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DEVELOPMENTS IN COMPUTER AIDED SELECTION: AN INTEGRATED APPROACH FOR STRUCTURAL APPLICATIONS

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PERMBLEDHJE

Ky artikull paraqet një metodologji projektimi për përzgjedhjen e kombinuar të materialit dhe të formës, të realizuar në programin kompjuterik CES. Problemi themelor është zgjedhja që maksimizon performancën, ndërmjet një game shumë të gjerë materialesh e formash profilesh që disponojmë. Duke përdorur metodën Ashby, janë marrë në konsideratë kushtëzime të shumëfishta dhe objektiva kompleksë, të zbatuar në trarët sekondarë. Kjo analizë të çon në identifikimin e katër indekseve të performancës, rëndësia e të cilave vlerësohet me anën e treguesve të ponderimit. Rezultatet e fituara, konfirmojnë vlefshmërinë e profileve prej çeliku, që kanë një përdorim të madh, sepse kanë kosto të ulët; por përveç çeliqeve, shumë mirë pozicionohen edhe kandidatët e tjerë: profilet prej alumini, druri dhe kompozitet. Ka shumë sfida që lidhen me një përdorim më të madh të materialeve të reja, por e para është që t'i marrim ata objektivisht në konsideratë ndërmjet alternativave të tjera.

Fjalët kyçe: material, formë, tra sekondar, ngurtësi, qëndrueshmëri, faktor ponderimi, përzgjedhje të shumëfishta.

SUMMARY

This paper presents a designing methodology for the co-selection of material and shape by using the CES software. The fundamental problem is how to choose, from among the vast range of available materials and sections of shape, the ones that maximize the performance. Using the Ashby method, multiple constrains and compound objectives applied to a secondary beam have been taken into consideration. Such analysis leads to the identification of four performance indices whose relative importance is evaluated according to the method of weight-factors. The results obtained confirm the validity of the steel sections, mainly used because of their low cost. Besides steels, the other candidates such as structural sections of aluminum, wood and composites, appear in a very good position. There are many challenges related to a larger use of innovative materials, but first of all it is important to consider them objectively among other alternatives.

Key words: material, shape, secondary beam, stiffness, strength, weight-property, multiple selections.

1. INTRODUCTION

Taking into consideration the shape at the beginning – point of a computer-aided approach for materials selection and integration of two concepts (material – shape) in unique operational approach is currently an important tendency for the research being done in this field [1, 2, 3, 4, 5, 6, 7]. The complexity of the problem precisely consists in the "multiplication" of the materials diversity with their various fabrication shapes, whereof an entity of solutions (tens of thousands of versions) generate, which make the traditional engineering design practice inefficient. Among the most typical cases, where the necessity to use new procedures called *rationale*, for a combined material – shape selection appears, are the beam sections used in structural construction components [8, 9, 10]. These structural sections:

rectangular hollow, rectangular solid, circular hollow, section I, angle L, channel U, etc., can be made out of various materials: steels, aluminum alloys, composites…and even wood, while the most used software's computer-aided by our designing staffs, are mainly focused on metallic materials, and in majority of cases, only on steels. The narrowing search spectrum of solution, favors a quick advance towards the dimension of component, but at the same time carries the risk of not considering the innovatory options and losing the opportunities. These limitations become more evident when material – shape selection needs to satisfy several objectives at the same time and when the optimal solution can be achieved only by means of the multiple criteria selection [2, 4]. These limitation can be avoided by means of several methods such as Dargie, Pugh, Dominic, Pahl-Beitz, [5, 11] etc., among which the performance indices or Ashby's method [1, 2], initially conceived only for material selection, actually constitutes one of the most seriously references for new developments, including those which deal with the combined *material-shape* selection. The aim of this paper is to explore the possibility and utilization of this method in a concrete general application dealing with the selection of some elements often found in secondary beams in structural constructions.

2. THE PRESENTATION OF THE PROBLEM AND THE "TRADITIONAL" SOLUTION

The case in issue represents the structural supporter of roof for a warehouse or an emporium object. The construction of the structure is formed by some trusses with a spam of 24m that are supported on columns at both ends for every 5m. The secondary beams are supported by two trusses next to each-other and they must meet the following conditions:

- To support the load without failure (the strength / resistant constraint),
- No elastic strain on bend beyond a certain limit, formulated with a mid-point allowed deflection, $[\delta] \leq l / 250$ (the stiffness constraint),
- The length, or spam of secondary beam is l = 5m (fig. 1).

