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Technical and economic study of striking and clearing operations in buildings under construction. Case study in Bogotá, Colombia

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Abstract
This paper evaluates the economic benefits of shorter construction times that can be attained by applying the New Simplified Procedure (NSP) in multi-storey buildings. The reference building was a multi-storey residential reinforced concrete framework structure with one-way slabs located in Bogotá, Colombia. The study was divided into different phases including the characterization of the components, a study of the different methods to determine load transmissions between slabs and shores, and a review of the cost of renting shoring and formwork materials and labor costs for the building under study. After applying the procedure, an economic assessment was carried out on the execution times obtained in each of the operations studied. The analysis of the construction process of the building structure using the NSP showed that considerable savings can be achieved in construction times without any risk for the integrity of the structure.

Keywords: New Simplified Procedure; shores; time estimations; load estimations; estimation of personnel and equipment costs.

Estudio técnico económico de los procesos de cimbrado y descimbrado en edificaciones. Estudio de caso en Bogotá, Colombia

Resumen
El presente artículo evalúa el beneficio económico de la aplicación del Nuevo Procedimiento Simplificado (NPS), reflejado en los plazos de construcción en edificaciones de entrepisos sucesivos. El edificio de referencia corresponde a un edificio residencial resuelto con pórticos y entrepisos en una dirección, de concreto reforzado ubicado en la ciudad de Bogotá. Las fases desarrolladas en cumplimiento del objetivo planteado, constaron de una caracterización de los componentes, el estudio de distintas alternativas para determinar la transmisión de cargas entre entrepisos y puntales, y una revisión de los precios de alquiler de equipo auxiliar y personal del edificio de referencia. Aplicando dicho procedimiento se realizó una evaluación económica de los plazos obtenidos en cada una de las operaciones estudiadas. Se destaca que el análisis del proceso constructivo de la estructura de la edificación empleando el NPS permite lograr ahorros considerables en la ejecución de la edificación sin poner en riesgo la integridad de la estructura.

Palabras clave: Nuevo Procedimiento Simplificado; puntales; estimación de tiempos; estimación de cargas; estimación costos personal y equipo.

1. Introduction

At the present time, building operations in Colombia related to the shoring and striking processes used in concrete frame structures are mainly based on the developer's individual experience and little attention is given to technical analyses. This situation is mainly due to the general lack of accurate information on this type of building operation and it often gives rise to building times that are longer and, consequently, more expensive than necessary. According to a study carried out by the *Cámara Colombia de la Construcción* (CAMACOL), between 2008 and 2012, the

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traditional framework system with one-way slabs is the most widely used system in the industry being the one preferred by most Colombian developers [1]. Among the most important reasons for this preference is the optimization of internal spaces, the ease of architectural design, or the possibility of carrying out renovations without endangering structural stability, among others.

In other CAMACOL studies, the structure is considered to be among the costliest work stages of the project [2]; therefore, the process used in its construction will have a big influence on the project budget. For this reason, it is necessary to find a method that allows keeping the costs associated with the construction of the structure at a minimum.

When reviewing the current building standards for shoring and striking processes in concrete structures, they are found to be general in nature and do not state any specific method for complying with the requirements of each standard, nor do they give clear recommendations for calculating striking times or about how to calculate the loads between shores and slabs during the construction process.

In accordance with the above, and bearing in mind that the safety of the structure under construction is one of the most important factors in determining building times, it is essential to know how the loads are transmitted between shores and slabs during these processes, since this will guarantee the safety both of the structure itself and of those working on it.

Various theoretical and experimental studies have been carried out in order to solve this problem with the purpose of determining how loads are transmitted between shores and slabs. In 1963, Grundy & Kabaila [3] proposed a simplified method for determining these loads which is still in use. This method is easy to apply and in most cases errs on the side of safety [4].

In later studies [5-9], various authors agreed in finding that Grundy & Kabaila's simplified method [3] overestimates the loads on shores and slabs. The most recent of these studies, by Calderón et. al [10], proposed a new procedure based on a simplified method that allows estimating shore/slab loads during different construction processes. This new simplified method was validated experimentally and through numerical models [11-13]; it is currently regarded as the best method for estimating shore/slab loads.

This paper describes a study of different alternatives for construction processes for a concrete frame system with one-way slabs; its purpose is to define a viable construction process as regards building times and costs. Calderón et al New Simplified Process [10] was used to calculate the loads on slabs.

2. Description of the building used as a case study

The building used for the study is part of a large project composed of eight traditionally built residential apartment blocks with a concrete frame structure and one-way slabs situated between 64th and 66th Streets in the *Modelo Popular* district of Bogotá, Colombia. The tower block is Nº 5 with 16 floors (13 above ground and 3 in the underground floors).

