EARLY AGE LOADING OF FLOOR SLABS

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ABSTRACT

In recent years, a 5 to 7 day floor construction rate has been very common. This has been one response to a financial climate that puts a great premium on reduced construction time. Possible construction schedules are increasingly becoming a major factor in the choice of structural forms and propping (shoring) systems. Consequently, there are economical advantages to be gained from early formwork removal. However, premature removal of formwork in concrete construction may result in dramatic failure. To ensure satisfactory performance and structural safety during construction, a thorough understanding of the construction load distribution and the performance of the concrete building during construction, is necessary. In addition, in multistory concrete construction, the construction loads imposed by the propping system may appreciably exceed the service loads for which the slabs were designed. Since the supporting slabs have generally not reached their full design strength, their capacity may be exceeded and early removal of props may lead to excessive deflections during construction. This paper presents an extensive investigation to determine the actual load ratios applied to floor slabs and reprops during construction. It includes a development of an analytical method and laboratory tests. The analytical method enables the deformation and stress state induced in floor slabs and propping system during construction to be predicted. The experimental program involves tests on simply supported slabs and creep tests on small concrete prisms.

keywords: Floors, Props, Early age, Reprops.

1- INTRODUCTION

In multistory cast-in-place concrete construction, each floor slab is supported by a system of props, reprops or backprops that transfer the weight of the concrete and equipment to the floors below. Typical construction procedure for floor slabs involves casting the new slab on props (forms) which are supported on a previously cast slab which in turn is partially supported by reprops or backprops to lower slabs in the system.

The engineer must ensure that the concrete has gained sufficient strength to support the loads transferred to the structure at all stages in the building sequence. A number of concrete construction disasters have occurred as a result of premature formwork removal. On 2 March 1972, premature removal of props supporting a 5 day-old concrete slab led to the progressive collapse of an entire structure at Bailly Crossroads, Virginia [1].

2- REVIEW OF PREVIOUS WORK

Previous work has been carried out to determine usable procedures to calculate the forces in concrete structures loaded at early age during construction, as well as the propping and repropping needed to build concrete structures safely.

Nielsen [2] and Grundy and Kabaila [3] proposed methods of analysis. The loads carried by the slabs and the props were expressed as the load ratio (i.e., ratio of the load carried by the slab to the self weight of the slab). It was assumed that the slabs behave elastically, the creep effects were ignored and the props were considered as continuous elastic supports in reference [2] and as infinitely rigid in reference [3] . In a particular example, using three levels of forms (props) for a 7-day casting cycle stripping after 5 days, the maximum load ratios obtained on a slab were 2.56 and 2.36 respectively. The effect of ignoring the flexibility of the props was thus relatively small. The calculation involved in this analysis is lengthy and has limited practical applications due to its high mathematical complexity.

Taylor[4] recommended a method of slackening and tightening adjustable props under a floor slab. Using this technique, and the same assumptions given by Grundy and Kabaila, Taylor showed that the maximum load ratio on a slab for three levels of props never exceeded 1.44 at a slab age of 21 days compared with 2.36 calculated by Grundy and Kabaila. The disadvantage of this technique is that strict supervision is required to achieve the desired objective.

Agarwal and Gardner[5] analyzed the loads imposed using the propping/ repropping method of construction, and the same simplifying assumptions adopted by Grundy and Kabaila. Using one level of forms and two levels of reprops for a 7-day casting cycle with stripping after 5 days, the maximum load ratio obtained was 1.34.

In the methods of analysis described above, several assumptions have been made ignoring the creep effects in the concrete, the variation of the stiffness and strength of concrete with time, and the stiffness of the props and reprops. All these variables are considered in the proposed method of analysis given in this paper.

3- EXPERIMENTAL PROGRAM

(a) *Objective*

The objectives of the laboratory test program were:

- To establish basic material data for concrete at early age.
- To provide data, obtained under known conditions, which would permit the mathematical model to be checked.

Tests were carried out on simply supported slabs loaded at mid-span and propped by a spring of known stiffness also at mid-span. Any more complex system would introduce uncertainties about the actual distribution of moments within the specimens.

(b) *Test program*

A total of eight simply supported reinforced concrete slabs were tested. All had the same dimensions, 200mm x 500mm and 4.0m long. Two percentage steel areas, 0.4% and o.8%, and two levels of concrete strength, 35 N/mm^2 and 65 N/mm^2 were used. In addition, creep prisms were tested for each mix. In parallel with the slab tests, cubes and cylinders were tested at different ages from 12 hours to 28 days, to determine the strength development of the concrete both in compression and tension.

All the slabs were loaded at mid-span to represent the load from the floors. The prop below was modeled by springs with two levels of stiffness, 8 kN/mm and 14 kN/mm, to represent different supporting conditions. Dial and demec gauges were used to measure the deflections and the strains respectively. Thermocouples were also installed inside the concrete to read the temperature during the first 3 days of the tests. A slab in the test rig is shown in Figure (1).

The slabs were stripped, repropped or backpropped and then loaded at a variety of times representing the construction steps similar to that in practice (see Table 1). They were stripped at age ranges between 12 hours and 3 days and repropped shortly after which models were loaded at a rate between 3 and 7 days per floor. The test program assumes one propped floor and two repropped floors. The additional loads on the slabs (loads on the floors above) at each phase were determined from the prop force at the previous stage during the test. Typical test procedure for slab 4 is shown in Figure (2).

