ENGLISH VERSION

Study of technical and economical alternatives of a shoring and striking process during the construction of a building with reinforced concrete slab floors

Estudio técnico económico de alternativas del proceso de cimbrado y descimbrado en la construcción de un edificio de forjados de losa maciza de hormigón armado

Y. Alvarado *, I. Gasch [1]**, P. Calderón **, B. Torres **

* Pontificia Universidad Javeriana, Bogotá. COLOMBIA
** ICITECH, Universitat Politècnica de València, Valencia. SPAIN

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Abstract
The aim of this paper is to define alternative construction processes for a building with reinforced concrete slab floors, thereby estimating which ones are most beneficial in terms of their execution time and cost. Three alternatives were proposed to solve the deadlines of the construction process: Shoring and Striking; Shoring, Clearing and Striking; and Shoring, Reshoring and Striking, considering 2, 3 and 4 consecutive shored floors. In order to evaluate what processes are valid, first it is necessary to calculate the loads during the construction process using the New Simplified Procedure and subsequently check whether or not the striking condition is fulfilled in each of the construction operations. Regarding the studied building, the feasible construction processes were: Shoring, Clearing and Striking with 3 and 4 consecutive shored floors.

Keywords: *Load transmission, clearing, construction process, shores, new simplified procedure*

Resumen
El objetivo del presente trabajo es definir diferentes alternativas de procesos constructivos, estimando cuáles resultan ser las más beneficiosas respecto a su plazo de ejecución y su coste, para un edificio de forjados de losa maciza de hormigón armado. Para resolver los plazos de ejecución se plantearon tres alternativas del proceso constructivo: Cimbrado y Descimbrado; Cimbrado, Clareado y Descimbrado; y Cimbrado, Recimbrado y Descimbrado, considerado 2, 3 y 4 plantas consecutivas apuntaladas. Para evaluar qué procesos son válidos, primero se calculan las cargas que se presentan durante el proceso constructivo mediante el Nuevo Procedimiento Simplificado y posteriormente se comprueba si se cumple o no, en cada una de las operaciones constructivas, la condición de descimbrado. Para el edificio objeto de estudio se han obtenido como procesos viables económica y técnicamente los procesos constructivos de Cimbrado, Clareado y Descimbrado con 3 y 4 plantas cimbradas.

Palabras clave: Transmisión de cargas, clareado, proceso constructivo, puntales, nuevo procedimiento simplificado

1. Introduction

During the construction of buildings with consecutive slab floors, the formwork (shores, straining pieces and formwork boards) for casting the consecutive upper slab floors is usually supported on recently cast slab floors. Thus, the construction's execution time and cost greatly depend on recovering the shoring components as soon as possible in order to reuse them in the construction of upper slab floors.

The basic condition of using the lowest possible number of components consists in partially or completely striking part of the structure in the lowest acceptable time. Estimating the execution times is a complex process, since they depend on factors such as: the shoring system and construction process used, the characteristics of the building's materials, the temperature and humidity conditions on site, among others.

Therefore, in order to establish a structure's execution time, it is essential to know how loads are transmitted between slab floors and shores during the construction process. Knowing about this load transmission allows executing the structure while guaranteeing its safety during the construction and it also allows adjusting the deadlines and materials needed for its execution. Authors Grundy and Kabaila (1963), Duan and Chen (1995); and Fang et al. (2001a,b) have designed theoretical models to calculate the load distribution on slab floors and shores during the construction process. More recently, Calderón et al. (2011) have developed a New Simplified Procedure, which allows calculating the load transmission between slab floors and shores in different construction operations. This new procedure takes into account the real stiffness of the shores and considers that the average deformation of the shores under a slab floor coincides with the average deformation of that slab. This New Simplified Procedure has been validated by experimental measurements on shores, in a real-scale building under controlled laboratory conditions, by Alvarado et al. (2009), and by the results of finite element models developed by Alvarado et al. (2010).