All the slabs were composed of a 0.50 cm thick lightened slab with a 0.05 cm upper layer. The height between floors is 2.45 m and the underground floor-to-ceiling height is 2.35 m.

The central and corner spans, measuring 6.17 x 5.5 m and 3.8 x 5.63 m, respectively, were selected for studying the slab/shore loads since these were subject to the highest forces.

2.1. Shore characteristics

In order to determine the steel shores elastic behavior, compression tests were carried out on two shores fitted with strain gauges supplied by the building equipment rental company contracted for the construction of the building under study. The results of the tests on both shores are given in Table 1.

2.2. Concrete properties

28 MPa concrete was used for slabs and foundations and 35 MPa for columns. The information on the evolution of the concrete supplied by the manufacturers was checked through tests on the concrete used in the project. Table 2 shows the results of the lab tests performed at 3, 7, 14 and 28 days.

3. Study of load transmission in various construction processes

A study on alternative construction processes for the project under study was made in order to define a viable construction process as regards building times and costs. The New Simplified Process [10] was used to calculate the loads on slabs under construction. This method is eminently suitable, as loads can be estimated on any of the shores under a slab, meaning that it is possible to determine deformations and mean loads on shores and slabs.

Table 1.
Modulus of elasticity of the steel shores.

Shore	Maximum load applied (N)	Strain (%)	Modulus of elasticity (MPa)
1	20064.54	0.019	196855
2	20046.00	0.016	208947

Source: The authors.

Table 2.
Results of evolution and concrete properties.

Test	Day	Strength (MPa)
Simple Compression (ASTMC39)	3	20.39
	7	25.23
	14	26.95
	28	31.64
Modulus of Elasticity (ASTMC469)	3	17609
	7	19589
	14	20247
	28	21937
Splitting Tensile Strength (ASTMC496)	3	2.17
	7	2.28
	14	2.44
	28	3.06
Flexural Strength (ASTMC78)	3	3.02
	7	3.30
	14	3.32
	28	4.19

Source: The authors.

The following were the hypotheses considered when carrying out the New Simplified Procedure [10]:

- Variations in the elasticity modulus with time of concrete elements.
- Infinitely stiff foundation.
- Incremental model – considering the accumulation of loads and displacements.
- Shores are elements with elastic behavior and finite stiffness.
- Uniformly distributed loads between shores and slabs.
- The deformation of the slab at any point coincides with that of the shore at that point; thus, mean slab deformation coincides with mean deformation of shores placed under the slab.
- Different slab boundary conditions; deformability measured by Scanlon & Murray's method [14].
- Negligible shrinkage and creep effects.

3.1. Striking criteria

The current Colombian and international building codes share the same general criteria for the striking process. However, no methods are proposed for calculating shore/slab loads during the construction of buildings.

3.1.1. Colombian Earthquake-Resistant Building Code NSR-10 [15]

The Colombian regulations specify the minimum worker and public safety requisites for shoring and formwork. Shores and formwork for concrete, including their design, construction and removal require the strictest criteria and correct planning to achieve safe shoring and formwork.

Construction loads and possible deflections must be taken into consideration in order to determine striking time.

The NSR-10 emphasizes the ACI-347 specifications.

3.1.2. Building Code ACI-347.2-R05 [16]

ACI-347.2-R05 proposes a rational analysis that considers different factors to determine the number of shored slabs under construction and to determine the loads transmitted between slabs and shores. This analysis includes:

- Analysis of the different loads and live loads applied to the structure.
- Consideration of dead load of concrete plus weight of formwork.
- Construction live loads including any work done on the slab and the accumulation of materials.
- Concrete design strength.
- Time cycle of the pouring of successive slabs.
- Concrete strength required to support shoring loads from above when pouring successive slabs.
- Distribution of loads between floors, shores and reshores, or backshores, at the time of placing concrete, stripping formwork and removing backshoring.
- Slab spans or structural members supported by shores.
- Types of formwork and component dimensions.
- Distribution of loads on individual shores.
- Minimum age at which concrete can resist construction and shore loads when pouring upper slabs.

As regards carrying out shoring and striking operations, special emphasis is given to safety precautions when shoring and striking the structure and when shoring and reshoring successive floors.

3.1.3. Method proposed by Calavera & Fernández [17]

Deciding the striking age involves verifying that, under the loads applied in this process, the forces created can be safely resisted by the strength of the concrete at this age (Calavera 1981).