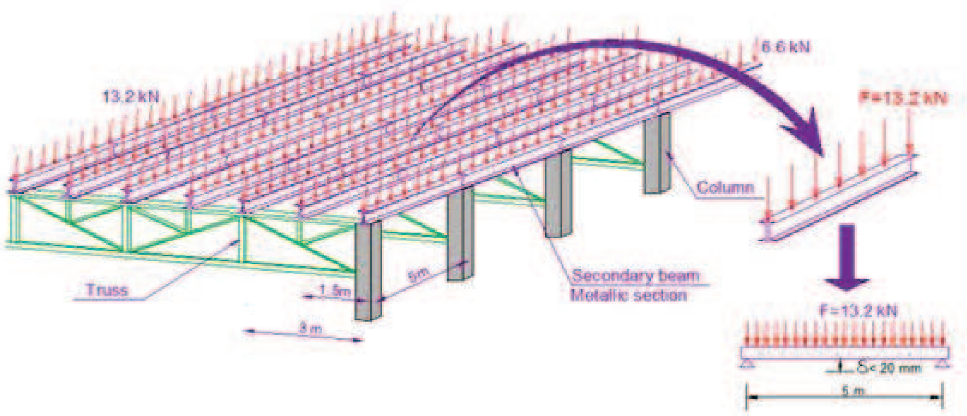

Figure 1: Schema of the roof metallic construction and the secondary beam separation

The method by means of which are computed structural construction components (in present engineering practice) is done by the **limit state** [12]. It will be accepted in this presentation that the element load (beam) will not exceed the limit of the material elasticity. To apply this method, all the acting loads in the structure (the vertical permanent load and the temporal one*) are primarily computed and the determining of the bending moment that is pressed over the studying component is reached. In this case the moment results:

M_b = 8.25 kNm

From this point, applying the *strength constraint*:

$$\sigma = \frac{M_b}{W_{net}} \leq \sigma_y \qquad (1)$$

For σ_y = 210 MPa [13] is determined the value of Major Section Modulus for Bending:

$$W_{net} \geq 39.29 \text{ cm}^3$$

The traditional solutions in our present practice are orientated towards several steel structural sections that are “proved” as suitable, among which the “Double T” is the most favorite. Following this “tradition” and starting from the requisite section modulus, $W_{el.y}$, from norm EN 10025 – 1993 [13], we find out that the smallest section that can used is IPE A 120. This section is checked by means of *stiffness constraint* and it results that the factual deflection is δ = 39 mm, that is, larger than it is allowed ([δ] = *l* /250 = 20 mm).

For this reason and starting from the stiffness *constraint,* new dimensioning of the beam is done. It results in section “Double T” IPE 140 (*h* = 140 mm, *b* = 73 mm, t_w = 4.7 mm), the deflection of which (18.9 mm) is within the norm.

We may also reach to this solution by using specific computer-aided approach such as that of ROBOT Millennium 19 software.

The authors haven’t considered it necessary to represent the complete procedure for determining the loads in truss in this paper because it resembles the traditional engineering design practice.

3. THE ESSENCE OF ASHBY’S METHOD AND THE ALGORITHM OF SELECTION

The essence of this method consists in “screening” by a certain algorithm for all possible alternatives (the sections with various combination of *material-shape-dimension*), that is included in the available database. A combination of properties and characteristics is used as a screening tool which synthesizes the usage value of the object and which is found in the *performance indexes* as well. The best solution will be the one which maximizes the performance of component (p), which in universal appearance is expressed through the equation:

$$p = \begin{bmatrix} \text{(function requiremen ts)}, \\ \text{(geometric parameters)}, \\ \text{(property of material)} \end{bmatrix} \qquad (2)$$

The algorithm of selection predicts the gradual limitation of research zone through constraints which become more and more restrictive until the identification of few records that in the long run can be compared according to the informal engineering considerations in analytic relations. The *Structural Sections* table of CES (Cambridge Engineering Selector) software [7] has been used as a database, which contains detailed information for about 1900 sections, of various shapes, dimensions and materials.

