NATIONAL CENTER FOR EARTHQUAKE
ENGINEERING RESEARCH
State University of New York at Buffalo

WORKSHOP ON SEISMIC COMPUTER ANALYSIS AND DESIGN OF BUILDINGS WITH INTERACTIVE GRAPHICS

August 3-5, 1987

Edited by

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Technical Report NCEER-88-0001

January 18, 1988

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Edited by:

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January 18, 1988

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A three day workshop was held at Cornell on August 3-5, 1987. Its basic aims were to facilitate technology transfer and to attempt to influence future directions in earthquake engineering practice, education, and research in the area of computer analysis and design. The first day's program consisted of demonstrations and hands-on use of Cornell interactive computer graphics analysis and design programs, plus a discussion of current and planned National Center for Earthquake Engineering Research computer analysis research. The morning of the second day was devoted to presentations by other academicians and practitioners. The last day and one-half were spent on panel discussions and the preparation of reports and recommendations in four pre-defined areas: research needs, hardware innovations, software innovations, and technology transfer. Working Groups in each area were established and each group prepared a report. The last four sections, which constitute the body of this publication, are the final reports of the Working Groups.

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ABSTRACT

A three day workshop was held at Cornell on August 3-5, 1987. Its basic aims were to facilitate technology transfer and to attempt to influence future directions in earthquake engineering practice, education, and research in the area of computer analysis and design. The first day's program consisted of demonstrations and hands-on use of Cornell interactive computer graphics analysis and design programs, plus a discussion of current and planned NCEER computer analysis research. The morning of the second day was devoted to presentations by other academicians and practitioners. The last day and one-half was spent on panel discussions and the preparation of reports and recommendations in four pre-defined areas: research needs, hardware innovations, software innovations, and technology transfer. Working Groups in each area were established and each group prepared a report. The last four sections, which constitute the body of this publication, are the final reports of the Working Groups.

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Several Cornell graduate students assisted with the conduct of the Workshop: Brian Aubert, Christos Chrysostomou, Gyula Greschik, Jerry Hajjar, Luiz Martha, Glenn Shen, Maya Srinivasan, Sanjeev Srivastav, Donald White, and Ron Ziemian. Valuable assistance was also provided by the staffs of Cornell's Computer Aided Design Instructional Facility and Cornell's Program of Computer Graphics: Gene Dykes, Tim O'Conner, Catherine Mink, Eileen McKelvey, Anh Look, Steve Gaarder, Dirk Taylor, Bob Covey, and Brian McKelvey. Staff support from the Department of Structural Engineering has been provided by Pam Kelley and Norma Nemecek. Assistance in using Cornell facilities and providing services to the participants was provided by Margaret Moy of Cornell Conference Services. Special assistance in greeting arriving participants was given by Jane White and Constance Ziemian. The assistance of all those mentioned is gratefully acknowledged.

TABLE OF CONTENTS

SECTION	TITLE	PAGE
1	**INTRODUCTION**	1-1
1.1	Goals	1-1
1.2	Workshop Program	1-1
1.3	Workshop Participants	1-2
1.4	Workshop Software Dissemination	1-2
1.5	Results	1-2
2	**RESEARCH NEEDS**	2-1
2.1	Introduction	2-1
2.2	Issues and Ideas	2-1
2.3	Recommendations	2-6
3	**HARDWARE INNOVATIONS**	3-1
3.1	Introduction	3-1
3.2	Issues and Ideas	3-1
3.3	Summary and Recommendations	3-5
4	**SOFTWARE INNOVATIONS**	4-1
4.1	Introduction	4-1
4.2	Issues and Ideas	4-1
4.3	Recommendations	4-2
5	**TECHNOLOGY TRANSFER**	5-1
5.1	Introduction	5-1
5.2	Issues and Ideas	5-3
5.3	Recommendations	5-4
APPENDIX A		A-1
APPENDIX B		B-1
APPENDIX C		C-1
APPENDIX D		D-1

SECTION 1
INTRODUCTION

A three day workshop was held at Cornell University on August 3-5, 1987. The basic aims were to facilitate technology transfer and to attempt to influence future directions in earthquake engineering practice, education, and research in the area of computer analysis and design.

