MODELING OF ALTERNATIVES FOR IN SITU UNIDIRECTIONAL SLAB

Esteban Fraile-García[(a)], Javier Ferreiro-Cabello[(b)], Eduardo Martínez-Cámara[(c)]

[(a)] University of La Rioja. Mechanical Engineering Department. EDMANS Group
[(b)] Qualiberica SL and University of La Rioja. Mechanical Engineering Department
[(c)] University of La Rioja. Mechanical Engineering Department

[(a)] estean.fraile@unirioja.es, [(b)] ferrecabello@yahoo.es, [(c)] eduardo.martinezc@unirioja.es

ABSTRACT

Slab is an element in which we consider basic criteria that structures, like any other human ingenuity, must satisfy: functionality, safety, economy and aesthetics. Technological developments have provided us with materials with high resistant performance level, appearing simultaneously concepts such as recycling or additional benefits of comfort (acoustic, thermal, fire resistance ...). This piece of research focuses on the case of unidirectional floor fully implemented on site, usually called "In Situ", and analyses the combination of such important criteria..

Keywords: slab, environmental impact, multicriteria selection.

1. INTRODUCTION

Slab is an element in which we consider basic criteria that structures, like any other human ingenuity, must satisfy: functionality, safety, economy and aesthetics. The basic criterion of structural functionality (stiffness) is combined with additional ones, such as the environmental impact (Elduque et al, 2014), ease of maintenance and management, recyclability (Jimenez et al, 2012), etc., which become more important added in more developed economies. Clearly, the relative importance of each of the criteria depends on the type of concerned structure.

This piece of research focuses on the case of unidirectional floor fully implemented on site, usually called "In Situ". This type of unidirectional floor has as main characteristic the absence of prefabricated structural elements. In this case the nerve of the child element is set to work with deformed bars, if necessary reinforcement is placed to withstand extreme shear. The other components are the usual lightening element (vaults in different materials), mesh in the compression layer and negative reinforced.

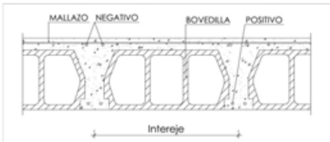

Figure 1 Unidirectional slab with in situ nerve

This configuration is quite wrought more flexible than those using prefabricated elements. In this case starting from a lightening element of constant width (56 centimeters) can be set different widths nerves and compression layers.

Moreover environmental issues become relevant in recent years and there are new concepts such as sustainable construction (Martinez et al 2009a, 2009b, 2010). In the shadow of the different ways that concept are established to quantify the environmental impacts of human activities on consumption (Azofra et al 2014a, 2014B) and its production. Carbon Footprint and Life Cycle Analysis (LCA) as parameters to measure these impacts; both values are used routinely. The carbon footprint is to quantify the total greenhouse gas (GHG) emitted by direct or indirect effect of a product / service or organization as a whole (eg CO2, methane, HFCs, sulfur hexafluoride, etc.). Determining the carbon footprint continues to be a study of Life Cycle Assessment (LCA) which calculates and considers only a single category of environmental impact, the Global Warming, whose measurement units are kg of CO2 equivalent (Evans 1994) (Armengou et al 2012) (Baldo et al 2002).

Global warming is an environmental impact category that has gained great importance in recent years. In this study the impact of CO2 equivalent emissions for various alternative unidirectional slabs (Carrascón et al 2007) CTE, EHE-08, EN 2006a, 2006b, 2012) (Danatzko et al 2013) is identified. This piece of information is added to the structural performance of different alternatives providing useful additional information for making correct decisions (Fernandez-Ceniceros et al 2013) (Ferreiro-Cabello et al 2013a, 2013B, 2013c, 2013d).

2. METHODOLOGY

The research methodology focuses on the analysis of structural performance and CO_2 emissions for the case of one-way (unidirectional) slabs executed in the work (in situ). The materials incorporated into the study alternatives are reduced to three, lightening elements, steel and concrete (Jönsson et al 1998) (Monahan and Powell 2011).