In our case, to make the “screening” of this database, we needed the determination of the performance indexes starting from the analysis of the secondary beam computed model.

Objectives	I.	Minimize of mass
	II.	Minimize of cost
Constraints (technical specification of design)	**A)**	**Stiffness**: [δ] = 20 mm
	B)	**Strength**: no plasticity, ($\sigma < \sigma_y$)
	C)	**Size** (geometric constraint): Span: 5.0 m

Table 1: Objectives and constraints of secondary beam design

4. THE COMPUTED MODEL AND THE DETERMINATION OF THE PERFORMANCE INDEXES IN THE SECONDARY BEAM

The limit dimensions, the loading schema and the requirements for the secondary beam are the same as &2, but applying Ashby’s method, with these dates we can express formally the *objective* (objectives) of designing and *constraints* that are put up against it (Table 1), a way that will serve us to search the optimized solutions.

Being based on the constraints, we define the analytic relations that connect the function requirements (the load) with geometric parameter of the beam and the properties of material.

A) *Stiffness constraint* is expressed:

$$\delta = \frac{Fl^3}{C_1 EI} \leq [\delta] \quad (3)$$

$$\text{or } EI \geq \frac{Fl^3}{C_1 [\delta]} \quad (3')$$

Where, F is the load that applies upon the beam (F = 13.2 kN), E – Young's Modulus, I – Second Moment of Area (major) and constant C_1, that accounting for equable disperse loads and end conditions, in this case C_1 = 384/5 [1].

From the equation (3'), by placing the values of decided parameters (so-called "solid" constraints), we display the condition that "free" parameters must fulfill, i.e. that which may be the optimizing object:

$$EI \geq 1.074 \text{ x } 10^6 \text{ Nm}^2 \quad (4)$$

In this way, by looking for the section optimization according to product EI, we practically concretize the idea for a combine *material-shape* selection (E – property of material, I – geometric parameter of section shape).

B) The strength constraint is expressed:

$$F \leq C_2 \frac{I\sigma_y}{y_m l} = C_2 \frac{ZY}{l}, \quad (5)$$

$$\text{here } ZY = \frac{I\sigma_y}{y_m} \text{ [Nm]} \quad (6)$$

It gives the moment of bending (major), the one that the section can confront without causing any plastic deformation. This specification, which will be called *Failure Moment*, emphasizes the influence of both the geometry of the section (I dhe y_m) and of the material property (σ_y). Referring to this specification, the strength constraint will be:

$$ZY \geq \frac{Fl}{C_2} \quad (7)$$

Considering the studying scheme C_2 = 8 [2] and knowing the values of F and l, we can find the numerical expression of strength constraint:

$$ZY \geq 0.825 \text{ x}10^4 \text{Nm} \quad (8)$$

C) The geometric constraint is expressed: l = 5 m

Such a constraint is an independent constraint in itself, but it influences the other constraints such as A and B (geometric parameter l counts at their expressions).

Based on analytic equations of A and B constraints (relation 3' and 7) and the objectives of design (Table 1), we can determine the performance indexes, M:

- Safety of stiffness with minimum mass:

$$M_1 = \frac{EI}{m_l} \quad (9)$$

- Safety of strength with minimum mass:

$$M_2 = \frac{ZY}{m_l} \quad (10)$$

- Safety of stiffness with minimum cost:

$$M_3 = \frac{EI}{C} \quad (11)$$

- Safety of strength with minimum cost:

$$M_4 = \frac{ZY}{C} \quad (12)$$

where C is the cost for unit length (USD/m), while m_l is linear mass (kg/m).

5. THE ASHBY'S METHOD APPLICATION IN COMPUTERIZED SELECTION OF SECTIONS

Preliminary selection

The selection of sections is done by using the options of CES software and it starts by placing the "solid" constraints (4) and (8). 385 "winner" sections, which are presented and visible in the box selected, up right in figure 2, come out in the first screening:

5.1. *Narrowing down of searching zone*

The narrowing of searching zone is done in accordance with the two objectives of the design project: the minimization of mass and that of cost. These are related both to the strength of constraint and to the stiffness of it (view performance indexes, *M*), but the latter being considered as too much tide (so results from calculation &2), we initially refer to it to find the *lightest* and *cheapest* solutions.