1.1 Goals

Research and development in computer-aided earthquake engineering is actively being carried on in NCEER institutions, other universities, and industry. It is resulting in a variety of methods and programs for the seismic analysis, design, and evaluation of systems and facilities. Many are already in use or are ready for practical use, some are still in research but have an imminent future in practice, and some are in emerging areas of advanced research such as the exploitation of graphics and supercomputer capabilities. Both design practice and research need an assessment of the present state of the art and a discussion of possible future trends and opportunties. The immediate aim of this workshop was to facilitate technology transfer and discussion by bringing together about 40 engineers from research and practice who are concerned with the computer-aided earthquake engineering of building structures.

The workshop's basic goals are long term ones: to influence future directions in earthquake engineering practice, education, and research through its published proceedings, to promote collaboration among researchers, and to establish a base for continued research cooperation and technology transfer in the area of innovative computer analysis and design.

1.2 Workshop Program

Appendix A is a program and schedule of the Workshop.

The first day's program consisted of demonstrations and hands-on use of Cornell interactive computer graphics analysis and design programs (CU-PREPF, CU-STAND, and CU-QUAND), plus a discussion of current and planned NCEER computer analysis research.

The morning of the second day was devoted to presentations by other academicians – Professor E. L. Wilson of the University of California and Professor Y.-J. Park of SUNY Bufflo – and practitioners – Messrs. N. Amin and M. Mulert of Skidmore, Owings and Merrill and Mr. R. J. Clayton of the Thinking Machines Corporation.

The last day and one-half was spent on panel discussions and the preparation of reports and recommendations in four pre-defined areas: research needs, hardware innovations, software innovations, and technology transfer. Working Groups in each area were established and each group prepared a preliminary report prior to departure. The preliminary reports were reproduced and circulated to each group member for comments and suggestions. The following four sections, which constitute the body of this publication, are the final reports of the Working Groups.

1.3 Workshop Participants

Appendix B is a list of participants. Twenty-three academicians and seventeen practitioners attended. Eleven states, Puerto Rico, Canada, Mexico, and the Republic of China were represented. All participants are concerned in one way or another with the computer-aided earthquake engineering of building structures.

1.4 Workshop Software Dissemination

Transportable versions of CU-PREPF, CU-STAND, and CU-QUAND were offered to all participants as soon as implementation of a useful version of each program in the DEC workstation environment is complete. These versions of the programs are expected to be available by mid-1988. Appendix C contains a brief description of each. The software dissemination policy is explained in Appendix D.

1.5 Results

The workshop has been completed. The test of the success or failure of any project such as this is the influence it has on future practice, education, and research. This will not be known until sufficient time has passed to assess the effect of the meeting. However, judging from the favorable comments of the participants and their own experience in other workshops, the co-directors believe this one will prove to be successful.

SECTION 2
RESEARCH NEEDS

2.1 Introduction

During the last twenty five years computers have played an important role in helping engineers gain a better understanding of the actual seismic behavior of buildings. The effects of recent earthquakes on buildings underscore the continuing need to understand better both the nature of the ground excitation and the dynamic behavior of structures, in order to arrive at more rational procedures for the design of earthquake-resistant structures.

In examining the structural performance of existing buildings during earthquakes, it is important to determine the potential extent of damage and their actual ultimate capacity to resist earthquakes. For new construction, understanding the inelastic dynamic behavior and ultimate capacity is essential for the design of safe and economical building structures. Efficient tools, including better modeling capabilities, improved numerical methods, and computer hardware and software, are required for these purposes. In addition, correlations with laboratory experiments and field observations are necessary for establishing and validating the analytical models.

The Working Group on Research Needs addressed several issues pertaining to these problems. Questions of hardware and software, however, were considered only in general terms since they were the subjects of separate Working Group reports. The main issues considered by the Research Needs Working Group are described in the next sub-section. Specific research recommendations are listed in a third sub-section.

