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OPTIMIZATION OF TECHNICAL SOLUTIONS TO ACHIEVE THE REINFORCED CONCRETE SLAB FLOORS THROUGH NUMERICAL SIMULATIONS

BY

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Abstract. Widely use of reinforced concrete frame structures highlights the elements study of this structure type. Analysis of reinforced concrete slabs is supported by technical and economic objectives that aim to obtain innovative and feasible solutions. In this respect, the solution of hollow voided slabs is analysed in comparison with classic slab floor, stating the advantages and disadvantages of these two solutions. Previous testing and study of these variant represent another factor to be achieved in terms of technical and economic efficiency. Modeling the behavior of the structure using the simulation of analytical model by computer represent the best solution in this regard, offering a variety of load combinations and types and sizes coming to provide data needed improvement. Economic efficiency of these testing solution and almost no environmental impact, fewer people involved in the development of modeling support and validate the current trend in scientific research, of analytical simulation.

Key words: reinforced concrete slabs; technical-economical performance; project management.

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1. Introduction

Construction domain, throught the work and the objectives sought, contain a substantial part of the testing and analysis of technical solutions before their implementation. Technological development and modern tools of research brought to the fore testing numerical models using computing units in parallel with experimental work in laboratories.

In terms of sustainable development, taking into account that the European construction sector produces about 25% of the total waste produced for one year, reducing this percentage by adopting analytical simulation is a great advantage for construction.

Increasing structural complexity and architectural construction in decades has led to the evolution of computers and thus to widen the approach to problems, from simple applications exclusively assess stresses and strains in complex software packages to address by numerically problems with high level of difficulty.

Using computers to solve mechanics construction problems caused important changes in concept regarding structures design. In the new conditions design engineer was released the high volume of calculations, being able to focus on optimizing constructive solutions.

Progress in recent years on the development of software used in engineering and especially in construction make possible to provide accurate information regarding the behavior under load and the reinforced concrete structures.

In literature domain is mentioned using computer assisted modeling in construction since 1987 (Hojjat, 2012). Today, research centers preponderant organizes its work based on computer-aided simulation.

Optimization in an analytical way of resistance structures is a difficult process because the range of time to be spent analysing several possible options for the same structure.

2. Impact of Reinforced Concrete Slabs Simulation Type on Development Costs

The theory and practice evolution of construction led to the development of new concepts for engineering calculations used to define and verify various technical solutions.

Studying the behavior under load of reinforced concrete structures involves conducting theoretical and experimental activities with the final purpose to ensure the safety of constructed structures. The two ways of dealing with construction safety are mutually dependent, as any scientific experiment is performed based on analytical results obtained by previous stages, the experimental values serving to confirm or refute the conclusions resulted from the analytical calculation.

We analyse the costs of achieving experimental simulations to model concrete slab floor, divided into three parts: *the cost of material, labor costs* and *the cost of the test equipment*. To perform this analysis experiments were undertaken both physical and analytical models.

To highlight the development costs of experimental tests are proposed for consideration two types of concrete floor slab.

2.1. Analysis of the Development Costs of the Experiment on Different Slabs Models

The analysis is made for the case of a reinforced concrete slab with a surface of 18.450 × 18.450 m plan and 0.23 m thick, divided into four equal areas in size (9.00 × 9.00 m) (Fig. 1), which were objected that cover project costs, duration of the project, feasibility and environmental impact. Is performed a budget comparison necessary to achieve an experimental test of an full slab and a slab with spherical voids, according to values presented in Table 1.

