DIDACTIC GAMES IN ENGINEERING TEACHING - CASE: SPAGHETTI BRIDGES DESIGN AND BUILDING CONTEST

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Abstract. *This work presents some observations about the use of didactic games involving practical activities of design and building of structures, complementing subjects of Structural Analysis and Solid Mechanics broached in regular classes. The practical activity proposed to the undergraduate students of several engineering and architecture courses is a load test of truss bridge models made of rods of spaghetti and several types of adhesives (adhesive resin, adhesive compound, liquid and melted glues). The models must span an opening of 1 m, support a concentrated load in the center of the span and have weight bellow 750 g. The building of the models should be preceded of a design optimization including variations of general shape (arc, bean, etc.), truss shape (number and length of truss members), transversal sections and building considerations. An estimate of final weight of the model and collapse load in the design stage is required. Two contests happen in two consecutive semesters, and some considerations about the results obtained are presented.*

Keywords: *spaghetti bridges, didactic games, design teaching*

1. Introduction

To motivate engineering students in early stages of their courses is a challenge to engineering teachers. Critics regarding lack of practical application of the first disciplines are usual. Students have difficulties to establish relationships between Mathematics and Physics courses and engineering application of the concepts seen in these courses. Even in Rigid Body Mechanics and Strength of Materials courses, the first disciplines of Structural Mechanics of engineering courses, it is common to observe unmotivated students due to difficulties in translating physical and mathematical concepts in applied knowledge, leading to high reprobation ratios. This way, is fundamental to propose alternative activities to motivate students in these courses.

Within this spirit, the Civil Department of Engineering School of UFRGS implemented a didactic game concerning a Spaghetti Bridge Design and Building Contest, where students are stimulated to design and build an truss bridge model of 1 m of span under 750 g of weight using only spaghetti rods and adhesives. In the contest, students have to develop all stages of a true structure design.

Initially, students have to present a preliminary sketch of the bridge model, which must respect several constrains established in the rules of the contest regarding minimum and maximum span, height, width and position of load point. Next, students must proceed to internal forces and stress analysis, using software or analytical approach, determining the transversal sections of each truss member based in mechanical properties of spaghetti experimentally obtained. The following stage is to optimize the project by introducing variations in some characteristics of the basic design as changes in height, number of truss nodes and members disposition. This stage is ended with the execution of a detailed report of the final design, containing all information about internal forces analysis, dimensioning and complete drawings of the bridge model.

After the design is completed, the truss bridge models are constructed, and the final structure must respect the contest constrains about dimensions, weight and materials allowed. Finally, the model is loaded up to collapse, and the model with highest failure load wins the contest. This kind of contest is not original, and have been widely used in universities and schools abroad and some educational institutions in Brazil.

Several abilities are required and stimulated in the contest: practical application of basic concepts of Strength of Materials, Structural Mechanics and Structural Stability, design of simple structural systems, optimization of structures, use of software of structural analysis, originality, creativity, capability of communicating and presenting projects, capability of work in group and capabilities of converting in drawings engineering ideas.

The results obtained with the two first editions of this contest are very stimulating regarding motivation of the students in the courses related to structure analysis and design, improving the approbation indexes of these courses.

In order to facilitate the implementation of this kind of didactic game in other educational institutions, the rules used to organize the contest and the technical data necessary to design of truss bridge models are presented.

2. Material characteristics

The bridge models are built with *spaghettoni* # 7. The brand *Barilla* was selected since it is the most used in other spaghetti bridge contests. The rod of *spaghettoni* #7 has average diameter $D_m = 1.8 \times 10^{-3}$ m, transversal section area $A = 2.545 \times 10^{-6}$ m^2, moment of inertia $I = 5.153 \times 10^{-13}$ m^4 and average length $l_m = 0.254$ m, and linear weight of 3.937×10^{-2} N/m.

The determination of the tensile strength and buckling behavior of the *spaghettoni* #7 was made by the students themselves in the fist edition of the contest. As most of bridge models were truss bridge models, no shear or bending strengths were studied.

Initially, both tensile and compression parameters were intended to be determined through the test machine of Figure 1a, that is fundamentally an lever mechanism formed by an horizontal member to amplify the applied load, pin jointed to two vertical members acting as supports. The tensile test is made with the rod of spaghetti attached to the metallic clamps and the compression test with the rod or member in the opposite side of the machine, as shown in Figure 1b.

