Shoring and Reshoring Of High-Rise Buildings

by X. L. Liu, H. M. Lee, and W. F. Chen

A simplified method developed by Grundy and Kabaila for determining loads and deflections during construction is introduced. The relationship between the loads imposed on the supporting system and the basic parameters including the number of shored floors, the number of reshored floors, the time parameters, and the concrete types is analyzed. Simple rules for an optimal choice of shoring and reshoring are proposed.

With the current trend of rapid construction of high-rise reinforced concrete buildings, it is a common practice to use shores and reshores to support a freshly-placed concrete slab on several previously cast slabs. Documented investigations and recent analytical studies have shown that construction loads on a supporting system that includes slabs, shores, and reshores may appreciably exceed its load carrying capacity and contribute to a significant portion of the failures of reinforced concrete buildings during construction. This is troublesome when the construction live load is small compared to the dead load. The premature removal of shores and reshores during construction is another major cause of failures.

To avoid these unexpected failures, a check is necessary to insure that the construction loads imposed on slabs are less than their available strength at all stages of construction. During the construction process of a concrete building, many parameters vary with time, such as the geometry of structures, concrete stiffnesses, and the creep of materials. Therefore, it is difficult and complicated to determine the load and deformation values accurately in the structure at every stage of construction. In 1963, Grundy and Kabaila developed a simplified method of determining the construction loads on the supporting system.[3] This method has recently been proven sufficiently accurate for practical use, and it is straightforward and easy to apply in practice.

Economically, it is obvious that the number of floors for shoring and reshoring be kept as small as possible when the safety requirements are met. But before making the optimal choice of the two numbers it is necessary to understand the effects of shoring and reshoring on the loads imposed on shores, reshores and slabs. An analysis is made of the relationship between the loads imposed on the supporting system and the basic parameters, including the number of shored floors, the number of reshored floors, the time parameters, and the concrete types. Against the background of this information, simple rules for an optimal choice of shoring and reshoring are proposed with only static vertical load being considered.

The simplified method

The simplified method of load analysis developed by Grundy and Kabaila is based on three assumptions:

- Relative to the bending stiffness of slabs, the axial stiffness of shores and reshores is assumed to be infinite. Therefore, when a new construction load is applied, all slabs interconnected with shores and reshores gain the same amount of deflection.
- The lowest level of shores or reshores is assumed to be supported on a completely rigid foundation.
- Despite the variety of ages during construction, all slabs are assumed to possess an equal flexural stiffness.

According to this method, a computer program was developed recently.[7] The loads imposed on shores, reshores, and slabs at every stage of construction can be easily obtained by using this program. It can also be used to check whether the slab loads are greater than the available strength during construction. The flow charts of the program are shown in Fig. 1 and 2.

Parametric studies

For the multistory flat plate concrete buildings, it is assumed that the slab weight is $1.0D$, and the weight of all shores or reshores is about $0.1D$. For the construction live load, ACI standard 347-78 recommends 50 lb/ft^2 (250 kg/m^2) as the minimum value. For a typical slab, the construction live load can be equivalently assumed to be $0.5D$.

To show the effects of the number of shored floors and reshored floors on the load distribution of the supporting system, it was assumed that M changes from 1 to 3 and N from 0 to 5, where M represents the number of floors with shores and N represents the number of floors with reshores. In each case, a computer program[7] is used to calculate the loads on shores, reshores, and slabs.

The shore loads

From the calculated results, it is found that the maximum shore load always occurs at the level of shores erected on the rigid foundation when a new slab is placed (Fig. 3). The maximum shore load can be determined by the simple relation:

$$\text{Max.}PS = FC \times D + (1.0 + FA)D \times M \quad (1)$$

where PS represents the shore load; FC represents the construction live load (in terms of D); and FA repre-

