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Decision Support for the Fabrication-Led Design of Tubular Trusses

Aide pour le dimensionnement de fermes à sections creuses pour un coût minimal de fabrication

Entscheidungshilfe zur fabrikationsbeeinflussten Bemessung von Fachwerken aus Hohlprofilen

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SUMMARY

This paper is concerned with the development of a knowledge-based system for the economic design of tubular trusses. The system interfaces to structural analysis and design packages and includes a module for checking joint capacities and a model for estimating the cost of fabrication of these trusses. Using this system, designers can analyse and design the structure and then judge the optimality of their solution based on the predicted overall cost of production and not on material cost only. The cost model is used to predict the relative cost of fabricating a design option compared to its feasible alternatives.

RÉSUMÉ

Cet exposé concerne le développement d'un système fondé sur la connaissance pour le dimensionnement économique des fermes à section tubulaire. Le système présente un interface pour l'analyse des structures et des logiciels de dimensionnement. Il comprend un module pour la vérification de la capacité des joints et un modèle pour l'évaluation des coûts de fabrication de ces fermes. Utilisant ce système, les ingénieurs peuvent analyser et dimensionner la structure, juger de l'optimalité de leur solution basée sur le coût global prévu de production. Le modèle d'évaluation de coût est utilisé pour juger le coût relatif de fabrication d'une solution comparée à ses alternatives.

ZUSAMMENFASSUNG

Die Arbeit beschäftigt sich mit der Entwicklung eines wissensbasierten Systems zur wirtschaftlichen Bemessung von Fachwerken aus Hohlprofilen. Das System verbindet Berechnungs- und Bemessungsprogramme, ein Modul zur Ueberprüfung der Knotenkapazität und ein Modell zur Schätzung der Herstellungskosten eines Fachwerks. Der Gebrauch dieses Systems ermöglicht dem Planer die Berechnung und Bemessung eines Tragwerks; darüber hinaus gibt es ihm die Möglichkeit, die Qualität seiner Lösung auf Basis der ermittelten Gesamtkosten und nicht ausschliesslich Materialkosten zu beurteilen und so eine optimale Lösung zu finden.

1. INTRODUCTION

At the conceptual stage of design of steel structures, decisions are made which influence the overall cost of the construction. This is mainly due to these decisions imposing constraints on the later stages, namely the fabrication and erection of the structure. Designers generally attempt to produce economic solutions by concentrating on producing efficient structures with minimum weight. It is a well-known fact, however, that minimising the weight of the structure is not only limited in scope but can also be counter-productive [1]. In many such cases an efficient structure would require stiffening at the joints, which is a costly fabrication operation likely to out-weigh the saving made from optimal weight. Often, though, this is the only option available to designers, since it is unlikely that they would have had extensive experience in the fabrication of structures in addition to their expertise in design. More importantly, they do not have the information about which of the options available to them is more costly with regard to fabrication and erection.

This situation is more relevant in the construction of tubular trusses than when using open sections. Tubular construction is relatively new and is not as widely used as open sections. Consequently, less expertise exists among designers and fabricators. In addition, variations in the joint detailing in tubular structures tend to produce high cost differentials for fabrication, especially when reinforcement is involved. This is mainly due to the complexity of the intersections between tubular sections, more specifically circular hollow sections, and to the large amount of welding involved in their fabrication. Therefore, the effect of decisions taken at the conceptual stage of design will have an even higher effect on the cost of construction of tubular structures than on that of open sections.

It is clear that more economical solutions would result if the information regarding the likely costs of design options was readily available. Designers would then be able to make better decisions being aware of the effect of these decisions on the overall cost of the structure. In a sense, this will widen the scope for economy since designers are then able to incorporate factors that influence the cost of fabrication in conjunction with minimising the cost of material.