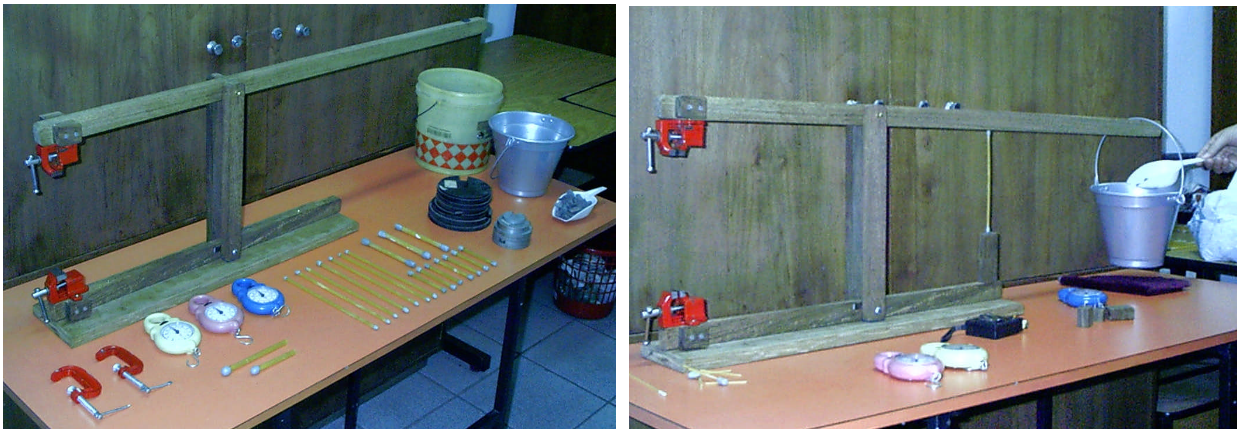

Figure 1. Test machine (a) and buckling test (b).

Tensile tests in this machine were considered not valid since all ruptures occurred in the clamps region, indicating interference of these devices in the rupture. The tensile test was then simplified to use a 15cm spaghetti specimen, with a string lace rolled and glued in both extremities, as shown in Figure 2, and the load was directly applied through calibrated test weights. Due to creep behavior of spaghetti, a load plan for tensile test was set, using weights of 10 N, 10 N, 5 N, 5 N, 5 N, 5 N, 2 N, 2 N, 1 N and subsequent steps of 1 N up to the rupture, load increments applied each 20 s. Table 1 shows the results obtained

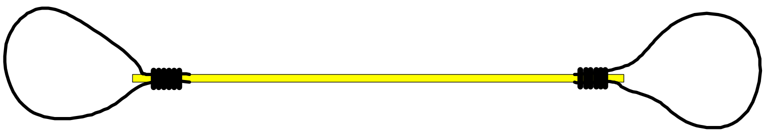

Figure 2. Specimen for tesnsile test.

Table1 – Tensile test results.

Sample	1	2	3	4	5	6	Average Load (N)	Standard Deviation (N)
Load (N)	45	45	40	42	40	44	42.7	2.3

The results of tensile tests show low deviation. Tensile tests with shorter specimens were made resulting in the same average strength. Specimens formed by several rods of spaghetti joined by epoxy showed rupture loads proportional to number of spaghetti rods used, resulting in the same average tensile strength obtained with one rod specimens.

Qualitative creep tests were performed, as shown Table 2, and, despite the few number of specimens used, the results obtained were used to base the rules about loading in the contest.

Table 2 – Creep test results.

Sample	Rupture Load (N)	Time of rupture (s)
1	40	540
2	39	960
3	37	1500

Buckling behavior were determined through 93 tests of specimens with different lengths and number of rods of spaghetti. The specimens with very low slenderness have to be tested in a standard test machine due to high loads necessary to lead them to collapse. As many students are in the initial stage of engineering course and haven't studied buckling yet, the results were initially grouped in graphs of buckling load versus length for the same number of spaghetti rods and buckling load versus number of spaghetti rods for the same length, as shown in Figure 3.