(c) *Results*

Construction Slabs with concrete strength of 65 N/mm^2, i.e., slab tests 6, 7 and 8, sustained the loads at stripping and during the construction procedure without cracks occurring anywhere in the slabs, irrespective of the stripping time. Deflections at removal of the shuttering ranged between 0.7mm and 1.0mm. However, slabs with lower strength (i.e., 35 N/mm^2), showed tensile cracks at the bottom face of the slabs at various positions along the length of the slab. Slabs stripped after 12 hours, (i.e., slabs 1, 4 and 5) cracked immediately after removal of the shuttering with a relatively large deflection up to 8mm. Slabs 2 and 3 which were stripped at 1 day and 3 days respectively, sustained their self weights after stripping without any sign of cracks, but cracked at a later stage when the prop was removed and the applied load was twice the self weight of the slab. Typical variation of the deflection and the load ratio with time for slab test 5 are shown in Figure (3) and 4 respectively.

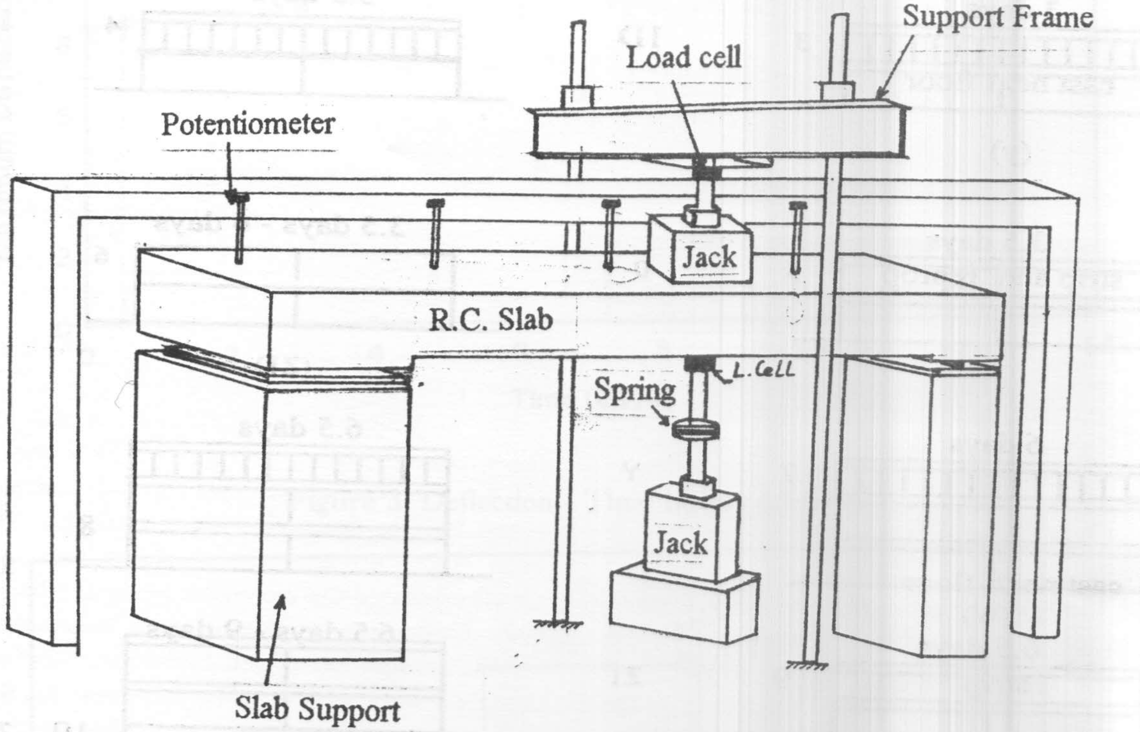


Figure 1. Test slab ready for test.

Table 1. Test programme.

Tests	Strength at 28 days N/mm²	Steel percentage	Prop stiffness (kN/mm)	Age of concrete (days)								
				strip	Reprop	Load 1	Unload 1	Load 2	unprop / unload 2	Load 3	unprop / unload 3	Live load
1	33 ‡	0.4	8	0.5	13 hrs	3	3.25	6	6.25 (+)	9	9.25 (*)	13
2	31	0.4	8	1	1.25	7	-	14	21 (*)	-	28 (+)	35
3	43	0.4	8	3	4	10	-	17	24 (*)	-	31 (+)	38
4	36 ‡	0.8	8	0.5	13 hrs	3	3.25	6	6.25 (*)	9	9.25 (+)	13
5	34 ‡	0.4	14	0.5	13 hrs	3	3.25	6	6.25 (*)	9	9.25 (+)	13
6	60 ‡	0.4	8	0.5	13 hrs	3	3.25	6	6.25 (*)	9	9.25 (+)	13
7	63 ‡	0.8	14	3	4	7	10	14	17 (*)	21	24 (+)	28
8	64 ‡	0.8	14	Backprop at one day		7	8	14	15 (*)	21	22 (+)	25

Table 1- Test programme

\+ Indicates unload
* Indicates unprop.
‡ Mean values of the compressive strength of the cubes cured in water and with the specimens.