2.2 Issues and Ideas

Discussion and presentations at the Workshop related to research needs for the computer-aided earthquake engineering of buildings were divided into four overall concerns: Performance Evaluation, Analysis, Computer Modeling, and Design. The ideas and issues raised in each of these areas are summarized in the following:

Performance Evaluation, including the behavior of systems and components, is not adequately addressed by the current state of the art of computer simulation. Among the issues that require further research attention are:

o The prediction of the full-range response of buildings, varying from linear behavior up to full nonlinear effects including collapse. Although analytical techniques exist and considerable progress has been made in understanding second-order elastic and inelastic phenomena, new efforts are needed to characterize damage and failure, including the definition and consideration of a variety of failure mechanisms.

o At a different level, the full range of behavior of individual components and subassemblages continues to require detailed computer simulation. The goals should be to gain a better understanding of three-dimensional response of components under seismic loadings, and to provide information needed to improve modeling at the coarser level.

o The complex systems aspects of building behavior need to be considered; that is, the interaction of local phenomena (such as buckling and fracture) with overall performance should be assessed, particularly with regard to the initiation of failure mechanisms. In addition, the contribution of so-called "nonstructural" elements, such as infill walls, to overall building response needs to be examined.

o Complete foundation-building systems should be considered, including the soil-structure-interaction and overall-response effects of various foundation types, if the structure is stiff relative to the surrounding soil.

o Computer simulation should be used to quantify the importance of variability of ground-motion characteristics in relation to variations in other modeling assumptions and analysis levels.

o Simulation of dynamic structural response should also be extended to provide information regarding potential damage to building contents and nonstructural components. The potential financial loss due to damage to contents may far outweigh that to the structural system. Appropriate parameters, such as local accelerations and relative story drifts, need to be identified, and information regarding them must be effectively communicated to building owners and occupants.

Analysis. While analytical techniques have received considerable attention in the past and progress has been made both for linear and nonlinear response, the following aspects of analysis require additional research.

- Simplified analytical procedures need to be developed both for the purpose of carrying out parametric studies in nonlinear phenomena and for development of procedures appropriate for design. Existing and future simple models should be evaluated against more sophisticated procedures and actual structural behavior.

- Existing algorithms for linear and nonlinear dynamic analysis need to be reassessed in light of computing hardware advances. Algorithms for more robust nonlinear computations should be sought. Techniques such as substructuring, which allow efficient computational treatment of complex structural systems, could be investigated as part of this effort.

- Techniques for providing more thorough correlation of laboratory and field experiments with analytical models should be investigated. Such techniques might include system identification and other parameter estimation techniques.

- Research efforts should be directed towards developing new ways of visualizing structural response through the use of advanced graphics, including color displays and graphic animation.

- In addition to deterministic studies, a probabilistic approach using appropriate ground motion simulations, and other nonstationary random excitations, should be undertaken in light of the sensitivity of inelastic response to the detailed form of the ground motion. The reliability of the building structure, as derived from structural models of increasing sophistication, should also be investigated.

Modeling. A number of issues and ideas addressed at the workshop were assigned to a category associated with development of improved models of the total structural system. The key areas of concern are:

o The influence of semi-rigid and nonlinear connections on performance of members and other components needs to be considered in subsequent research.

o Soil-structure interaction effects should be included in the model, if appropriate, and the influence of variability in soil parameters and in the type of foundation should be specifically addressed.

o A hierarchy of models, possessing different levels of sophistication and representing various stages of the performance of the total system, should be utilized in analysis.

o So-called "nonstructural" components (e.g., cladding, infill, etc.) should be incorporated into the total system model so that one accounts for all elements which could potentially influence system behavior. These components, however, may not be effective through the full range of behavior of the structure.

o The unique problems associated with structures of various materials, or combinations of materials, need to be addressed. The level of understanding of behavior of structures of different materials (e.g., steel, concrete, precast, masonry, etc.) has not progressed at the same rate and should be considered in future research.

o The problems associated with uplift and no-tension or no-compression elements in structures and structural subassemblages are worthy of special research attention.

o The addition of damping elements and other means of passive and/or active control in structures must be explored.

o Base isolation concepts have received considerable research attention, and limited application. They appear to be worthy of more in-depth future study, including the development of effective computer models.

o The possible use of expendable elements, referred to as "structural fuses," may be a fruitful area for future research. Introducing such elements may lead to a structure in which inelastic action is more localized. The dynamic behavior of such systems may be easier to predict and control.

o The idealization of floors as completely rigid diaphragms may not be appropriate in many cases. The use of flexible diaphragms may be advisable in many instances if a more realistic assessment of the lateral stiffness distribution at floor levels is to be utilized in the model.

o Development of models for existing structures for which only limited documentation is available poses special problems worthy of research attention in the near future.

