Microcomputers in Civil Engineering

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The speed and capacity of microcomputers, coupled with their portability and inexpensiveness, make microcomputers attractive to the engineer. Microcomputers have the greatest potential for civil engineering projects being undertaken by individuals and small firms and for projects of a more modest size. In these situations mainframe computer processing has not been feasible because of costs and inconvenient access methods. Microcomputers can be useful even for large engineering firms and large projects because they can support cheaper and more efficient communications, and they can provide graphics, spread sheets, and other utilities that are not available in the mainframe environment. Virtually every area of civil engineering can profit from the use of a microcomputer. Standard utility programs alone can provide extensive and useful capabilities. In addition, a number of applications packages are becoming available to support specific civil engineering activities. Computer-aided design (CAD) and critical path method (CPM) systems are useful in most engineering operations, irrespective of the specific application. Some examples of application-specific software include various coordinate geometry systems for roadway and site layout, earthwork programs that calculate cut, fill, and slope stability, and structural design programs that handle simple beam design and member selection, plane frame and grillage analysis, and two-dimensional stress and truss analyses. In addition, hydraulics analysis and pavement design programs are available, as well as systems for evaluating existing pavement conditions and for assisting in establishing the priority order of maintenance measures.

The conventional wisdom of the 1980s is that microcomputers are revolutionizing business and professional practice. The civil engineer who designs roads, bridges, buildings, and other elements of the infrastructure has probably used computers for years, and so the question, "What is the big deal?" is probably well founded. In this paper an answer to that question is attempted by juxtaposing the concerns and capabilities of mainframe computer processing against those of microcomputing, and some typical civil engineering design applications are discussed that can use the microcomputer most effectively.

MAINFRAME COMPUTER VERSUS MICROCOMPUTER TRADE-OFFS

Since its earliest days civil engineering design has been a numerically oriented discipline, so civil engineers are continuously searching for better ways of performing their computations, for both better accuracy and greater speed. The development of the slide rule was a revolutionary event because this device provided the engineer with a tool that would accurately yet quickly perform computations and was also conveniently sized and easy to use. The development of mainframe computer processing in the 1950s and 1960s also revolutionized engineering, but by contrast the mainframe computer was tremendously inconvenient and expensive. Yet it enabled the engineer to tap tremendous computational powers and data base facilities that eased the work. The blending of these two technologies was begun with the desk-top and pocket calculators, but this was actually only an evolutionary step from slide rules, because even the more advanced programmable calculators were primitive in their capacity to store data and their ability to communicate with the user. The development of microcomputers, however, is a revolutionary event that has transformed the computational environment, and has even begun to change the engineer's approach to problem solving in general. The friendliness, speed, and capacity of microcomputers have been amply discussed. When coupled with these factors, the portability and inexpensiveness of microcomputers make them attractive to the engineer.

This is not to say that mainframe computing is on the wane. On the contrary, no realistic substitute has been found for the massive shared data bases, the multiuser environments, and the computational speed and memory capacity of these large machines. Particularly in a large design organization and for large projects, these features of the mainframe computer are of vital importance. But, much of civil engineering is being accomplished by individuals and small firms and for projects of a more modest size. For these groups, which have been effectively locked out of mainframe computer processing because of costs and inconvenient access methods, microcomputers have great potential. Even for committed users of mainframe computers, microcomputers can be useful because they can support cheaper and more effective communications and can provide graphics, spread sheets, and other utilities that are not available in the mainframe computer environment.

The microcomputer can operate in the design process in three modes.

1. In stand-alone operation the computer operates independently and self-sufficiently. This is probably the most common use of microcomputers.
2. The microcomputer can serve as a distributed extension of a central mainframe computer, with fully integrated operations and data bases both locally (in the microcomputer) and centralized (in the mainframe). Because of the strenuous software and system demands of this mode it is probably the least common operating mode.
3. The microcomputer can be an intelligent terminal, which provides the convenience of a local data base, the user-friendliness of full-screen data preparation tools, and consequent cost reductions in communicating with the applications on the mainframe computer.

The advantages of using the microcomputer as an intelligent terminal over a conventional terminal for accessing a remote mainframe computer derive from a relatively new trend in computing costs. Considering both personnel and operating costs, the costs of communicating between terminals and the computer have become a relatively larger portion of the total cost package. This is because the costs of computation are decreasing at a faster rate than those of communications, and the cost of personnel continues to increase. Thus, applications that use the microcomputer to assist in the preparation of data and speed its communication to the mainframe computer are of great potential and, in this sense, microcomputers greatly complement mainframe computer applications.