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[1] *Corresponding author:*

Doctor Ingeniero en Organización Industrial. Profesor Contratado Doctor, Dpto Mecánica de los Medios Continuos y Teoría de Estructuras, Escuela Técnica Superior de Ingeniería del Diseño, Universitat Politècnica de València. Spain
E-mail: igasch@mes.upv.es

In recent works, Gasch (2012) and Gasch et al. (2013, 2014) have confirmed that the New Simplified Procedure has a very good adjustment degree, with regard to different experimental measurements made in real buildings, to calculate the loads generated during the construction process.

On the other hand, establishing a judgement on the age to carry out any of these construction operations means to verify that, under the actions applied at that moment, the materializing stresses may be resisted, with enough safety, with the strength that the concrete presents at that age. Calavera y Fernández (1991) proposes that if the load acting on a slab floor during striking is α·p, where p is the project's total characteristic load (own weight plus permanent loads plus overloads), the slab floor can be stroked when the concrete of the slab itself presents a tensile strength of $f_{ckt,j}$ *so that* $f_{ckt,j} \geq \alpha \cdot f_{ckt,28}$*. According to a large number of authors, this is the main condition to determine the execution time of the construction process operations.*

2. Objectives and new elements of the study

The present study continues the previous work carried out by the research group focused on studying the load transmission between slab floors and shores during the construction process of reinforced concrete buildings.

This paper analyzes different alternatives of construction processes for a building with reinforced concrete slab floors, with the purpose of defining a feasible construction process in relation to building deadlines and cost for the respective work. The New Simplified Procedure of Calderón et al. (2011) is used for calculating the loads acting on slab floors during the construction process.

Usually, a building's construction process is not dealt with from a technical point of view based on a numerical calculation, but rather on the experience of the works' technical staff. Consequently, the main novelty of the present study lies in obtaining a feasible construction process regarding cost and deadline, calculating the loads that act on slab floor through the New Simplified Procedure (Calderón et al., 2011).

3. Case Study

3.1 Description of the studied building

The studied building is an execution project of 101 apartments, common areas, storage facilities and garages located in Madrid.

The building has 4 basements and 14 floors with a maximum height of 45.10 m. The ground floor is 3.65 m high, while for the rest of the floors the height between floors is 3.05 m. In the basements, the height between floors is 3.00 m, except in the first basement which is 3.43 m high. The structure has been designed with reinforced concrete slab floors, plus walls, columns and beams, also of reinforced concrete. Figure 1 shows a section of the building studied herein.

The reinforced concrete structure has the following characteristics:

- *Foundations: given the conditions of the foundations ground, reinforced concrete slabs of 150 cm and 60 cm depth were designed.*
- *Basements: the basement slab floors were resolved by reinforced concrete slabs of 30 cm depth.*
- *Ground floor: the slab floors of the ground floor were resolved by a reinforced concrete slab of 60 cm depth. Moreover, this slab floor has hanging beams up to 100 cm depth.*
- *Slab floors 01-15: slab floors were designed with reinforced concrete slabs of 22 cm depth, except slab floor 13 which is 30 cm depth. The built surface for slab floors 1 to 14 is 510* m^2*, and 320* m^2 *for slab floor 15.*

3.2 Materials

The materials used in the construction of this building are the following:

- *Foundations slab concrete: HA-30/B/40/IIa+Qa*
- *Column concrete: HA-35/B/20/IIa*
- *Slab floor concrete: HA-25/B/40/IIa*
- *Reinforcement Steel: B-500-S*

3.3 Actions

The actions considered in the calculation of the structure comply with the specifications of the Technical Building Code (Ministerio de Vivienda, 2009).

3.4 Study area

In this building, an experimental study was made by instrumenting different shores, with the aim of finding out the load transmission between slabs and shores (Gasch, 2012 and Gasch et al., 2014).

A border span and a corner span were chosen, because they are more likely to deform and, thus, here is where the shores are subjected to maximum loads. A total of 12 shores were instrumented in each floor (6 for each span).

Therefore, 36 shores were instrumented with three strain gauges each, in order to know exactly to how much load they were being subjected to in each stage of the structure's construction. Three strain gauges were placed, on the same level for every shore, with the purpose of correctly compensating the effect of the shore's flexural deformation. Figure 2 shows the instrumentation used.