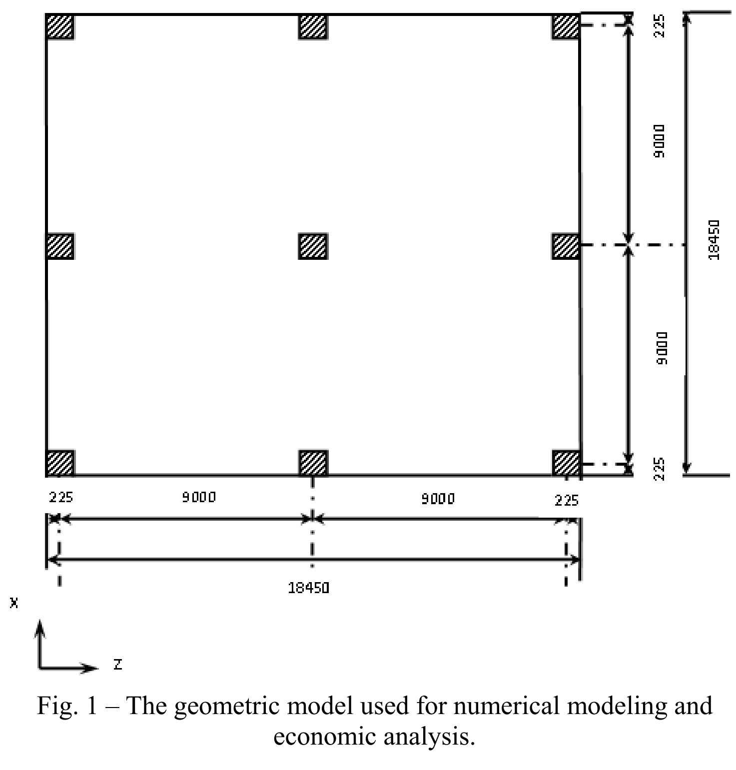


Fig. 1 – The geometric model used for numerical modeling and economic analysis.

Table 1
Voided Slab Compared with Full Slab

The type of floor and interpretation of results		Quantities of materials required			Labor RON	Implementation cost RON
		Concrete m^3	Reinforcement kg	Formwork m^2		
1	Full slab	88.96	10,296	516	15,063.146	87,054.069
2	Spherical voids	84	6,113	466	13,079.323	78,774.340
Benefits 2 *vs*. 1		– 5.51%	– 40.62%	– 9.70%	– 11.00%	– 9.51%

In terms of the budget required for experimental tests analysed in Table 1, there is a decrease of 9.51% of voided slab compared to full slab. The representative percentages of reducing the materials quantities show that the proposed solution can be considered both economically and environmentally efficient.

Of course, these results certify the advantages of the proposed solution for the experiment preceding its implementation. Comparing budget required any technical solution for experimental testing with the one necessary for analytical testing, are listed below in § **3**.

3. Advantages and Disadvantages of Numerical Simulation by Comparison with the Experimental Testing

From structural elements of reinforced concrete buildings, the floors togheter with columns, load-bearing walls and foundations should reflect best constructive solutions, which previously requiring testing.

The size and characteristics required by technical solution implemented by the model analysed, the financial impact and resource consumption for their physical simulation, is alongside environmental impact, basic criteria in adopting numerical simulation or physical.

Advantages of virtual experiments as compared to those phisycals are numerous and undeniable (Marin, 2002)

a) reduction of material costs by eliminating costs of physical execution of the experimental program (realizing the resistance structure, purchasing the necessary equipment, etc.).;

b) possibility of studying certain aspects of behavior of resistance structure, which would be difficult or impossible to reveal throrugh physical experiment;

c) capacity to archive large volumes of information for their subsequent use;

d) opportunity to made any and repeat simulations (virtual experiments) in the worst conditions (possibly, until structural failure) by modifying the geometrical characteristics, the load and boundary condition systems and the physical-mechanical properties of constituent materials.

3.1. General Information Regarding the Modeling Concept in Construction

Structure modeling can be done by two methods: experimentally and / or analytically.

a) *Experimental modeling* is an organization methodical, rational and practical, which is for testing structural models with normal or reduced scale, in which case the correlation is based on the similarity laws on geometrical dimensions, constitutive materials and loading system. In other words, the experiment is a situation caused, under well defined conditions, for knowledge structures response to the action of external loads, depending on the influencing factors established in an earlier stage.

The physical model is equipped with equipment and actuars, recording, measuring and processing devices of response parameters (displacement, strain, acceleration). Using experimental program, on which the study is performed, characteristic physical quantities are obtained either by direct measurement (solution adopted when tried is the real model) or indirectly, by creating mathematical processing based on similarity theory, method used for small-scale models (Marin, 2000).