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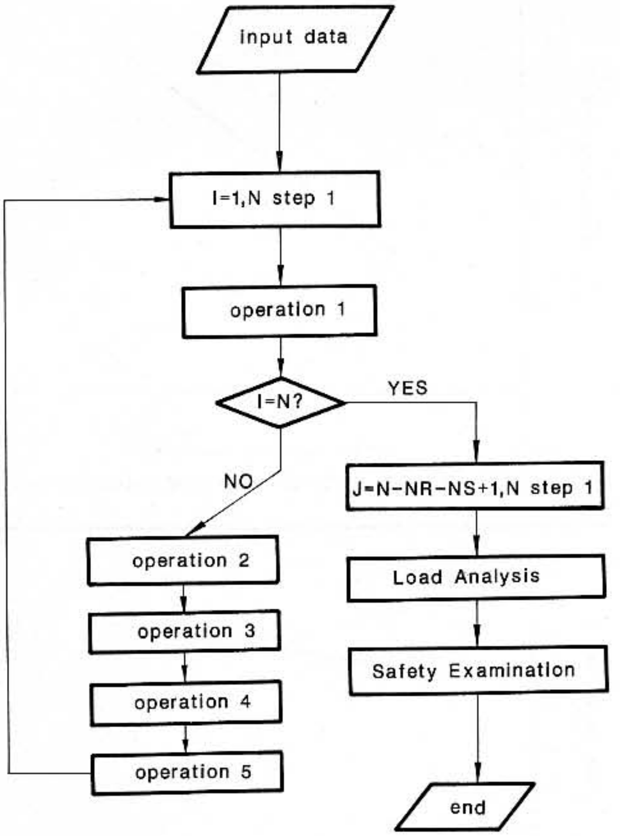

Fig. 1 — The overall flow chart for the five construction operations.

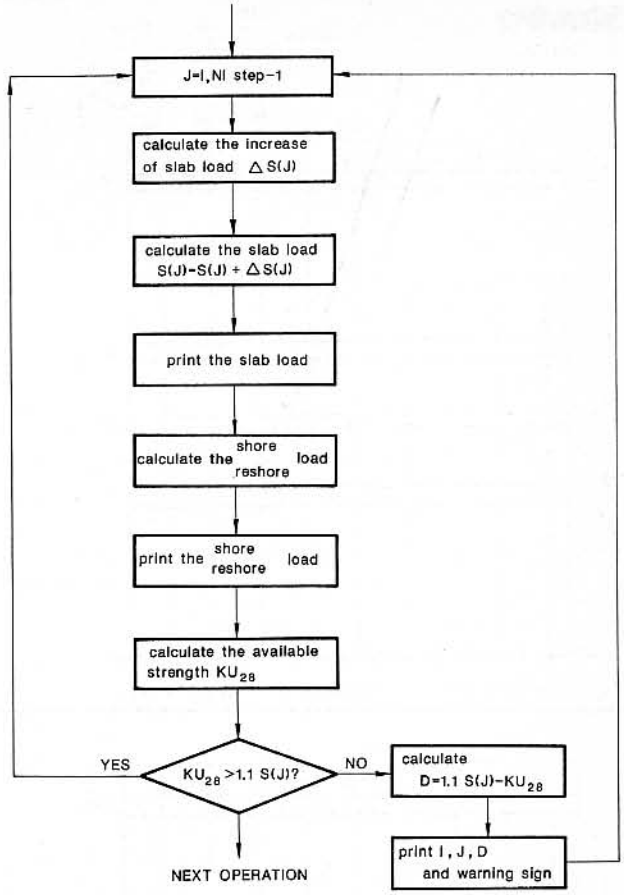

Fig. 2 — The flow chart of each operation in the five-operation construction process.

sents the self-weight of all shores on one floor (in terms of D).

When $FC = 0.5$, and $FA = 0.1$, Eq. (1) reduces to:

$$\text{Max.}PS = (0.5 + 1.1M)D \quad (2)$$

where $M \geqslant 1$.

Eq. (2) is illustrated in Fig. 4, where it can be seen that the maximum shore load increases linearly and significantly with an increase of M, the number of shored floors.

