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Didactic strategies for comprehension and learning of structural concepts

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Abstract

In previous papers we have established the convenience of formulating educational strategies at the university level for both disciplines: Civil Engineering and Architecture, which involves academic topics of mutual interest by means of shared practices. As a particular matter of this approach, the application of **physical experimental models** is considered of special usefulness, in order to understand in better ways the performance of materials and structural systems.

Several strategies of selection and development of such physical models will be discussed in this work, considering as a first step, the establishment of its correspondence with the different levels of structural complexity studied in curriculum plan: statics, strength of materials and structural design, among others.

This task constitutes a part of the work program of the Laboratory of Structural Models, which is an academic project that develops and applies different didactic prototypes to structure courses in the Universidad Autónoma Metropolitana, campus Azcapotzalco, in Mexico City, project we have already presented in recent forums.

Two different modes of application are implemented in classroom sessions and in structures workshop: the devices for functional demonstration of typical cases of structural work as well as the experimentation with student's own designs of destructible models where certain typologies are tested up to its failure limit.

The first one allows teachers to explain adequately the theoretical principles and formulas (that usually are expressed on the blackboard) by means of didactic models identified in accordance to specific cases of the curriculum on variable level of complexity. This kind of practice allows the students of architecture and civil engineering to realize in better ways the possibilities of use and application of the different structural typologies. Such experimental models are part of more than fifty devices of the Laboratory's catalog.

In the same sense, the possibility of observation of structural work of their own architectural designs, allows future professionals to achieve a better conception of the structural solutions that affect positively their designs. Based on specific predefined guides, the students develop their own architectural-structural projects and subject them to diverse loads, observing their behavior under the influence of variable stresses leading up the experiment to its last resistance.

From both experiences a significant learning is obtained for the student's formation and training, who will be capable in his future professional work to use better tools of comprehension of the structural concepts applied to architecture as well as of increasing his conscience of the benefits and convenience of multidisciplinary work.

Keywords: Educational strategies, architectural-structural projects, physical experimental models, structure courses, significant learning.

1. Introduction

In the professional fields of Architecture and Civil Engineering, there is an approach that improves in acceptance with respect to construction, which is to consider that they are interdependent disciplines that perform in parallel and complementary ways, having a shared objective: to achieve efficient buildings, economically viable and with constructive quality that meet norms and functional expectations. Adding to these considerations the concepts that have special new relevance such as sustainability and respect for the environment.

Promoting the coordinate and complementary work between the very alike disciplines, as Civil Engineering and Architecture will help to derive in an integral and richer professional practice, with efficient spatial and constructive designs, and a more logical conception of their structure and gratifying aesthetical results.

It has been established that both disciplines not only are complementary but also, without being so different or so distant, they share the academic interest on teaching structures in order that the students of both degrees incorporate this topic as principal argument in their design proposals, considered, in any case, from the particular standpoint of each specialty.

One of the most common problems that the students of Architecture and Civil Engineering face is related with the teaching-learning process in subjects like Structures and Materials Resistance. "The difficulty is present from the moment in which two of the basic sciences are necessary and converge to make possible the understanding of the structure calculus…" (GARCÍA MALO, 2008: v). [1]. These sciences are: Physics and Mathematics, from which abstract knowledge and logic operations emerge. Some of these factors are not familiar to the student.

Understanding to its full extent the structural phenomenon, is a didactic task that can be supported by practice in the laboratory with physical models that allow a better comprehension of the performance of materials and structural systems.

At previous Symposium IASS 2008 we have insisted in the necessity of the establishment of academic programs, at university level, where both engineers and architects are involved in shared practices emphasizing a high level of importance about the complementarity of each specialty in group work, since early stages of the conceptual architectonic proposal.

It was also described the method of interdisciplinary work that has made the Laboratory of Structural Models viable at the Universidad Autónoma Metropolitana - Azcapotzalco Campus, in relation to teaching of structures within the Curriculum of the Architecture degree.

The strategies of selection and development of such physical models will be discussed in this paper, considering first its correspondence with the different levels of structural complexity studied in curriculum plan: structural and constructive systems, statics, strength of materials and structural design.

In this analysis it is briefly explained the contents of each of the most representative teaching subjects as well as the applicability of the models designed to demonstrate the structural work of the elements and systems studied in each one. The correspondent prototypes are shown next with a selective description of some of them, in order to show the mechanics of the strategies used for the development for this didactic project.

