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Computer-Aided Design Evaluation of Steel Structures

Evaluation de projets de construction métallique assistés par ordinateur

Computerunterstützte Projektierung von Stahlbauten

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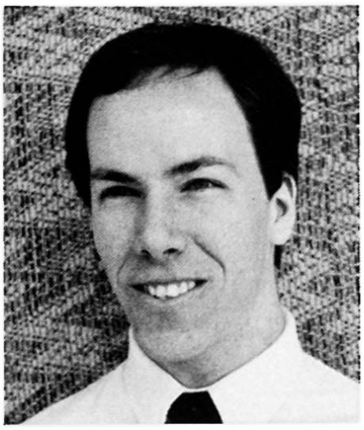

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SUMMARY
This paper presents the results of an extensive research and development project which was aimed at improving design/fabrication interaction by implementing an information system which utilizes a microcomputer for monitoring the fabrication process. The information collected by this system is analyzed and converted to provide the engineer with data which will be used in the evaluation of designs and in the assessment of the fabrication plant.

RESUME
Ce rapport présente les résultats d'un vaste projet de recherche et de développement visant l'amélioration de l'interaction conception/fabrication. Cette amélioration se réalise par l'implantation d'un système d'information utilisant un micro-ordinateur pour la gestion du procédé de fabrication. Les informations recueillies par le système sont analysées et converties pour fournir à l'ingénieur des informations utiles à l'évaluation des différents projets ainsi que du procédé de fabrication.

ZUSAMMENFASSUNG
Ergebnisse eines ausgedehnten Forschungs- und Entwicklungsprojektes werden dargestellt, das die Konstruktion und Herstellung und deren gegenseitige Beeinflussung verbessert durch die Einführung eines Informationssystems, das den Herstellungsprozess mit Hilfe von Microcomputern beschreibt. Die durch dieses System gesammelten Informationen werden analysiert und aufbereitet, um dem Ingenieur Daten bereitzustellen, die entweder zur Konstruktionsbewertung oder zur Betriebsaufnahme dienen können.

1. INTRODUCTION

In the past, "experience" has been the key to efficient structural steel design. Successful engineers have established design guidelines which take advantage of information that has been acquired through interaction with fabricators. However, in an effort to maintain confidentiality of their direct costs, fabricators are likely to provide the designer with information of only a qualitative nature. The fabricators have a more quantitative look at the information since they are able to directly view the operation and can account for the costs as they are incurred. Nevertheless, even the fabricators are somewhat unsure of the exact costs associated with various structural forms, due to the variation of the type and quantity of work done for any one project.

The size and complexity of the projects that are undertaken by most structural steel fabricators has a significant variation over time. It is this inherent variability of the fabrication process which poses the largest problem to the designer. In order to assign a cost to an arbitrary structural form, costs for each component can be calculated from a standard set of fabrication variables, which are in turn determined and updated through analysis of past projects. The fabrication process, although composed of physically simple operations, as a whole is extremely complicated; hence, associating costs with the fabrication of specific structural components is difficult. In fact the volume of work involved in the collection, organization, and analysis of data required to identify where costs are incurred has effectively eliminated this approach from conventional practice.

Recent developments in microcomputer technology have opened a new area of research in structural engineering. Addressable memory sizes are now adequate and affordable for even medium or small fabricators. Through cooperation with local steel fabricators a tool for evaluating structural steel designs has been developed at the University of British Columbia. Information can now be gathered at the activity level, and stored in digital form, permitting the designer to evaluate the efficiency of an arbitrary design by means of an estimation program.

This paper describes a systematic procedure for determining structural steel fabrication cost data, based on an information system which utilizes a microcomputer for monitoring the fabrication process. The information collected by this system is analyzed and converted to provide the engineer with data which will be used in the evaluation of designs. The information system will also provide a means of assessing the fabrication plant, so that areas of weakness may be identified.

2. STRUCTURAL STEEL FABRICATION

2.1 Design Efficiency

The efficiency of a structural design can be defined as the extent to which it satisfies structural, architectural, and cost constraints. The role of the structural engineer in the design process has traditionally been to choose and design the most efficient structural system subject to the given constraints. This has been no easy task, since the constraints are linked so that there must be some tradeoff made in reaching the optimal design. Architectural requirements are generally defined by the owner as a given requirement of the project, so structural form is to be varied to provide the most economical design.