Starting from a base geometry for the lightening element and changing the other geometrical parameters to incorporate, the case study (Reza et al, 2011) (Ximenes and Grant 2013) are defined.

24 geometric arrangements in which we vary the structural depth between 15 and 40 centimetres are modeled. These geometric arrangements record three different rib widths (12/14/16 cm), four depth of regular slabs (15/20/25/35 centimetres) and two compression layers (5/10 centimetres), to determine a variation of the resistant section (% SR) which runs from the maximum of 53.33% to 29.41% minimum. This percentage represents the amount corresponding to the reinforced concrete section compared to the total.

The implementation of the cases using lightening materials of vibratory concrete and polystyrene foam, incorporates solutions with distinct structural impacts and response.

This structural element is modeled on a primary beam structure. For the analysis of the responses of the floor, it was considered a means and constants for the consumption of concrete and steel structure of this primary values. With the usual loads in buildings, wide beam (primary structural element) of 60 centimeters and a consumption of 11 kg Fe/m2. The evaluation is made for discrete cases 4, 5, 6 and 7 meters span slab to visualize the results according to level of structural stress.

From these changes in geometry, materials and lighting calculation a total of 192 models were obtained. The charges referred to are constant and correspond to 2.5 kN/m2 for dead loads and 2 kN/m2 for overhead use.

Structural analysis of different solutions is performed discarding those that do not comply with regulations. For structural analysis alternatives are modeled by CYPECAD software. Assumptions for calculating are made both for "Ultimate Limit States" (ELU) and for "Serviceability Limit States" (ELS), complying with regulations of the Technical Building Code (CTE).

Defined dimensions, materials, loads, and assumptions, to determine the next step we must calculate the 192 possible solutions through professional program for calculating concrete structures, CYPECAD. The analysis of the stresses is performed by a calculation in 3D space by stiffness matrix methods, with a model consisting of all the elements that define the structure: columns, beams and slabs.

Compatibility of deformations at all nodes is established, considering 6 degrees of freedom, and the indeformability of the plane hypothesis of each plant is created to simulate the rigid behavior of the floor, preventing relative displacements between its nodes (rigid diaphragm) . Therefore, each plant can only rotate and move as a whole (3 degrees of freedom).

For all charge states a static calculation is performed (except when considering earthquake dynamics actions, in which case the spectral modal analysis is used) and a linear material behavior is assumed and therefore, a calculation of the first order, in order to obtain displacements and efforts.

Through this structural analysis, the different armed elements are defined according to the stresses in each of the sections, applying the rules of Spanish concrete currently in force (EHE-08). Our objective is not to stop at this point, but trying to assess and compare the structural performance of each alternative studied. For this, stiffness is selected as the most significant parameter.

In engineering, the stiffness is the capacity of the structural element to withstand stresses without acquiring large deformations and / or displacements. Therefore, if we control the deflections and deformation we will know how rigid the structure is. In reinforced concrete constructions in which the deformation of the considered as structural elements can affect those considered as non-structural, it is necessary to control the values of active and total deflection at infinite time in these structural elements.

Active deflection of a structural element referred to one damageable as nonstructural means hath deflection occurs in the first from the existence of the second one.

The total deflection at infinite time is the deflection obtained as the sum of the active deflection more deflection developing the structural element (slabs, beams ...) until the moment of the construction of damageable element (partitions, walls, party walls ...).

Since the active deflection is what causes the damage to nonstructural elements, it has been selected as a parameter for the evaluation of different alternatives.

Given current regulations EHE-08 and CTE-DB-SE as to the limitations of time, we have considered to take the following in our research: limitation of deflection active for one-way slabs: FAct = L/500 or L/1000 FAct = +0.5.

Additionally, in all cases it has been considered a limit deflection at infinite time: Inf FPlazo +1 = L/500 or L/250.

