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Title: **LIFT SLAB STRUCTURES INSTABILITY DURING CONSTRUCTION**

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Abstract: *Lift slab structures are built in a method, which makes them inherently vulnerable to static and dynamic instability during the construction stages. The columns cannot be laterally braced in the areas, where temporarily anchored slabs are to be lifted to higher levels, because the bracing will make the lifting process of the slabs to higher level impossible. Thus the columns will stay long and slender above the anchored slabs until the shear walls are built at the lower levels, This situation requires the checking of the whole structure above the shear walls for its stability against its own load. A formula was derived to help in checking the stability of such structures, based on the number of slabs, anchored temporarily at different levels, the distances between those anchored groups and the rigidity of the columns. A computer program was written to enable the construction process envision the critical situation which may cause instability.*

Keywords: *slender column, lift slabs, static stability, dynamic stability, construction process.*

Introduction

Lift slab structures are one of the most efficient and economic ways of construction. The slabs are cast on the ground, with plastic sheets in between them. Embedded steel shear heads in the concrete around the columns, leaving a hole to facilitate the lifting process to their final positions. The process of the slabs is done in a very slow process by jacks placed on top of the columns. However, the unstable condition of such structures, during the construction stages, has caused some disasters, such as the collapse of L'Ambiance Plaza in Bridgeport, CT, which killed 28 workers. This instability threatens to cause the abandonment of such efficient method, unless a solution is found. Therefore it was extremely necessary to find a solution for the unstable condition of the structure during construction, to protect this valuable and efficient construction method from becoming extinct.

Many papers were written, about the publicized collapse of L'Ambiance Plaza building in Bridgeport, CT., which collapsed during the construction. The most notable paper about the subject was one by Moncarez et al. (1992), which asserted that the force of the 12-ton jack used to plumb the west building had caused the whole structure to be elastically unstable. Masih (1995) went one step further and stated that the structure could be statically or dynamically unstable during the construction. As an example of dynamic instability was the collapse of a lift slab structure in Armenia, when an earthquake took place during the construction. Each paper, written about the collapse of L'Ambiance Plaza, gave different direct reason for the collapse, even though the instability was the indirect cause. Furthermore, it can be shown that if the structure was subjected to a dynamic force, it could become unstable dynamically before becoming unstable statically. The dynamic force of the jack, which was used to plumb the structure before its collapse, could have been the force which acted upon the structure, causing its collapse because of the dynamic instability, before even the structure could become statically unstable. It is notable to say that the first mode of any lift slab structure during the construction has a very low natural frequency, which could match or almost equal the frequency of the hand operated 12 tons jack, causing the collapse.

Although the authors, as well as the experts agreed that lift slab structures are unstable during the construction, because they are considered like the house of cards, yet very few, such as Scribner et al and Masih acknowledged this fact in their work, or tried to prove it.

Mathematical Model

In order to develop a mathematical model, it was necessary to describe the construction process and its stages. During the construction the slabs are lifted by hydraulic jacks, then parked at intermediate positions along the height of the columns. They are supported in their temporary position by wedges and tack welded to the columns. The lower slab is usually parked at its final position, while the rest are parked above it at different locations. New sections of columns are spliced at the top of the existing columns. The lifting process continues while the workers work at the lower levels to fully integrate the slabs with the columns. In the mean time at the ground level the concrete shear walls are poured between the steel columns, after the columns are fully integrated at one level above, to give the structure the much more needed rigidity. Accordingly, the following assumptions can be made:

1. The columns are fixed at the level, where they are integrated with the slabs and free to deflect above that level.
2. To make the computer program predicting the worst case of parking of the slabs, the slabs are parked at the worst possible locations. Such parking will make the columns unstable. Thus those slabs, which are not close to their final position will be stacked at the top of the columns, because such parking is favored by the constructors, since it shortens the construction period.
3. The weight of one slab is considered concentrated load P on the columns, at level number i, where the slab is parked. If more than one slab is stacked at that level, then the weight P is multiplied by $\alpha_{i,}$ which represents the number of slabs parked at level i.
4. The columns are oriented in such a way to give almost equal rigidity for the building in both directions.
5. The lateral movement of the slabs will force all the columns to move in the same direction, thus forcing the structure to collapse at its first mode.
6. All columns deflection can be represented by a form of cosine equation, which has the same shape and boundary conditions for the first mode of deflection. The above statements can be seen clearly in Fig.14.