Another important fact complicates the situation: structural steel fabrication is usually not a mass production, owing to the nature of the construction process which makes each project unique. However, elements of jobs may be similar and can be used as a basis for comparison. Assuming that the scope of the project has been set and that the design criteria has been reduced to cost, the designer is posed with the problem of associating costs with various structural forms. In most situations, the designer will not have access to the necessary cost data; hence, the formulation of the design objective can not be in terms of a cost function, and the designer is unable to perform formal structural cost optimization. To surpass this barrier, the designer must investigate the nature of the costs associated with the fabrication process.

2.2 Fabrication Costs

The cost of fabricating steel structures may be broken down into four major categories:

1. Material ;
2. Labour ;
3. Equipment;
4. Overhead .

Steel is purchased from a mill at a unit cost per weight, plus some additional charges also based on weight; hence, the cost of material is approximately proportional to the weight of the structure. This has been the major driving force for minimum weight design, since minimizing the weight also minimizes the material cost.

Labour and equipment costs are not so easily related to the form of the structure. Obviously some designs are more efficient than others in terms of ease of fabrication, but it is difficult to determine why. A key factor in these costs is material handling, which appears to be one area in the fabrication process which has large potential for improvement. Handling costs are presently assumed to be some percentage of the costs directly related to the fabrication operation. The reduction in costs associated with repetitive structural forms may be attributable to improvement in productivity for many operations in the fabrication process, such as material handling, set-up time, and labour efficiency. Designers try to account for this by using as many similar components as possible in a structure. The rising labour and machinery costs are becoming an increasingly important part of the overall cost, so a more deterministic approach to their evaluation is needed.

The fabrication cost of the ith structural member type can be written as:

$$c_i = N \left[\sum_{j=1}^{n_i} c_{m_j} W_j + \sum_{k=1}^{o_i} c_{\ell_k} T_k\right] \qquad (1)$$

where c_m, c_ℓ are unit costs for material and labour.
W_j is the weight of material j.
T_k is the time required to perform operation k.
n_i, o_i are the number of components and operations for member i.
N is the number of identical members.

The quantity of material fabricated has an unknown influence on the productivity; hence, an interaction diagram must be developed from experience relating N to T. One method of doing this is to monitor the daily operations of the fabrication plant so that a time-history plot of the work being done is available. This information can be used to identify the rate at which work is proceeding on various components of the structure as functions of time, which can be translated into curves which represent productivity improvement due to repetition of similar acts.

The total cost of a structure can be written as the sum of the component costs:

$$\text{Total Cost} = \sum_{j}(C_i) + O \qquad (2)$$

C_i = cost of component i (as given in equation 1)
O = overhead costs

Examining these equations reveals that: c_m and c_ℓ, are known constants; W and T are known functions of N; and N is the variable that we can play with to optimize the costs.

2.3 Erection Costs

The current procedure for estimation of erection costs has a large uncertainty associated with its accuracy. The estimated cost of erecting an arbitrary structure has commonly been based on the material weight, without provision for the complexity of the erection procedure. Obviously, some structures are more erection friendly than others; hence, some fabricators will alter their costs by a factor from experience. Decisions of this nature have been in error by as much as 100% and more due to the large variations in productivity associated with the erection activities. These variations may be attributed to the same kind of improvement trends which result from repetitive activities as encountered in the fabrication process.

The proposed procedure for evaluating erection costs follows a similar outline as for fabrication costs. Costs associated with an arbitrary structure will be calculated from a set of standard activities performed during erection (transportation, sorting, lifting, bolting, etc.). A large portion of equipment used during erection is rented; hence, equipment cost is proportional to the erection time. This is quite different from the fabrication process where most equipment is owned by the fabricator and can be essentially considered as overhead.