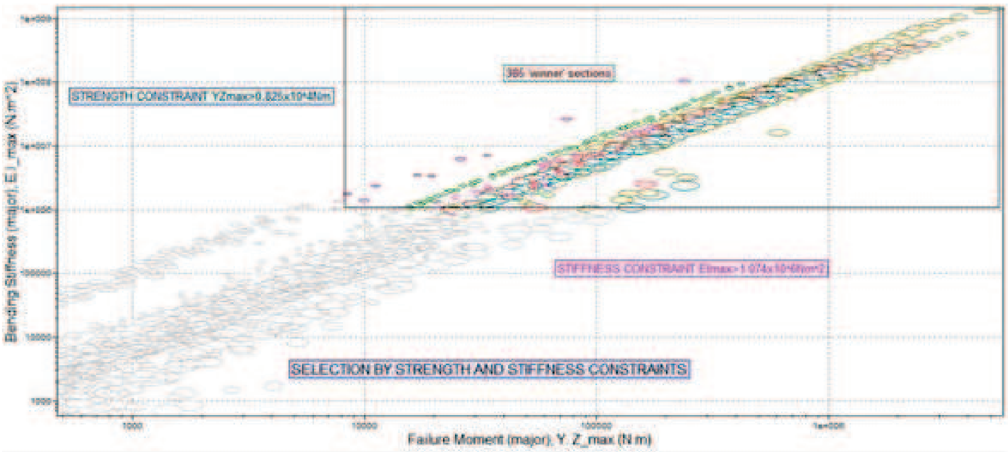

Figure 2: The chart *EI-YZ* (selection by strength and stiffness constraints)

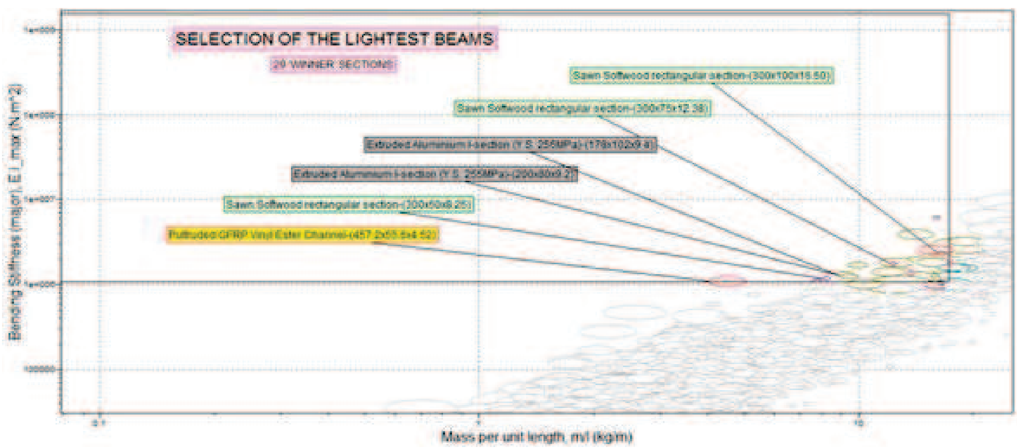

Figure 3: The chart *EI-*m_l (identification of the lightest sections)

Because of the above mentioned fact we have limited the searching zone to the identification of the most" viable" candidates as seen in the electronic charts *stiffness – mass per unit length* (fig. 3) *and stiffness – cost per unit length* (fig. 4).

In the chart of figure 3 we can view that the winner lightest profiles are the composites, aluminum, steel and wood materials.

The achieved solutions, as expected, make the steel sections evident when the minimization of the cost is requested, while the aluminum and composites sections are related with the minimization of the mass. It is to be noted that the latter are little known in our engineering practice and as a result are not estimated as possible alternatives towards traditional materials.

5.2. *The multiple objectives research:*

In order to fulfill an optimal selection (in other words, to do a multiple research) of secondary beam, we have to take the four performance indices into account, by the relativity of their weight. This approach is based both on the combination of Performances Indices method (Ashby's method) and the Weighted Property Index method, meeting the requirements of multiple objectives design [5].