This paper concentrates on describing the way in which an integrated system for the design of tubular trusses makes use of a model for the cost of fabrication in order to arrive at fabrication-led economical solutions for tubular structures. The development of the system is being funded by the Engineering and Physical Sciences Research Council (EPSRC) UK. It includes structural analysis and design modules and a module for the analysis of joint capacities of tubular joints and an economic appraisal module. The economic appraisal module advises on available options for design aspects and employs a cost model that estimates the likely cost of fabrication of tubular trusses. A more detailed description of the integrated system can be found in reference [2].

2. THE COST MODEL

The major factor influencing the variations in the cost of fabrication is the complexity of joint detailing. The simpler the details the less costly they are to fabricate. Conversely, the more complex the details, especially those which include stiffeners, the more costly they become. One of the major objectives of the model is to be able, for a fabrication content, i.e. the amount of cutting, profiling, welding, etc., to estimate the likely cost of fabrication and to be able to compare this cost to that of alternative details. Hence the aim is to predict the relative cost and not the absolute cost of the structure.

The cost model has been developed using knowledge acquired from expert designers and estimators working in the construction of tubular trusses. This knowledge was then interpreted and represented within a computer program capable of manipulating knowledge, encompassing rules of thumb and heuristics, as well as algorithms, here termed knowledge based system [3]. The techniques used in acquiring the knowledge, the way the knowledge was interpreted and the way it was represented in a computerised form is described elsewhere [4].

The model was implemented using the object oriented methodology [5]. The process of estimating the cost of fabrication is carried out through message-passing between objects representing the various entities and relationships of the model. The main objects adopted in this representation are: fabrication-machine, fabrication-operation, section, member, joint, and truss. An instance of the fabrication-machine object represents a specific machine with associated specifications. A fabrication-operation object, eg WELDING, estimates the cost of this operation, in minutes, given relevant data such as the details of the operation, eg weld length and thickness, and the fabrication-machine to be used. A joint object, composed of a number of member objects, will divide its fabrication content into the various fabrication operations and request a cost estimate for each by communicating with the relevant fabrication-operation objects. A truss object, composed of a number of joint objects, will add together the cost of fabricating each of its joints.

The model also allows for the concurrent costing of a number of instances of objects. Hence, the costing of joint detailing and its alternatives can be carried out concurrently. Similarly, the cost of a number of trusses can be obtained.

3. FABRICATION-LED DESIGN PROCESS

The fabrication-led design process applied to tubular trusses can be carried out using the integrated system. This is achieved by providing within a single system all the tools required for this purpose. In the following the dynamics of this process are explained in more detail while concentrating on the way the cost model is used to achieve the aim of this process.

At the conceptual stage, a designer might propose a number of conceptual solutions for the structure. These proposed solutions will most likely be based on experience gained from previous design cases. The designer may choose to structurally analyse and design only one or a number of these conceptual solutions. The likely uses that can be made of the system in order to produce economical solutions are given below.

3.1 Joint capacities

The conventional process requires designers to produce structurally adequate solutions where the geometrical configurations, the section sizes, and the welding requirements are specified. Detailed design of joints will not usually be carried out by designers. It is assumed then that the resulting joint details are capable of transmitting the forces adequately and that it is the responsibility of fabricators to ensure that the joint capacities fulfil this function.

It is often the case, however, that the resulting joint capacities are inadequate and joint stiffening might be required. This is especially true when dealing with tubular joints, where adequate member stiffness does not automatically mean adequate joint capacities even if full strength welds were specified. In tubular structures the joint capacities depend, among other factors, on the geometrical properties of the joint, eg for circular hollow sections they depend on the ratios of the diameters of the section sizes and on the diameter to thickness ratio of the chord member. This is in addition to limiting geometrical requirements such as minimum overlapping distance of bracing members. Therefore, if costly joint stiffening is to be avoided, the section sizes should be chosen with joint capacities in mind as well as the strength of members.

