Evaluation of Structural Costs in Building - Simulation of the Impact of the Height and Column Arrangement

Javier Ferreiro-Cabello [1] Esteban Fraile-García [1] Eduardo Martínez de Pisón-Ascacíbar [1]
Emilio Jiménez-Macías [2]

[1] Department of Mechanical Engineering, University of La Rioja, Spain, {javier.ferreiro,esteban.fraile, eduardo.mtnezdepison}@unirioja.es

[2] Department of Electrical Engineering, University of La Rioja, Spain, emilio.jimenez@unirioja.es

Abstract

Modeling is a useful tool for decision making in the project phases. In the case of reinforced concrete structures, we must be able to locate representative parameters in order to optimize costs. This paper assesses the impact of the column arrangement and building height. The variation of the costs for the foundation and two floor interaxis are discussed. The results are assessed by the ratio of cost per square meter executed. The optimization of the geometry of the building is determined by the interaxis distances and the selected structural thickness. In the case studied the arrangement of the pillars in a 6x6 meters grid using 4 heights offers the best economic results.

Keywords: reinforced concrete, costs, columns arrangement, structures, modeling

1 Introduction

The decisions made in the early stages of a project have a significant impact on its future development. The economic costs can and should be dimensioned so that the investor has the smallest possible uncertainties. Despite this construction projects have a long deployment time that introduces those unwanted uncertainties. This work focuses on structural solutions through the use of reinforced concrete (Amir, 2013; CTE, 2006; CYPECAD, 2015).

The intensive application of reinforced concrete has been produced largely by the advancement and study of the behavior of new materials and the development of new technologies. This is the origin of structural engineering that deals with the conception, design and construction of structures emerged. We want to emphasize that in the same way that society evolves, technology, materials and available tools do (De Albuquerque *et al*, 2012; Delijani *et al*, 2015; EHE-08 2008).

The structural solution costs represent a significant percentage within any project. With an eye to the future by implementing algorithms it is necessary to know the impact of different variables that affect the final cost of a given solution (Fernández-Ceniceros *et al*, 2010; Kaveh *et al*, 2011; Koksal *et al*, 2013).

As representative geometric variables in the definition of one building they have been considered the number of pillars or columns and the height of the building. For the structural solution of the floors a bidirectional forged or slab structure recoverable coffer with a constant structural depth has implemented, but modifying the interaxis (Moretti, 2014; Poluraju *et al*, 2012; Porwal and Hewage, 2012).

This range of solutions is made by using three elements mainly: Concrete, steel and formwork elements.

2 Proposed Methodology

The proposed methodology focuses on assessing the economic impact incurred in the process of building a reinforced concrete structure assuming that the reticular forged recoverable coffer is selected for the horizontal structure. This choice is not accidental because, it presents some remarkable features:

- Materials incorporated to the structure are permanently only two, in this case steel and concrete. In all cases it is used concrete HA-25/P/20/IIa and steel B-500S.
- In this case the difference in the performance of each alternative is faithfully reflected in the variation of the quantities consumed of steel and concrete.
- The use of recoverable coffer.

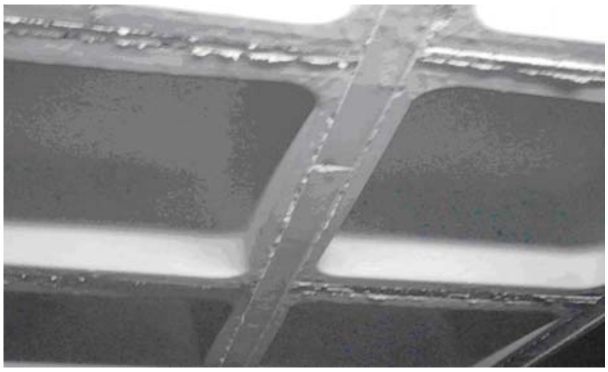

Figure 1. Final result after removal of the provisional formwork.

To execute these structures, once consolidated the pillars, a framework is used (Figure 1). Once the structure consolidates these elements are retrieved and used in subsequent structures. For the assessment of costs it is important to establish the number of uses. In this paper this variable is 50.