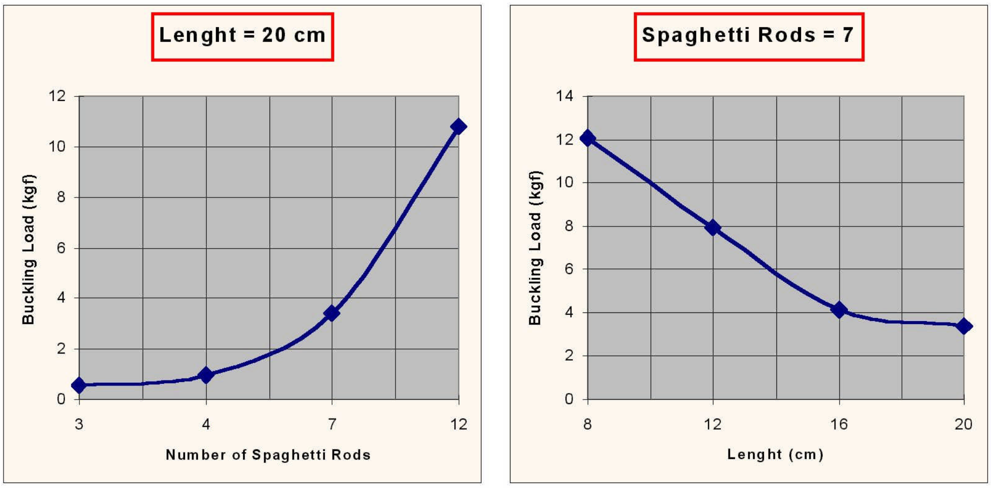

Figure 3. Buckling behavior for fixed length truss member (a) and fixed section truss member (b)

All results were grouped in a Buckling curve, where Euler behavior was considered, as shown in Figures 4. Blue dots are experimental values, black line is an interpolated function of type power with 94% of determination index , and yellow dots are the Euler equation with Young Modulus E = 3600 MPa

3. Contest Rules

To warrant the equality of conditions for all student in the contest and the standardization of the procedures, it was established contest rules (Segovia-González, 2005) that specify the norms that must be followed in the construction and presentation of the bridges and in the accomplishment of the load tests.

For the construction and presentation of the bridges, the regulation of the competition specifies:

a) The bridge model should be indivisible.
b) The bridge model should be built just using pasta of the type spaghetti and glue of some types.
c) The weight of the bridge model (considering the pasta spaghetti and glue) cannot be superior to 750 g.
d) The bridge model shall be free-standing and must span two level surfaces which are one meter apart.
e) The maximum vertical depth of the bridge model, from the lowest point to the highest point, should not exceed 50 cm.
f) The bridge model should have a minimum of 5 cm and maximum of 20 cm wide across the full span.
g) The brige model must have inserted in the half span an horizontal transverse bar of civil construction steel of 8 diameter mm and the same length than the width of the bridge, in the same level of the leaning extremities. The applied load will be transmitted to the bridge model through this bar. The weight of the bar won't be counted in the total weight of the bridge.
h) In the bottom surface of the bridge model extremities, 2 regular PVC water pipes with diameter of ½' and 20 cm of length must be glued to warrant support conditions planarity.
i) Before the test, the dimensions and weight of the bridge model must be check by the organizing committee of the contest.

