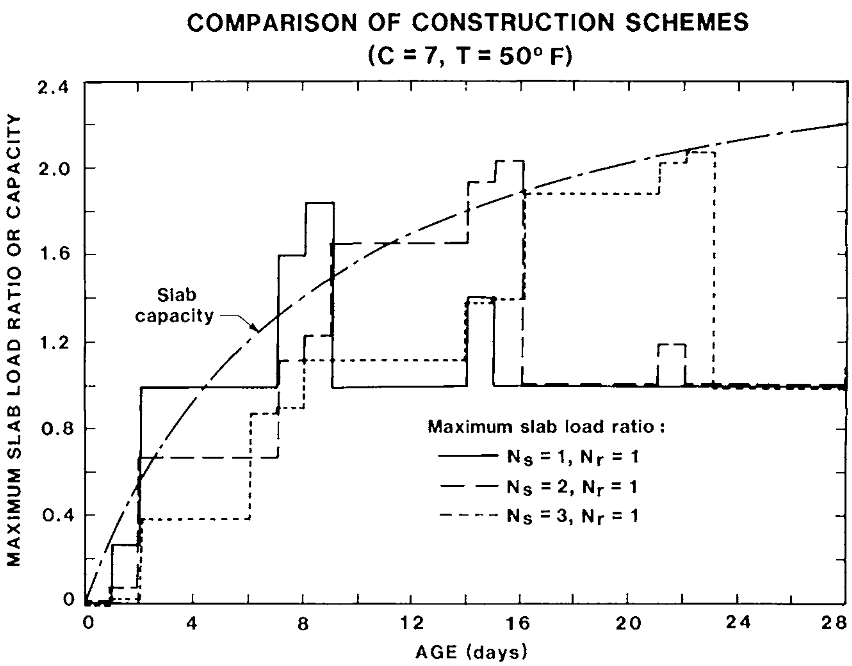

Fig. 8--Comparison of construction schemes (N_s and N_r)

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SP-90-10

Reshoring a Multistory Concrete Frame — a Practical Approach

by W. Thomas Scott

Synopsis: As the speed of construction of concrete frame structures has increased and the sophistication of design has improved, there has been an increased need for a more thorough understanding as to the way construction loads are disbursed into the structure. During the 60's and 70's, several designers and researchers proposed methods of analyzing the loads in multistory structures during construction. A computer program employing one of these methods has been developed. In the 1982 PCA conference the author used the results of this program to show how the number of levels of equipment, cycle time, and attained concrete strength affected the number of levels of reshores required.

This paper describes in detail the process used to calculate the reshoring requirements for a 35 story flat plate structure built using a three day construction cycle. The discussion includes the practical implications of providing reshoring for a mild steel structure. The hand calculation procedure presented parallels the computer program and is sufficiently detailed to provide the reader a practical procedure that can be used on the next project.

Keywords: columns (supports); computer programs; concrete construction; concrete slabs; flat concrete plates; framing systems; high-rise buildings; loads (forces); reinforced concrete; shoring; structural analysis

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Introduction

When building a monolithic reinforced concrete frame it is common for the weight of the newly placed concrete plus the weight of the formwork plus the construction live load, which is normally taken as 50 lbs. per sq. ft., to far exceed the capacity of the floor slab on which the forming system is resting. Through the years, there have been a number of different procedures developed by constructors to analyze the distribution of this load to the floors below. In 1963, Grundy and Kabaila (1) suggested that certain procedures might induce loads as high as 2.3 times as great as the construction load on certain slabs. Agarwal and Gardner (2) through experimentation, have shown that the Grundy and Kabaila findings are correct. Taylor (3) shows that by judiciously releasing the shores between poured floors the magnitude of the load carried by the most highly stressed floors can be reduced.

At the 1982 PCA International Forming Conference the author (4) introduced the terms "Reshoring" and "Backshoring" to distinguish between prevailing concepts of load distribution at the time of stripping a recently poured concrete floor slab. The author demonstrated a preference for the use of the reshoring concept and showed how the number of levels of equipment, cycle time, and attained concrete strength affected the number of levels of reshores required. The definitions of the terms "Reshoring" and "Back-shoring" will be presented later.

Purpose

This paper describes, in detail, the process used to calculate the reshoring required for a 35 story hotel structure in Miami, Florida. Though a

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computer program was used to analyze the reshoring requirements, this paper represents a detailed hand calculation procedure which parallels the computer program. A sample data form (Fig. F) is enclosed which the reader may use to analyze a structure.

Assumptions

The procedure is based on the following assumptions. (Fig. 1)

1. Hooke's law is valid. Stress is proportional to strain. A floor slab not allowed to deflect cannot transmit any load to the structure.

2. Shores, backshores, and reshores are infinitely rigid when compared with the amount of deflection required to allow a significant amount of the load to be transferred to the floor. A 12' high 4 x 4 shore, for instance, with a load of 5,000 lbs. will have a longitudinal shortening of 3/100 of an inch. A heavy duty steel scaffold unit of the same height and load conditions would only shorten 2/100 of an inch.

3. The load carrying capacity of the concrete floor system is proportional to the percentage cure of the concrete based on compressive tests.