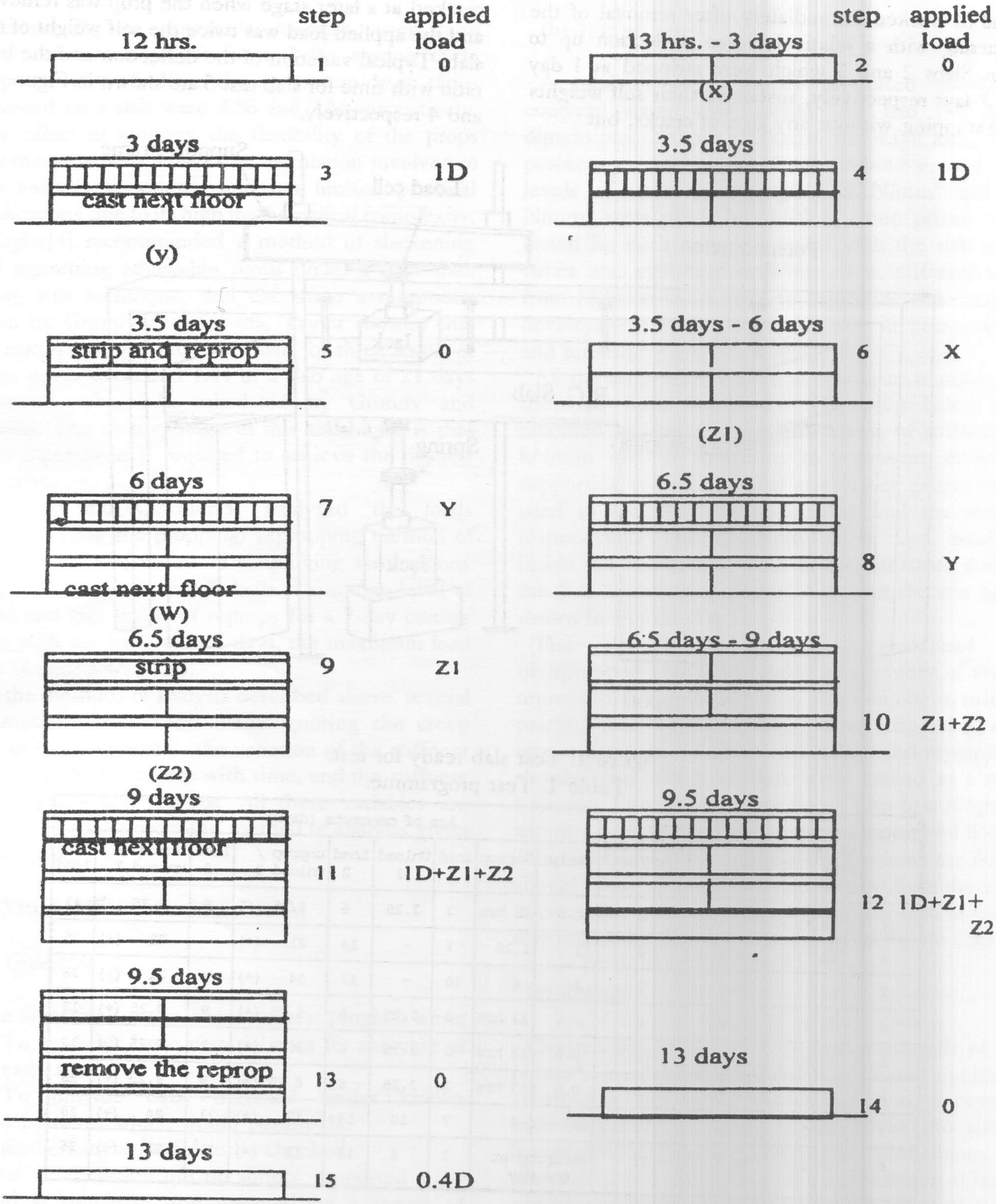


Figure 2. Typical test procedure (slab 4).

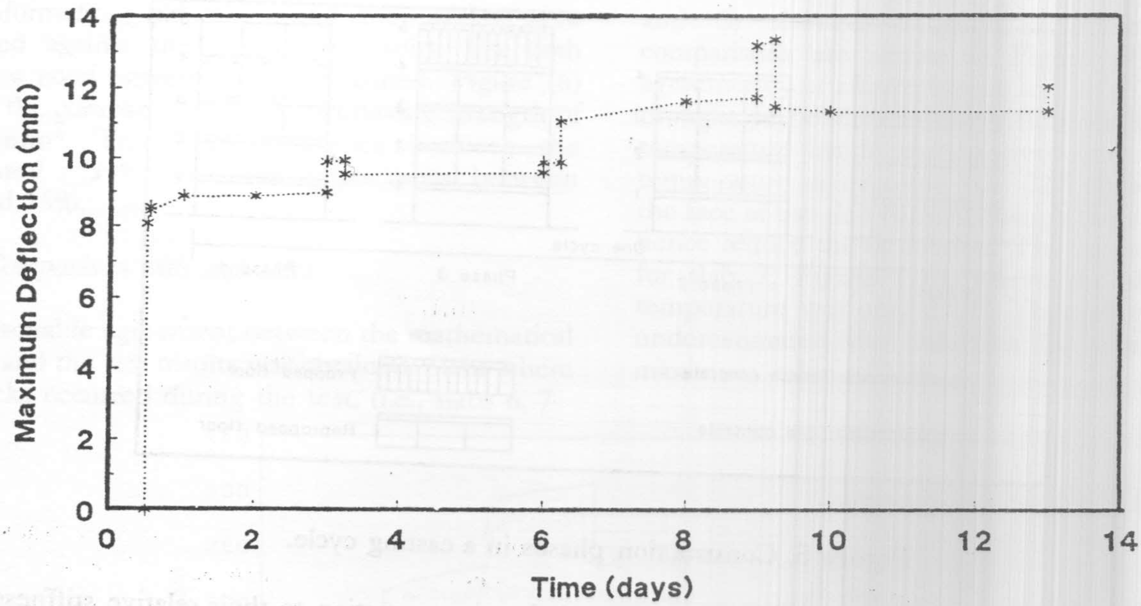


Figure 3. Deflection - Time history (slab 5).