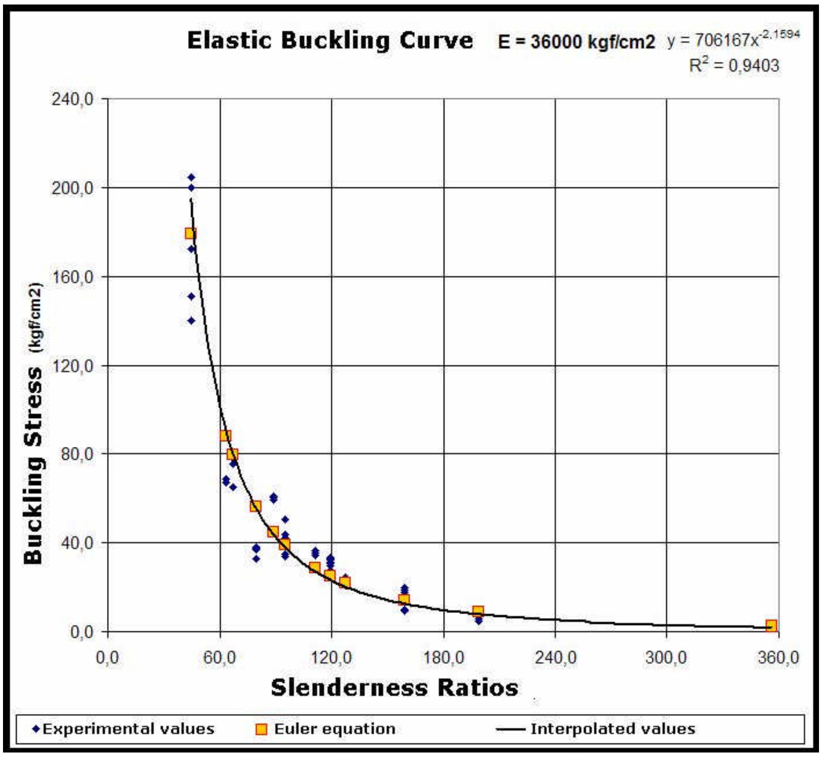

Figure 4. Buckling behavior of spaghetti truss members

Figure 5 illustrates some specifications detailed in the contest rules:

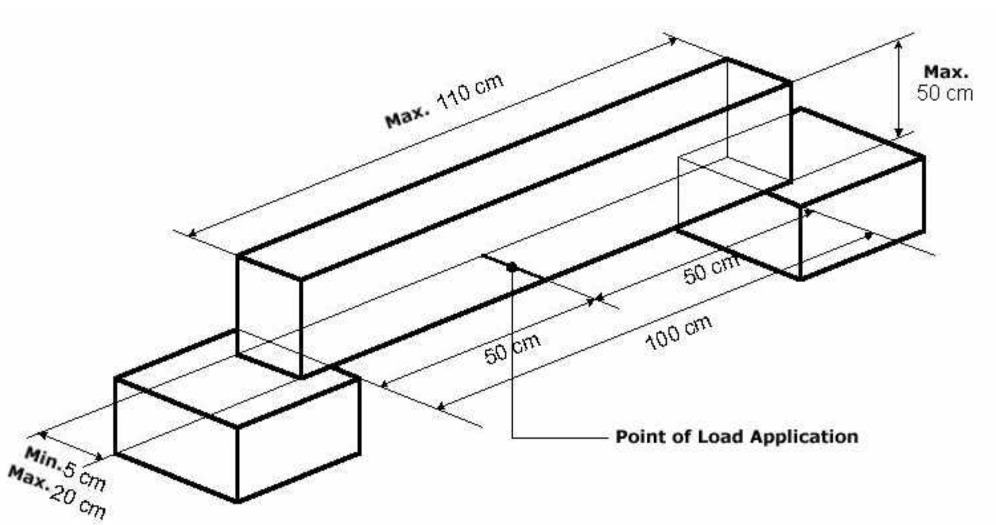

Figure 5: Spaghetti bridge and dimensions specified in the rules

For the accomplishment of the load tests, the contest rules specify:

a) One member of each students group will do the load test of the respective bridge. During the loading, the student should use protection glasses to avoid accidents in the moment of the collapse of the bridge.
b) The bridge model must resist an initial load of 20N during 30 seconds with no visual structural damages to be qualified to participate in the test of the collapse load.
c) Consecutive loads will be applied in increments defined by each group and must be applied during at least 10 seconds to be considered. The last load supported by the model during this full time interval will be considered the collapse load.
d) After the collapse, the tested bridge model or its fragments should be examined by members of the organizing committee to verify if the used material are concerned with contest rules.

4. Structure Analysis

The structure of the bridge is analyzed as two plane truss, disregarding the effects in three dimensions (Gordon, J., 1978) (Ressler, S. J., 2005). This simplification in the analysis is justified due to many of the students of the contest are still coursing Rigid Body Mechanics, and they just possess the necessary knowledge for the calculation of internal forces in truss members.

In these conditions, the total load applied in the central point of the structure is divided in two and each plane truss is analyzed considering one of these loads.

The effects related with the buckling of the truss members are considered through the curves obtained in the compression tests, as was presented when describing such tests. The effects related with the lateral buckling of the structure are considered through lateral bracing placed in the structure, without design, due to the limitations of the analysis.

5. Test apparatus and loading methodology

In the first edition of the contest, no special device was used to test the models, which were put over two ordinary desks to be loaded up to the rupture. This configuration is problematic due to lack of planarity of the support surfaces, which could generate twist in the models during loading, and does not have any fragment protection to the person who applies the load, as shown in Figure 6.