Microcomputers also can compete directly with mainframe computers in a number of areas, primarily because of the extremely high screen transfer rates that are possible without interposing telephone lines between the microprocessor central processing unit (CPU) and the user. Although the graphics and text displays of a microcomputer might be somewhat less elegant than those of a Tektronics or IBM-3270 screen, the complete microcomputer probably costs less than the terminal alone, and the costs of mainframe computer processing to drive the terminal are added each time it is used. Thus economical graphics, electronic spread sheets, and full-screen editors are possible in the microcomputer environment but may only be dreamed about in the mainframe computer environment because of their extreme cost.

The comparatively small memory capacity of a microcomputer generally forces larger application programs to be broken down into menu-driven modules. This, in a sense, is an advantage for the problem-solving process, which is then also broken down into manageable segments. Programs can then be written in a way that minor amendments can be made without having to run large sections of the program again, and an iterative or stepwise approach to the solution of the whole problem is more common. In this mode of operation the slower computation of the microcomputer is less noticeable and is more than compensated for by the more direct control of the problem-solving process.

In summary, microcomputers can have a very real and effective place in even a highly mainframe-oriented organization. Care must be taken, however, to thoroughly integrate their use into the organizationwide computational scheme so that data structures, algorithms, and techniques are controlled, and the most useful features of both the mainframe and the microcomputer are used.

TYPICAL CIVIL ENGINEERING DESIGN APPLICATIONS

An attempt at defining the uses for a microcomputer in civil engineering design practice is somewhat akin to defining the potential applications for a slide rule or a typewriter. With a reasonable amount of imagination virtually every area of practice can profit from its use. Some applications are generic and common to all the various disciplines of engineering; others are more specifically tailored to particular disciplines and require specialized software. In discussing these applications, the following is not intended to be a comprehensive listing of potential uses, but rather it is intended to demonstrate the breadth and power of microcomputer hardware and software systems and to pique the imagination. Some guidelines for selecting a system are also given.

Generic Applications Using General Utilities

Quite likely the most significant aspect of microcomputers is not the technical sophistication of the hardware but rather the profusion of useful, well-designed software. Each discipline has its own elegant software; nowhere are these advances more obvious than in the general utility programs now being offered. They fall into five general areas, and a practice that taps the fullest potential of a microcomputer would use each:

1. Word processing,
2. Electronic spread sheets,
3. Data base management,
4. Graphics, and
5. Communications.

Until only recently each of these applications stood virtually by itself, which limited the usefulness of that software package. The latest trend (as exemplified by the Apple III SOS Operating System) is to integrate the operation of these utilities through common file structures and disk operating systems, and even (as the Apple LISA will do) through the same overall program environment. Thus, computations developed by the electronic spread sheet can be fed directly into graphics, for example, and the results of both can, in turn, be incorporated directly into the word processor for reporting.

Word Processing

Word processing has been used effectively by engineers since its inception. Reports are an obvious application for word processing; however, probably the greatest usefulness in the design shop relates to the preparation of construction specifications. A complete set of standard specifications can be kept on-line, and minor modifications, additions, and deletions can be made to tailor them to a particular project. The time savings for both professional and clerical staff can pay for a microcomputer system quickly in this application alone.

Electronic Spread Sheets

Electronic spread sheets are an entirely new medium of computation that has been made possible by the microcomputer and should be made a mainstay of the software repertoire of every engineering office. These programs (of which VISICALC, SUPERCALC, LOGICALC, and MULTIPLAN are notable examples) give the user complete flexibility to define a computational spread sheet on the order of 50 columns wide and 250 rows long. In each cell of this spread sheet can be inserted text, values, or mathematical relationships among cells, and a large number of intrinsic functions are provided to support those mathematical relationships.

Each spread sheet tableau can be saved on diskette and recalled, tableaus can be overlayed and merged, and computational results can be transferred among tableaus, to other applications programs, and to word processing and graphics packages. As an example of a spread sheet's use, a construction cost estimate can be developed that contains all likely cost items and their unit cost. For a particular construction project this template is then recalled and the quantity of each item is entered. The spread sheet calculates the total cost for each item automatically and the overall construction cost is stratified in whatever way the user sets up the model. The resultant estimate can be printed directly or incorporated into the word processor, and the entire tableau can be saved (with quantities intact) and recalled for later updating. Other applications could include unit hydrograph computations, earthwork quantitites, pavement design models--in short, virtually any mathematical model that can be expressed in row and column format and does not require extensive iteration.

Data Base Management

Data base management is probably less well developed in the microcomputer environment, principally because of the extensive amount of disk storage and memory space required to support effective data base management. With larger CPUs and Winchester hard disks, which are becoming available at reasonable prices, fully relational data base management systems are now also becoming available. In an engineering practice data base management is probably less useful directly, but it is an absolute necessity to support some facilities such as computer-aided design (CAD) systems and project management systems.

