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ECONOMIC AND TECHNICAL CRITERIA FOR DESIGNING PRESTRESSED CONCRETE BEAMS

BY

IOAN-LUCIAN STAN[1,*] and PETRU MIHAI [2]

Technical University “Gh. Asachi” of Iaşi,
Faculty of Civil Engineering and Building Services,
[1]Doctoral School of the Faculty of Civil Engineering and Building Services,
[2]Department of Concrete, Materials, Technology and Management

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Abstract. The efficient design of prestressed concrete elements represents a difficult task, the number of parameters involved in design being correlated in the first case with the technical criteria. In order to obtain elements with the lowest financial effort, it is necessary to optimize the solutions by identifying the cost of the solutions which satisfy the technical requirements. However, from the current practice, only optimal models can be obtained due to the restriction imposed by service and construction stages. Thus, the solution to this problem refers to the effective design of prestressed precast concrete elements based on the minimum cost criteria. The inappropriate design may result in unreasonable costs. Integrated engineering enables conception and simultaneous design of associated products, production and maintenances process. In this way is taken into account issues such as quality, timing, costs and user requirements. This paper illustrated in what manner technical and economical criteria influence significantly the cost of manufacturing a prestressed precast element.

[*]Corresponding author; *e-mail*: stan.ioan.lucian@gmail.com

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1. Introduction

By using the applied engineering in designing prestressed concrete elements it is intended to determine the economic effort by solving the quality-cost-time equation. Inappropriate design of the solutions may result in unreasonable costs. Integrated engineering as is shown in Fig. 1 enables the simultaneous design of associated products, production and maintenance processes. This way they are taken into account from conception, realization, etc. and eliminating thus issues such as quality, timing, costs, user requirements.

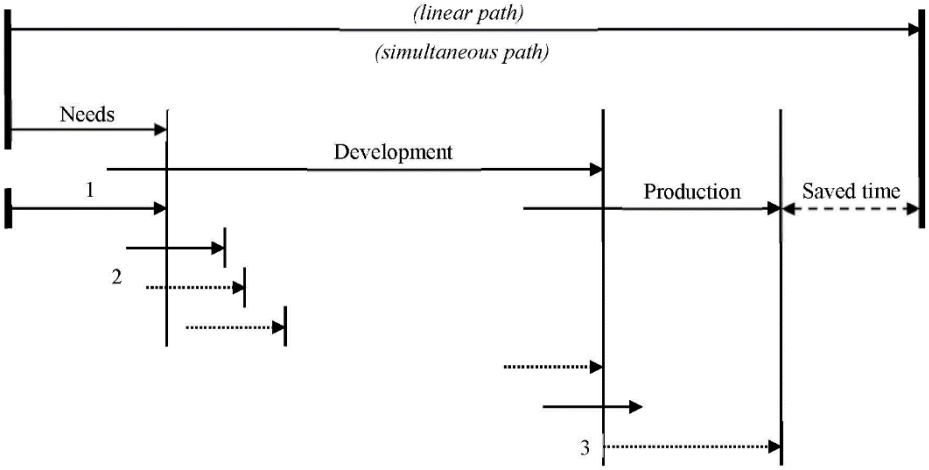

Fig. 1 – The linear development of a product.

2. Technical and Economic Criteria

The technical criteria are all the criteria that are needed to be taken into account when carrying out a design process (Pascu & Zybaczinski, 2012). In order to satisfy each technical criterion, it is necessary to provide at least one valid solution, the materialization of that solution resulting in a series of costs. By cumulating all solutions results in a series of products with certain costs. Thus, it can be justified the correlation between the technical criterion and the cost of achieving the finished product as is shown in Fig. 2.

In the field of construction, the establishment of technical and economic relations is an important step, as this is a precursor stage for determining the

final cost, thus establishing the plausibility of the finished product. Satisfaction of technical criteria is implicitly achieved (Marti *et al*., 2016).