Limiting the opportunities of making experiments on a normal or reduced scale models, due to technical-material difficulties and the need to consider many factors influence has led experts in the domain to develop methods of numerical analysis to determine solutions of the differential eq. that characterize behavior under load of constructions (Marin, 2002).

b) *Mathematical modeling* is an analytical process that involves obtaining the physical-mechanical response parametrs of the structure: displacement, efforts unit (stresses), temperature, speed and so on, which are functions which depends on space and time coordinates.

Determination of unknowns assume existing a mathematical model (analytical), formulated on the basis of three conditions that resistance structure must satisfy: equilibrium conditions (static and / or dynamic), geometric compatibility and physical conditions (the behavior of materials) and at the end of their use resulting the three characteristic eqs. for calculation: of the equilibrium eqs., the geometric (regarding the strain) eqs. and physical eqs.

Taking into account the many technical solutions possible for design of resistance structures, but also the variety and complexity of connections between structural elements, it is necessary to obtain a simplified structural model (ideal model) which will be used to conduct the entire process modeling.

The model is a symbolic representation, developed to simulate and evaluate the behavior of a real system built. It is obtained by schematization of resistance structures and its components as shape, geometric dimensions and constitutive materials. Similarly, internal and external links are idealized, reduced to three basic types supported (simply support, articulation and encastration) and the forces which act the assembly are reduced to known forms, specific to structural calculation (forces and moments concentrated or distributed).

An important condition concerning the imposed physical model is that these must reflect adequately the real system investigated, a prerequisite condition for the results obtained provide accurate information on its behavior in service.

Creation of physical models, which attaches mathematical relationships, aims to better understand the studied phenomena, since it is easily possible to change the physical and mechanical characteristics of the models.

4. The Use of Numerical Experiments in Structural Analysis of Behavior under Load of Slab Floors

Construction research on the behavior under operating loads of reinforced concrete slab type is based on the modeling process (experimental or mathematical) of the studied constructive system. This complex process involves identifying and analysing the influencing factors and their action in the investigated domain so that the resistance structure considered to be fully safe in use. Also, it must satisfy the aesthetic functional and economic requirements, in order to avoid inappropriate elements capable of obtaining leads to excessive consumption of materials and labor, or long-running.

4.1. New Solutions to Achieve Slabs Floor

One of the main objectives in the construction sector is to improve the technical and economic performance through the design and implementation of new structural systems, able to satisfy superior functional requirements and architectural. In this context it is explained the emergence and expansion of slab floors, which have incorporated hallow voids.

There are many such types of floors, design engineers seeking to find rational solutions of floor, according to the technical and economic requirements specific area and period.

Introducing voids in the floor may generate benefits not only technical or architectural but rather economic advantages. The cost for the construction of a building that consists of such floor is significantly reduced by the elimination of a significant amount of concrete in the middle of the plate, most of these construction systems being derived from classical floor systems without beams (full slab).

Design engineers, based on analysis of old systems, have created new solutions for floor, have conducted experimental tests, ascertaining the validity of the assumptions accepted. Finally resulted efficient type of hollow voided floor, which allowed finishing the construction in a shorter time and with a much lower labor consumption.

Worldwide, voided slabs are widely used in various types of construction, regardless the shape or appearance of voids. This is due to technical advantages, economic and architectural as well: fast execution, material economy, the possibility to create floors with large openings from the classic slab systems, reducing the self weight of the floor and possibility to achieve outstanding architectural forms.

Voids embedded in the floor can be grouped according to their shape, into two categories namely

a) voids with regular shape: cubic or spherical;

b) voids with irregular shape: bell-shape.

Theoretical and practical research estimates that the impact of using voided elements will be felt in the near future, especially in our country where their benefits are less known and used.

For this reason it is important to study the behavior under load of these elements, phenomena that develop inside voided plate and identify all the parameters that affect, in one way or another, the response of structures made with these systems. Thus, it is necessary to intensify the experimental study, numerical simulations and mathematical modeling for different conditions and situations that provide important informations and solutions superior to those currently applied.