Graphics

Graphics is a key capability of the microcomputer. General utility graphics packages are readily available commercially and can be integrated with electronic spread-sheet programs to assist in the display of results. These graphics packages are typically business oriented, however, and provide bar charts, line graphs, and pie charts. To the extent that these formats can be used to summarize technical findings they are of use to the practicing engineer. For many engineering applications, however, specifically tailored engineering graphics packages must be used.

Communications

Communications is an important feature of microcomputers to the engineer because it permits communication with mainframe computing systems. As discussed previously, communication enables the engineer both to complement mainframe operations with the microcomputer capabilities and also to use mainframe resources to expand microcomputer power. A number of communications programs are available that, with little or no modification, will allow the engineer to communicate with virtually any mainframe system. These packages essentially turn the microcomputer into an intelligent terminal, enabling conventional manual communication and control with a time-sharing system, complemented by the ability to transmit and retrieve entire files of data. These files can then be input to other utilities such as spread sheets, grahics packages, and the word processor, or to specific application programs on the microcomputer.

Summary

Even if only these general utility packages are used, the microcomputer can be made into a powerful tool for engineering design. The programs are generally inexpensive to purchase, readily available commercially, and need virtually no software development to support their use. The key ingredient on the engineer's part is creativity--the ability to envision and develop ways of using these tools.

Generic Engineering Applications Programs

In addition to the more readily available and less expensive utilities, a number of applications packages are becoming available to support engineering specifically. Because of the more limited marketplace and often more rigorous software and hardware demands, these packages are considerably more expensive than the general utility packages; however, they too can be of great use in an engineering practice.

CAD Systems

CAD systems are beginning to appear in the marketplace. For obvious reasons of disk storage space and CPU size, they do not match the power of mainframe CAD systems. Yet, high-quality, two-dimensional drawings and design capabilities are provided. CAD techniques have been heavily incorporated into other engineering disciplines such as mechanical and chemical (both dealing with industrial design); however, CAD has not yet been used extensively by civil engineers. Relatively inexpensive CAD systems that use the microcomputer (with costs on the order of $10,000 to $20,000, including hardware) may begin to encourage civil engineers to use them also. Examples of CAD systems include CASCADE II by CGD Systems in Anaheim, California; CADAPPLE II by T&W Systems in Fountain Valley, California; AUTOCAD by AutoDesk, Inc., of Mill Valley, California; and the PALETTE system developed by Structural Programming, Inc. of Sudbury, Massachusetts, for the DEC VAX system, which has now been modified to operate on the DEC 300-series microcomputer.

Project Management

Project management, both of in-house operations and of construction projects, is an application that is well suited to the microcomputer environment. A number of critical path method (CPM)-type network scheduling systems have been developed and are available commerically. One of the most notable construction project management systems is the management and project planning system (MAPPS), which was originally developed by Structural Programming, Inc., for the VAX system. This management system, which integrates both costing and scheduling, will soon be available for the DEC microcomputer. A number of utilities are available for in-house control of design projects, including Project Control/Micro, a system of software tools that allows a manager to model a project or resource environment and to track, analyze, and simulate it. Both tabular and graphic outputs are provided.

DISCIPLINE-SPECIFIC APPLICATIONS

Software packages that support specific engineering design problems are less common, more expensive, and of inconsistent quality. Undoubtedly, many organizations have been developing systems to support their own practice but, because of the efforts needed to finalize, document, market, and support software systems, few of these packages reach the marketplace. Presumably, time will remedy this situation, and this is evidenced by the ever-increasing number of software advertisements in professional journals.

One trend that seems to be helping the distribution of engineering systems is that larger software suppliers are assembling and mass-marketing civil engineering programs developed by practicing engineers. As part of this process they throughly test and document each program, thereby giving better assurance of its quality. Examples of these packages include the CIVILSOFT line marketed by Advent Products, Orange, California; the systems developed by Advanced Engineering Software for hydrology and hydraulics, by Advanced Engineering Software, Irvine, California; and the DISCO-TECH products by Morton Technologies, Santa Rosa, California.

In addition, computer manufacturers that have a traditional engineering orientation, such as Digital Equipment Corporation (DEC) and Hewlett-Packard (HP), have well-developed engineering packages available for their microcomputers that are thoroughly integrated with their hardware.

Some examples of application-specific software systems for the microcomputer include the following.

1. To support roadway and site layout, various coordinate geometry (COGO) systems are available. They are designed to run on virtually any CPM machine (including a suitably equipped Apple II). Notable examples include the COGO System in CIVILSOFT, a COGO developed by Weltech, Dayton, Ohio, the Coordinate Geometry Program by DISCO-TECH, and systems by HP and DEC. These systems are typically menu-based and provide many capabilities to compute curve, line, and traverse data. Other location-related systems include vertical curve design programs, survey packages, and field note reduction systems.