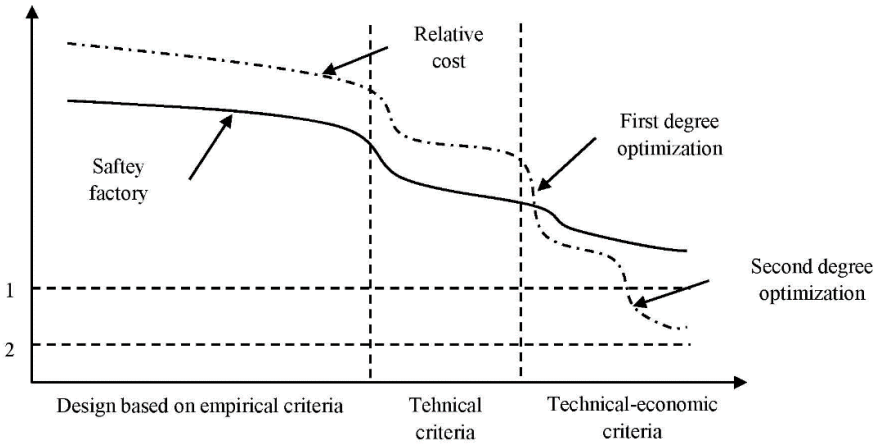

Fig. 2 – The evolution of design criteria.

The appearance of prestressed concrete elements was possible with the development of technical criteria. These types of elements have emerged as an evolutionary step in solving the defective behaviour of concrete to tension.

New concepts have been achieved by the division of structures into sub-assemblies and structural elements, with regard to static schemes, as well as the computation of rigidity distributions, structure-related actions, rheological phenomena, aspects concerning cooperation of structures with the terrain foundation, etc. The extension of the design criteria is a general tendency aimed in particular at a concurrent coverage of a growing number of economic criteria in addition to the well-defined technical criteria (Drăghici, 2000).

3. Stages of Calculation and Sizing

The dimensioning of members only on the basis of technical criteria leads to mathematical models which usually comprise equilibrium relations of effort, limitation of deformation, to the limitation of normal or tangential stress at certain values.

The additional attachment of economic criteria to the technical criteria allows for the achievement of elements/structures with a lower financial effort on the part of the builder and the simultaneous achievement of the degree of safety corresponding to the applied technical criteria. In this manner, an iterative process is used and the steps taken to obtain an efficient solution depends on the desired accuracy.

The solutions are obtained by creating models based on design concepts both in the preliminary design stages, calculation (static and dynamic), as well as in the phases of execution, exploitation and post-use. By choosing the calculation models, the admitted assumptions are made to obtain an accurate representation of the context in which the member or structure is situated. Probabilistic or semi-probabilistic conceptions are considered to be the closest to the way the elements or structures work.

4. Dependence Between Technical and Economic Criteria

The main studies carried out on the economic design of the structures or elements were carried out mainly by minimizing the costs by reducing their own weight or elaborating new calculation methodologies in close correlation with the technical criteria considered (Marti & González-Vidosa, 2010). For a more accurate evaluation of costs, it is necessary to identify all relations of sub-ordination between the technical criteria, the principle being illustrate in Fig. 3.