The usefulness of this teaching-learning strategy could seem obvious but it has an important impact in the student through the explanation of the theoretical principles of the structures by the professor and its physical demonstration with the support of the models. However, it may result very useful to keep a statistical record of the results of the application of this resource in the classroom and the experience in the laboratory, comparatively with the results obtained through traditional teaching.

In a second moment we will discuss the need of the direct and creative participation of the students with activities where, taking an important part of the responsibility of their own learning, they raise their particular doubts about structural topics, constructing and testing by themselves simple designs under the expert guide of the teacher.

Based on specific predefined guides, the students develop their own architectural-structural projects and submit them to diverse loads, observing their behavior under the influence of variable stresses leading up the experiment to its last resistance. The result of this experience always will be gratifying.

The use of experimental models allows the understanding of the behavior of the materials and structural systems. In this respect, Meli says “A valuable help in the process of design, can be obtained through experimentation; it is about studying phenomena; not through analytical models of the structure, but through physical models of it…Sometimes it helps to understand a partial aspect of how the structure responds to a certain type of load…This is easier for the minds that are not well suited to abstract reasoning; and it is more reliable than the results obtained from an analytical model” (MELI, 2000: 32,33) [2]

Among the functions of the teacher, the next are considered: the constant update in the field of teaching; the checking, revision and elaboration of programs and study plans; the evaluation, advising and preparation of the classes. In the latter, the teacher will design the appropriate environments to facilitate the teaching-learning process of the students.

In order to understand the structural behavior and to support the abstract reasoning, an experimental Laboratory of Structural Models is created, where the students can elaborate and manipulate material models. This kind of resource could be more interesting by introducing a strategy where the students participate and are involved in the learning process.

To achieve these objectives, the teacher employs teaching-learning strategies focused on both; the student and the teacher. The teaching strategies, "are focused in the teacher activities: organize programs, define objectives, plan activities and evaluate the teaching-learning process" [3]. In relation to the learning strategies, Gutierrez says: "The possibility to learn through learning strategies, that is, through the conscious decision making, facilitates the significant learning. It allows students to establish relations between their knowledge and the new information (objectives and characteristics of the present assignment)…" (GUTIÉRREZ, 2003:24) [4].

2. Didactic models and its correspondence to Architecture Curriculum.

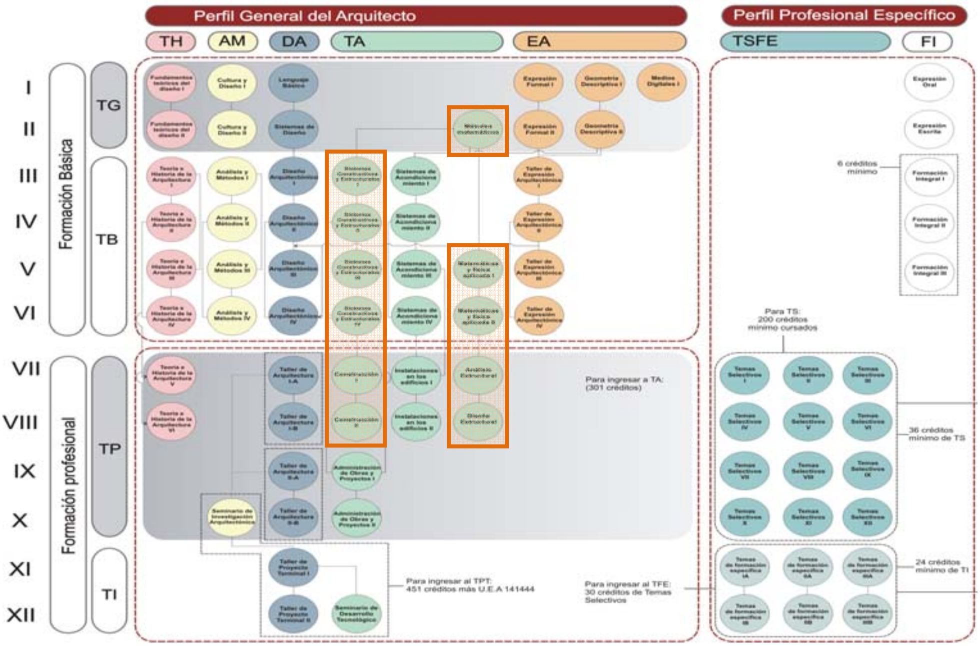


Fig. 1. Architecture Curriculum Map

The study plan of Architecture was modified in the recent years and began its operation in 2005. In the body of subjects related to structures, there were included in the initial courses of the career, besides the traditional matters of statics, strength of materials, analysis and structural design, four courses of "Constructive and structural systems" with the purpose of relating from basis of the knowledge of construction, the structural work notions that allows to identify the building as a system.