The numerical value of the active deflection in centimetres allows comparison between different alternatives by determining the degree of goodness of the solution in order to stiffness.

The construction, like any other activity of human character, has effects on the environment with which it interacts, as it requires a significant amount of resources and energy.

The environmental impact of different proposals was evaluated according to the CML methodology and software package SIMAPRO. The research details the construction sector are incorporated by Spanish databases (BEDEC-CYPE) and a more extended and specific stroke worldwide (ECOINVENT), complementing all this information with EPD.

From a scientific point of view, academic analysis suggests the use of CML and to compare the results of impact categories, these being those shown in Table 1 with their respective units.

Impact category	Unit
Abiotic depletion	kg Sb eq
Global warming (GWP100)	kg CO2 eq
Ozone layer depletion (ODP)	kg CFC-11 eq
Human toxicity	kg 1,4-DB eq
Fresh water aquatic ecotox.	kg 1,4-DB eq
Marine aquatic ecotoxicity	kg 1,4-DB eq
Terrestrial ecotoxicity	kg 1,4-DB eq
Photochemical oxidation	kg C2H4
Acidification	kg SO2 eq
Eutrophication	kg PO4--- eq

Table 1 Impact categories depending on CML

As the ultimate goal is to compare different solutions, the task of comparing these 10 CML categories separately for the 192 solutions and obtaining optimal solutions is neither trivial nor recommended. The Global Warming (GW equivalent CO2 emissions) category is selected as the representing one.

For the development of the LCA a division in main structural components of the proposed solution is established, which allows to incorporate the contribution of each of the components at different stages of the life cycle, from cradle to grave. To achieve this goal the manufacture of the components is taken into account, and the transport to site, installation and assembly, and processing of the waste at the end of its useful life.

The functional unit is considered one m2 structure executed in reinforced concrete, being outside the limits of field of study the following activities: foundation, auxiliary transport elements within the work, different residential uses, values of operations that are constant in the construction process, and final dismantling of the structure of its useful life.

During the development of life cycle inventory, and to facilitate the final calculation of the environmental impact associated with each of the different structural solutions raised, a division in three main components has been established: rebar, concrete and lightening elements.

With this parameterized information on the basic components of the studied structural solutions, assigning a numerical value to the environmental impact produced by each solution is achieved, in this case the Global Warming (GW Emissions of CO2 equivalent). With this value we can compare the different solutions from the point of view of environmental impact.

At this point we have a database in which the amounts of materials used for each alternative and its benefits in stiffness are reflected, as a result of the structural analysis. Moreover we know the CO2 emissions produced by the realization of the solution proposed, as a result of environmental analysis. From this database, we can graph the results as reflected in the following section.

3. RESULTS

The presentation of the results using graphs includes information corresponding to each material emissions, and the structural response of the solution. This is repeated for each of the studied span, which represent different levels of structural stress.

The representation presents on the vertical axis the value of the equivalent CO2 emissions in kg. This information is presented fractionated, making possible to appreciate the emissions from each of the elements of the slab. For each case the top reports the stiffness value in centimeters.

Meanwhile on the horizontal axis the percentage of resistant section and the summary of the case definition for forging are presented. The option of using lightening concrete vibratory element (H) or expanded polystyrene (P) are shown in each case. A specific case is illustrated in Table 2.