4. The stiffness of a floor is proportional to the percentage cure of the concrete based on compressive tests.

As a result of these assumptions, the following observations can be made: (Fig 2)

1. As long as the structure is shored or backshored to the ground, no load can be carried by the floors.

2. Floors that are connected together by shores, reshores, or backshores will, when loaded, deflect equally.

3. Since the floors deflect equally, the portion of the distributed load carried by each floor is proportional to the ratio of the stiffness of that particular floor to the total stiffness of the floors that deflect together.

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As a point of review, it is desirable to define the terms "Backshoring" and "Reshoring". Backshoring is installed in a fashion which effectively replaces the centering shores without disturbing the slab. The load in the backshore is the same as it was in the centering. The system acts as though the centering had not been removed (Figure 3). Reshoring is installed after the centering has been removed and the slab has been allowed to assume a natural deflected shape. At the time of installation reshores carried no significant load (Figure 4). Since the writer's preference for reshoring has been previously established, this paper will deal only with the reshoring concept.

Description of Structure

The structure to be analyzed is a 35 story, 6½" flat plate with a perimeter upturned spandrel beam. Due to the building shape, shown in Figure 5, the floors were divided into 3 pours. Aluminum truss flying forms were selected as an effective system for maintaining the desired 3 day construction cycle. Due to construction problems the 3 day cycle was met only for the 9th through the 30th floors. The trusses were spaced 6' center to center (Figure 6) and had legs at 5' centers along the truss (Figure 7). This system of forming essentially provided concentrated live loads at approximately the third point of spans and at column lines rather than approximately uniform loads experienced in most non-flying form systems.

Effects of Concentrated Loads

The concentrated live loads (Figure 8) are being applied to slabs which have already been allowed to deflect under their uniform dead load. Therefore, the slabs are subjected to both a uniform and a concentrated load. An exact solution would require a detailed structural analysis of the concrete slab for the anticipated concentrated loads. An approximate solution may be obtained by finding the maximum moments developed by the concentrated loads and then determining what amount of uniform slab load would induce the same maximum moments. Combining this uniform load with the actual uniform load produces an equivalent uniform load which may be compared to the developed carrying capacity of the slab at any given stage of the construction cycle to give an approximation of the safety of the cycle being investigated. When applying this

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solution to a two-way slab, remember that it is assumed that the slab carries the entire load in each direction. In Fig. 9, assume a load in area A. A portion of this load is carried in the north-south direction and a portion in the east-west direction. However, the portion carried in the east-west direction must be picked up by another north-south strip to reach the columns. Therefore, 100 percent of the load must be carried by north-south strips. Likewise, 100 percent of the load is also carried by east-west strips. In design, procedures have been established which establish the percent of the total load to be carried by strips in the center of the slab and strips which are close to the columns. Examples of the relationships that exist between moments produced by uniform and concentrated loads for various support, restraint conditions and locations of concentrated loads, as shown in Figure 10, may be found in many handbooks.(5)

In the example being considered, the load is being applied as two concentrated live loads at third points of a span assumed to be fixed at either end. This produces moments which would be produced by a uniformly applied load of total magnitude equal to 4/3 times the total magnitude of the concentrated loads. While this procedure is not exact, it does provide an acceptable solution when used with proper judgement.

Hand Calculation Procedure

The hand calculation procedure is shown in Figures A, B, C, D & E. Before reviewing the numerical input a brief explanation of the form is in order.

Column #1 is the floor number of the building.

Column #2 shows the construction load that is present on that particular floor. Normally, the construction load value for the upper most floor being considered will include the dead weight of the concrete plus some allowance for the formwork plus some allowance for construction live load. The construction live load value is normally taken at 50 lbs. per sq. ft. per ACI 347 recommendations and the form weight value is frequently conveniently taken at 10 lbs. per sq. ft. The weight of the reshores is usually neglected and therefore the floors below the floor being poured generally have construction loads consisting of only their concrete weight. Space for calculating

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the construction load is provided at the edge of the form.

Column #3 is an accumulation of construction load values appearing in column #2 and will be used to determine the shore load.

Column #4 is a graphic representation of what the structure looks like at this time. It is suggested that the user use a series of closely spaced vertical parallel lines to represent shoring between two slabs and one or two vertical parallel lines between two slabs to represent the reshores. When the entire system is being supported by shores or reshores which are resting on grade, a series of diagonal lines may be used to indicate that a slab is at grade. The number of levels of reshores and the percent cure are the variables in the solution and are determined primarily by trial and error. The number of floors required to support the construction load of the new slab is approximately equal to the construction load of the new slab divided by the sum of the building design live load and the partition load. The number usually needs to be increased by 1 or 2 floors to account for slabs not being 100% cured.

Column #5 lists the age of the concrete at this time.

Column #6 indicates the percent cure of the concrete in each floor slab at this time. The percent cure may be determined from a standard curing curve as shown in Figure 11 or from previous cylinder tests. Usually the critical time for percent cure is at stripping time. Values of 65 to 75 percent are usually required. This column provides the opportunity to use actual percent cures for the concrete to provide a realistic assessment of the relative stiffness of each slab in column #7.