3. DESIGN/FABRICATION INTERACTION

3.1 Current Practice

Most steel structures that are constructed in Canada follow a process which has been established for historical, political, and economical reasons. The three parties involved in the construction process are: the owner, a consultant, and a contractor. The owner employs the consultant to design the structure, and to supervise the contractor who performs the construction of the structure. Since the design is partially or fully complete at the time when the contract is put up for tender, the design usually will have been done without any interaction between the designer and the contractor. This kind of practice is only acceptable if the designer can foresee the costs associated with various structural forms, so that the design with minimum cost can be chosen. For steel structures, the majority of the cost is incurred in a fabrication plant, of which the designer has only a little knowledge. In this case it is apparent that the consultant is unable to design the most cost efficient building, unless there is some interaction with the fabricator.

Presently, several structural steel fabricators receive design drawings from the consultant with the invitation to tender. A detailed fabrication cost estimate is made from these drawings and submitted back to the consultant in the form of a bid. At this time the fabricator has identified some areas where savings can be made by suggesting some structurally equivalent, but more cost efficient designs for certain components of the structure.

Quite often the designer may receive notice from the fabricator at the time of the bid that there may be some means of cutting costs, since this is an effective means of making his bid more attractive. But after this time, these changes are usually not suggested by the fabricator due to the inability of the design process to easily accept changes.

The characteristics of each fabrication plant depends on the size, and type of projects that the fabricator is involved with. This means that every fabrication plant will have its own set of cost variables which make it more suitable for the fabrication of certain types of structures than for others. Thus, interaction between the designer and the fabricator is essential for all projects, and must become an integral part of the construction process.

3.2 The Proposed Information System

An information system is a planning and control process which is based on the collection, organization, and analysis of data utilizing a computer. The implementation of an information system in a non-computerized environment is likely to be done over some period of time; hence, it must be compatible with the present manual system so that regular operation can be maintained during the transition period. The requirement of compatibility is to have the ability to accept and transmit information that is normally handled by the present system without requiring extensive changes at the base level. This can be achieved by doing the replacement in a modular nature. Care must be taken to avoid simply duplicating the present system in a computerized form, since this may accentuate the limitations and inefficiencies inherent in the manual system while ignoring the newly available computer graphic aids.

The operation and efficiency of an information system is dependent on the "language" of the data communication. A work breakdown structure, which represents the fabrication process in code form, must be implemented to facilitate effective communication between users of the system. The design of a work breakdown structure must be independent of the organization-responsibility structure, so that information pertaining to one item has the same meaning at various levels of production. Information which has been translated into code should be meaningful to the users, so that the work breakdown structure can be associated with physical operations in the fabrication process.

The data collected using the work breakdown structure can be organized to provide two types of information: project data, and process data. Project data pertains to a particular project or structure, and will be organized in a structure database. Each item in the structure database will be tracked through the plant by monitoring item progress at key operation checkpoints. A time/progress record for each item will be available to the fabricator, so that a deterministic analysis of the costs incurred during the fabrication of various structural components may be performed.

Process data pertains to all plant processes (cleaning, cutting, drilling/punching, welding, material handling, etc.). This data is assembled from the same monitoring operation as project data, but is organized to provide information about the efficiency of the plant itself. Simulation of the fabrication plant operation is required in order to evaluate the efficiency of the plant configuration, and with the use of the process data examination of expansion or replacement investments are made possible. Thus, an interactive plant optimization can be done by investigating each activity in the fabrication process. Monitoring the job progress from the component level provides information which would be used by engineering, drafting, purchasing, shop, shipping, and managerial operations. This information could then be used to interactively optimize the processing of material through the plant.

