and the corresponding concrete strength was 3, 8 and 19 N/mm^2 respectively. The time is given in a linear scale (a) and in a square root scale (b).

5.2 Deflection by creep

The compressive strength of the three slabs (No. 10-12) in the long-term (1 month) test was at form stripping f_{cc} = 3, 8 and 15 N/mm^2 and after 28 days f_{cc} = 22 N/mm^2. In these tests the principal interest was bound to the creep deflection. The measured deflections are given as a function of the time after casting in a linear scale, FIG 14a, and as a function of the loading time in a square root scale, FIG 14b. During the creep test the load only consisted of the dead weight. Wilson /3/ has calculated the deflection of the three slabs in connection with a theoretical study of creep. The author presents a calculation method which brings the calculated values into a good agreement with the test results. The final deflection including the instantaneous one Wilson calculated to 35, 27 and 22 mm respectively for the three slabs in FIG 14. A few days after form stripping the curves in FIG 14b appear to be straight lines. According to Wilson this is a frequently occurring phenomenon over a period from one or two days to six or seven weeks. Assuming that the slope of these lines is 1/14 Wilson /3/ gives the following formula for estimation of the final deflection by creep $Y_c^{(\infty)}$

$$Y_c^{(\infty)} \cong \{Y(t) - \bar{Y}(0)\} \cdot \frac{14}{t^{\frac{1}{2}}}$$

where Y(t) corresponds to an arbitrary point at the straight line.

The creep deflection during the first hours after the form stripping is shown in FIG 15. There was a clear difference in creep between the specimen (No. 10) with the stripping strength 3 N/mm^2 and the two specimens (No. 11-12) with 8 and 19 N/mm^2 respectively. Thus, with exception of very low strengths, the deflection caused by creep seems to be more or less independent of the form stripping strength. In order to get a limited final deflection it is more important to restrict the instantaneous one, FIG 12.

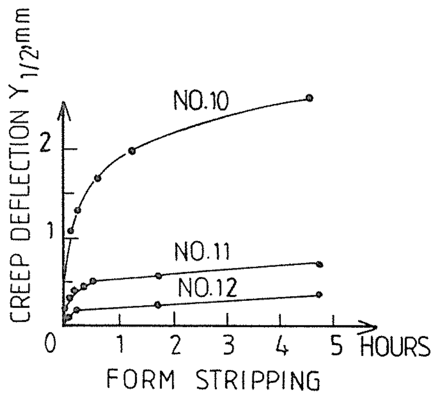


FIG 15. The deflection of creep $Y_{1/2}$ in the middle of the span during the first five hours after the form stripping.

5.3 Cracking

The lowest concrete strength without visible cracks at form stripping was f_{cc} = 5 N/mm^2 and the highest concrete strength with visible cracks was f_{cc} = 6 N/mm^2. This was valid if all the shores were removed and so far the above-mentioned form stripping strength f_{cc} = 10 N/mm^2 hardly involves any problem with cracking. However, the long-term (1 month) tests showed some cracking after the form stripping, No. 11 in FIG 14a. For that reason it could be advisable to increase the stripping strength above the strength demanded with regard to deflection.

In the interviews with site engineers there was mentioned form stripping strengths for residential buildings in the interval of 6-15 N/mm^2. If not special steps are taken there is real risk ot cracking and undesirable deflection with the lowest strength.

5.4 Ultimate load

The measured ultimate loads were in tolerably good accordance with the calculated ones. However, in this investigation the main interest was connected to the deflection.

6. CONCLUSIONS

In practice form work can be stripped at a compressive concrete strength of 2-3 N/mm^2 with an acceptable low risk of mechanical damages. The highest value concerns permeable rough surfaces. In connection with burrs there is a risk of damages at edges even if the strength exceeds 10 N/mm^2.

Normally in free-standing walls the form work can be stripped at a compressive strength of 5 N/mm^2. However, with an increased reinforcement it can be done at a lower strength with a preserved resistance against horizontal loads.

In order to restrict the deflection of floor slabs in residential buildings (∿ 4 m span) the lowest strength at form stripping has to be about 10 N/mm^2. To avoid cracking the strength may be increased to about 15 N/mm^2. It seems to be possible to calculate both the instantaneous and the final deflection in an acceptable way. If the surface form work could be removed with the central shores left for some time a lower form stripping strength than the above-mentioned one is possible.

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