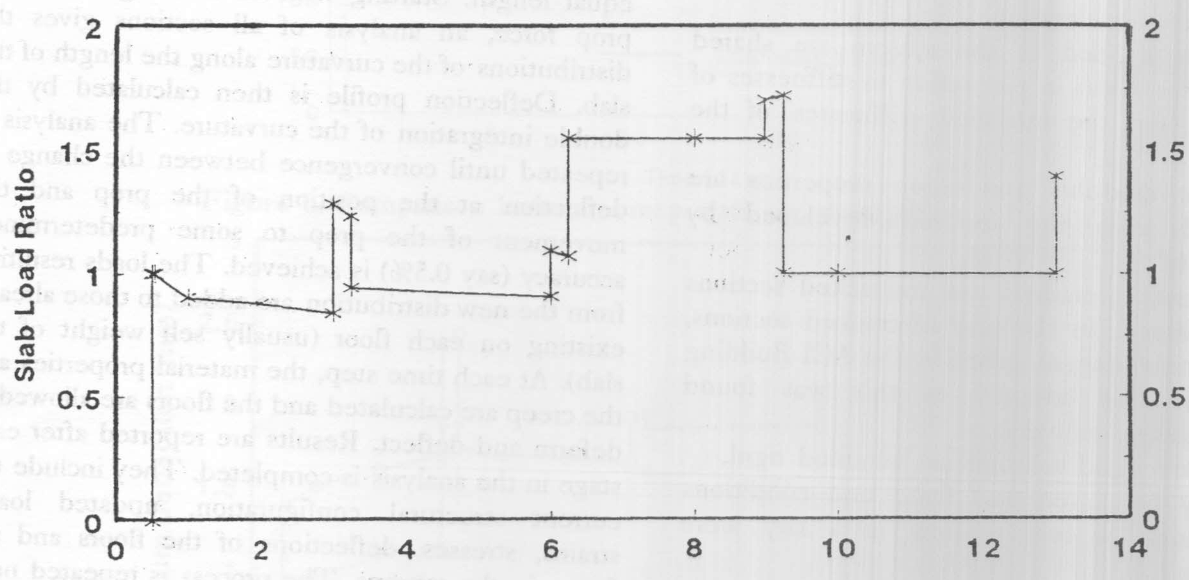


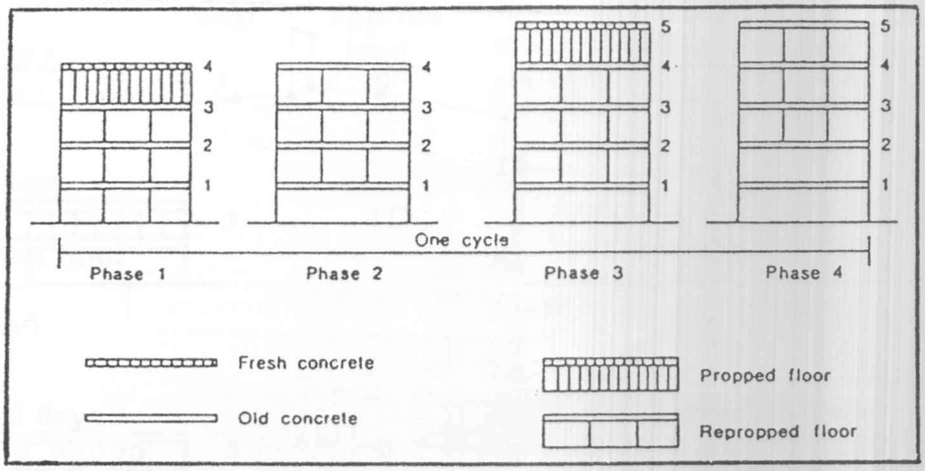
Figure 4. Slab load ratio vs. Time (slab 5).

4- MATHEMATICAL MODEL

(a) *Assumptions*

A typical construction procedure consists of four phases as shown in Figure (5) of repeated sequences was assumed. During these phases the strength of the concrete, the creep proand the forces on props were considered. The following assumptions were considered in the analysis:

- The props are not rigid and allow some deflections to occur due to their elasticity and the deflection of the lower supporting floors.



Sequence of propping.

Figure 5. Construction phases in a casting cycle.

- The stiffness of the reprops at each level was modified where appropriate to take into account the stiffness of the floors and reprops below the level under consideration.
- The loads applied to the system are shared between the floors in proportion to stiffnesses of the slabs and the modified stiffnesses of the reprops.
- he elastic modulus and creep properties are computed from the method developed by Neilsen [6].
- In the analysis, cracked and uncracked sections are considered. In the case of cracked sections, the recommendations given by the ACI Building code [7] were adopted as this was found mathematically convenient.
- Ground level and columns are assumed rigid.

Both simply supported and fixed end conditions with only one or two reprops in a bay were considered.

(b) *Solution procedure*

Essentially, the model builds the structure in the sequence defined by the construction schedule, which describes the phase and the day on which it is executed. Props and reprops are installed or removed, as applicable, according to the schedule, and a new distribution of forces within the structure is computed. The additional loads (from the floors above) are distributed to the interconnecting floors below in proportion to their relative stiffnesses and the modified reprop stiffnesses. This was achieved by dividing each floor slab into several sections at equal length. Starting with an initial guess of the prop force, an analysis of all sections gives the distributions of the curvature along the length of the slab. Deflection profile is then calculated by the double integration of the curvature. The analysis is repeated until convergence between the change of deflection at the position of the prop and the movement of the prop to some predetermined accuracy (say 0.5%) is achieved. The loads resulting from the new distribution are added to those already existing on each floor (usually self weight of the slab). At each time step, the material properties and the creep are calculated and the floors are allowed to deform and deflect. Results are reported after each stage in the analysis is completed. They include the current structural configuration, updated loads, strains, stresses, deflections of the floors and the forces in the reprops. The process is repeated until all the floors are analyzed. This procedure has been programmed in Basic and runs on a PC computer.