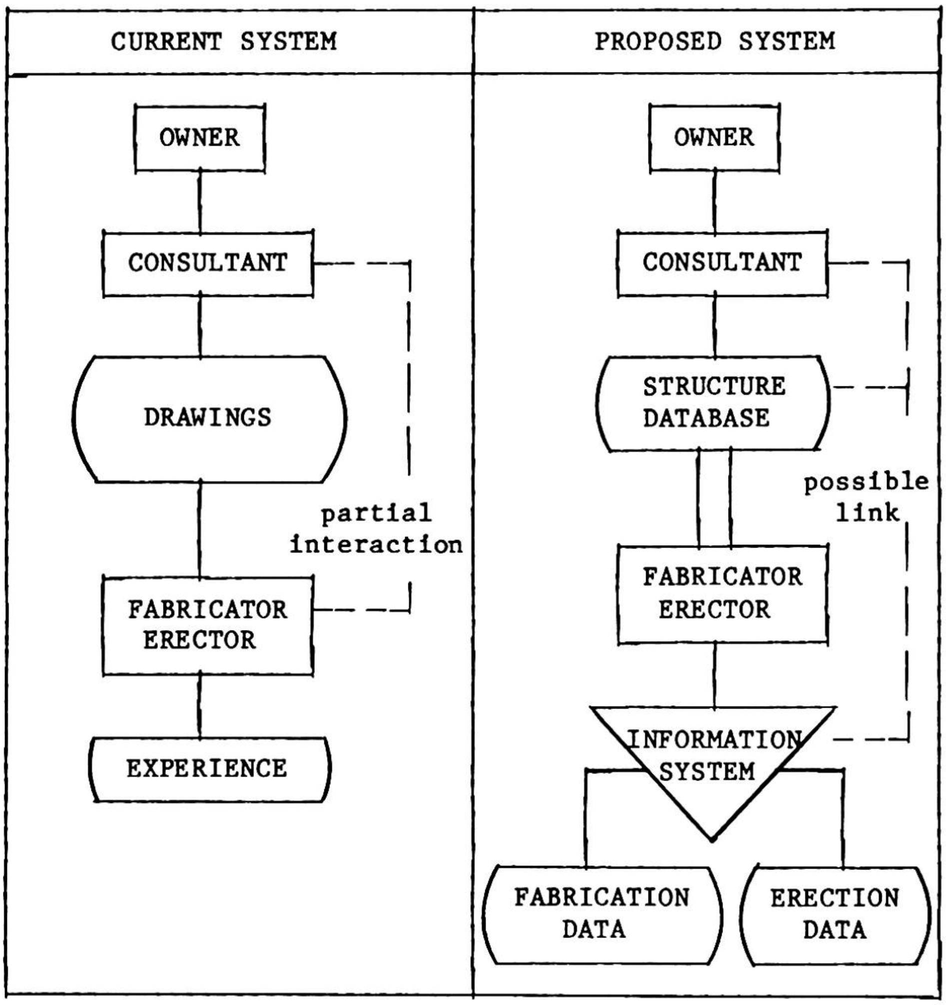


Figure 1. Current and Proposed Systems.

3.3 Optimization

As previously explained, structural cost optimization has not been performed in the past due to a lack of cost information. During this time, the design profession has used some other design tools, combined with some good common sense, to attain near optimum cost designs. One not very successful approach has been to calculate a minimum weight design in order to minimize the material costs. Experienced designers recognize that cost savings due to the peculiarities of the fabrication process could be attained through design simplification and repetition of elements. The problem facing designers, is still to determine the tradeoff point between these philosophies which produces the minimum cost design.

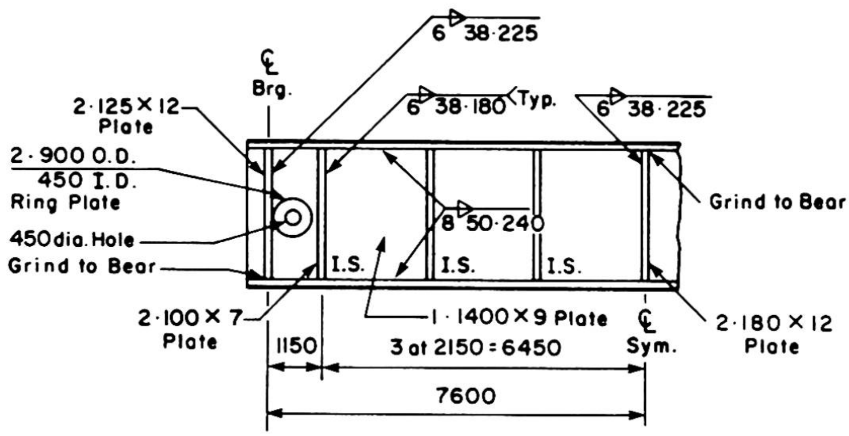
The proposed new design process takes the above procedure one step further. The consultant can directly compare the costs associated with alternative designs thereby identifying the components with minimum cost. The combination of components which produces an overall minimum can be selected from the available alternatives by using a dynamic program. This program can identify the optimal structural design by examination of alternative structural components and fabrication productivity curves.