Obviously the cost of a structure will be lower when the material consumption are optimized (reducing the amounts of concrete and steel) and the use of formwork materials and labor.

The proposal is to make the modeling of a square building of dimensions 24x24 meters using different arrangements of columns and number of plants (Figure 2). For the arrangement of pillars three values of the grid have been selected: a situation of short lights of 4x4 meters, another common situation in building alternative of 6x6 meters, and 8x8 meters with overhead lights. The modeled cases include 4 floors, 6 floors, 8 floors and 10 floors. The buildings have a height on the ground floor of 4 meters and the rest of floor slabs with heights of 3 meters, devoting the last forged to a flat roof.

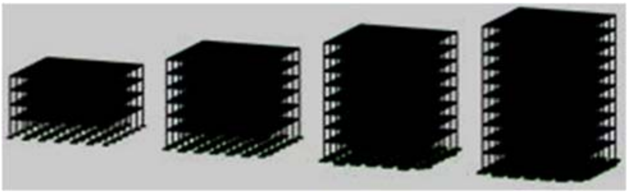

Figure 2. Modelling buildings.

All the floors have been solved using a structural depth of 30 centimeters (25 of box more 5 cm of compression layer). The distances of the models are varied using two discrete solutions of 60 and 80 centimeters (Figure 3), the width of nerve and the coating remained constant. Thus the own weights of the two alternatives of the implemented floor slab are 4.70 kN/m^2 and 4.03 kN/m^2 respectively.

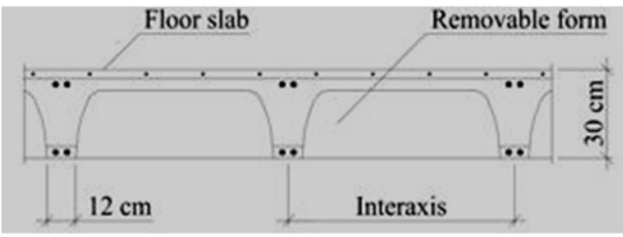

Figure 3. Alternative sections of implemented floors.

Regarding the considered loads, facade loads have been introduced as uniform loads on the perimeters of the floors with a value of 7 kN/m, and on deck this value is reduced to 3 kN/m. For surface loads on the floors 2kN/m^2 has been considered for permanent loads and 2kN/m^2 for overhead use. In the cover these values have changed, 3 kN/m^2 for permanent loads and 1kN/m^2 for overload use. Wind loads were implemented considering the Spanish legislation and snow loads are included in overload considered indoor use. For dimensioning the foundation, it has been considered an average benefit in the soil bearing capacity, on the maximum permissible stress, 0.2 N/mm^2.

Table 1. Unit Cost Items Considered.

Description	Cost (€)
m² System formwork foundation plinth.	19.94
m² lean concrete layer (thickness 0.1 m).	10.22
m^3 foundation of reinforced concrete, concrete made with HA-25/P/20/IIa manufactured in plant, and discharge from truck.	104. 70
Reinforcing steel kg UNE-EN 10080 B 500 S, developed in industrial workshop. Including transportation and placement work.	1.00
m^3 of concrete for pillars made of concrete HA-25/P/20/IIa manufactured in central and poured with cupolas, assembly and disassembly of reusable formwork system metal sheets.	349.65
Reticular m², total depth 30=25+5 cm, made with concrete HA-25/P/20/IIa manufactured in central; discharge with pump on continuous formwork system; nerves "in situ" 12 cm, welded wire in compression layer. No impact of pillars.	37.60
Unites of recoverable formwork PVC, 76x80x25 cm for 50 uses, including special pieces.	2.29
Unites of recoverable formwork PVC, 56x60x25 cm for 50 uses, including special pieces.	1.75
m^3 of concrete for slabs manufactured in Central HA-25/P/20/IIa.	76.88

The definition of the structure will be made following the Spanish legislation and using a structural calculation software tool named CYPECAD. Performing calculations provides data on the consumption of materials, which in the selected type represent significant values used in the comparison. By using a database of construction, the prices of each of the studied alternatives are obtained.