5- VERIFICATION OF THE MATHEMATICAL MODEL

(a) *Comparison with creep tests*

The creep method used in the model to calculate the deformations (i.e., elastic and creep strains) were checked against the creep test results. For both mixes a good agreement was obtained. Figure (6) shows the comparison for the mix having strength of 35 N/mm^2. The strain difference between the calculated and the measured values varied between 4% and 15%.

(b) *Comparison with slab tests*

A reasonable agreement between the mathematical model and the test results was obtained. Slabs where no cracks occurred during the test, (i.e., slabs 6, 7 and 8) showed a good agreement. Typical comparisons are shown in Figure (7). The poor agreement just after stripping in slab 6 (Figure 7a) is thought to be due to the difference between the temperature inside the concrete and the ambient temperature at stripping (i.e. 22 °C) which caused the face of the slab to cool, change the curvature and hence reduce the deflection. The agreement is best for slab 7, Figure (7b), where the difference in temperature was only 2 °C. Thereafter, the model underestimated the defection by approximately a maximum value of 15%.

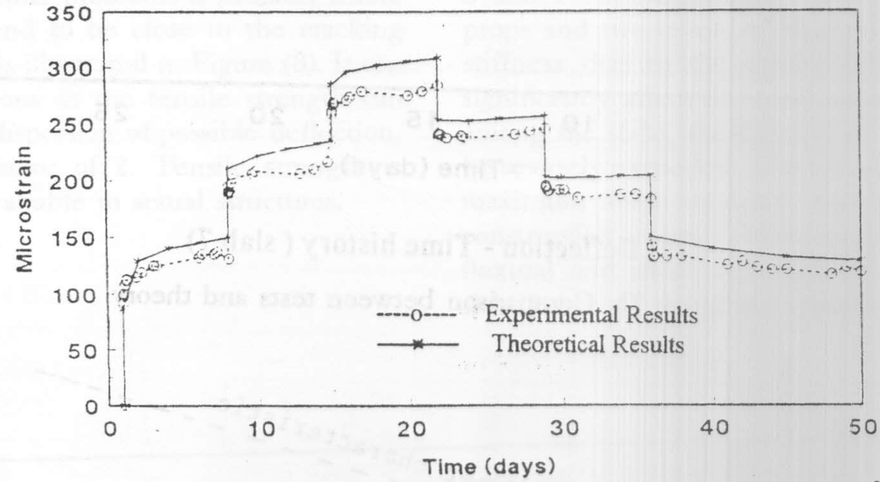
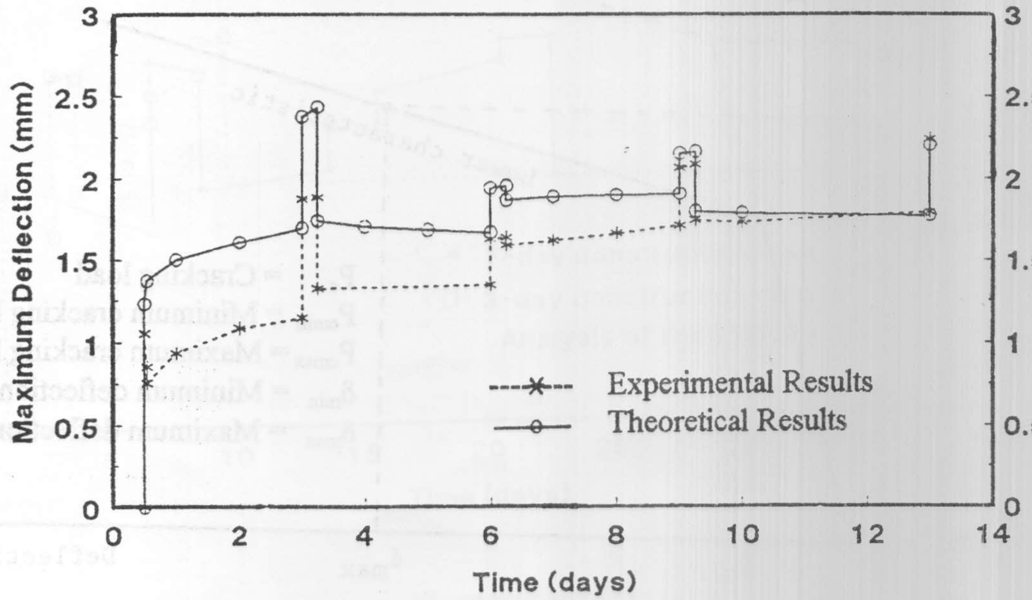
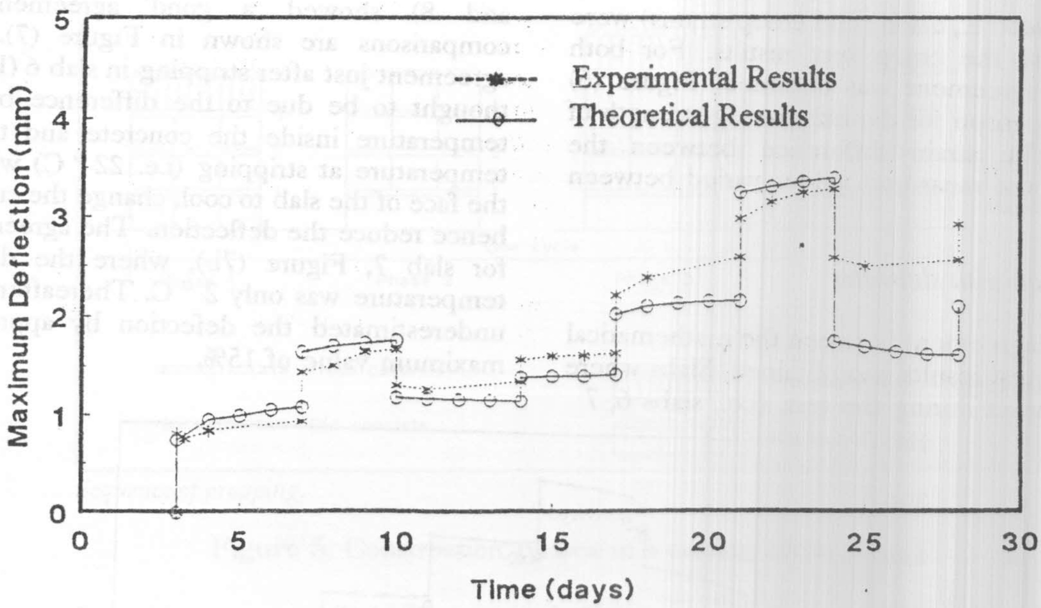