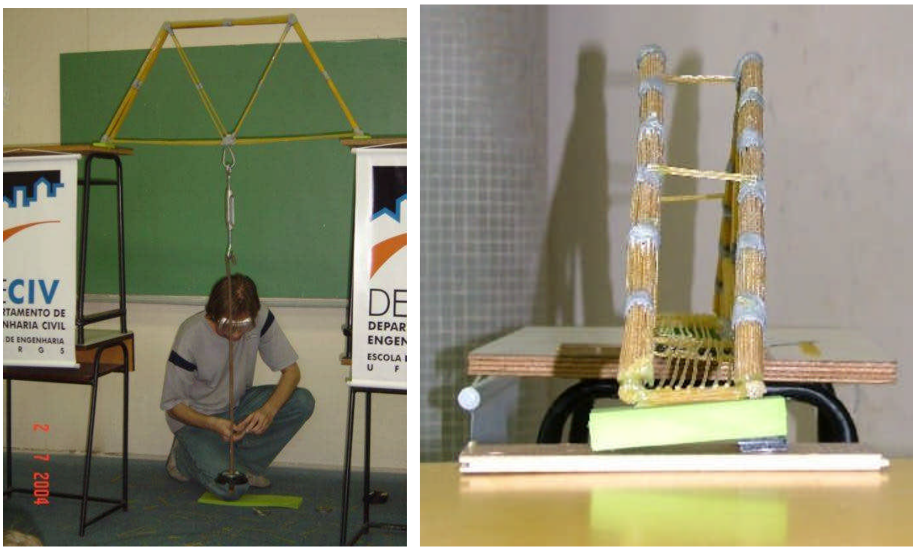

Figure 6. Original test configuration for the first edition contest, showing the lack of protection from cracked bridge fragments (a) and the potential lack of planarity of the surfaces (b).

In the second edition of the contest, the bridge models were tested in an apparatus specifically built for this purpose, basically consisting of a table of 1,4 x 0,60 x 1,0 m (length x width x height, respectively) with support blocks in both extremities and a hole of 10 cm of diameter in the center, as shown in Figure 7. The bridge model is put with its extremities on the blocks, and a load rod is placed through the central hole of the apparatus and hooked in the load point of the bridge. The blocks are free to be moved over the table, in order to accommodate small variations in models length, but they are heavy enough to remain immovable during the test. The blocks upper surface is coated with melamine to reduce the friction in the supports of the models.

The test apparatus allows that the student remains seated bellow the surface of the table, becoming protected from fragments resulting of the rupture or collapse of the model. Each student determines the load plan and executes it. There are load weights of 5N, 10N, 20N, 40N 50N and 100N, and the model must resist each load step for 10 s before the next can be applied.

6. Results

In the first edition of the contest, 16 groups of students participated, developing projects with wide variety of basic shapes and configurations, as shown in Figure 8.

Figures 7. Test apparatus (a) and load methodology (b).

Figure 8. Samples of the variety of solutions proposed by the students for the same problem.

The theoretical collapse loads of these projects varied from 500N to 1500N, but the average failure load obtained in the tests was in the 25N range, with the winner project reaching 55N. The huge difference between design and real collapse load can be explained by several factors:

a) There was no previous experience in the institution in building such kind of models. So, no execution hints or clues could be passed to the students in order to improve the quality of the models building.
b) The support conditions of the models were left free, without any kind of element to correct some static instability originated from the lack of straightness and planarity of the models, as can be seen in Figure 6b.
c) All students were in the beginning of Engineering course, having concepts of Rigid Body Mechanics and Strength of Materials but none of structural stability or buckling. The models were conceived fundamentally as plane

structures, and built as two plane trusses weakly jointed by transversal members, frequently without any kind of bracing, as shown in Figure 9a.

d) Several projects try to maximize the stiffness and strength of the models using the maximum height and minimum width allowed by the contest rules, producing structures that were very sensitive to lateral buckling, specially when no bracing were planned, as shown in Figures 9b 9c and 9d.

e) Two isolate desks were used as base surfaces, making difficult to set a single planar surface for the models. Besides, rubber layers were used to distribute the contact stresses at the support extremities (Figure 9a) but under load they presented differential displacement, making even more difficult stabilize unstable models. As a result, several models fail under low loads due to rigid body falling.