Table 2. Items Considered for Each Block Of The Structure.

	items	units
foundation	Cleaning concrete HL-15 / P / 20	m ^{3}
	Reinforcing steel B 500 S	kg
	Concrete HA-25 / P / 20 / IIa	m ^{3}
	Shuttering fundation	m ^{2}
columns	Column formwork	m ^{2}
	Reinforcing steel B 500 S	kg
	Concrete HA-25 / P / 20 / IIa	m ^{3}
floor	Formwork wrought	m ^{2}
	Reinforcing steel B 500 S	kg
	Concrete HA-25 / P / 20 / IIa	m ^{3}
	boxes	units

The cost of the structure is divided into three sections: foundation, pillars or columns and floor. This scheme follows the construction process, and the prices for the various items are presented in Table 1.

These prices combined with the results of consumption of each alternative allow us to obtain the costs of the proposed solutions. Table 2 lists the items that are incorporated in each block with the units used.

Table 3. Consumption Obtained for Each Solution

			consumption Foundation				*consumption pillars*			*Forged consumption*		
I (cm)	**R (mxm)**	**H (nº)**	**HL (m^3)**	**Fe (kg)**	**HA (m^3)**	**E (m^2)**	**E (m^2)**	**Fe (kg)**	**HA (m^3)**	**Fe (kg)**	**HA (m^3)**	**C (Ud)**
60	4X4	4	15	2196	55	125	694	4238	51	16213	537	4224
		6	23	3761	116	210	1011	7040	75	24841	805	6336
		8	32	6347	238	368	1341	11573	100	34570	1073	8448
		10	41	1068	366	499	1674	22563	126	46543	1341	10560
	6x6	4	14	2660	96	151	360	3507	27	23555	497	5184
		6	22	5307	201	260	539	8792	42	37219	746	7776
		8	30	9095	307	344	736	16570	60	53793	994	10368
		10	38	11921	397	396	965	24209	85	75531	1242	12960
	8x8	4	14	3659	143	182	250	5538	21	40697	492	5272
		6	22	6752	232	236	383	13554	34	63716	738	7908
		8	31	11011	356	307	541	20154	52	91923	984	10544
		10	38	14444	463	356	720	27793	76	125531	1230	13180
80	4X4	4	16	2279	62	137	694	4238	51	16544	576	1512
		6	24	4149	127	226	1011	7350	75	25603	864	2268
		8	33	6389	264	402	1347	12259	101	36131	1151	3024
		10	42	11294	372	503	1678	23405	127	49036	1439	3780
	6x6	4	14	2385	89	145	360	3284	27	21524	451	2820
		6	21	5007	186	249	539	8409	42	34075	677	4230
		8	29	8314	293	335	733	15580	60	50216	902	5640
		10	37	11400	376	385	957	26114	83	70901	1128	7050
	8x8	4	14	3329	137	176	250	5322	21	39751	446	2880
		6	21	6618	217	228	385	12518	34	63391	669	4320
		8	29	10405	333	297	534	19485	51	91053	892	5760
		10	37	13885	446	347	713	26657	74	124024	1115	7200

Table 4. Costs of Different Structural Proposals

I (cm)	**R (mxm)**	**H (nº)**	**€ Foundation**	**€ Pillars**	**€ Slabs**	**€ Structure**	**€/m²**
60	4x4	4	12.006	22.227	153.676	187.910	79,6
		6	22.359	33.253	231.036	286.648	80,9
		8	41.832	46.681	309.484	397.997	84,2
		10	53.482	66.776	390.169	510.427	86,4
	6x6	4	17.238	13.021	159.665	189.924	80,4
		6	33.829	23.554	241.381	298.765	84,3
		8	51.199	37.703	325.983	414.885	87,8
		10	65.340	53.866	415.772	534.979	90,6
	8x8	4	23.751	12.783	176.604	213.138	90,2
		6	38.042	25.428	267.555	331.025	93,4
		8	57.571	38.350	363.709	459.630	97,3
		10	73.916	54.227	465.260	593.403	100,5
80	4x4	4	13.142	22.227	153.081	188.450	79,8
		6	24.388	33.563	230.408	288.360	81,4
		8	45.407	47.703	309.187	402.296	85,2
		10	64.508	67.870	390.341	522.720	88,5
	6x6	4	16.051	12.798	151.484	180.333	76,3
		6	31.572	23.140	229.006	283.717	80,1
		8	48.681	36.521	310.108	395.310	83,7
		10	62.185	55.289	395.787	513.261	86,9
	8x8	4	22.591	12.567	169.490	204.647	86,6
		6	36.097	24.518	257.979	318.594	89,9
		8	54.148	37.247	350.499	441.894	93,5
		10	71.244	52.629	448.337	572.209	96,9