Figure 6. Comparison between creep tests and theory (f_{cu}=35 N/mm^2).



(a) Deflection - Time history (slab 6)

Figure 7a. Deflection-Time history (slab 6).



(b) Deflection - Time history (slab 7)

Figure 7b. Comparison between tests and theory.

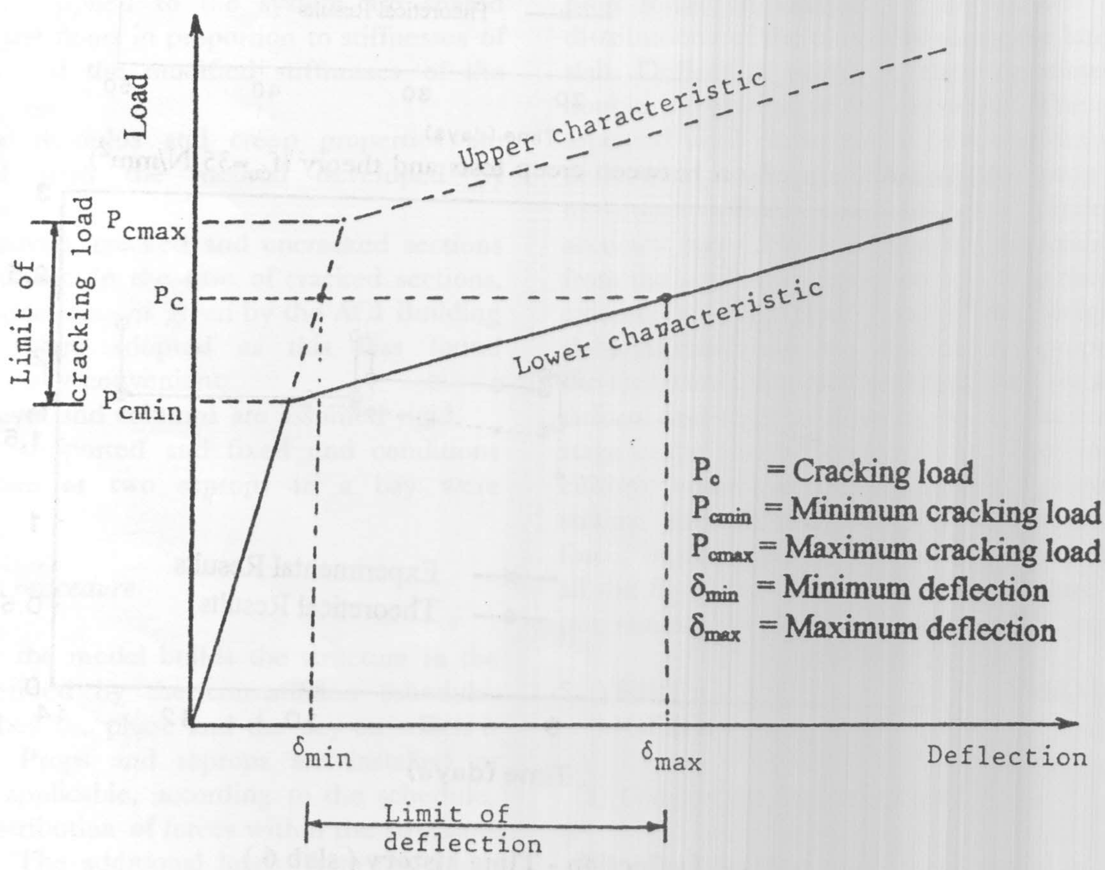


Figure 8. Variation of deflection in a cracked section.

In slabs where cracks occurred, wider dispersion between the calculated and measured values of the deflections were obtained (20%). This may be attributed to the fact that there are many sources of uncertainty that affect the calculation of the deflections of a cracked member particularly:

- Tensile strength of concrete.
- Behavior of cracked section zone.

Some other factors have been considered in the analysis, such as level of loading, elastic modulus, creep, age at loading etc. Many of these factors can have very large effects on the resulting deflection. An area giving particular problems is in slabs, where the service loads tend to be close to the cracking load. This situation is illustrated in Figure (8). It can be seen that variations in the tensile strength can lead to a very wide dispersion of possible deflection, probably up to a factor of 2. Tensile strength is likely to be highly variable in actual structures.

6- PARAMETRIC STUDY

A parametric study was carried out to determine the influence of different factors on the construction load distribution. The parameters studied were slab and reprop stiffnesses, number of repropped floor levels and their positions in the structure.