Since the number of components is proportional to the number of alternative structural forms the memory requirements of the program expand dramatically as the structure size increases. Fortunately the productivity curves associated with the fabrication process level off to approximately constant values once the number of components is sufficiently high. This may allow us to separate the structure into modules which can be individually optimized while ensuring that an overall optimum is reached.

4. APPLICATION OF THE DESIGN EVALUATION PROGRAM

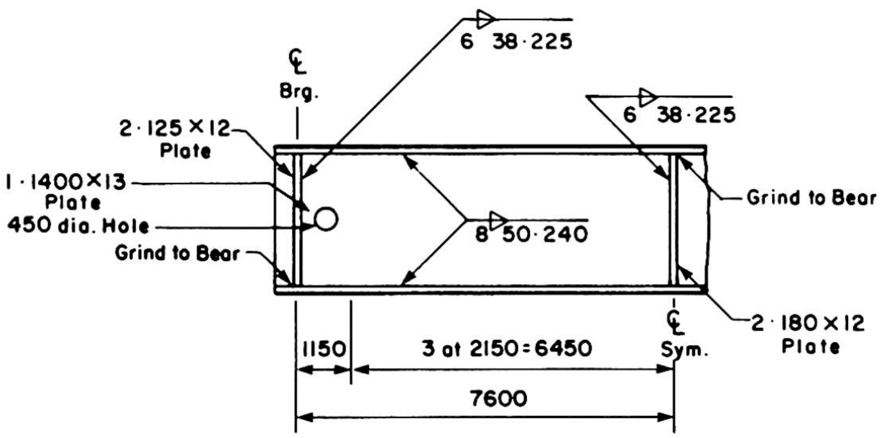
The following example illustrates the use of a routine which utilizes part of the design evaluation program. Using the most recently available fabrication data, and a cost estimation program based on equation 1, two designs for a girder are compared. The results do not intend to show that one scheme is necessarily better in all cases than the other, rather the purpose is to demonstrate how a consultant could use this tool to achieve more economical designs.

4.1 Girder With Stiffeners and Doubler Plate



The total cost of material and fabrication excluding flanges is $2411.

4.2 Girder Without Stiffeners and Doubler Plate, Web Thickened to Achieve Same Capacity as 4.1



The total cost of material and fabrication excluding flanges is $2049.

5. SUMMARY

The benefit provided by this procedure is a direct means for evaluating the efficiency of the current design, fabrication and erection processes. Since the designer will be able to identify the fabrication and erection costs associated with a given design, this tool can be used to interactively or automatically optimize the design of a structure. By providing the contractor with a device for monitoring and controlling the fabrication and erection activities, areas of weakness can be identified and modified appropriately.

The final aim of this research is to provide better access to "experience", so that more cost efficient designs can be obtained with ease. The hope is that once the designer is free from the conventional tedious tasks associated with evaluating the efficiency of a design, innovation and productivity will improve.

6. REFERENCES

1. BERRY, G.L., Shop Floor Information System: Design and Implementation, Engineering Digest, (1984).
2. CISC, A Project Analysis Approach to Building, 1980.
3. DONNELLY, J.A., Determining the Cost of Welded Joints, Engineering Journal, AISC, (October 1968).
4. DE GARMO, E.P., Materials and Processes in Manufacturing, 5th Ed., New York: MacMillan Publishing Co., Inc., (1979).
5. MOSES, F., and GOBLE, G., Minimum Cost Structures by Dynamic Programming, Engineering Journal, AISC (July 1970).
6. NIXON, D., Estimating the Cost of Small Steel Buildings, C.J.C.E., Vol. 1, No. 2, (December 1974).
7. PEURIFOY, R.L., Estimating Construction Costs, 3rd Ed., New York: McGraw-Hill Book Company, 1975.
8. RUSSELL, A.D., Cost Optimization of a Structural Roof System, M.A.Sc. Thesis, University of British Columbia, 1970.
9. SHOEMAKER, M.M., The Building Estimator's Reference Book, The Frank R. Walker Company, 1977.