The reshore loads

The maximum reshore load also occurs at the level of reshores supported on the rigid foundation when a new concrete slab is placed (Fig. 5). The maximum reshore load can be expressed by the simple relation

$$\text{Max.}PR = (FC + FA + 1.0)D + FB \times N \times D \quad (3)$$

where PR represents the reshore load and FB represents the self-weight of all reshores on one floor (in terms of D).

When $FC = 0.5$, $FA = 0.1$ and $FB = 0.1$, Eq. (3) reduces to

$$\text{Max.}PR = (1.6 + 0.1 \times N)D \quad (4)$$

where $N \geqslant 1$.

This relation is shown in Fig. 6, which shows that the maximum reshore load increases only slightly with an increase of N (the number of reshored floors), because FB is very small compared to the slab weight D.

The slab loads

To show the effects of M and N on the load distribution of a supporting system, Table 1 lists the calculated results with several combinations of M and N. Using Table 1, the corresponding shore loads and reshore loads can be found from Eq. 1 and 3, respectively. The maximum slab loads tabulated in Table 1 are generally greater than those loads listed in reference 1, because the present method considers additional factors that influence the load distribution of a slab-shore system, and is therefore more reliable in its predictions.

The effect of reshores

Referring to Table 1 and Fig. 7, it can be shown that the more floors of reshores that are installed, the less the maximum slab load. The more heavily loaded slab in each stage of construction is the slab at the lowest level of the inter-connected slabs when a new load is added.[4,5,6] Therefore, when more floors of reshores are used, more previously cast slabs will be connected to support the freshly-placed concrete. This is why the maximum slab load decreases with an increase of the number of reshored floors N.

In any case, the method of increasing N can be used to decrease the slab load and thus make the construction process safer.

The effect of shores

Referring to Table 1 and Fig. 8, it can be seen that the higher M is, the

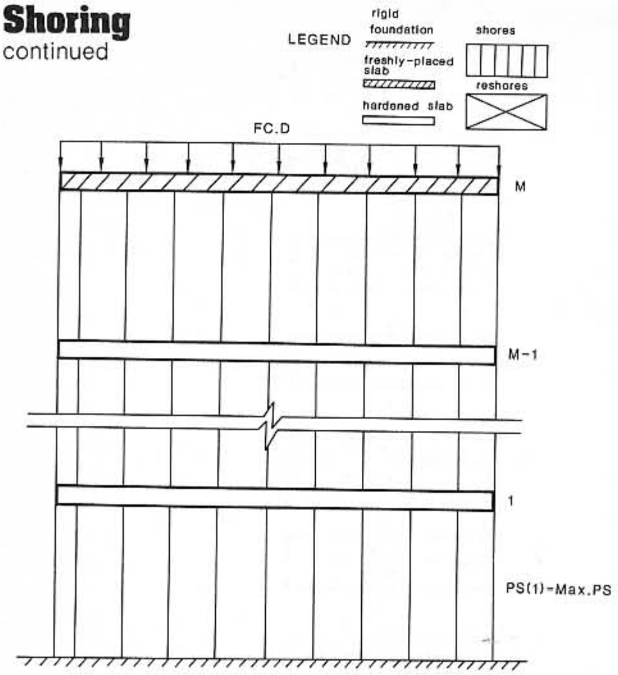

Fig. 3 — The location of maximum shore load.

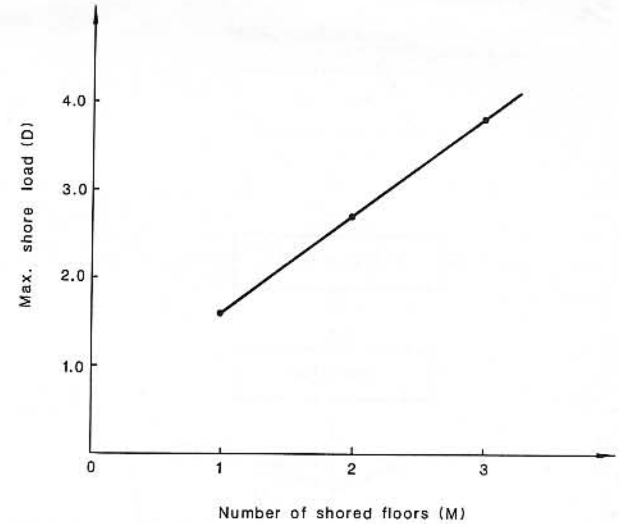

Fig. 4 — The relationship between M and maximum shore load.