Calavera [17] proposes that if the load acting on a slab on striking is $\alpha \cdot$p; p being the total project characteristic load (self-weight plus dead loads plus live loads), the shores can be removed from the slab when the slab concrete has a tensile strength $f_{ckt,j}$ such that:

$$f_{ckt,j} \geq \alpha \cdot f_{ckt,28} \quad (1)$$

$f_{ckt,28}$: Characteristic strength of concrete at the age of 28 days.

$$\alpha = \frac{q_{const}}{p} \cdot \frac{\gamma'_{fg}}{\gamma_{fg}} \quad (2)$$

Where q_{const} is the construction load, p is the project's load, γ'_{fg} is the factor of safety for construction actions and γ_{fg} is the factor of safety for project actions.

The value of α cannot be higher than the unit; otherwise, the loads supported by a slab floor in the construction stage would be higher than those designed, thereby making the construction process unfeasible.

Eq. (1) is the principal criterion used by a large number of authors to calculate the times for carrying out the different construction processes.

3.2. Alternatives studied

There is a number of different construction processes for consecutive slab floor construction. Alvarado [18] gives the most important as: Shoring and Striking (SS), Shoring, Reshoring and Striking (SRS), and Shoring, Clearing and Striking (SCS).

These three alternatives (see below) were considered for the frequently used 1, 2, 3 and 4 consecutively shored floors in order to find the execution times.

3.2.1. Shoring and Striking (SS)

There are only two clearly defined stages in this process: i) placing the shores where the concrete is poured and ii) its later removal. The required number of sets of shores is used in this process, and two, three or more floors may be consecutively shored in this way.

Table 3 gives the mean loads on slabs (Q_{Emed}) obtained by the New Simplified Procedure [10] for the most critical operations in the different cases studied.

Table 3.
Mean load on slabs in critical operations (CO).

Span	Consecutively shored floors	C.Op.	Floor	Q_{Emed} (kN/m^2)
Central	1	Concrete Placement Floor 2	1	16.24
	2	Concrete Placement Floor 4	2	17.13
	3	Concrete Placement Floor 6	3	16.63
	4	Concrete Placement Floor 6	2	16.81
Corner	1	Concrete Placement Floor 2	1	16.24
	2	Concrete Placement Floor 5	3	16.46
	3	Concrete Placement Floor 6	3	17.53
	4	Concrete Placement Floor 8	4	16.94

Source: The authors.

3.2.2. Shoring, Clearing and Striking (SCS)

or partial striking, consists of removing formwork and more than 50% of the shores that support the slab a few days after pouring the concrete so the material required for shoring and formwork is considerably reduced. This technique reduces building costs and rationalizes the construction process.

The mean loads on slabs (QEmed) for the most critical operations of the cases studied obtained by the New Simplified Procedure [10] are shown in Table 4.

3.2.3. Shoring, Reshoring and Striking (SRS)

In this process, the shores are removed from certain floors, thus completely unloading the shores so that the loads are redistributed among the different floors. The slabs are then reshored, ensuring contact between shores and slabs so that the shores will bear part of the future load increments. The slabs are made to bear solely their own self-weight when reshored at an early age through this method.

Table 5 shows the mean loads on slabs (Q_{Emed}) obtained by the New Simplified Procedure [10] for critical operations in the different cases studied.

4. Economic study of the different alternatives

4.1. Review of the prices and times used in the building used as case study

The information relative to the project budget, processes and building times was obtained from the building company involved. It refers only to the staff that actually took part in the construction processes analyzed including: site manager, foreman, building surveyor and construction workers. The office staff consisted of the project supervisor, project manager, safety manager, assistant safety manager, storeman, assistant storeman, secretary, and private security guards. The auxiliary equipment was composed of: shores, straining pieces and other equipment necessary for the construction of slabs with an Clearing, area of 714 m^2. Table 6 shows the daily cost of staff and equipment for the case study in 2013.

Table 4.
Mean loads on slabs in critical operations (SCS).

Span	Consecutively shored floors	Crit.Op.	Slab	Q_{Emed} (kN/m^2)
Central	1	Concrete Placement Slab 2	1	16.24
	2	Concrete Placement Slab 4	2	13.17
	3	Concrete Placement Slab 5	2	11.95
	4	Concrete Placement Slab 6	2	11.68
Corner	1	Concrete Placement Slab 2	1	16.24
	2	Concrete Placement Slab 5	3	13.87
	3	Concrete Placement Slab 6	3	13.77
	4	Concrete Placement Slab 8	4	13.21

Source: The authors.

Table 5.
Mean loads on slabs in critical operations (SRS).