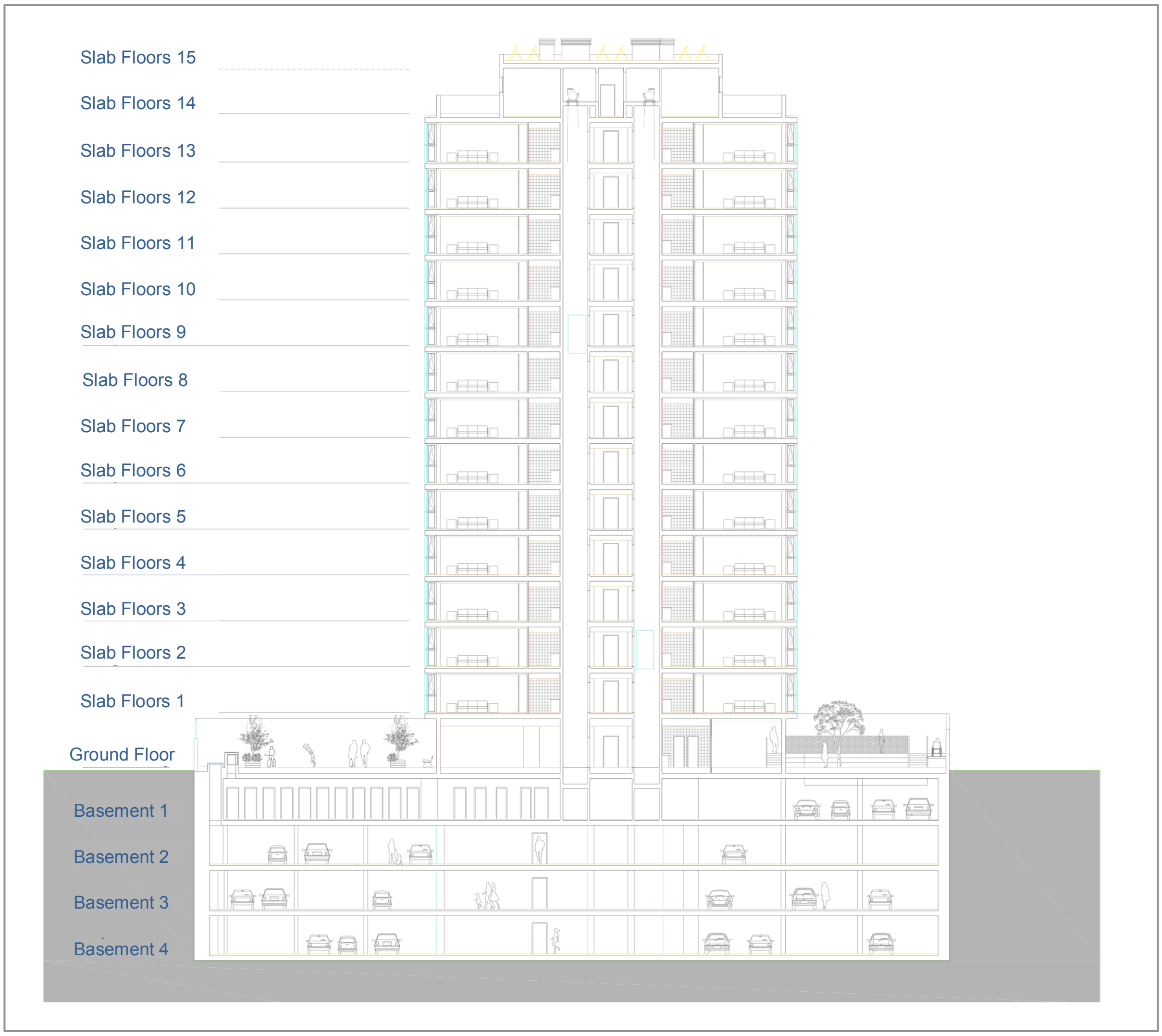

Figure 1. *Building section*

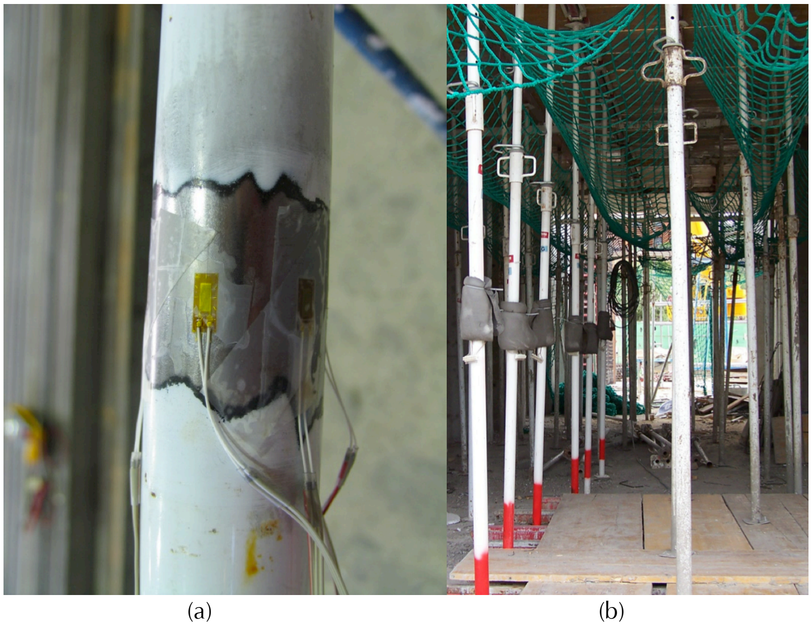
(a) (b)

Figure 2. *(a) Instrumented shore (b) Set of shores instrumented on site.*

Considering that the building's floor repetitiveness produces a cyclic load transmission between shores and slab floors, only the first 6 floors were instrumented, which correspond to the complete rotation of the shoring equipment (3 consecutive shored floors). The details of the experimental results can be found in Gasch et al. (2014).

While considering the real stiffness of the shoring system, simplified methods as those of Duan and Chen (1995), Fang et al. (2001 a,b) and, more recently, Calderón et al. (2011), can be applied to processes where clearing operations are likely to be used. The loads calculated for these simplified processes have been compared with the experimental results obtained by Gasch et al. (2014) (see Table 1).

When comparing experimental measurements with the estimate of different simplified methods, the New Simplified Procedure of Calderón et al. (2011) was validated for the calculation of load transmission between slab floors and shores (Gasch, 2012 and Gasch et al., 2014).

4. Study of different alternatives for a building's shoring and striking process

Once the simplified method was validated, a study of different alternatives of construction process was undertaken, referring to the case study building herein, with the aim of defining a feasible construction process regarding its building time and cost. The New Simplified Procedure (Calderón et al., 2011) was applied to the calculation of loads acting on slab floors during the construction process.

Concerning the case study building, described in Section 3, and given its particularity in the ground floor slabs, which are much thicker than the lower slabs, the construction process was divided in two clearly distinguished stages:

- *The first building stage uses a shoring and striking process up to the ground floor slab, while keeping the four floors shored up to the foundations. This is due to the heavy weight of the ground floor slab, which cannot be resisted by the lower basements alone and needs a considerable amount of shores to transmit this load to the foundations. Once the concrete has been cast on the ground floor, the striking process in these floors may start, which is done from top to bottom.*
- *The second stage consists in the construction of slab floors from 1 to 15 (slabs above ground level) considering the construction process that is being studied in each case.*

Since the first stage is a very common one, regardless of the construction process used in the second stage, we decided to analyze the latter.

The construction process distinguishes the corner opening and the party wall opening individually.

4.1 Calculation basis

The actions, materials and geometrical characteristics of the studied building are described in Section 3.

4.1.1 Factor of safety

The current EHE (Code on Structural Concrete) version corresponding to the EHE-08 (Ministerio de Fomento, 2008) does not give a specific recommendation on factors of safety for construction actions. Therefore, the present study considers a factor of safety of 1.35 in the analysis, which is the minimum allowed by the EHE-08 (Ministerio de Fomento, 2008).