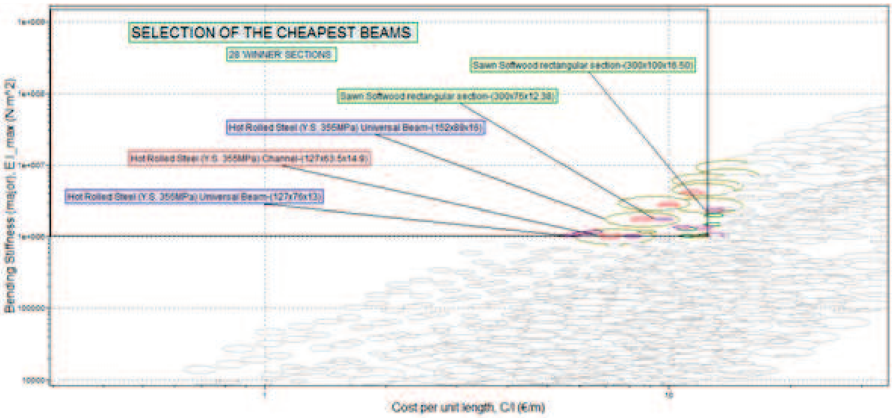

Figure 4: The chart *EI-C* (identification of the cheapest sections)

Material - shape	γ_1	γ_2	γ_3	γ_4	$\gamma = \Sigma\gamma_i$
Section I, steel (152 x 89 x 16)	0.1	0.05	0.25	0.25	**0.65**
Section I, aluminum (200 x 80 x 9.2)	0.16	0.11	0.05	0.08	**0.40**
Channel U, composite (457 x 56 x 4.5)	0.25	0.25	0.06	0.14	**0.70**

Table 2: Relative and summation performance indexes for three sections

A weighted-property value is obtained by multiplying the numerical value of the property (M_i) by the weighting factor α_i. With condition $\Sigma\alpha_i = 1$, we can accept an equilibrate pondering, i.e. $\alpha_i = 0.25$ (to minimize the effect of subjective preference for either one or the other objective). The individual weighted-property values of each section are then summed to give a comparative sections performance index, γ.

$$\gamma = \Sigma\gamma_i \qquad (13)$$

Accepting an equilibrate pondering, that is $\alpha = 0.25$ (to minimize the effect of subjective preferences of either one or the other objective), we calculate the *γ* value of the groups of sections selected with unique objectives (&5.2).

In table 2 are shown the results of calculation for "the best" factors from three different material classes: steel, aluminum and composites.

Surveying the results, it is obvious that the steel section "I" and the composite channel "U" are night competitors (with light vantage for the composite material) with the highest performance, while aluminum sections fall behind the first two.

6. DISCUSSION

1. Four Performance Indices covering the main functional and economic aspects of materials-shape selection were considered. This shows that metallic sections cannot be considered the obvious solution.
2. The composite sections show a strength/mass ratio (γ_2) about five times larger than analogous steel sections, but the disadvantage can be their outer dimensions of cross section. A similar ascertainment goes for wood sections too.
3. The steel "I" sections selected by the CES software have dimensions in the range 127 – 152 mm. While the traditional mechanical design leads to the dimension of 140 mm. The results are approximate, but not identical. The reason lies in the wide values range contained in the CES database [14]. More discrete information, such as standard EN 10025:1993 is needed, and this

has induced us to create new database called FOR-MAT [15].

7. CONCLUSION

3. The structural section selection results performed by using the Ashby Method and the traditional mechanical design method are principally the same: both reveal in the short list of winners, the steel profiles. However, the Ashby Method has the advantage of quick identification of alternative solutions too; among which are the composite sections. It's important that this option is seen at the screening stage of selection.

4. Although a large number of factors are considered and their relative importance is taken into account by Weight Property Indexes during the application of the method, there are a lot others which remain quite outside the possibility of formalization. For this reason, the list of selected candidates should not be considered as definitive; it can be corrected and reaffirmed after analyzing all the factors that determine the selection.

3. In order to raise the efficiency of material-shape selection with CES software, it is necessary to widen the Structural Sections database with more new data from specialized European Standards. This may be a direction for further improvement of this project in future.

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