

# Computer-Aided Design in Civil Engineering

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*Invited Paper*

**Abstract**—The paper reviews the development and current status of computer-aided design (CAD) in structural engineering, a branch of civil engineering. The similarities to and differences from electrical engineering practice are emphasized. The presentation deals first with well-developed CAD application areas, namely those supporting analysis, component selection and the preparation of design documents. Problematic areas, still subject to intense research, in synthesis, optimization, the representation of design specifications, the use of databases and the role of software engineering tools are briefly described.

## I. INTRODUCTION

### A. Nature of Civil Engineering Profession

IN ORDER to put computer-aided design (CAD) in civil engineering into proper perspective for a predominantly electrical-engineering-oriented audience, three salient facts about the civil engineering profession need to be brought out.

First, civil engineering deals with a very broad range of problems, including structures, foundations, transportation systems, environmental systems, and others. A simplified definition of civil engineering is that it is concerned with the design, construction and management of *constructed facilities*. Implicit in this definition is that civil engineers deal with large, one-of-a-kind and unique projects, and have no opportunity of building "breadboard models" or prototypes. Consequently, civil engineers have to rely on analytical modeling, and by extension on CAD, possibly to a larger extent than other engineering disciplines.

Second, civil engineering is highly dispersed. There are thousands of design and construction firms, either specializing in particular technical disciplines or doing general work on a limited geographic basis. The separate responsibilities for design and construction are often legally enforced, creating major constraints to widespread, integrated CAD. Thus in publicly financed construction awarded on the basis of competitive bids, all contractors bid on the same set of plans and project specifications. The designer's database generated by CAD cannot be passed on in computer-processable form to the contractor's computer-based project management system.

Third, as a direct result of the separation of responsibilities between the designer, constructor, owner and regulatory agencies on a project, many of the constraints affecting design are external to the designer, embodied in the building codes, standards and design specifications governing acceptability. While there is a move towards performance-type design specifications, which prescribe only the requisite performance of the system, structure or component, many building codes and design speci-

fications are still highly prescriptive, describing in detail exactly what is to be done, or are highly procedural, defining a procedure the result of which is deemed acceptable. The dispersion of the civil engineering profession is further reinforced by local and regional variations in building codes and by major differences among design specifications for, say, steel buildings, highway bridges, and railroad bridges on one hand, and specifications for steel, concrete, and wood buildings on the other hand.

A recent study by the General Accounting Office [1] discusses the aforementioned factors and others which inhibit wider acceptance of CAD in building design.

Because of the great diversity of civil engineering, a single survey article cannot cover CAD in all of its subdisciplines. This paper will concentrate on structural engineering, which encompasses the design of fixed structures, such as buildings and bridges. Design of fixed structures is closely allied to the design of other structures, be they automobile or aircraft bodies, ships or offshore structures. In fact, CAD in structural engineering has been strongly influenced by developments in the aerospace and shipbuilding industries, where large organizations with single overall responsibility for design and manufacturing could pioneer comprehensive CAD systems. In several key aspects of CAD, there have also been influences from other fields, notably electrical engineering; some of these will be highlighted later.

### B. Origins of CAD

Notwithstanding the impediments described, civil engineers have been early users of computers in design. Computer use emerged in the late 1950's in response to two major developments. First, the rapid expansion of the aerospace program accelerated the development of new, powerful analysis techniques, to be discussed in Section II, predicated on the computer's capability of handling large sets of discrete equations and requiring new, general approaches to modeling structural systems. Second, the equally rapid pace of design and construction of the interstate highway system introduced the need for computer applications involving basically simple calculations (earthwork quantities, horizontal and vertical roadway alignment, etc.) on large volumes of data. These dual trends of using the computer's capacity to store and manipulate very large models and its speed to process large volumes of data are still the primary manifestations of the use of CAD in civil engineering practice.

The progress of CAD in structural engineering is well documented in the seven *Proceedings of the Conference on Electronic Computation* sponsored by the ASCE Structural Division Committee on Electronic Computation [2]–[8], and in journals such as the *International Journal of Computers and Struc-*

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