On the Figure 2, the list of the subjects contemplated in the curriculum that have relation with the structural topic, identifying in shallow form its contents and the correspondence of these with the didactic models proposed by the LSM to support experimentally the theoretical principles demonstration.

	T	Subject		Thematic	Models
A	3	Constructive and structural systems	I	Building like a system Simple and combined stresses	SD-21,37, 12, 13, 10, 11, 28
B	4		II	Loading wall Concrete slabs	SD-33
C	5		III	Foundations, supporting elements Gravitational loads, earthquake.	SD-31, 21, 07, 32
D	6		IV	Rigid frames, side loads	SD-19, 50
E	5		I	Statics: forces in one plane, equilibrium truss	HST, SD-12, 13, 38
F	6	Applied mathematics and physics	II	Strength of materials: cross sections, moment of inertia, shear, bending moment.	SD-29, 13, 15, 26, 27, 38
G	7	Structural analysis		Beams Frames	SD-18, 19, 50, 07/32, 21
H	8	Structural calculus		Vertical and side loads concrete: beams and slabs Foundations	SD-19, 50, 07/32 SD-13, 15, 26, 27, 33, 31

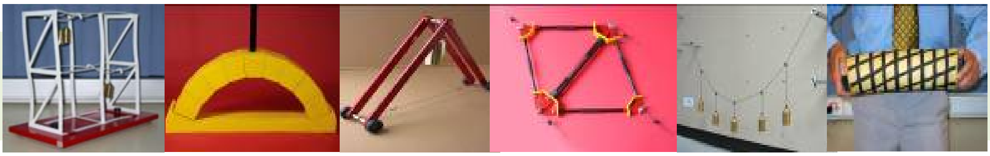
Figure 2. Subjects related to structures and corresponding models.

In accordance with the increasing degree of difficulty of every subject, some of the related prototypes can be used in order to demonstrate elementary principles of the structural work in the initial courses, as well as for other outposts, where they will be useful also for concepts of major complexity.

Only like example we have selected and described the following academic units: for the third quarter of the degree, " constructive and structural Systems I " relating seven devices of demonstration; for 6th quarter " Applied Mathematics and Physics I (Strength of Materials) with four devices and for 7th quarter " Structural Analysis " with seven.

For each of the topics, a model has been selected with the intention of verifying the didactic components that integrate them: a) Objective, b) Theoretical support, c) Description of the device, d) Operation.

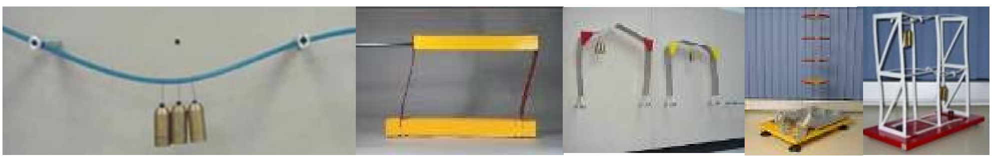
A	3	CONSTRUCTIVE AND STRUCTURAL SYSTEMS I	
		Content	SD-21 Portal frame system SD-37 Keystone arch SD-12. 3 elements simple truss SD- 13,14. 5 elements truss SD-10 Catenary curvature SD-11 Parabolic curvature SD-28 Torsion bars
		1. Building as a system	
		2. Single stresses. Tension, compression	
		3. Compound stresses. Bending, torsion, shear	



SD-21 **SD-37** **SD-12** **SD-13, 14** **SD-10** **SD-28**

Figure 3. Constructive and structural systems I.

G	7	STRUCTURAL ANALYSIS	
		Content	SD-18 a) Beam with 2 supports b) Continuous beam c) Continuous beams with joints SD-19, SD-50 Frame with different kinds of supports SD-07 y 32 Flexible five levels structure SD-21 Portal frame system
		1. Fixed beams	
		2. Continuous beams	
		3. Flat frames	



SD-18 **SD-19** **SD-50** **SD-07, 32** **SD-21**

Figure 4. Structural Analysis

2.1. SD 37 – Keystone Arch

Stony materials, in contrast with steel, Word and other materials, have the capacity to work only under compression, a characteristic that is appreciated specially to arches.