(a) *Influence of slab stiffness*

Figure (9) shows the maximum slab load distributions with respect to the slab age in days for 3 and 7 day construction rates, with one level of props and two levels of reprops. Although the slab stiffness due to the ageing of concrete does not significantly affect the construction load distribution among the slabs, the flexural or shear capacity may be severely exceeded. The age of the slab where the maximum load occurred was different for both construction cases. Therefore, depending on the flexural and shear capacities of the concrete floor slab, 3-day or 7-day construction rate can be adopted.

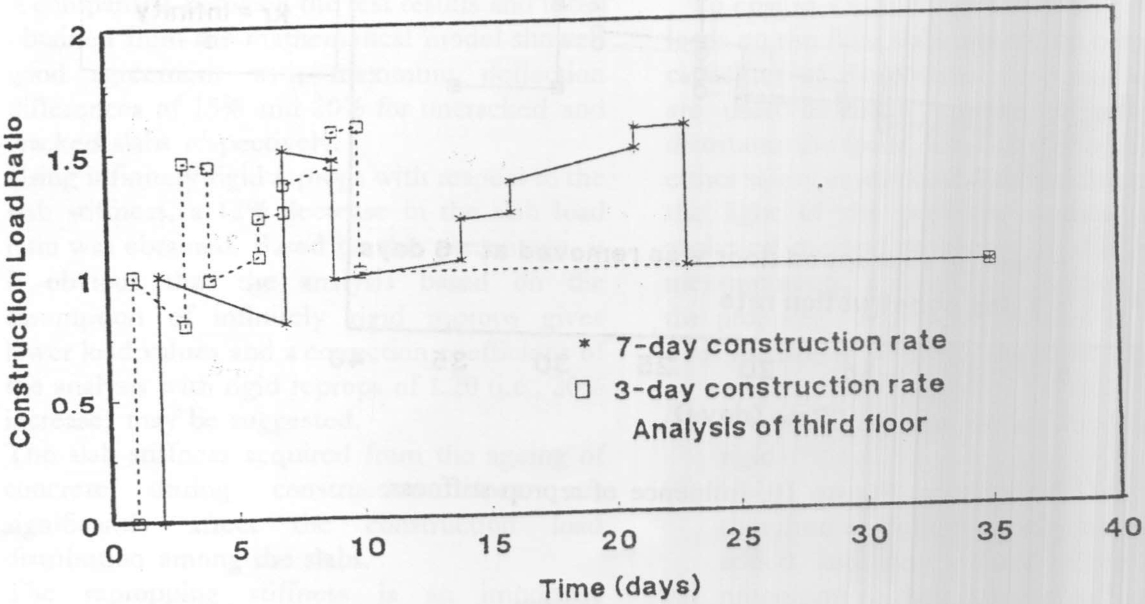


Figure 9. Influence of construction rate (1 prop & 3 reprops).

(b) *Influence of reprop stiffness*

To determine the influence of the reprop stiffness on the load distribution, the reprop stiffness was increased from 20 kN/mm to 100 kN/mm. The slab stiffness and the number of repropped floor levels were kept constant in a 7-day construction cycle with one propped floor and three repropped floors. The results are shown in Figure (10) that indicated that the reprop stiffness has a significant effect on the construction load distributions. Slabs with reprop stiffness of 20 kN/mm seem to undertake a significant part of the applied load. As the reprop stiffness increases relative to the slab stiffness, the slabs are relieved and most of the load is transferred to the ground through the repropping system. The predicted slab load ratio using infinitely rigid reprops was compared with 1.51 using reprop stiffness of 20 kN/mm.

(c) *Influence of the number of repropped floor levels*

Figure (11) shows the relationship between the number of repropped floor levels and the maximum slab load ratio. The later decreased at a decreasing rate as the number of repropped floor levels increased up to a certain limit. For this particular construction of propping/repropping system with one propped floor, the reprops are effective up to three levels. Beyond this limit, additional repropped levels do not appear to significantly affect the maximum slab construction load. This may be attributed to the fact that when compressible reprops are used, any applied construction load is distributed among the interconnected slabs in proportion to the stiffnesses of the slabs and the equivalent stiffnesses of the reprops with the uppermost floor slabs taking most of the applied load.

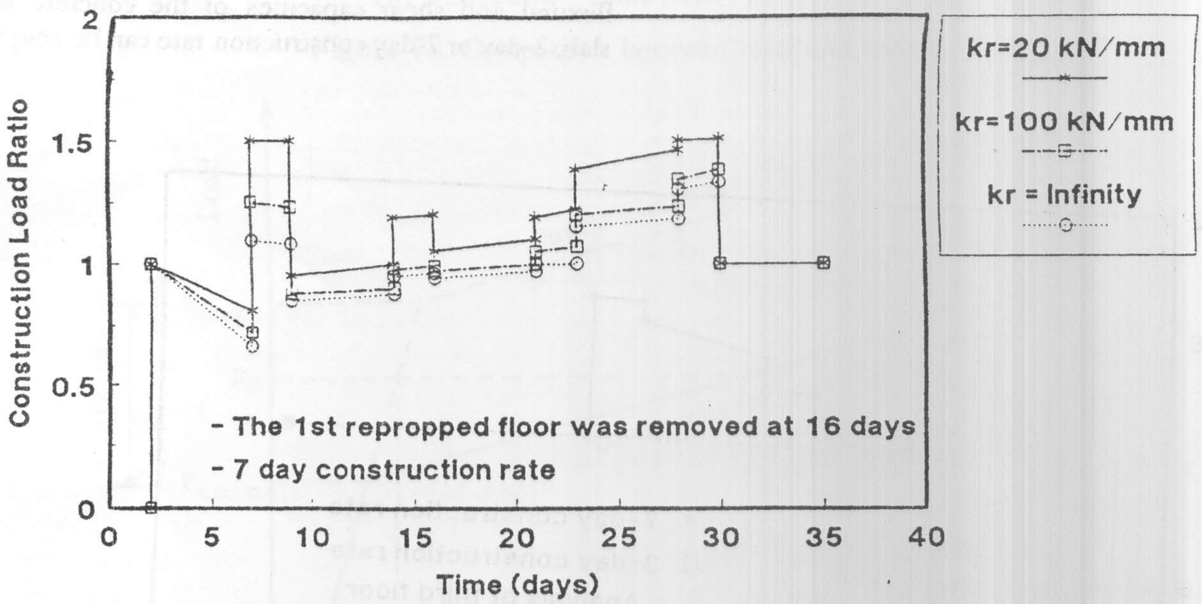


Figure 10. Influence of reprop stiffness.