4.2. Virtual Experiments on New Plate Models

Software evolution gave rise to orientation changes in structural calculation by changing the way of considering the methods for determining linear and nonlinear response of structures. This is achieved by reconsidering old theoretical methods (numerical) analysis and effective implementation by different programming languages, resulting complex software packages that show with high fidelity the behavior under load.

A commonly used method for this purpose is the finite element method, currently existing numerous software analysis justifying the behavior modeling of structures and the determining factors in static response of structures (physical and geometrical nonlinearity, geometrical and mechanical imperfections) with a high precision.

Numerical modeling based on finite element analysis provides flexibility and accuracy, with broad applicability regardless of the element geometry and the boundary conditions.

The central point of any simulation program is the mathematical model which can be different from one program to another depending on its destination, so some may prove to be very accurate for general analysis, but inaccurate for extreme situations.

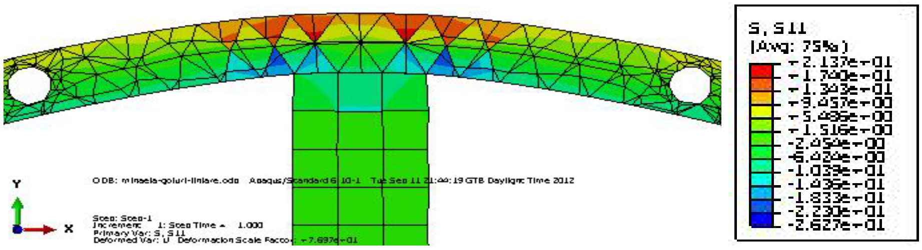
The user must know and master very well the fundamental principles of modeled phenomena, so that the results to be interpreted correctly. It also must ensure that the studied phenomenon may reflect reality by maintaining coherence values and metrics introduced and those obtained by running the simulation program.

Some programs performed automatically maps tensions, others provide only data in tabular form, the user is the one who can put graphics as maps. It is necessary that the results be analysed before being used. This can be done based on intuitive physical analysis of some simple calculations or estimates of additional results provided by the model (model similar situations, intermediate results, etc.).

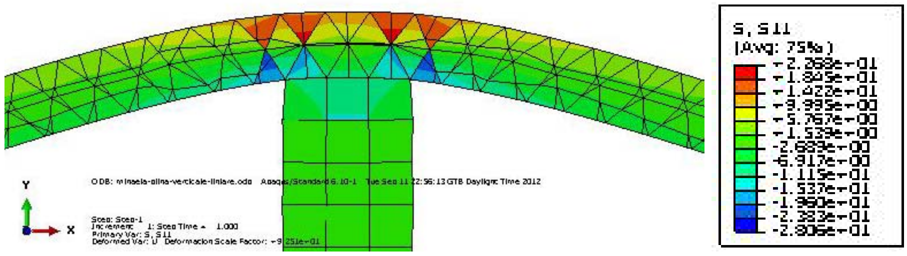
After generating geometric models (establishing of size components, determining the loads applied to each type of structure and identification of the boundary conditions), they are introduced into the simulation program and are running virtual experiments on models of structures, resulting thus chromatic maps of elastic stress and strain for each model, which can be viewed on deformed or undeformed structure.

Numerical simulations in this case aimed to determine the linear response of slab-type elements, considering the elastic properties of materials (weight by volume, γ_v, longitudinal elasticity modulus, E and Poisson's ratio, ν), resulting thus color maps of elastic stress and strain for each model part. Decision to run this type of analysis stems from the motivation that the stage I of behavior (elastic analysis) is used to determine the mechanical characteristics of elements as the concrete is uncracked.

In Figs. 2 and 3 are shown the distribution maps of elastic normal stress σ_{xx} after the directions Ox of the floor described in Fig. 1, considering as model plate a full slab and a spehrical voided slab, requested to both vertical and lateral load. It is specified that, because of the symetry of the structure, the distribution of elastic normal stress, σ_{zz}, after the directions Oz of the floor are the same as σ_{xx} and these maps will not be presented bellow in this paper.