If the strain energy stored in a column, bent elastically to certain shape, is more than the work done by the axial load, going through the vertical movement, then the column will snap back, otherwise it will become unstable and collapse. The mathematical work on this problem led to the derivation of the following formula:

$$P_{cr} = \frac{p^3}{4h^2} \frac{\sum_1^m EI}{\sum_{i=1}^n a_i \left[\frac{ph_i}{h} - \sin\frac{ph_i}{h} \right]} \qquad (1)$$

Where: P_{cr} is the critical load. h is the height of the columns from the top of the concrete shear walls to the center of the highest parked group of slabs. h_i is the height of the columns from the top of the shear walls to the center of parked slabs at level i. EI are the modulus of elasticity and total moment of inertia of the columns.

The P-d effect is not considered in this derivation

The formula shown above, without the detailed derivation, was derived by Masih and Hambertsumian (1997), and published in the ASCE Journal of Performance of Constructed Facilities (JPCF). The formula is easy to apply numerically and accurate enough to indicate that a specific stage of construction is stable or not. Although the formula does not take into consideration the P-δ effect, it was considered safe if a margin of safety of 1.3 was maintained. This margin of safety should be more than enough to offset the P-δ effect. In fact, a research done by the same authors, which was published later on in the same JPCF, investigated the reliability of this method and its formula. The follow up research, which used the available numerical methods to solve the same cases, handled by the formula. That research of Masih and Hambertsumian (1998), showed that the formula is quite reliable, when the structure condition is becoming critically close to the unstable condition. In fact the formula takes care of the P-δ effect, without applying any margin of safety.

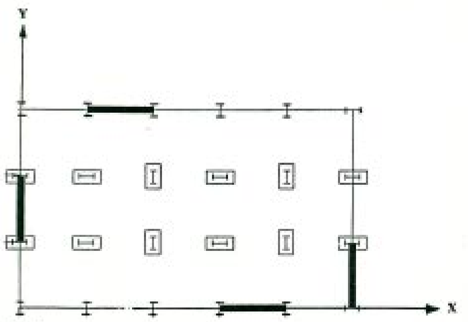

FIG. 1. Columns Layout Plan of 16-Story Building (All Internal Columns Are 14W311, All External Columns Are 14W159)