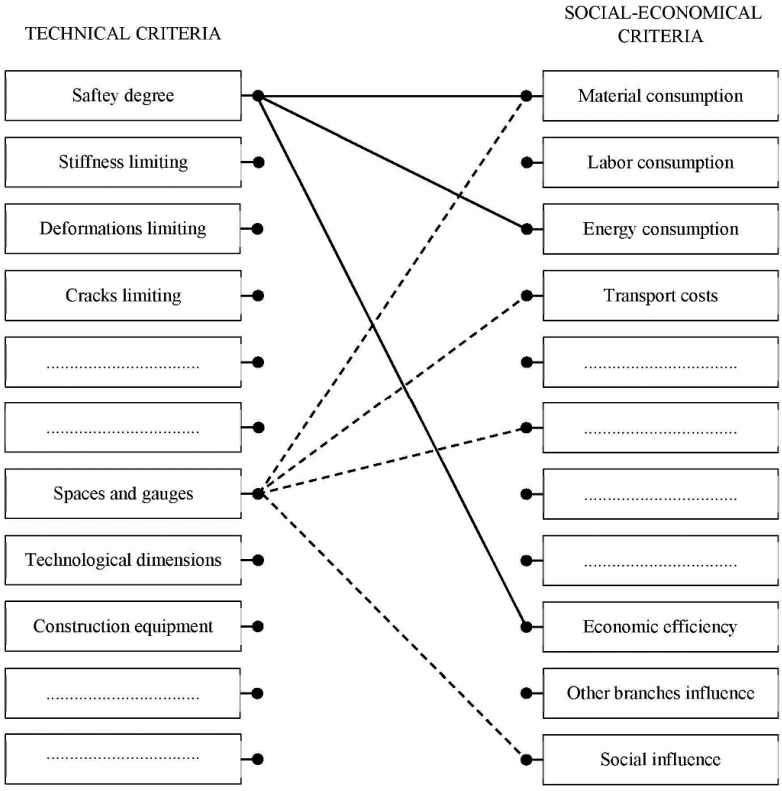

Fig. 3 – The relationship between the design criteria.

Starting from the fact that structural safety is the most important technical criterion (and at the same time mandatory), it is always used in designing to optimize it. By linking the safety degree with one or more economic criteria, a function is highlighted, which shows the efficiency of the investments, called the performance function, goal function or objective function, which synthesizes the studied aspect.

Therefore, all new technical criteria considered are assigned a new parameter, the cost one (Hassanain & Loov, 2003). Given that the current methodology is developed in such a way as to provide us with efficient solutions that meet the technical criteria, as is shown in Fig. 4, the cost of building solution is not necessarily the smallest. It is, therefore, necessary to adapt the methodology for the new parameter considers, the expected effect is to obtain solutions with minimal cost but which, implicitly, satisfy the minimum technical criteria considered.

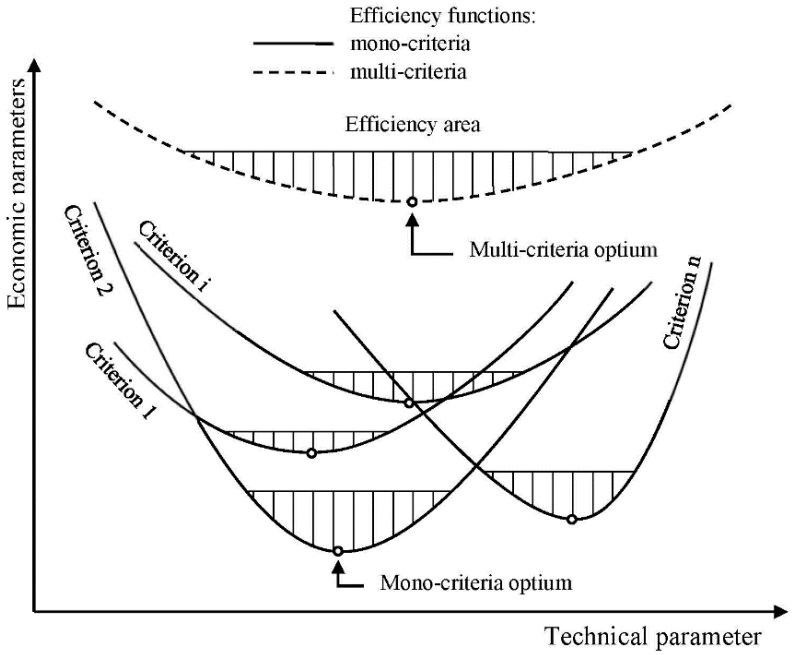

Fig. 4 – Efficiency function.

The design solution or the conceptual solution has the lowest cost when the solutions to the technical criteria taken into account are the lowest in terms of costs. This approach is not feasible, because treating technical criteria as

independent elements return a nonconformity solution from the point of view of continuity and cannot be applied in practice. An optimization operation determines a number of effective solutions in relation to the minimum cost criterion. This is due to the restrictions imposed during the design or conception process through various restrictions such as meeting structural requirements, technological endowment, etc.

There may be situations when a structure is optimal based on a certain criterion (*e.g.*, cement consumption) but in correlation with the economic system, do not present the maximum efficiency at the time of the analysis (Erbatur *et al.*, 1992). Even if the optimization is based on the minimum criterion, all the related criteria needed to be met all the technical requirements. The minimum cost is not the predominant or mandatory criterion, which is adopted by the specialists in order to assess the degree of economic performance of a technical solution. For this reason, at the end of the analysis, it is necessary to take into account the totality of the real conditions characterizing the economic situation of the area and ultimately to choose the solution closest to a multi-criteria optimum.