2. Further support of the highway design process is available through earthwork programs such as the EARTHWK program available from CIVILSOFT. This program calculates cut and fill by various methods and allows input from a digitizer. The SLOPE program is available from CIVILSOFT to deal with slope stability of an earthen embankment. Its solution

consists of a factor of safety for a given slope condition.

3. Structural design has many applications that use microcomputer processing. More obvious applications include simple beam design and member selection, where loads are computed and appropriately sized members are selected from a data base automatically. Other applications include beam, plane frame, and grillage analysis. Various programs are also available for two-dimensional stress and truss analyses. A useful program to the highway designer is a cantilever retaining wall design program. Programs are available from DISCO-TECH, CIVILSOFT, HP, and DEC.

4. A number of hydraulics analysis and design systems are also available. A comprehensive storm water detention design program is available from Garmen Associates, Whippany, New Jersey, and other available programs include pipe network analysis programs, open channel hydraulics programs, and backwater analysis programs such as those available from DISCO-TECH and CIVILSOFT.

5. In the area of pavement design, a number of concrete and bituminous-mix design programs are available from CIVILSOFT and other sources to assist the engineer in designing a pavement. Another useful program is COMPAVE, developed by Allan Davis Associates, Stamford, Connecticut. This is a comprehensive system for evaluating existing pavement conditions and for assisting in establishing the priority order of maintenance measures.

These analysis and design packages do not have the power of mainframe packages to deal with complex and large-scale design problems. ICES COGO/ROADS is an extremely powerful tool for coordinate geometry, roadway design, and earthwork computations as are the U.S. Army Corps of Engineers' HEC-II system for hydraulic modeling, and various STRUDL systems for structural analysis. Often the resources of these mainframe programs are unused in a typical design problem; however, the ease, economy, and utility of microcomputer applications makes this environment a practical alternative.

ISSUES AFFECTING SYSTEM SELECTION

The potential purchaser of an engineering system is faced with a dilemma--the costs of time spent in identifying and evaluating systems may far exceed the actual costs of the systems. The systems will most likely become a major element of his or her practice; therefore, this is reasonable up to a point. This aspect of the acquisition process should be controlled though, and the engineer should be willing to take some chances because even the purchase of a totally wrong system would waste only a few hundred dollars and, in reality, virtually any system will have some usefulness. Technical validity is obviously of paramount concern in evaluating the candidate programs. Also important, however, is that the programs be easy to use and that they have the flexibility to be driven by the user rather than driving the user. Therefore, a well-defined system should have the following features.

1. Technical merit--Clearly, if invalid algorithms are used, the system will be worthless, no matter how elegant. Products of the candidate system should be checked carefully against the results of known procedures to check their accuracy.

2. Open design--Piracy is a real and valid concern of software suppliers, but provision still should be made for the user to have access to the program code, particularly for those portions that relate to the model algorithms. This will enable the user both to further validate the algorithms and to modify them if so desired.

3. User expandability--Related to the open design feature is the ability to accommodate user expansion of the system. This should be supported by documentation of the file structures and any utility modules in the system that assist in file access and other tasks. This feature would permit a user to modify the system to suit particular needs.

4. Menu drivers--To ease the selection of program options and the chaining of program modules, the entire system ought to be menu-driven. This considerably eases the user's learning process and also makes the system considerably easier to operate.

5. Full-screen data edits--Many user interfaces are holdovers from the original punched card input modes of mainframe computers, with line-by-line viewing of data. The high-speed screen capabilities of microcomputers offer a much more effective and easy-to-use means of entering and updating data via full-screen edits. Any system ought to use full-screen displays wherever possible.

6. Interfaces with other programs--For maximum usefulness, a system ought to provide easy-to-use interfaces with other utility and application programs. This can be through standard file structures such as the Data Interchange Format (DIF) file structure associated with VISICALC. These special format files can then be incorporated in the spread sheets and graphics.

The key objective in all of these features is to maximize the usefulness of a system to the user by giving flexibility in use, and by easing the learning experience as well as day-to-day operation of the system. In general, engineering systems have the technical algorithms well worked out and are dependable from a technical perspective. Often, however, their shortcomings occur in communication with the user and inability to communicate with other packages or to be expanded or modified by the user.

SUMMARY

The development of the microcomputer signals a new era of computer use. The user-friendliness and usefulness of general utilities such as word processors, spread sheets, and graphics when complemented by effective engineering applications programs make these computers significant additions to any engineering practice. Their usefulness is bound only by the imagination of the engineer and his or her ability to modify problem-solving techniques and office procedures to harness the computer's power more effectively.