4.1.2 Average temperature on site

In accordance with the temperature readings taken during the execution of the structure, a mean temperature of 25°C is adopted.

4.1.3 Characteristics of the shores

The shore used for the construction of the building had a 4-m maximum height. This shore is manufactured with a high-quality steel pipe S275JR (ST-44). The base, thread and fastener are also made of steel, and the shore's body and brace are coated with polyester paint. Table 2 shows the geometrical characteristics of the shore used.

***Table 1.** Adjustment of experimental measurements with the new simplified procedure estimate*

	Duan & Chen (2)		**Fang et al. (3.4)**		**Calderón et al. (5) (NSP)**	
$\frac{C_{exp}*}{C_{nsp}*}$	***Corner span***	***Border span***	***Corner span***	***Border span***	***Corner span***	***Border span***
Mean	*1.49*	*1.13*	*2.59*	*1.46*	*1.09*	*0.98*
Typical dev.	*0.43*	*0.20*	*1.17*	*0.41*	*0.23*	*0.20*

** Load ratios that relate the load on slab floors in each construction operation with the construction load, obtained experimentally (C_{exp}) and using simplified procedures (C).*

***Table 2.** Geometrical characteristics of the shore*

Type of shore	**Body length (m)**	**Body diameter (mm)**	**Body thickness (mm)**	**Brace diameter (mm)**	**Brace thickness (mm)**	**Weight (Kg)**
4-m Shore	1.88	48	2	41	2.5	11.25

4.2 Studied alternatives

There are different construction processes for buildings using consecutive slab floors. For Alvarado (2009), the most important processes are: Shoring and Striking (SS); Shoring, Reshoring and Striking (SRS); and Shoring, Clearing and Striking (SCS).

In order to determine the execution deadlines, the construction process envisaged three alternatives explained below, considering 2, 3 and 4 consecutive shored floors, which is a common practice in the construction of high-rise buildings. Furthermore, a building execution rate of one slab floor per week was considered.

- ***Shoring and striking process**: the shoring and striking process (SS) has only two clearly defined stages, the installation of the formwork where the concrete is cast, and the withdrawal of the same formwork. This process may contain as many formwork sets as necessary in each floor, and two, three or more consecutive shored floors are possible.*

  Table 3 shows the minimum times adopted in the present study to carry out each construction operation, depending on the number of consecutive shored floors and considering the time usually needed on site.
- ***Shoring, clearing and striking process**: Clearing or partial striking is a usual operation in Spain, which consists in withdrawing the formwork and over 50% of the shores supporting the formwork a few days after the concrete is cast. Thus, the materials needed for the formwork and shoring process is considerably reduced. This technique significantly lowers the costs and rationalizes the construction process.*

  Table 4 shows the minimum times adopted in the present study to carry out each construction operation, depending on the number of consecutive shored floors and considering the time usually needed on site.

- ***Shoring, reshoring and striking process**: In 1967, Taylor (1967) designed the shoring, reshoring and striking process (SRS), which consists in striking certain floors and completely unloading the corresponding shores, thereby redistributing the load between the slabs. The next step is underpinning again, by ensuring the contact between shores and slabs, so that shores help to support future load increases. In this manner, at early ages and at the time of reshoring, slab floors only have to support their own weight.*

  Table 5 shows the minimum times adopted in the present study to carry out each construction operation, depending on the number of consecutive shored floors and considering the time usually needed on site.