Design. The last concern examined was design.

o The use of inelastic design spectra needs to be examined. Simple, precise and reliable procedures need to be established for determing "R-factors" for use in design.

o The evolution of seismic codes depends strongly on the lessons learned from recent strong earthquakes. These codes should be examined for possible revisions following the occurrence of highly destructive earthquakes.

o Base isolation and supplemental damping have been found to be beneficial to building performance in highly seismic areas. Additional research is needed for the development of models and methods for considering these passive control mechanisms in the design phase.

o Optimization techniques have been used in practice for structures which are produced in significant quantities, such as transmission towers. New, efficient optimization procedures, involving a combination of mathematical models and heuristic rules, should be explored for buildings.

o Besides being a useful tool in analysis, advanced computer graphics could be used to better integrate the complete design process, from conceptual architectural design, to selection of structural system, to reanalysis and final structural design.

- Connection design demands both a clear understanding of structural performance and knowledge of construction operations. Research is needed to establish simple and logical computer-aided methods for safe and economical connection design. These methods should include knowledge-based systems, which incorporate the expertise of design professionals.

2.3 Recommendations

On the basis of the presentations of panel members and subsequent discussions involving all workshop participants, several key areas in which future research should be focused were identified. These are listed below in logical groupings and not on the basis of any prioritization of research needs.

- It is important to consider the full range of behavior of the entire structure, from elastic through inelastic response up to and including collapse, using both simple and sophisticated models, consistent with reality. In addition, detailed evaluation of subassemblages and components, which is essential for the modeling of complete buildings, should continue to be a topic of basic research.

- Related to the above, research should also be directed at establishing a hierarchy of models and desired levels of CAE sophistication by assessing the efficacy, validity, and limitations of different levels of modeling and analysis for various situations.

- Buildings should be viewed as complete systems composed of structure, nonstructural elements, and foundation. The full system, including both local and overall interaction between these individual systems should be considered, if necessary, in seismic analysis and design. Additional studies are needed to determine the conditions under which such interactions can significantly affect building performance.

- Validation and correlation of models using experimental and field data, along with a dose of inspiration, are essential in the modeling process. Hence, experimental research and installation of data acquisition equipment in selected buildings within highly seismic areas worldwide should be strongly encouraged.

- Effective collaboration and communication among researchers, practitioners (designers), and industry representatives is strongly encouraged.

- Exploration of innovative concepts (e.g., base isolation) should have a high priority.

- The full range of advanced computer hardware and software, including visualization through single-frame (static), real time, and playback color graphic display should be utilized.

- CAE techniques should be brought to bear on the problems associated with low-rise buidlings (say 5 stories or less) because low, wide buildings are frequently outside the applicable range of standard seismic design codes.

- Problems unique to the modeling of concrete structures should receive special consideration.

- Last, specific research topics worthy of detailed study were identified in the previous section. They will not be repeated here.

Working Group Members:
Jacobo Bielak, Chairman
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SECTION 3
HARDWARE INNOVATIONS

3.1 Introduction

The intention in having a Hardware Innovations Working Group was to determine how structural engineers interact with the realm of computer hardware, and how that interaction could be changed if necessary. It was also intended that participants voice their opinion on what the future hardware environment should be. The conclusions are not necessarily representative of the profession as a whole. They are those of the approximately forty structural engineers present. The essence of the discussions is reported below, and is followed by a summary and set of recommendations.

3.2 Issues and Ideas

Disinterest in Hardware. The first thing that came to light with regard to structural engineers and their feelings about computer hardware is an apparent lack of interest. Of thirty-two structural engineers responding to the questionnaire on preference for working group assignments, not one indicated hardware as his first choice. Nevertheless, once a discussion was begun, most of the participants had something to say about hardware.

A possible reason for this apparent disinterest in hardware is the lack of education needed to better understand hardware, such as basic computer architecture and software (operating systems and compilers). Clearly, it is difficult to maintain interest in a subject that one knows little about. The suggestion that future engineers be given this education was met with indifference at the Workshop.

Another obvious reason for the lack of interest is the inability of most structural engineers to keep up with the rapidly changing hardware scene. It would take an individual a significant amount of time to remain informed of the latest hardware, and in most cases time is already a limited resource.