Human being have used this structural element since their origins as it was found naturally in the form of caverns. Afterwards it is manufactured in stone and clay or brick, taking advantage of its high load capacity, for the construction of domes, bridges and other buildings. The arch, according to the cultural region is of different kinds. We find round full-centered arch, segmental, lobbing and others. But in all cases the work principle of its components is the same.

The keystone arch is made of cuneiform elements known as keystone that are disposed radially and whose origin is, according to the type of arch, one or several focal points.

The central and superior element of the arch is a keystone named key because it is the main piece that receives and distributes the vertical load onto the adjacent keystone in a lateral and symmetric way. The load, as indicated, has to be applied vertically on top of the key or in a uniform compression along the arch to make it work optimally.

Figure 5. Keystone arch

2.1.1 Objective of the experiment

To show by means of the model that the keystone arch is a stable structure when loads are applied adequately on it. In this way, it is shown how the keystone, working through cohesive compression, transmits the load from the key to the supports equally and how a minimal eccentric load, outside of the key, provokes a collapse of the arch.

2.1.2 Description of the model

It is integrated by a wooden base of 64 x 64 x 500 mm in length with two fixed supports in the ends called cushion with a slope of 20 degrees with respect to the horizontal plane to receive a section of the keystone circular arch with a radius of 250 mm and with the same cross section of the base. The keystone, a group of nine, is oriented towards the focal point with a radial magnitude of 15 degrees. Each keystone key has 20 degrees.

Figure 6. Keystone arch. Deformation under different types of loads.

2.1.3. Development of the experiment

The model is subject to an axial load of 60 kg that has to be stood up by the arch without deformation. Under the application of a reduced load, between 5 and 8 kg, over one of the outer thirds of the arch, it will become unstable and will collapse.

2.2. SD-50 Frame with different kinds of supports

2.2.1. Introduction

Each element of any structure keeps a relation of interdependence with those adjacent and even with those remote. The action of forces over a particular element may very rarely be considered an isolated effect, thus to a greater or lesser extent will have repercussions on the whole, especially in those that, because of their geometry, it is impossible to differentiate each of its components or when the joints between elements are rigid and cannot be treated separately. In consequence, the design of these structures must observe the principle of continuity.

2.2.2. Deformation in frames

Columns work efficiently along its axis but when they are subject to horizontal loads, they have the same effect of deflection that cantilever beams, considering that the fixed is at the base, which may lead to important deformation unless the cross section of the column increases considerably, which is not a premise of efficient design. Such condition will not improve even in the case of two columns joined by a horizontal element if the joints are articulated, because both posts will work together but will not increase their resistance to flexion.

If the columns are solidly joined at the lintel, then it can be considered that they constitute a system called frame, where the connecting nodes are rigid, which means that, although the node is subject to rotation, the angle made by the concurrent elements does not change, increasing in an important way the resistance capacity of the posts to deformation.

Figure 7a, 7b. SD-50 Frame with different kinds of supports

Under a uniform load the beam of a frame deflects and the ends rotate freely with respect to the post that, by keeping the angle at 90º at the rigid joint, tends to move laterally at the support. The stability of the system then requires a convergent horizontal force that stops such displacement, for which the posts are fixated at their base, by fixing it to the land, or by a reinforcement of a foundation designed "ex profeso", or the action of a tension cable between both supports, preventing the structure from splitting under a vertical load.