It is, therefore necessary in advance, for each technological criterion considered to determine the economic impact that it manifests on the final solutions. Once the technical criterion has been established, the variation of criterion which influences significantly the cost, it is possible to roughly determine the solution with the lowest cost resulting from the efficiency of that criterion based on the minimum cost criterion. However, this hypothesis is not generally valid, being necessary, in most cases being resolved with dynamic programming. Specific to dynamic programming is that at each characteristic step (step who provide a local solution) the most advantageous result (in our case the lowest cost solution) is chosen after having previously evaluated all the possible results. The method always determines a single solution, ensuring a local but not always a global optimum. In order to determine the minimum global, it is necessary to perform a series of simulations, as is shown in Fig. 5.
Correlation with a single economic criterion leads to optimized safety based on a mono-criterial efficiency analysis. Taking into consideration several socio-economic criteria leads to optimization of safety based on a multi-criteria efficiency analysis. Such optimization, based on the probabilistic concept of safety leads to the first degree of optimization. Geometric optimization of the cross-section, quantity and distribution of the reinforcement on the concrete section, leads to a second degree optimization (Spasojevic, 2006).

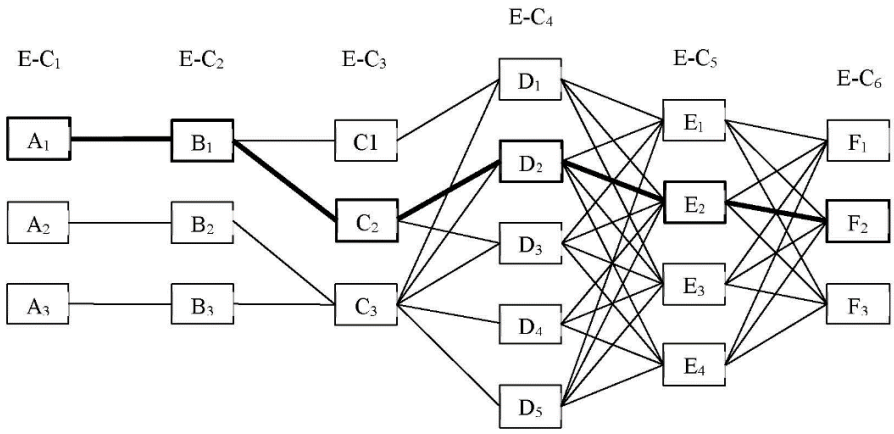

Fig. 5 – The simulation graph.

5. Computational Consumption and Construction Consumption

Each technical criterion is characterized by a certain cost. This is quantified by a ratio of a quantity of money to measure the realization of that criterion. The costs are not standard, and they may vary. Thus, the amount of money needed to make a unit of measurement is marked as a variable (Sahab *et al*., 2005).

Total costs are set for each solution provided by the analysis. Depending on the cost variation specific to the technical criteria, the minimum cost of the technical solutions can become any of the technical solutions determined. This is mainly due to the possibilities of realizing the determined solutions: material cost, labour cost, duration of realization, technological endowment, transportation cost, etc.

In all optimization cases, mathematical programming is required, with multiple parameter situations possible. If the variable parameters are not linearly independent, such as the design of concrete elements on technical and economic criteria, the simulation theory, probabilistic methods and stochastic network are used.

Depending on the number of efficiency criteria considered, the mathematical algorithm for determining solutions may be mono or multi-criteria. By imposing a higher number of efficiency criteria, a very complex mathematical algorithm is achieved, which in some cases becomes an undefined compatible system, thus solving it is impossible. Therefore, the degree of criteria considered in the mathematical algorithm must be correlated with the existing theories, the literature and the pursued accuracy (Alqedra *et al*., 2011).

The choice of the optimal constructive solution on a certain criterion or on several criteria are simultaneously taken into consideration is done by a set of methods and calculation algorithm for operational research. Any simulation can be attached to a chart, called the first-order simulation graph or the macro-optimization graph. By the first order simulation, the optimal constructive solution, the optimal topology of the structure and the members of the structures are obtained. Analysing the possible cross-sectional variation of the elements of a structure, selecting the optimal variants, mono or multi-criteria, is called the second order simulation or micro optimization.