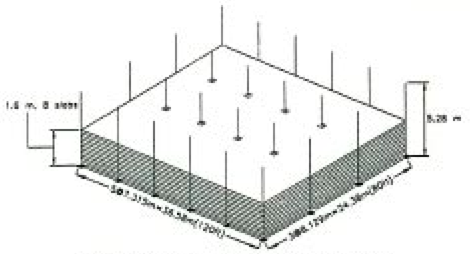

FIG. 2. Isometric View: Slabs on Ground

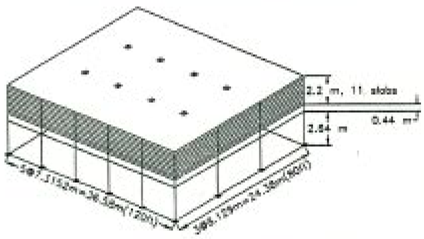

FIG. 3. Isometric View: Stage Number 1

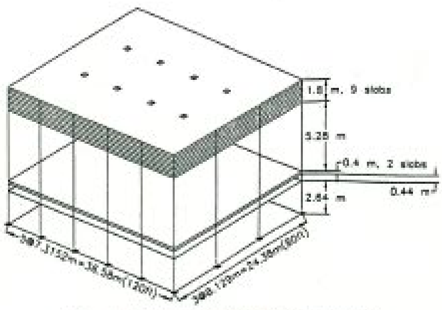

FIG. 4. Isometric View: Stage Number 2A

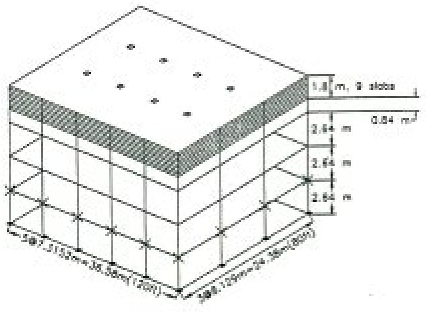

FIG. 5. Isometric View: Stage Number 2B

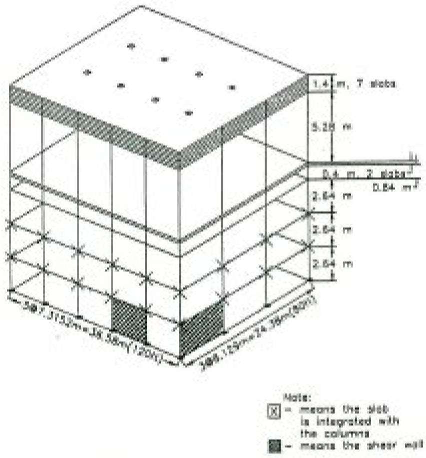

FIG. 6. Isometric View: Stage Number 3A

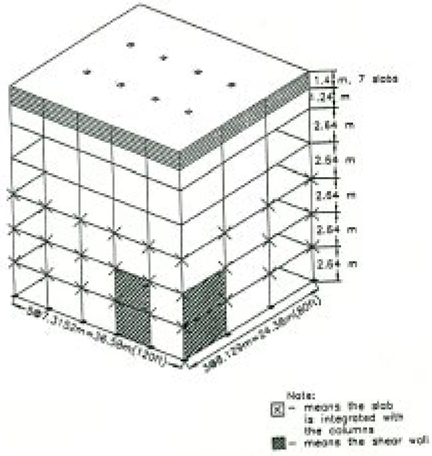

FIG. 7. Isometric View: Stage Number 3B

Modeling construction process

Fig.1is the plan of a lift slab building, twelve story high. It shows the column orientations and the location of the concrete shear walls. Fig.2 shows the columns attached to the foundations and the concrete slabs are being cast on top of each other. It also shows how the columns are sticking above the slabs through the openings of the shear heads. Fig.3 shows how all slabs are lifted to the top of the columns, except the one, which has reached its final destination. Fig.4 shows upper level columns have been spliced to the ones below and the slabs are lifted to the top of those columns, except the ones, which will be moved to their final positions. Every stage is split to two stages, A and B. Stage A is lifting the slabs to the top of the columns and stage B is spreading the slabs below and moving them to their final position. The best example on that is what is shown in Fig.4 and Fig.5. Fig.6 shows how the concrete shear walls are being poured in between the columns to stabilize the structure. Fig.7 through Fig.13 show the sequence of the process of lifting, anchoring the slabs, adding columns and pouring the concrete shear walls. The lifting process of the slabs starts after all the slabs have been cast and they became strong enough to be lifted by jacks placed on top of the installed columns. The lifting is done in a slow motion of few centimeters per hour, so that all jacks will have equal lifting to avoid creating unequal displacements, which will create forces acting to damage the slabs. Usually the columns are extended to two story heights above the