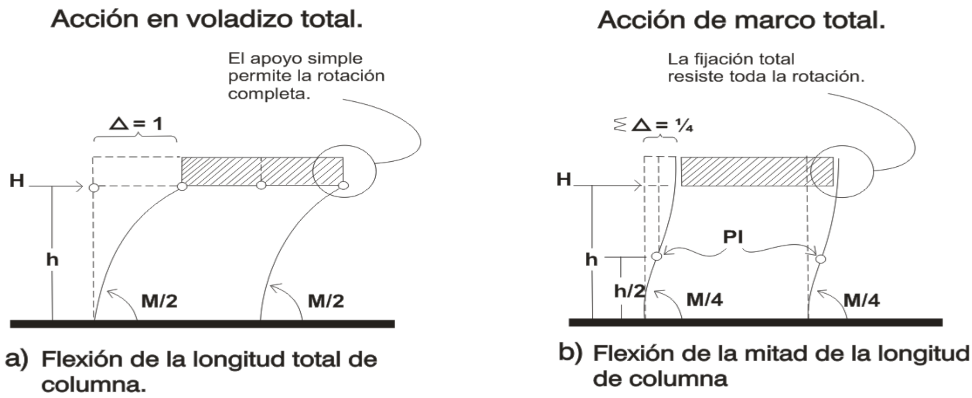


Fig. 8a y b Deformation in frames with different type of fixing.

2.2.3. Objective of the experiment

Demonstration of the different deformation that undergoes a rigid frame with respect to an articulated one, both by a vertical load as well as by the action of horizontal forces.

At the same time it will be clear the different resistance the frame shows according to the condition of the fixed or articulation at its foundation.

2.2.4 Description of the model

A steel strip of 52 mm in width bent to form a frame. A piece of wood with the same dimension and a cross section of 40 mm, made to form the lintel and to make the 90o rigid nodes. A base of 64 cm x 64 cm x 50 cm with slots to insert the frame.

2.2.5 Development of the experiment

The frame is setting by inserting the columns at the slots of the base, to fix them.

a) The application of a vertical load produces flexion in columns and beam. This deformation will be smaller if the columns are firmly fixed at the base.

b) The lateral load over the columns without connection with the lintel produces an action of cantilever total and an important deformation.

c) If the lintel is flexible and even if the nodes are rigid, when applying a horizontal load a rotation is produced in them, bending all elements of the structure. The rigidity relation between the lintel and the columns is 1:1 and the action in half the frame.

d) A total fixation of the nodes is achieved when stiffing the lintel, eliminating the rotation and reducing the flexion of the columns. The relation of rigidity between the lintel and the columns is of 4:1 and the action is of total frame resisting better the incidence of horizontal forces.

3. A learning strategy based in problems. Laboratory practice with destructible models.

As we commented earlier, the proposal of the experimental Laboratory for Structural Models could be more interesting if we create a strategy where the students participate and are involved in the learning process.

To achieve these objectives, the teacher employs teaching-learning strategies focused on both; the student and the teacher. The teaching strategies, "are focused in the teacher activities: organize programs, define objectives, plan activities and evaluate the teaching-learning process" [3]. In relation to the learning strategies, Gutierrez says: "The possibility to learn through alternative strategies, that is, through the conscious decision making, facilitates the significant learning. It allows students to establish relations between their knowledge and the new information (objectives and characteristics of the present assignment)…"(GUTIÉRREZ. 2003: 8) [4].

Among the teaching-learning strategies are: "Learning Based on Problems, Learning Based on Projects and Study Cases")…" (GUTIÉRREZ. 2003: 24) [5]. The Learning Based on Problems consists of the exposition of a problematic situation where its construction, analysis and solution are the central focus of experience, and where the teaching consists of promoting the development of investigating and solving the problem" (DÍAZ BARRIGA. 2006,62) [6].

In just a few words, one way of involving the students in the teaching-learning process is with the elaboration of physical models by the students through the Learning Based on Problems.

Finally, a pilot example is presented that shows the teamwork done by the students to analyze a beam. The beam is 40 cm long and is supported by its ends to carry two types of load: a) the uniform distributed and b) the one concentrated in the middle. The beam was made with "battery" fine cardboard and glue, and it is supposed to support four kilograms. Next, some images of the experiment are shown.

Figure 9a. Test that shows the resistance of the beam under uniform load.

Figure 9b. In this picture we can appreciate the beam breaking.

4. Conclusions

4.1.

The didactic project of Laboratory of Structural Models materializes the chimera of an auxiliary academic space to increase the knowledge of the structural phenomenon by means of the employment of physical models capable of making evident the theoretical principles that govern it.

4.2.

Based on the curricular analysis of the bachelor's degree it is possible to define the particular aspects of the academic basic units of structures and its elementary components. The topics susceptible of being supported by physical models are identified and then, the prototypes are designed and manufactured.

4.3.

The strategy of application and use of designed models by de LSM is essentially experimental and demonstrative, and it can be complemented by a second didactic way that essentially focuses on active participation of students in the construction of their own learning by means of the manufacture and testing of their own models.

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