3 Objective

The main objective is to have a vision of the cost of the entire structure. The inclusion of three variables will allow to compare different alternatives and select the one that is most viable from the economic point of view.

The novelty lies on the inclusion of variations in the geometry of the building (arrangement of the pillars and building height) combined with the definition of the structural solution used (forged 60x60 and 80x80 centimeters interaxis).

To facilitate the monitoring of the cost of the structure it has been divided into three blocks with a different treatment. The foundation with four blocks for the lean concrete, steel foundation, structural concrete and formwork needed. The pillars are elements with a production process in which the cleaning concrete disappears, repeating the previous three blocks and presenting totally different yields.

4 Case study

Performing calculations by regulations currently in use in Spain determines the technically viable alternatives. From those viable solutions, material consumption are found: steel, concrete and auxiliary elements (formwork and caissons) at different values for each block of the structure; the data are reflected in Table 3. The modeling analysis allows controlling deformations and adapting the optimal arrangement of the structure, all rigorously complying with current regulations.

Known data set consumption and prices of each item can determine the cost of each alternative as reflected in Table 4.

The production cost is done add the amount of each item. In this case we have taken into account the variations in consumption of both materials and auxiliary means necessary.

The total cost of the structure has been obtained and the graphical representation of the results is divided into two blocks. Figure 4 represents the impact of each block in each studied alternative.

For this configuration of the floor inside buildings of four floors, solution employing fewer supports (8x8) has a total cost that is 13.43% higher than the alternative with the highest number of supports (4x4). In the case of solutions for buildings of 10 floors this difference becomes greater resulting in a 16.26%. If we analize the results in regard to the foundations these values are completely different in low buildings since the cost of the foundation is increased by 97.83% whereas in tall buildings the decreased number of pillars an increase of 38.21%. Reducing the number of supports makes the starting pillars decrease.

With 60x60 interaxis configuration total costs increase as the number of carriers it is reduced for all modeled buildings.

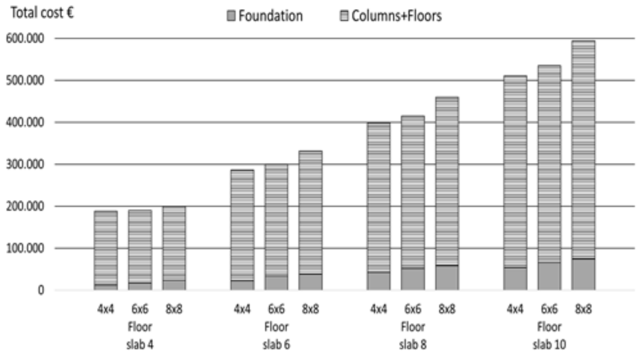

Figure 4. Total cost alternatives interaxis 60x60.

The results for structural solutions that employ larger interaxis (80x80) are shown in Figure 5.

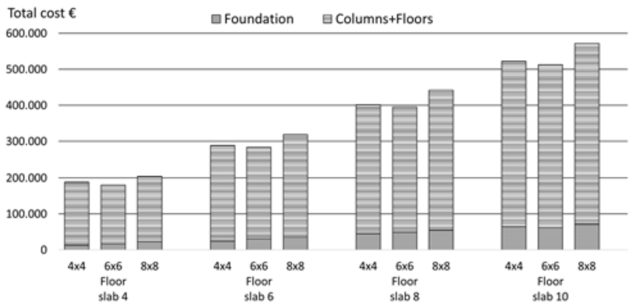

Figure 5. Total cost alternative interaxis 80x80.