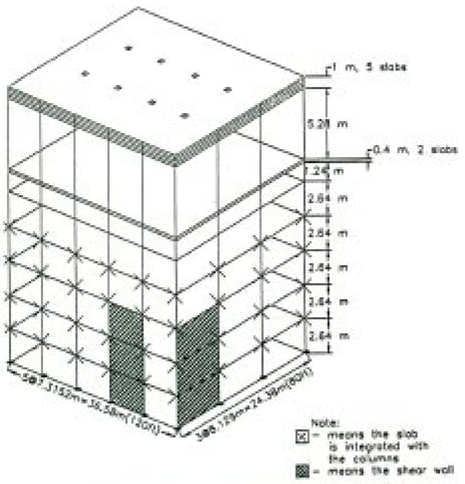

FIG. 8. Isometric View: Stage Number 4A

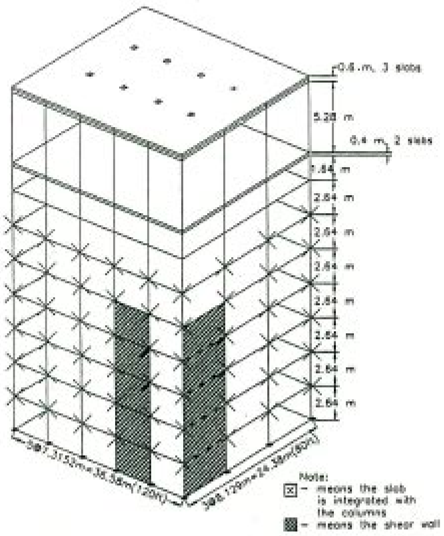

FIG. 10. Isometric View: Stage Number 5A

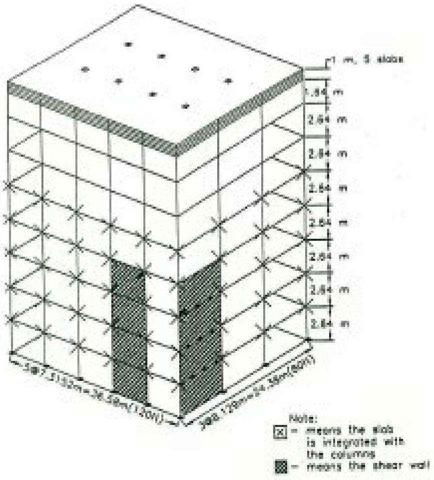

FIG. 9. Isometric View: Stage Number 4B

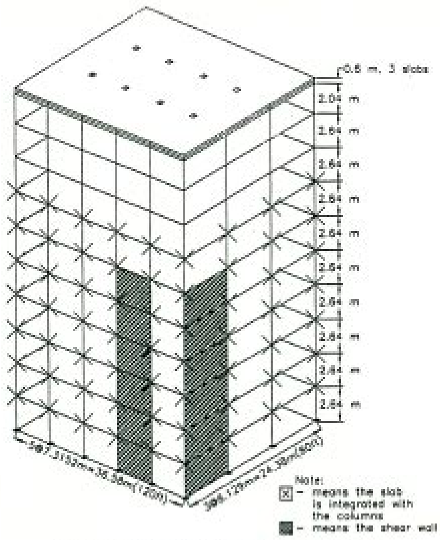

FIG. 11. Isometric View: Stage Number 5B

ground in the first stage of lifting. All the slabs are lifted to the top of the columns, except the ones which have their final destiny is along the height of the columns. The slabs are lifted in a group of 3-5 slabs at a time. The workers start the preparation of splicing the upper level column to the lower columns, which carry the slabs, using the top slab as a platform for their work. In the meantime the workers at the lower level are busy anchoring the slabs and integrating them with the columns by welding the shear heads to the wedges and to the columns. Such construction sequence represents the configuration, which could bring the structure close to being unstable.

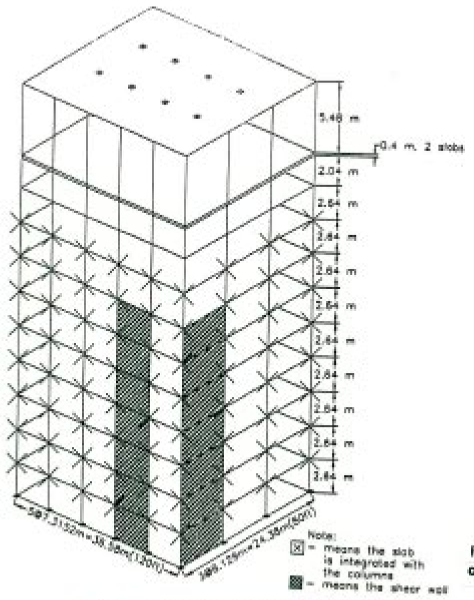

FIG. 12. Isometric View: Stage Number 6A

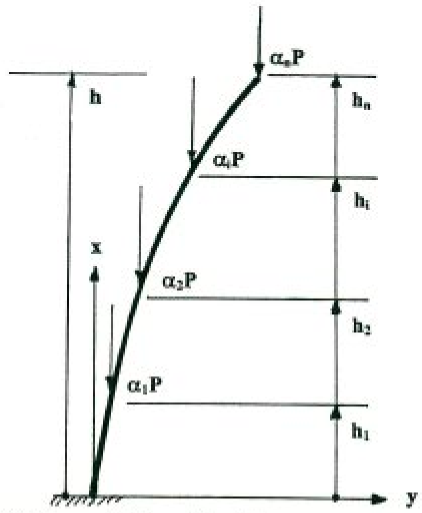

FIG. 14. Assumed Shape of Buckled Column, $y(x) = [1 - \cos(\pi x/2h)]$

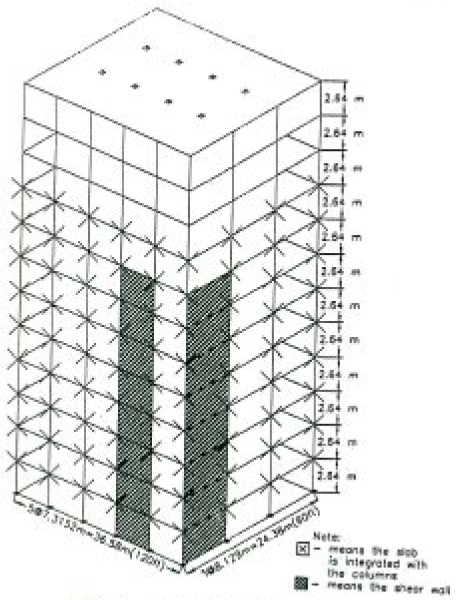

FIG. 13. Isometric View: Stage Number 6B

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