%SR	29,41%	H
Bov+CC Intereje	30+5 68	P

Table 2 Identification of slab and resistant section percentage

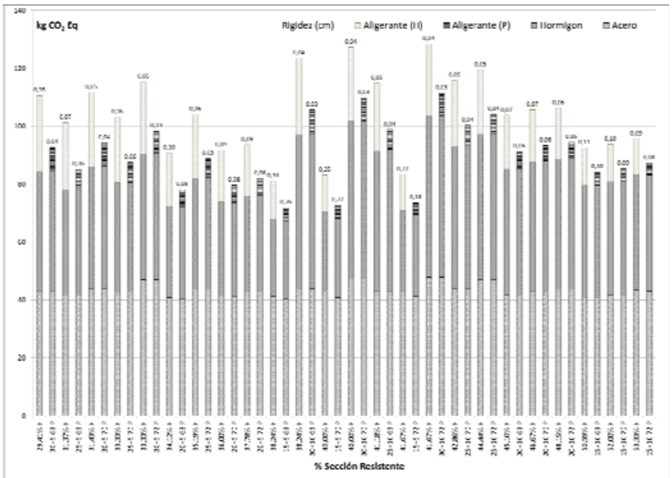

Figure 2 Results of Stiffness/Emissions (4 meters span slab)

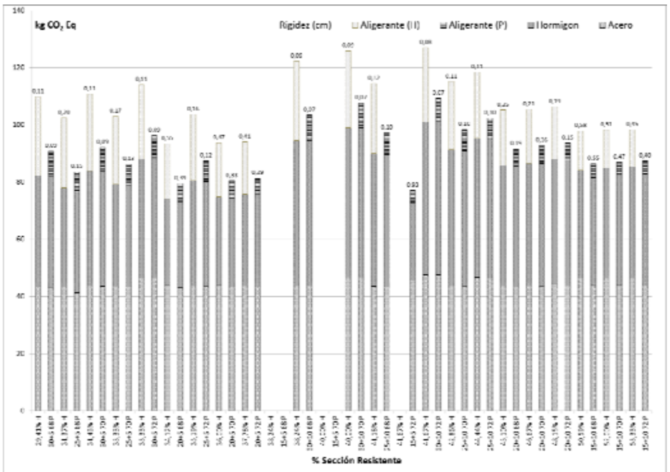

Figure 3 Results of Stiffness/Emissions (5 meters span slab)

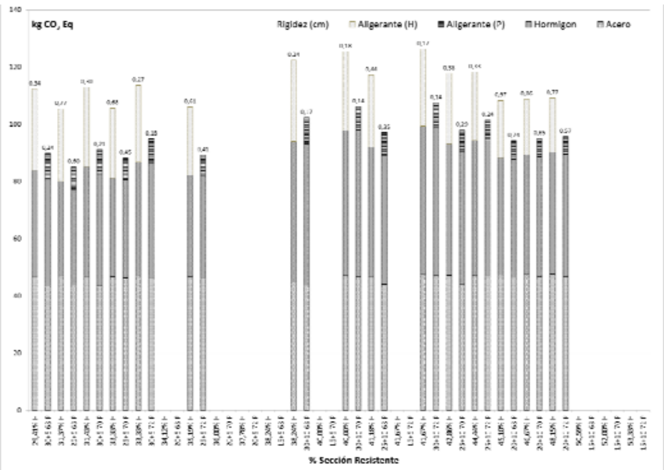

Figure 4 Results of Stiffness/Emissions (6 meters span slab)

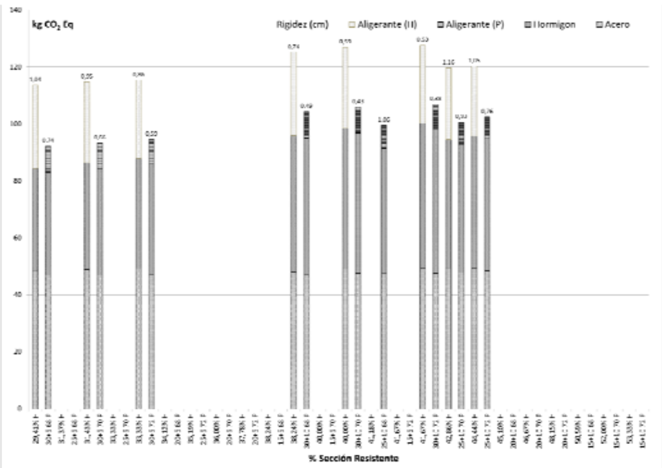

Figure 5 Results of Stiffness/Emissions (7 meters span slab)