***Table 3.** Minimum time required for operations in a shoring and striking process*

Number of consecutive shored floors (set of shores)	Minimum time for loading the slab floor (days)	Minimum striking time (days)
2	7	8
3	7	15
4	7	22

***Table 4.** Minimum time required for operations in a shoring, clearing and striking process*

Number of consecutive shored floors (set of shores)	Minimum clearing time (days)	Minimum time for loading the slab floor (days)	Minimum striking time (days)
2	2	7	10
3	2	7	17
4	2	7	24

***Table 5.** Minimum time required for operations in a shoring, reshoring and striking process*

Number of consecutive shored floors (set of shores)	Minimum reshoring time (days)	Minimum time for loading the slab floor (days)	Minimum striking time (days)
2	3	7	11
3	3	7	18
4	3	7	25

4.2.1 Shoring-striking process

In order to determine the execution deadlines of the studied building in a shoring and striking process (considering 2, 3 and 4 consecutive shored floors), we have to start by calculating the loads during the construction process (Gasch, 2012 and Gasch et al., 2014) and verify if the striking condition is fulfilled in each one of the construction operations (Calavera and Fernández, 1991). This striking condition is subject to the ratio between the evolution of the concrete properties and the capacity of the slab floor to support a specific load value. This condition is the following:

$$\frac{f_{ckt,j}}{f_{ckt,28}} \geq \beta \qquad \textbf{(1)}$$

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

$$\beta = \frac{q_{const}}{q_{pry}} \cdot \frac{\gamma'_{fg}}{\gamma_{fg}}$$

Where q_{const} is the construction load, q_{pry} 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.

Formula 1 allows concluding that the value of β 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.

The deadlines obtained from the analysis of the load transmission, which fulfill the striking condition (Formula 1), correspond to the lowest possible execution time complying with the minimum deadlines established in Section 4.2.

The analysis procedure followed to identify the different feasible alternatives for the execution of the structure is expressed in Figure 3.