For this configuration of the floor inside buildings of four floor employing fewer supports (8x8) has a total cost which is 8.59% higher than the alternative with the highest number of supports (4x4). In the case of buildings of 10 floors this difference becomes greater resulting in a 9.47%. If we analyze the results in regard to the foundations these values are completely different in low buildings since the cost of the foundation is increased by 71.90% whereas in tall buildings the decreased number of pillars drives to an increase of 10.44%. Reducing the number of supports makes the starting pillars decrease and the cost of the slabs being greater increases in recent increases.

This configuration of the floor, increasing the interaxis, allows better solutions in total cost when the 6x6 grid for the same height of the building is implemented. In the four heights minimum cost values are obtained.

Solutions with more supports (4x4) have similar costs for both interaxis being lower in 60. The differences are below 2.40%. Solutions with fewer brackets (8x8) costs are similar, being lower in 80. The resulting differences are extended below 4.01%.

While these results are interesting, we consider much more relevant to compare the ratios of the structural solution. In this case the cost per executed square meter is analyzed, and the numerical results are reflected in the last column of Table 4, while graphical results are presented jointly for both interaxis in Figure 6.

The extreme values have a variation of 31.72% and are:

- The minimum cost 76.3 € / m2 for a building of 4 heights with me interaxis 6x6 grid 80 cm.
- The maximum cost 100.5 € / m2 for a building of 10 heights with me interaxis 8x8 grid 60 cm.

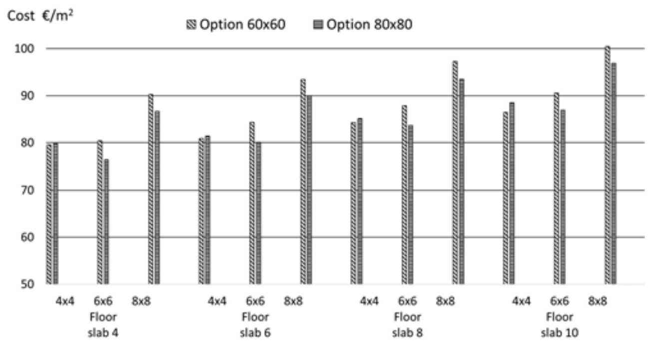

Figure 6. Ratio of cost € / m2 different alternatives.

Interaxis solutions by 60 cm range from 79.6 € / m2 for buildings of 4 heights and 4x4 grid to 100.5 € / m2 in the case of 10 heights and 8x8 grid. This is a variation of 26.26%. For proposals by interaxis 80 cm range from 76.3 € / m2 for buildings of 4 heights and 6x6 grid to 96.9 € / m2 in the case of 10 heights and 8x8 grid. This is a variation of 27.00%.

5 Conclusions

As a preliminary conclusion, it is noteworthy that variations make that the results present significant oscillations. The own reinforced concrete structural definition incorporates decisions affecting the cost produced in the design phase and implementation.

The tool implemented here is very useful when combined and incorporated the cost or impact of the land on which it is intended to build. The combination of both values allows the designer to locate a lower cost alternative.

Disregarding the impact of the land, and for a structural thickness of 30 centimeters, the most economical solutions are located in low buildings of 6x6 meters grid and interaxis distances of 80 centimeters. The worst alternative is located when employed 60 centimeters interaxis and reticles of 8x8 meters.

Structurally, the 30 centimeter thickness is oversized for reticles of 4x4 meters and it presents very high amounts of steel for reinforcement grids of 8x8 meters. This is the reason why the best solutions appear in the grid of 6x6 meters. This phenomenon is more pronounced when increasing the interaxis distances. This is one of the reasons why this is the most used structural thickness in structures in buildings in Spain.

This novelty presents a clear practical application to real cases, since the casestudy has been selected only as a way to present the proposed methodology based on the ratio of cost per square meter executed, but the methodology is widely applied to real cases. In fact, this piece of research is based on the information obtained from thousands of real cases, from a building interprise, which have also been used to validate the proposal.

Furthermore, the use of the results of this work by the designer permits the optimization of the decisions based on the conclusions obtained in the general case.

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