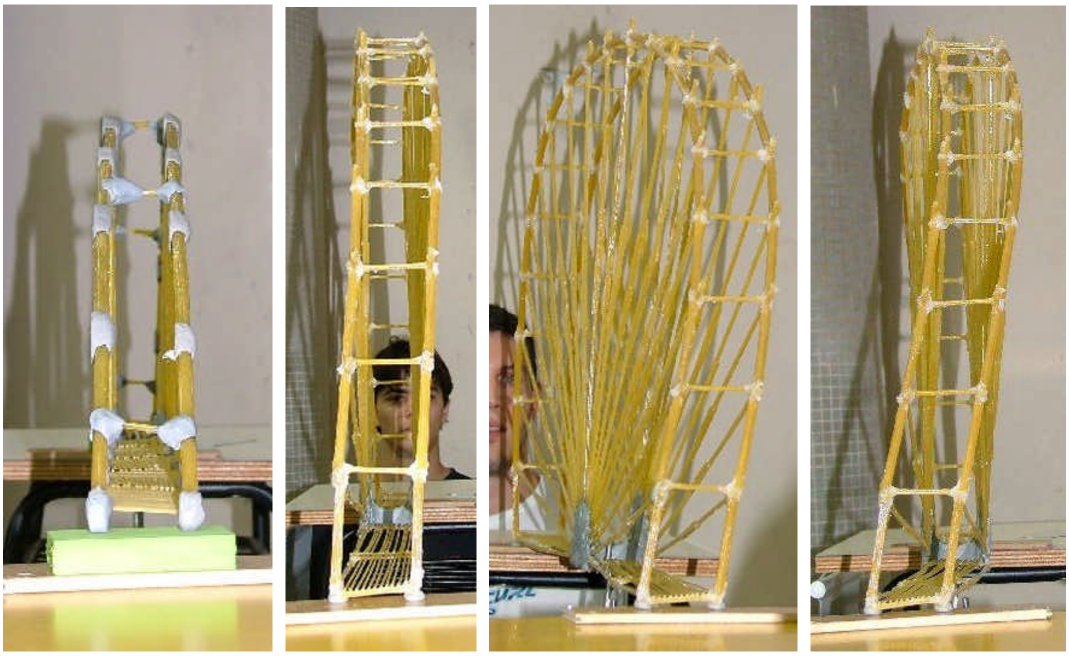

Figure 9. Lack of buckling and stability concepts leading to laterally unstable structures without any kind of bracing.

In the second of the contest, 48 groups of students took part. The average failure load obtained in the tests was in the 200N range, with the winner project reaching 440N, eight times the winning load of the first contest. The causes of such improvement can be considered as:

a) Experience acquired in the former contest resulting in better advice for the students regarding building techniques, dimensions and bracing, as shown in Figure 10a.

b) Better support conditions due to the use of PVC water pipes in the extremities of the models, as shown in Figure 10b. These pipes worked as pin jointed supports in the plane of trusses, avoided rigid body lateral falling of higher models and, as they were glued at the end of building process, corrected any lack of planarity of the models in the support points.

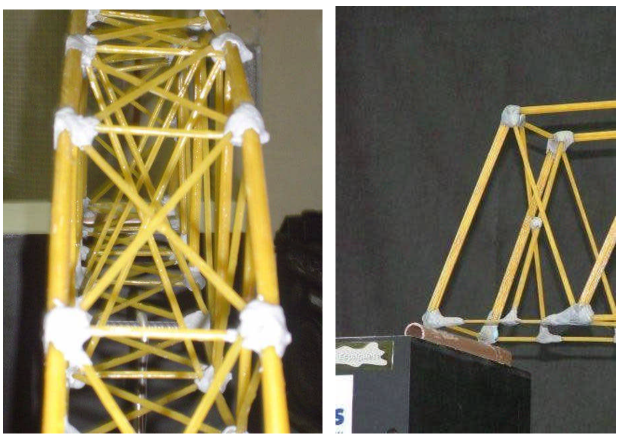

Figure 10. Better bracing (a) and better support conditions (b) in the second contest.

c) Establishment of a culture of truss bridge model in the University, with great exchange of experiences between the students of several stages of Engineering courses, resulting the students felt themselves more confident to dare more challenging structures, as seen in Figure 11.
d) A better test apparatus, that warranted perfect planarity for the base surface of the models and protection for students from cracked bridges fragments.