One criterion can be evaluated taking into account several concepts of efficiency. This approach is often impossible to achieve for the reason already illustrated. Thus, solutions can only be determined by simulations, the optimal being completed only after a significant number of scenarios. The huge amount of calculations can only be achieved by using electronic computing.

Economic efficiency is surpassed by a number of requirements such as strength, stability, applicability, functionality, plausibility, etc. The necessity of obtaining an economic solution was mainly imposed by society, expressing the desire to build lower-cost buildings with lower consumption of materials and a degree of compliance specific to the norms (Lanikova *et al*., 2016).

The economic criteria upon which a structure can be analyzed are multiple, each having a different optimum in relation to the same technical parameter.

All solutions that fit into the allowed efficiency area are called economic solutions. Solutions that meet the efficiency mileage and satisfy at the same time a multi-criteria optimum are called effective solutions. Effective solutions have a greater degree of fidelity than economic solutions, and for their determination, a larger and more complex workload is needed. The economic design of member/structures is based on the principle of optimality, which declares an optimal structure if it consists of elements with optimal sections. The assurance by the designers, for each element, of some economic sections, leads to the achievement of the economic structure.

6. Conclusions

The design of prestressed concrete elements, as well as structures made of such elements, presents a degree of increased difficulty. By pursuing the solution with the minimum cost, the degree of difficulty of the algorithm which needs to be solved becomes more complex. The design stage represents an important step in the technological flow of making such an element. It determines all the technical criteria that contribute that must be considered:

evaluation of loads, choice of materials, determination of the sectional characteristics, distribution of the materials in the element, correlation of the measures imposed by the technological equipment available, the way of putting the element into operation, transport and assembly. All the above-mentioned aspects are evaluated objectively, thus obtaining a logical algorithm to be applied when solving aspects of determining optimal solutions. The optimal solutions previously determined can also be evaluated in relation to the operating costs (maintenance) and the post-use costs of the elements.

Thus, a solution can only be issued for an eloquent situation, the degree of generality is very large in order to establish a set of generally valid rules. Depending on the context of the element to be achieved (location, gauges, minimum strength, used materials, available technological equipment, number of elements to be achieved, duration of execution, etc.) optimal solutions differ from one context to another. The cost of the efficient solution is obtained only by simulations made taking into account all the technical criteria underlying the building of the elements.

The implementation of the minimum cost criterion is subordinated to the detailed reasoning in the previous chapters. The mathematical model underlying their conception/realization is detailed in the literature, and based on this, a significant number of solutions can be developed with different realization costs. By determining the optimal solution, a methodology can be issued that can be applied when it is desired to optimize the design process of prestressed concrete elements based on the minimum cost criterion.

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CRITERIILE TEHNICE ŞI ECONOMICE ÎN PROIECTAREA ELEMENTELOR DIN BETON PRECOMPRIMAT

(Rezumat)

Proiectarea eficientă a elementelor din beton precomprimat reprezintă o sarcină dificilă, numărul de parametri implicați în proiectare fiind corelat în primul rând cu criteriile tehnice. Pentru a obține elementul cu cel mai mic efort financiar, este necesar să fie optimizate soluțiile identificând costul minim a soluțiilor ce satisfac cerințele tehnice. Cu toate acestea, din practica curentă se pot obține numai modele optime datorită restricțiilor impuse de etapele de construcție și de exploatare. Astfel, soluția acestei probleme se referă la proiectarea eficientă a elementelor prefabricate precomprimate pe baza criteriilor de cost minim. Proiectarea necorespunzătoare poate duce la costuri nerezonabile. Proiectarea integrată permite concepția și proiectarea simultană a produselor asociate, a procesului de producție și întreținere. Astfel, ele sunt luate în considerare încă din faza de concepție, integrând astfel aspecte precum calitatea, durata de executare, costurile și cerințele utilizatorilor. Astfel, în această lucrare sunt ilustrate în ce manieră criteriile tehnice și economice influențează costul de fabricare a unui element prefabricat precomprimat.