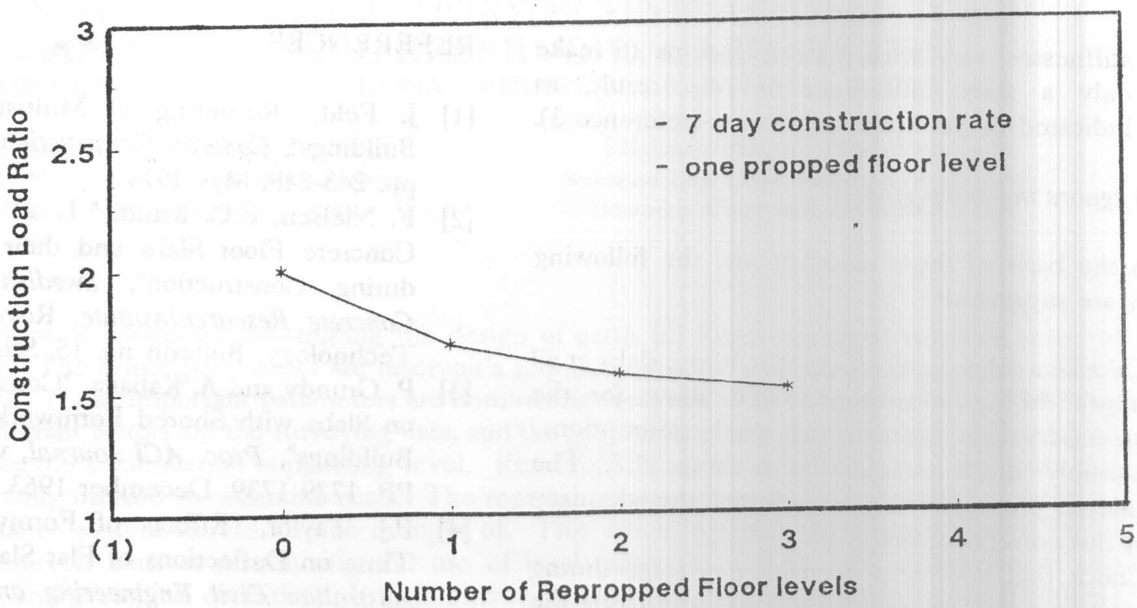


Figure 11. Influence of the number of repropped floor levels.

7- CONCLUSIONS

The conclusions and observations of this study can be summarized as follow:

(a) A comparison between the test results and those obtained from the mathematical model showed good agreement with maximum deflection differences of 15% and 20% for uncracked and cracked slabs respectively.

(b) Using infinitely rigid reprops with respect to the slab stiffness, a 12% decrease in the slab load ratio was obtained. Based on this percentage, it is obvious that the analysis based on the assumption of infinitely rigid reprops gives lower load values and a correction coefficient of the analysis with rigid reprops of 1.20 (i.e., 20% increase) may be suggested.

(c) The slab stiffness acquired from the ageing of concrete during construction does not significantly affect the construction load distribution among the slabs.

(d) The repropping stiffness is an important parameter in the calculation of the construction load distribution. As the reprop stiffness increases, the construction load ratio decreases.

(e) The maximum slab load ratio decreases as the number of repropped floor levels increases up to a certain limit. Beyond this limit, additional repropped floor levels do not significantly affect the construction slab load.

8- RECOMMENDATIONS

To ensure a safe construction scheme, the applied loads on the floor slabs should be compared with the capacities of these slabs. Propping and repropping are used to make up the difference and helps distribute the loads. 'Capacity' may be controlled by either safety or serviceability conditions. However, in the light of the previous studies, the suggested analytical method developed in this project and test measurements, a simplified method of analysis for the propping / repropping system is recommended. This method is based on the following assumptions:

(a) Props and reprops are assumed to be infinitely rigid.

(b) Slabs are interconnected by reprops, and therefore all deflect equally when a new load is added, and carry a share of the added load in proportion to their relative stiffnesses.

(c) As a further simplification, slabs are assumed to have equal stiffnesses and so added loads are shared equally by the interconnected slabs. This is not precisely true, but whether we assume this or the more accurate case that the stiffnesses vary with maturity seems to make stiffnesses vary with maturity seems to make only a small difference in the result, as indicated in the literature review (reference 3).

(d) *Ignore the creep effect.*

On the basis of these assumptions, the following steps are suggested:

- Calculate the maximum stresses in the slabs at all stages during construction. To allow for the unconservative nature of the assumptions, multiply these stresses by a factor 1.2. The analysis presented earlier indicated the adequacy of this correction factor.
- Check that no cracks occur at any stage during construction. This can be done by comparing the calculated flexural tensile stresses with the flexural tensile stresses of the concrete.
- As the bond and shear failure conceivably occur before flexural load distribution could take place, the structure should be checked and designed for maximum loads derived by elastic considerations.

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