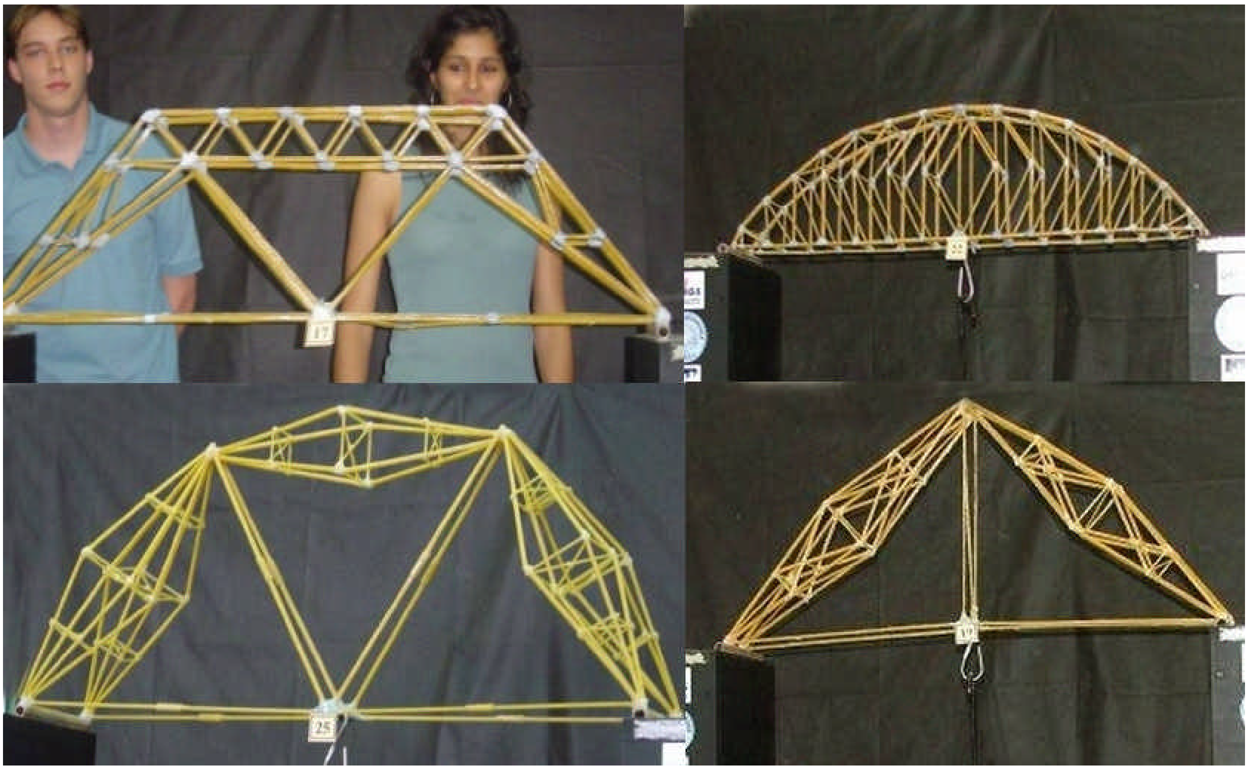

Figure 11. Experience leading to daring structures.

7. Conclusions

The proposal of such kind of contest was a valuable experience in teaching structures for engineering students of initial courses. They become much more motivated and interested in the design activity, several of them dedicating several hours in autonomous learning of computer programs for structural analysis, in testing different shapes and configurations of structures and in building techniques. Part of the motivation come from the fact that in this kind of activity students can link the basic concepts of Physics, Structural Mechanics and Strength of Materials with applied engineering.

8. References

Botelho, M. H. C. 1998. "Resistência dos Materiais para entender e gostar". São Paulo. Studio Nobel.

Brohn, D. M. 1992. "A new paradigm for structural engineering". The Structural Engineer, Vol. 70, No. 13, pp. 239-242.

Gordon, J. E. 1978. "Structures, or Why Things Don't Fall". Penguim Books. Harmondsworth.

Jennings, A. & Gilbert, S. 1988. "Where now with the teaching of structures?". The Structural Engineer, Vol. 66, No. 1, pp. 3-7.

Ressler, Stephen J. 2005. "Designing and Building File-Folder Bridges: A Problem-Based Introduction to Engineering". Defense Dept. Army, United States Military Academy. http://bridgecontest.usma.edu/manual.htm.

Segovia-González, Luis Alberto. 2005. "Competição de Pontes de Espaguete". Departamento de Engenharia Civil. Escola de Engenharia. Universidade Federal do Rio Grande do Sul. http://www.cpgec.ufrgs.br/segovia/espaguete.

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