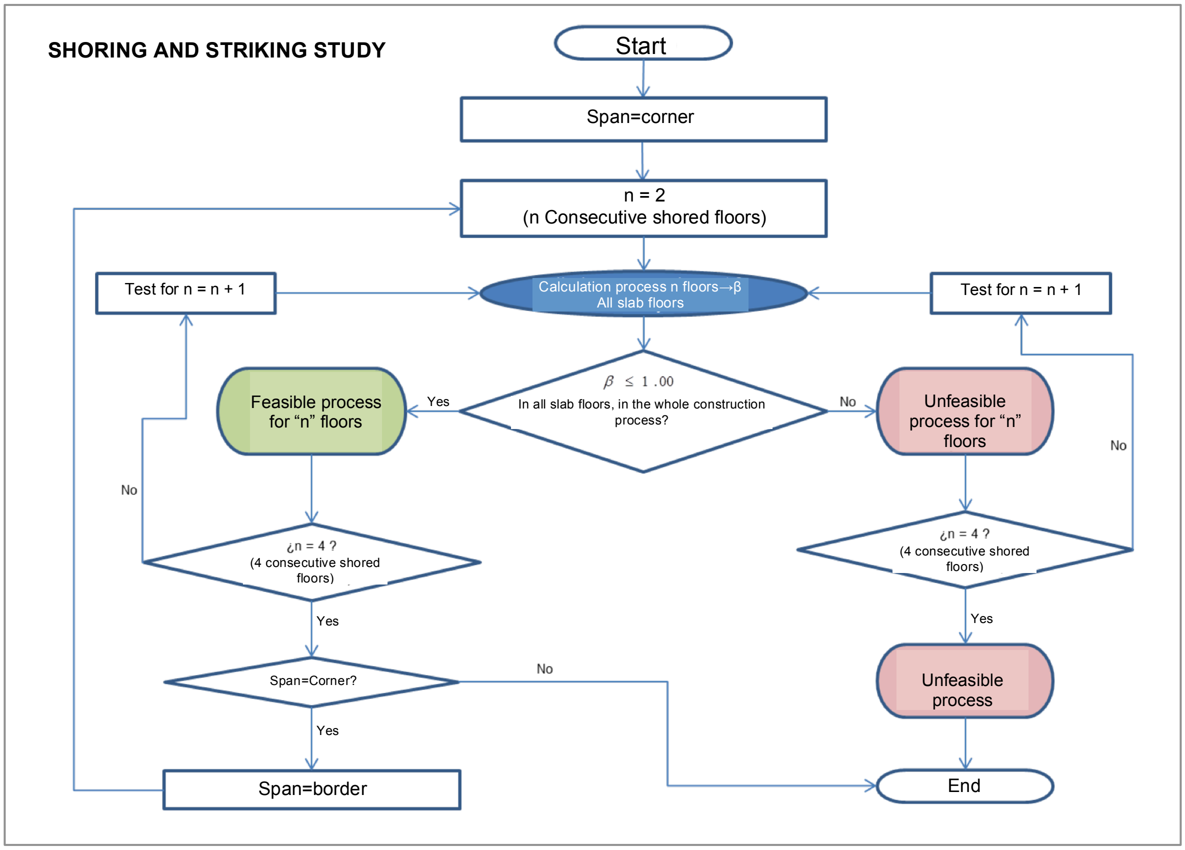

***Figure 3.** Analysis procedure of feasible shoring and striking process for the building studied in this research*

Table 6 shows the values of coefficient β, for an SS process, as well as the critical operation of the construction process and the slab floor where this critical operation is produced.

The results shown in the above Table, where β is higher than 1 in all studied cases, demonstrate that the shoring and striking process is not feasible, in any of the assumptions concerning the building analyzed in the present study. While not fulfilling the striking condition for the corner opening, this process is not feasible; therefore the calculation for the party wall opening is omitted.

Table 6. *Coefficient β values for a SS process*

Consecutive shored floors	Span	Critical operation	Slab floor	β Value
2	Corner	Casting Slab Floor 4	Slab floor 2	1.30
3	Corner	Casting Slab Floor 6	Slab floor 3	1.29
4	Corner	Casting Slab Floor 7	Slab floor 3	1.28

4.2.2 Shoring-clearing-striking process

The procedure to obtain feasible solutions that allow meeting the conditions indicated above, is the same one shown in Figure 3 (for a shoring-striking process).

Table 7 shows the results for a SCS process, which indicates the critical operation of the construction process, the slab floor where this critical operation is produced and the values of coefficient β.

Table 7 shows that the construction process of shoring, clearing and striking is feasible in the case of 3 and 4 consecutive shored floors. The execution time of the structure is 101 days, both for 3 and 4 consecutive shored floors.

4.2.3 Shoring-reshoring-striking process

In order to identify the different feasible alternatives for the execution of the structure, the analysis procedure is the same as the one shown in Figure 3.

Table 8 shows the critical operation of the construction process, the slab floor where this critical operation is produced and the values of the coefficient β for a SRS process.

Table 7. Values of coefficient β for a SCS process

Consecutive shored floors	Span	Critical operation	Slab floor	β Value
2	Corner	Casting Slab floor 3	Slab floor 2	1.03
3	Corner	Casting Slab floor 14	Slab floor 13	0.98
3	Border	Striking Slab floor 13	Slab floor 13	0.95
4	Corner	Casting Slab floor 13	Slab floor 12	0.98
4	Border	Striking Slab floor 12	Slab floor 12	0.98

Table 8. Values of coefficient β for a SRS process

Consecutive shored floors	Span	Critical operation	Slab floor	β Value
2	Corner	Casting Slab Floor 15	Slab Floor 14	1.08
3	Corner	Casting Slab Floor 15	Slab Floor 14	1.06
4	Corner	Casting Slab Floor 15	Slab Floor 14	1.06

The results of the Table above, where β is higher than 1 for all studied cases, demonstrate that the shoring, reshoring and striking process is not feasible, in any of the assumptions concerning the building analyzed in the present study. While not fulfilling the striking condition for the corner span, this process is not feasible; therefore the calculation for the border span is omitted.

5. Economic assessment of the feasible studied solutions

In the previous section, different alternatives of construction processes were analyzed for the execution of a building with consecutive cast-in-place concrete slab floors. The analysis shows different feasible solutions that do not compromise the capacity of the structure to safely support the loads that are present during the construction process.

The above analysis allows confirming that the SCS construction process is the only, among those usually employed, that is feasible when considering 3 and 4 consecutive shored floors.

Considering these aspects, an economic assessment for each of the previously studied feasible solutions was carried out. This economic assessment considers strict material needs, without taking into account the safety margins regarding the quantity of materials used.