For the case of low beams (four meters), given the level of stresses, 100% of cases are technically feasible. Solutions with lower CO2 emissions correspond to the configuration of 15+5 68 using both vibratory as expanded polystyrene concrete with total emissions of 81.26 and 72.02 kg CO2 Eq/m2. Emissions steel used for the same values ranging from the difference in emissions attributable to lightening element. In the section of the proposed stiffness, options with lower emissions cause major deformations, in this case 0.26, and 0.34 using expanded polystyrene if raised by lightening of vibratory concrete. Minimum deflexion provides similar results being 0.03 (P) and 0.04 (H) the estimated values (Figure3).

In the case of five meters span an increase in the level of the stresses is produced, and slabs of 20 centimeters of total depth are viable only using expanded polystyrene and 16 inches wide rib lightening element. Solutions with lower CO2 emissions are: a configuration 15+5 72 using expanded polystyrene with total CO2 emissions of 77.06 kg Eq/m2 and 20+5 68 configuration using vibratory concrete with total emissions of 93.42 Eq/m2 kg CO2. The emissions for the steel used in this case are lower in cases (P), equaling slightly on the high ridges. Regarding stiffness the options with lower emissions assume major deformations, in this case being 0.93, and 0.55 using expanded polystyrene, if raised by lightening of vibratory concrete. Minimum deflection provides similar results, being 0.07 (P) and 0.08 (H) with 109.29 and 127.02 emissions respectively (Figure 4).

In the case of six meters span it occurs a further increase in the level of stresses, and technically viable slabs are reduced to 62.5% of the initial options. Solutions with lower CO2 emissions correspond to the configuration 25+5 68 using both vibratory as expanded polystyrene concrete with total emissions of 85.14 and 105.53 kg CO2 Eq/m2. The emissions for the steel used in this case have a lower swing, only 2.91 kg of CO2 emitted in cases (H) and 3.53 in cases (P). Regarding stiffness, the options with lower emissions assume major deformations, in this case 0.74, and 1.04 using expanded polystyrene if raised by lightening of vibratory concrete. Minimum deflection now presents similar results, being 0.14 (P) and 0.17 (H) with 107.50 and 126.28 emissions respectively (Figure 5).

Finally, in the case of seven meters span, an extreme level is presented for the stresses, and technically feasible slabs are reduced to 35.4% of the initial options. Solutions with lower CO2 emissions correspond to the configuration of 68 to 30+5 lightening the two materials, with total emissions of 92.26 and 113.63 kg CO2 Eq/m2. The emissions for the steel used in this case have a lower swing only 1.6 kg of CO2 emitted in the cases H (47.9 to 49.5) and 1.75 where P (46.75 to 48, 5). Regarding stiffness, the options with lower emissions assume major deformations, in this case 0.74, and 1.04 using expanded polystyrene if raised by lightening of vibratory concrete. Minimum deflexion now shows different results being 0.38 (P) and 0.53 (H) with 106.91 and 127.72 emissions respectively.

4. CONCLUSIONS

This research reflects on alternatives for one-way slabs in situ concrete structures, justifying the need for further multi-methods as decision making support. The current means and techniques of modeling and simulation allow us to incorporate existing metadata in the planning stages.

The conclusion from this study is that, as the stresses increase, solutions with lower emissions are achieved by decreasing the resistant section (singing increases without increasing widths nerve).

Indeed the rigidity optimum and the emission optimum do not match. It is necessary to implement selection algorithms to obtain the best definitions for each level of stress.

Emission of 1 kg of expanded polystyrene are greater than 1 kg of vibratory concrete. But incorporating lightening elements, less densely, derives in lower emissions caused in cases (P).

With the increase in the stresses, the system moves to higher emissions and lower rigidities. This phenomenon is more pronounced in cases (H) due to the weight of the implemented solutions.

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