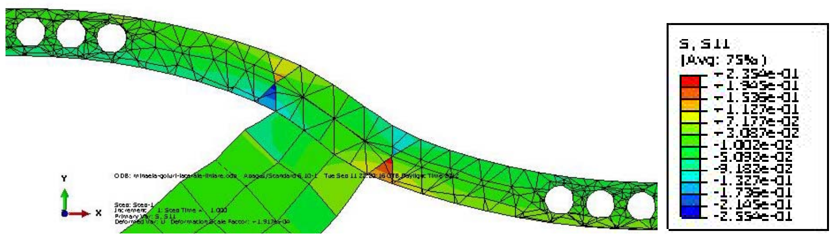


a



b

Fig. 2 – Map of elastic stresses distribution, σ_{xx} , under vertical loads-detail on central column: *a* - voided slab; *b* - full slab.



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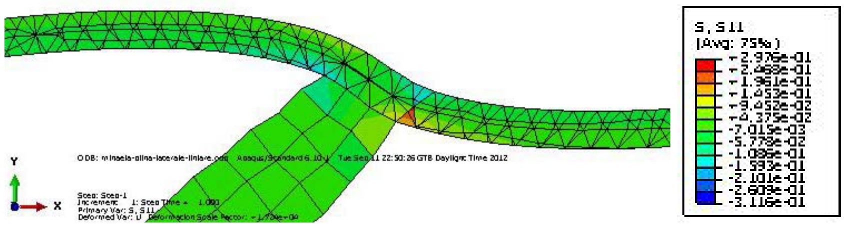

b

Fig. 3 – Map of elastic stresses distribution σ_{xx} under lateral loads-detail on central column: *a* - voided slab; *b* - full slab.

4. Conclusions

Developing computer use and computer techniques for reinforced concrete structures facilitate the study of reinforced concrete slabs in analytical modeling. Variety of combinations of loads and boundary conditions for computer simulation is a first advantage which brings to the fore this method in research.

Experimental and analytical simulation generates economic impact characteristics described in Table 2.

Table 2
Influencing Factors of the Final Cost

Type of simulation	Resource cost					Execution time	Environmental impact
	Materials			Labor	Test equipment		
	concrete	reinforcement	formwork				
A	no	no	no	yes	no	yes	no
B	yes	yes	yes	yes	yes	yes	yes

A – about numerical (analytical); B – experimentally;

Thus is evidenced the tendency sustained in research practice of structures behavior in civil engineering, represented by computer-assisted analytical simulation.

The solution of voided slabs is supported in its widespread use by the advantage of reducing self weight of the buildings, thus seismic force, the economy of materials and labor that are reflected in a reduction of development costs up to 25%.

Study of voided slab solutions using analytical modeling and simulation computer aided through computer programs brings to researcher numerous and various experimental data in order to create great opportunities to research.

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OPTIMIZAREA SOLUŢIILOR TEHNICE DE REALIZARE A PLANŞEELOR DALĂ DE BETON ARMAT PRIN SIMULĂRI NUMERICE

(Rezumat)

Utilizarea structurilor în cadre de beton armat pe scară largă aduce în prim plan studiul elementelor din această structură. Analiza plăcilor dală de beton armat este susținută de obiective tehnico-economice care au ca scop obținerea de soluții inovatoare. În acest sens soluția planşeului dală cu goluri spațiale este analizată în comparație cu planşeul dală clasic, menționându-se avantajele şi dezavantajele celor două soluții. Testarea prealabilă şi studiul acestei variante reprezintă un alt element care trebuie realizat în condiții de eficiență tehnică şi economică. Modelarea structurii utilizând varianta simulării modelului analitic asistată de calculator constituie soluția optimă, oferind o multitudine de combinații de încărcări şi tipo-dimensiuni care vin să furnizeze date necesare îmbunătățirii continue a acesteia. Eficiența economică a acestei soluții de testare şi impactul aproape inexistent asupra mediului, personalul redus implicat în realizarea modelării, susțin şi validează actuala tendință în cercetarea ştiințifică a simulării analitice.