Column #7 indicates the slab design load for each individual slab. Space for the calculation of this value is provided at the edge of the form. If the user can substantiate such action, higher than service load slab capacities may be utilized for the pour concrete condition. Safety factors of 1.3 or 1.4 on ultimate loads have been suggested by some users.

Column #8 indicates the allowable uniform load the slab may carry which is the product of the percent

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cure times the slab design load or the product of column #6 times column #7. This procedure was stated in assumption #3.

Column #9 contains the relative stiffness of all slabs which are connected together in the shoring/reshoring systems. Since the slab stiffness is proportional to the percent cure of the slab(see assumption #4), it is usually convenient to use the same values for relative stiffness as were used for percent cure, when all slabs in the system will have the same stiffness when they are fully cured. If slabs have varying design load capacities or have different thicknesses, it may be that they do not have the same stiffness when fully cured. This relationship may also be incorporated in the relative stiffness column. A reasonably accurate procedure is to establish stiffnesses proportional to the slab's gross moment of inertia. These values may then be proportioned by the percent cure.

Column #10 contains the distribution ratio which is the percentage ratio of the total applied load which will be absorbed by each floor. This value is obtained by taking the value in column #9 and dividing it by the sum of values in column #9 (see observations in figure #2 as the basis for values in columns 10, 11, 12, 13).

Column #11 is the change in the load in the floor as reflected by the distribution ratio. This value is obtained by multiplying the value in the change in load box by the distribution ratio in column #10.

Column #12 is the previous load that existed in each floor and is usually found by looking at the value in column #13 at the completion of the previous operation. Each time a new floor is introduced its previous load is obviously zero.

Column #13 is the load in the floor. This value is found by adding columns 11 and 12. The value in this column must be less than or equal to the value in column #8 in order for an acceptable solution to exist.

Column #14 is the accumulation of the load in the floor and is the accumulation of values appearing in column #13. This column is also used to calculate the shore load.

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Column #15 is the shore or reshore load. It may be obtained by summing forces on freebody diagrams or more conveniently by obtaining the difference between the accumulated construction load in column #3 and the accumulated floor load in column #14.

Column #16 is the adjusted floor load. This column is used to adjust for affects such as concentrated shore loads. In the case of concentrated shore loads this column would be obtained by applying a factor to the concentrated portion of the load and adding that value to the uniform portion of the load. The concentrated portion of the load may usually be obtained by subtracting the uniform construction load value from the value in column #13.

The form is divided horizontally into three operations. The first operation is pouring concrete. A space has been provided to reference the floor number being poured. A space is also provided to indicate the change in load. When completing the pour concrete operation the change in load value will always be the total load being applied to the newly poured deck. This value would be the sum of the concrete weight plus the form weight plus the construction live load. A space has also been provided to record the cycle day number.

The second operation is to remove the construction live load. Again, a space has been provided to record the floor number from which the construction live load is being removed and a space has been provided to indicate the change in load. The change in load to the system in this operation will always be a negative of the construction live load value which is normally 50 lbs. per sq. ft. A space for the cycle day number is also included.

The third operation is to strip and reshore. A block to indicate the floor number being stripped is included. A block to indicate the change in load to the system is also included along with a block for the cycle day number. When stripping is performed, two operations are taking place simultaneously. The floors above the shores being removed are absorbing additional loads equal to the uplifting force previously provided by those shores and the floors below the shores being removed are being relieved of loads equal to the downward force previously provided by those shores. The load to be applied to the slabs above the shores being

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removed is the shore load value appearing in Column #15 of the remove construction live load operation less the formwork weight carried by these shores.

It may be easily demonstrated by the reader that if reshores are installed initially with no load in them and then are loaded as a result of applying loads to the slabs above them and if this load is subsequently removed, the loads in the reshores will return to zero. If this occurs, the loads in the slabs will also return to their initial loading condition which was their dead load only. In reality there may be some minor accumulation or depletion of the load in slabs which have been reshored resulting from the fact that due to their curing their relative stiffnesses may have changed between the time the load was applied and the time the load was relieved. This procedure neglects any changes due to this possibility and therefore assumes that when shores are removed that all slabs below those shores which have been removed will return to the condition of supporting only their own dead weight and the loads in the reshores will return to zero. Because of this no calculations need to be performed on the floors below the shores being removed when working in the strip and reshore operation.

Note, also that within each operation a space has been provided for the summation of the stiffnesses in column #9. A space for the summation of the change in load in the floor, column #11, has also been provided. In each instance this summation must add up to the value in the change in load box.

At the right edge of the form are spaces to record the building design loads and construction loads. Note that the building design live load shall be the minimum reduced live load value used for a given floor. A nominal 50 psf design live load listed on the structural drawings may have been reduced to as low as 20 psf by the structural engineer. This reduction may be applicable to both one and two-way construction. A live load reduction taken for a beam reduces the capacity of the entire bay even though the reduction was not taken for the supported slab.

Review Of Numerical Calculations For Figures A, B, C, D & E

In the interest of brevity it has been assumed that the first five floors of this structure are the

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