There also appeared to be a group feeling that no matter the level of interest in hardware, hardware developments are outside the realm of influence of structural engineers. Given this belief, it is natural that structural engineers would allocate their time to pursuits where they feel they can have more meaningful input.

Finally, there seemed to be a consensus among the Workshop participants that the software generally used by structural engineers does not use the full capabilities of the hardware currently available, and there is therefore no need to stay abreast of or push hardware developments.

Hardware of the Future. After hearing from a few that the desktop computer of the future (within the next five years) would be comparable to the 32-bit workstation of today, most people conceded that this was probably true. People will always form a spectrum with respect to the way new computing power is used in their work. It seems that researchers tend towards the high end of computing while practitioners tend towards the low end, with a broad middle ground where the two come together and in cases overlap.

In the mid and late seventies, a few still used slide rules on a regular basis, the majority probably used hand-held calculators, and a few were fully embracing the 32-bit mini- and mainframe computers available. In the mid and late eighties the slide rule has all but disappeared and everyone uses hand held calculators, the former role of the hand held calculator as the mid-range tool has been filled by 8- and 16-bit personal computers, and 32- and 64- bit computers are heavily used for high-end computing. Within the next five to ten years the hand held calculator will grow in power and may be called a hand held computer and the mid-range tool will become more powerful and will probably be comparable to today's 32-bit workstation and may contain an array processor.

It will be interesting to see if this spectrum of computing in structural engineering narrows, broadens, or stays the same in the future. It is easy to speculate that a narrowing of the spectrum would promote a more unified structural engineering community, but it is doubtful that this will occur.

The future of high-end computing is too difficult to speculate on, but significant gains are being made in parallel processing, the scalar and vector speeds of machines continues to climb, and memory continues to become less expensive. Historically there has been a large discrepancy between the power that sits on one's desk, and what is available across campus or across town, or across the country. Because that is still true today, there is no reason to believe that the trend will not continue. The supercomputer of the future will still be a remote device for most users, and there will therefore continue to be a multi-tiered computing environment. A final note on future high-end computing is that as the machines become more powerful and promote the attempted solution of much larger and more complex problems, the precision of the machines should increase to avoid truncation and round-off errors; it was noted that 128-bit machines would be welcome even today.

Expected Effects of Improved Hardware. Given access to more but less expensive power, it seems certain that more structural engineers will use it. The use of three-dimensional numerical models and more sophisticated constitutive models, and nonlinear analyses, will become more commonplace if the cost of such analyses comes down, and the computer power is more readily available.

The future may also bring more special purpose machines. These task dedicated machines may range from customized chips, for example to do graphic image processing in hardware, to a computer that simulates the construction environment as a training tool and a management aid. This trend needs to be monitored because there is a balance to be reached between the advantages of special-purpose machines and the burden of needing several different computers to get a job done.

Quality Assurance. A note on software distribution and quality assurance is appropriate. As more engineers are able to do more powerful computing at their desks, much of the software that today resides on a single CPU will probably reside on several CPU's. If this is true, multiple CPU licenses will become more common and will in most cases have to become less expensive. Also, as software is distributed to multiple CPU's, quality assurance becomes more difficult. Will each piece of software have to be quality-assured on each CPU? Also, how will the software be distributed to insure that each CPU is using the same software, or is this necessary? These questions remain to be answered.

Expectations for Future Hardware. Wishes for the future start with improved networks. Communication speeds need to be faster and the reliability of the data exchange needs to be improved. Higher communication speeds promote more communication and are important for graphics as higher resolution monitors become more popular. With more reliable communications, more people will be inclined to use remote hardware, such as the supercomputers that are now available in centers across the country that are not being fully utilized. On the smaller scale of a design office, improved networks would allow several CPU's to have common resources such as disk space. Improved communications will also enhance technology transfer.

With more sophisticated analyses comes a need for easier visualization of output. Currently, color and dynamic display capabilites help in this respect, but there are now only limited means for creating hardcopy of this information, making it difficult to file the information or convey it to clients without having them present at the computer. Improved color hardcopy is being worked on, but there remains much room for improvement. Moreover, means for storing results of dynamic analyses are desirable. It would be convenient, for example, if one could store the results of a dynamic analysis on a laser disk to take to a meeting with a client or to a conference.