For this purpose a module for checking joint capacities is integrated within the system. Having achieved a structurally adequate solution for the members, the designer can then carry out joint capacity checks. Future enhancements to the model will provide advice on appropriate modifications in order to improve the capacities of unsatisfactory joints. Of course a designer can insist on the use of a certain configuration despite this resulting in the need to reinforce the joint.

3.2 Fabrication cost

Having arrived at a structurally adequate solution for members and joints, the solution can then be assessed in terms of the likely cost of fabrication. The designer can obtain a summary of the cost of fabrication of the whole of the truss. The cost, in this case, consists of the total time required to carry out all fabrication operations (in minutes), the total weight of the truss (in tonnes), and the total surface area of the truss (in square metres). The estimated time taken to carry out one type of fabrication operation is also available, eg cost of all welding and cost of profiling all members.

Four 'global' parameters are provided to convert costs in minutes, tonnes and square metres into monetary figures, i.e. cost per hour for manual-intensive fabrication, cost per hour for equipment-intensive fabrication, cost of steel per tonne, and cost of paint per square metre. Consequently the designer can obtain the likely cost of the structure in monetary values. However, this is not the primary use of the system. All the information and rules provided in the cost model, although they are obtained from up to date sources, are 'tuned' to give relative costs. Therefore the intended use of the model is to compare the obtained figures for the various alternatives. A number of feasible solutions for the structure could then be compared by fabrication content, weight, and surface areas. Monetary values can be used to compare a number of feasible solutions, where the global parameters should be calibrated to reflect the current cost balance between material and production costs.

Designers are also able to inspect the cost associated with individual joint detailing. In addition a *what-if* scenario can be followed by modifying details and requesting cost assessments. For example, the designer can assess the sensitivity of the cost of a detail to changes to the joint geometry, welding specification and/or member thickness. Consequently, a designer can appraise the likely saving that can be made from changes to one or a number of joint details before making final decisions. A breakdown of the cost of joints detailing between individual fabrication operations, and the total cost of certain operations, eg cost of assembly of joints, is available for inspection.

Costs can also be grouped in terms of individual members and in terms of individual fabrication operations. Thus, the cost sensitivity of fabrication operations to certain parameters can be obtained. For example, the cost of welding two specific items can be inspected and its sensitivity to parameters such as welding thickness, welding length resulting from geometry and welding type, can be assessed.

3.3 Decision support

The integrated system is not intended to automate the process of the design of tubular trusses but to aid in the making of informed decisions. The main benefit of the cost model is as a decision support tool for designers. The model makes available information that can be used to appraise the effects of decisions on the overall cost of the structure. The information can be used in many ways depending on the priorities and constraints imposed on the aesthetic appearance and the function of the structure. The designer can modify certain parameters, within the constraint imposed, in an attempt to optimise the solution based on the criteria of economy and practicality. For example, if the designer is restricted to a geometrical configuration and a certain range of diameters for section sizes, the types of connections, section thickness, and fabrication specifications can be calibrated to arrive at optimised solutions within these constraints.

4. SUMMARY AND CONCLUSIONS

A system for the economic appraisal of tubular truss designs has been developed; it is aimed at aiding designers in obtaining economical solutions. The system includes, in addition to analysis and design modules, a joint analysis module and an economic appraisal module. The joint design module calculates joint capacities. The economic appraisal module advises on feasible alternatives and uses a cost model to estimate the cost of fabrication of tubular trusses.

Economical solutions are achieved by indicating where joint reinforcement would be required and by estimating the relative costs of a number of feasible alternatives to the design. Therefore designers will be able to avoid costly reinforcement and to make informed decisions on which alternative to choose based on knowledge about the effects of these decisions on the cost of fabrication. This approach to design is termed fabrication-led design.

The main benefits of this system are that it provide designers with an integrated system containing all the tools necessary to produce economical designs covering all the stages of design and production and that it provides them with information not usually available to them, thereby, allowing them to consider all factors affecting cost and not only the weight of the material.

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