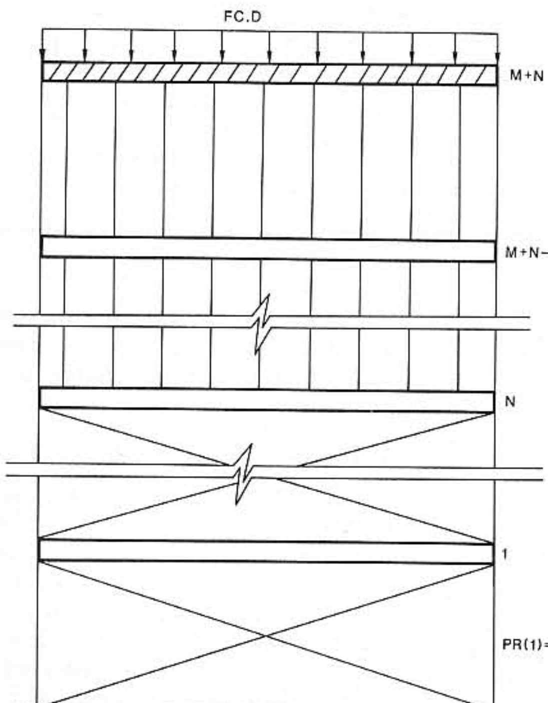

Fig. 5 — The location of maximum reshore load.

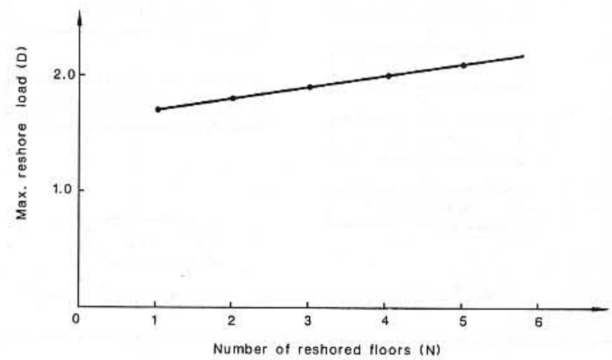

Fig. 6 — The relationship between maximum reshore load and N.

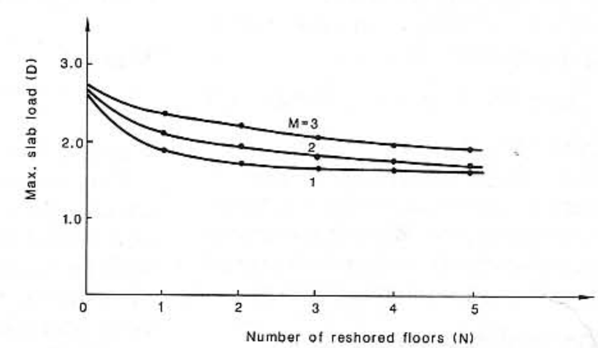

Fig. 7 — The relationship between maximum slab load and N.

higher the maximum slab load is.

The load history curves of slabs on which the maximum loads are carried are illustrated in Fig. 9. From these curves, it can be concluded that when more floors of shores are used, the peak load occurs later.

It is known that after a concrete slab is cast, its strength and stiffness grow with time (Fig. 10). Thus, increasing the number of shored floors, *M*, is helpful for the safety of slabs during construction.

Increasing *M* brings the advantage of benefiting from the strength growth, but also the disadvantages of increasing the maximum slab load and the maximum shore load. What is the trade off here? How can one make the best choice for *M*?