Span	Consecutively shored floors	Crit. Op.	Slab	Q_{Emed} (kN/m^2)
Central	1	Concrete Placement Slab 2	1	16.24
	2	Concrete Placement Slab 3	2	13.39
	3	Concrete Placement Slab 6	5	12.90
	4	Concrete Placement Slab 3	2	12.84
Corner	1	Concrete Placement Slab 2	1	16.24
	2	Concrete Placement Slab 3	2	13.39
	3	Concrete Placement Slab 4	3	13.04
	4	Concrete Placement Slab 4	3	12.80

Source: The authors.

Table 6.
Daily cost of staff and auxiliary equipment.

Description	Units	Cost
Office Staff	Day	$ 1,040,217 COP
Building Staff	Day	$ 311,127 COP
Auxiliary equipment	Day	$ 199,935 COP
Total		**$ 1,551,278 COP**

COP = Colombian Pesos
1.00 USD = 2,615 COP (August, 2016)
Source: Constructora Marquis S.A.

In addition to the above costs, a tower crane was hired at a total cost of $12m COP per month, including the operator.

For the construction of the tower blocks in the case study, only two sets of shores were used and the construction process chosen was that of Shoring and Striking.

The time for laying the slab was set at seven days, including five days for transporting and installing auxiliary equipment and two days for placing the concrete. Striking time was set at 10 days.

Table 7.
Total times for the alternatives studied (results in days).

Consecutively shored slabs	SS		SCS		SRS	
	Central Span	Corner Span	Central Span	Corner Span	Central Span	Corner Span
1	225	225	225	225	225	225
2	87	83	56	56	62	60
3	72	67	61	54	61	61
4	66	66	65	59	66	66

Source: The authors

Table 8.
Percentage savings or excess costs of the economic variables analyzed for each construction process.

Consecutively shored slabs	Building Staff			Office Staff			Auxiliary Equipment			Tower Crane		
	SS	SCS	SRS	SS	SCS	SRS	SS	SCS	SRS	SS	SCS	SRS
2	2%	-9%	-7%	6	-30%	-23%	5%	-48%	-52%	6	-30%	-23%
3	-3%	-7%	-7%	-11%	-24%	-24%	22%	-29%	-43%	-11%	-24%	-24%
4	-6%	-6%	-6%	-18%	-20%	-18%	40%	-12%	-32%	-18%	-20%	-18%

Source: The authors

4.2. Study of times

The execution times for the different alternatives studied were obtained from the analysis of the load transmissions (Table 7) and they agree with the striking times proposed in Calavera [17].

4.3. Study of costs

The results of the striking time calculations were used to determine the execution costs, which were then compared with the actual costs involved in the construction of the project used for the case study. The different results for each construction process and the economic variables analyzed can be seen in Table 8. Negative values signify savings and positive values signify excess costs.

5. Analysis of the results

The behavior of loads on one-way slabs and shores in a concrete frame structure was analyzed for a series of construction processes. Also analyzed were the times required for each of the construction processes studied and an assessment was made of their economic costs using the actual costs of building an eight-storey block as a reference.

The slab design load was not exceeded in any of the processes showing that all of them are viable. According to the subsequent analysis, the best behavior was obtained by the SCS process. In this technique, after clearing, only 50% of the shoring was required to support the loads between the slabs.

Construction cycles play an important role, as building times can be reduced when the shoring assembly process is optimized. From the results obtained in the building times, it can be concluded that faster execution times are not always achieved by using more shores. In fact, the best results are obtained by an SCS process with two consecutively shored floors.

The results from using only one set of shores indicate that this system is not advisable due to the long execution times required, which were the same in all the construction processes.

As regards costs, the biggest savings (approximately 30%) are obtained by implementing SCS with two sets of shores, since faster times are obtained with savings in both equipment and labor costs.

6. Conclusions

Using the New Simplified Procedure [10] to calculate shore/slab loads provides developers with a tool that guarantees correct building practice without exceeding the permitted loads on slabs during this construction stage. Secondly, calculating striking times by Calavera's method, as validated by Fernandez [17], aids in planning concrete frame projects without any risks to safety. This system allows loads to be analyzed in order to establish the minimum time requirements to guarantee the stability of the slabs.

The cost analysis of these two methods showed that considerable savings can be made over the traditional methods used for this type of project, achieving savings between 6 and 33% in equipment and labor costs.

As regards the construction processes studied, all of these are valid as long as the appropriate analyses are carried out on loads and times. The best results are achieved by using the SCS system. These methods should be recommended in Building Codes in order to guarantee the safe and effective laying of slabs in reinforced concrete framework structures.

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