The prices, rental of materials and labor force used in this study are used for comparison purposes and under no circumstances should they be understood in absolute terms.

The productivity rate considered for executing each construction operation has been estimated from the observation of different works.

5.1 Unit prices and productivity

Table 9 shows daily rental rates for materials and labor force costs.

Table 10 shows the productivity rate estimated for each construction operation.

5.2 Execution cost in a shoring, clearing and striking process

The cost of feasible solutions obtained from a construction process with shoring, clearing and striking is shown below. As previously remarked, the analysis considers only Stage 2 of the construction process.

5.2.1 SCS process for three slab floors

Table 11 shows the amount of materials used in the execution, together with the necessary man-hours. The quantity of materials has been obtained considering a surface of 510 m^2 per slab floor. For the execution of 3 consecutive shored floors, considering the minimum possible amount of materials, it is necessary to rely on 1 set of formwork boards and 2 sets of shores and straining pieces. Working hours of the site staff are obtained from the construction operations to be undertaken and the productivity rate indicated in Table 10. The cost of that stage is also shown, and it is obtained from unit prices (Table 9), quantity of materials and staff, and the execution time (101 days).

The total execution cost of a constructive process with shoring, clearing and striking for four consecutive shored floors, considering an execution time of ***101 days****, amounts to* ***€129,217.43.***

Table 9. *Unit prices*

Unit	*Price*	
Rental of straining pieces	*0.055*	*€/m*
Rental of formwork boards	*0.23*	*€/m^2*
Rental of 4-m shore	*0.05*	*€*
Labor force	*18.10*	*€/hour*

Table 10. *Productivity*

Construction Operation	**Productivity (hours/m^2)**
Shoring	*0.47*
Clearing	*0.10*
Striking	*0.18*

Table 11. *Quantity of materials, necessary staff and execution cost*

Unit	*Quantity*	*Cost (€)*
Straining pieces	*1,020 m*	*5,666.10*
Formwork boards	*510 m^2*	*11,847.30*
Shores	*1,020 units*	*5,151.00*
Labor force	*5,737.5 hours*	*103,848.75*
Total Stage 2		***126,513.15***

5.2.2 SCS Process for four slab floors

Table 12 shows the quantity of materials used in the execution, together with the necessary man-hours. The quantity of materials has been obtained considering a surface of 510 m^2 per slab floor. For the execution of 4 consecutive shored floors, considering the minimum possible amount of materials, it is necessary to rely on 1 set of formwork boards and 2.5 sets of shores and straining pieces. Working hours of the site staff are obtained from the construction operations to be undertaken and the productivity rate indicated in Table 10. The cost for that stage is also shown, and it is obtained from unit prices (Table 9), quantity of materials and staff, and the execution time (101 days).

*The total execution cost of a constructive process with shoring, clearing and striking for four consecutive shored floors, considering an execution time of **101 days**, amounts to **€129,217.43.***

***Table 12.** Quantity of materials, necessary staff and execution cost*

Unit	***Quantity***	***Cost (€)***
Straining pieces	*1,275 m*	*7,082.63*
Formwork boards	*510 m^2*	*11,847.30*
Shores	*1,275 unidades*	*6,438.75*
Labor force	*5,737.5 horas*	*103,848.75*
Total Stage 2		***129,217.43***

6. Conclusions

The application of the New Simplified Procedure allows analyzing different alternatives of construction processes for the execution of high-rise buildings with consecutive slab floors. Through this procedure, the present study analyses 3 different construction processes:

- *Shoring and striking process (SS)*
- *Shoring, clearing and striking process (SCS)*
- *Shoring, reshoring and striking process (SRS)*

Considering the striking condition proposed by Calavera, the application of the new simplified procedure enables to determine what construction processes are feasible in order to resolve the structure. In the case of the studied building, the SCS process, which considers 3 and 4 consecutive shored floors, is the only feasible process.

Based on this analysis it is possible to make a cost assessment for each feasible construction process. Regarding the building studied herein, it was determined that the minimum cost for the construction of the building is obtained through a shoring, clearing and striking construction process with 3 consecutive shored floors.

7. Acknowledgements

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