The construction cost

In concrete construction, the formwork, shores, and reshores are the major part of the construction cost. Therefore, the number of shored and reshored floors, *M* and *N*, should be kept as small as possible. When the construction live load and the self-weight of shores and reshores are given, the minimum values of *M* and *N* depend mainly

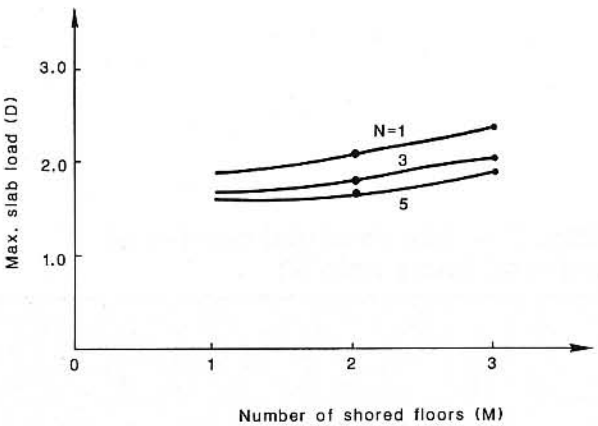

Fig. 8 — The relationship between maximum slab load and M.

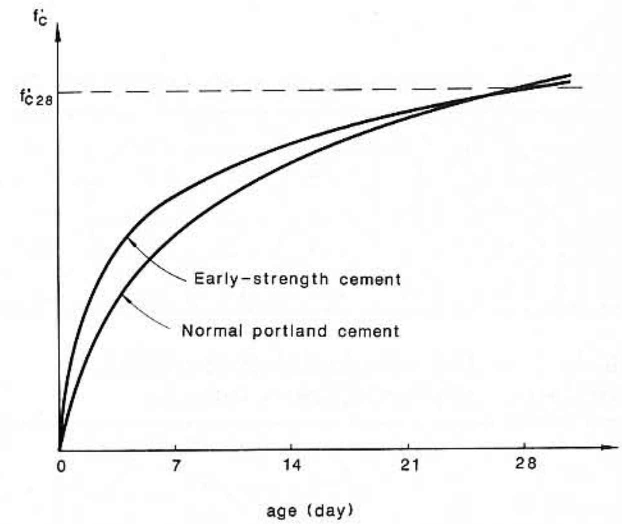

Fig. 10 — Development of concrete strength with age.

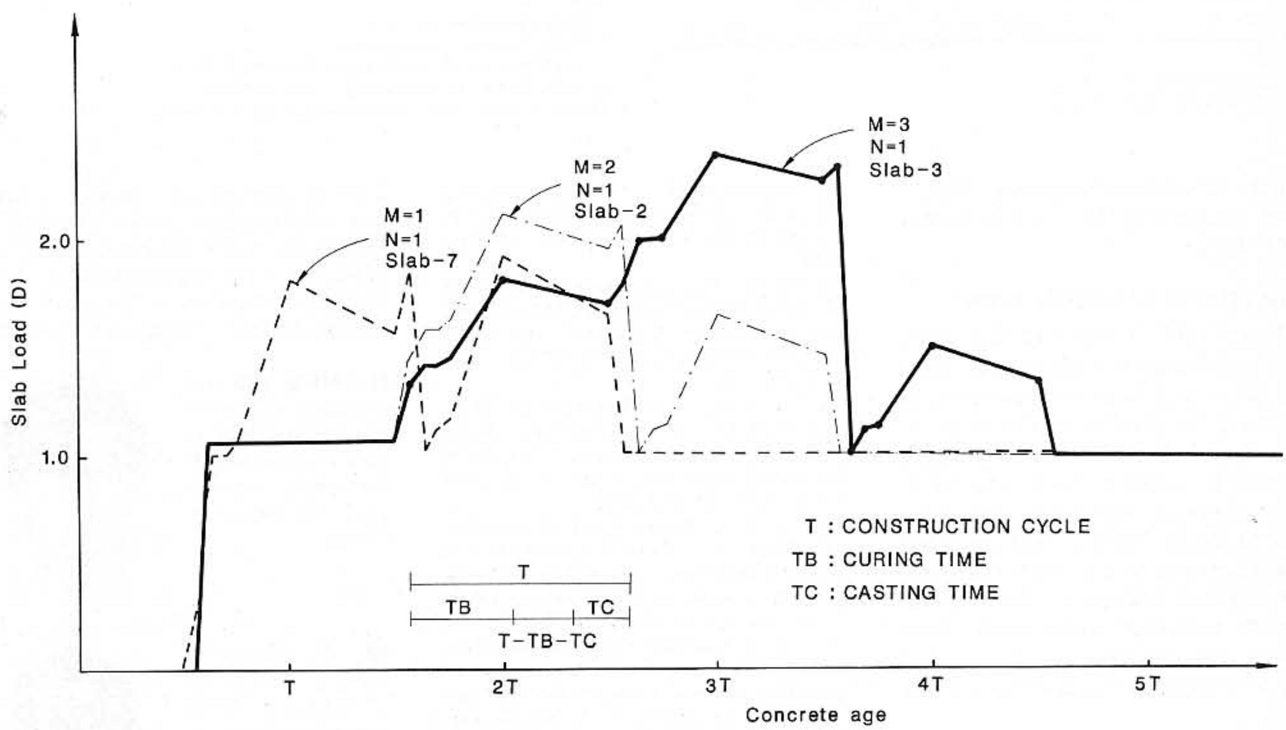

Fig. 9 — The relationship between slab load and concrete age.

on the time parameters and the type of cement used.

The effects of time parameters

Time parameters include the following: the construction cycle, *T*; the casting time of a slab, *TC*; and the curing time, *TB*. By varying the time of *T, TC,* and *TB,* and changing the number of shored floors, *M,* from 1 to 3, we can determine the essential number of reshored floors (min. *N*) by using the above mentioned computer program. The program has to be subjected to the condition that the safety of all slabs is assured (Table 2). Also, normal portland cement is used. From Table 2, the following conclusions can be made:

- When the construction cycle, *T,* and curing time, *TB,* become shorter, the value of min. *N* increases.
- Despite the variety of time parameters, it is always preferable to use one floor of shores during construction. The corresponding number of reshores, *N,* can be determined by using a computer program.[7]
- It appears that increasing the number of floors of shores, M,

Table 1 — The maximum slab load (Unit *D*)

M	*N* = 0	1	2	3	4	5
1	2.60	1.90	1.73	1.69	1.66	1.64
2	2.65	2.11	1.98	1.81	1.77	1.69
3	2.72	2.39	2.22	2.06	1.99	1.91

Table 3 — The recalculated essential number of reshored floors (min.*N*)

M	*T*	3.5		
	TC	0.25	0.5	1.0
	TB	2.75	2.5	2.0
1		3	3	3
2		> 5	> 5	> 5
3		> 5	> 5	> 5

Notes:
1. Curing temperature = 22.8 C
2. Early-strength cement is used.

Table 2 — The essential number of reshored floors (min.*N*)

M	*T*	3.5			7.0				14.0	
	TC	0.25	0.5	1.0	0.5	1.0	2.0	3.0	1.0	2.0
	TB	2.75	2.5	2.0	5.5	5.0	4.0	3.0	11.0	10.0
1		> 5	> 5	> 5	2	2	2	2	1	1
2		> 5	> 5	> 5	3	3	3	4	2	2
3		> 5	> 5	> 5	4	4	4	4	4	4

Notes:
1. Curing temperature = 22.8 C.
2. Normal portland cement is used.
3. *T* indicates the construction cycle (in terms of day).
TC indicates the time for casting a slab (unit day).
TB indicates the time for the concrete curing (unit day).

brings more disadvantages. Therefore, increasing *M* is not a favorable choice.

The effects of cement type

From Table 2, it is seen that when the construction cycle is too short (⩽ 3.5 days), it is uneconomical to increase the number of floors of reshores, *N*. Instead, early-strength cement is recommended. The recalculated results, under the same conditions as in Table 2, indicate that when the type of cement is changed, the essential number of floors of reshores decreases appreciably. As a result, the construction economics are improved as illustrated in Table 3.

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