Having hardware develop in a fashion that facilitates software transportability is also considered important. Today's software is becoming so sophisticated that major rewrites will be expensive. There will of course be cases where software needs to be tailored to the hardware, for example restructuring code so that it vectorizes, and/or makes good use of parallel processors. Considering the growing use of the C programming language, the UNIX operating system, and X-Windows, it is appropriate that hardware in the near future support these.

Expected New Issues. For the desktop computer it is desirable that the owner be able to maintain and upgrade the equipment much as many do today with their personal computers. This leads into another point of consensus; the more hardware that can be maintained locally the better. People do not want to have to buy a service contract for their desktop computers. In the university arena it was brought out that hardware maintenance is also an issue for the more powerful computers. The annual maintenance contract often is a major financial burden that is not handled as well as it might be. The suggestion was made that along with donated hardware, a portion of the service contract should also be donated. The rest of the contract should be split between overhead on the research and overhead money from the university.

There was also something of a consensus on the need for improved user interfaces. Currently one can use the keyboard to make command selections, or use a mouse or digitizing tablet to make selections from on-screen keypads and menus. The interface of the future might include a sketch pad similar to today's digitizing tablet, but much more sophisticated, using a wireless pen with eraser, and a table that serves all functions as opposed to the tablet and monitor situations found today, and that could also be positioned much like a typical drafting table. Widespread use of voice communication with the computer also seems to be on the horizon given the advances that have been made in this area and given that it is one of the most natural form of communication.

3.3 Summary and Recommendations

o For a variety of reasons, structural engineers do not seem to pay close attention to computer hardware developments.

o Software for structural engineering does not use the full capabilities of existing hardware.

o Today's desktop computer, the PC, will in the next five years be replaced by a 32-bit color-graphics workstation, possibly with an array processor.

o With more distributed computing power, software distribution, software licensing, and quality assurance of analyses will become more significant issues.

o Computing power will continue to increase, and a small group of structural engineers will always make use of high-end computing.

o The high end of computing will continue to be a remote capability for most. The state-of-the-art supercomputers of the future will still be prohibitively expensive. However, desktop "supercomputing" will be an alternative as today's enhanced computational capabilities trickle down into the hands of the many.

o With more computing power, more three-dimensional and nonlinear analyses will be performed, and more sophisticated constitutive models will be employed; first on the fringes of typical practice, but probably evolving into a more commonplace position.

o Researchers need to give more thought to funding for hardware maintenance, with a potential split of maintenance costs between the hardware vendor, the research budget, and the university.

o Desirable directions for hardware include:

1. Improved network communications for use of remote supercomputers, for workstations, and for local and long-distance exchange of data and software
2. Better color hardcopy
3. Better capability to record results of dynamic analyses for playback at remote locations and for archiving
4. Hardware improvements without need for frequent software modification
5. Desktop computers that are simple to maintain
6. Improved user interfaces, possibly in the form of sophisticated sketch pads or voice communication with the computer

o Software development is time-consuming and expensive and it is important that the engineering profession plan software developments to accommodate future hardware environments. Planning software strictly for the personal computer domain will result in software with a limited life expectancy. It is obviously difficult to plan too far into the future, but as an example, given the current directions of hardware development it is apparent that any ongoing software development should now be giving consideration to vector processing and concurrent or parallel processing.

Working Group Members:	Christopher Conley, Chairman Andrei M. Reinhorn, Vice-Chairman Donald P. Greenberg G. Robert Morris Mark Mulert

SECTION 4
SOFTWARE INNOVATIONS

4.1 Introduction

The working group on Software Innovations reviewed current software tools and programs for interactive graphic analysis and design of structures. Based on the growing trend to consider multi-disciplinary design environments (e.g., where the structural design database also needs to be used by architectural, mechanical, and construction disciplines), many software innovations are focused on developing computer application environments that maximize integration and extensibility opportunities. The topics discussed included the overall computer software architectures, the likelihood of their implementation on various hardware platforms, and the range of applications development tools suitable for effective use in practice, research, and education.

4.2 Issues and Ideas

Innovative man-machine interfaces are enabling more effective and more intelligent "conversations" with software packages. Such modes as interactive type-in, spreadsheet editing, and command languages have allowed the engineer to make immediate changes to data that is used in his application. Menu systems (possibly using "accelerator keys" from the keyboard as alternative triggers) allow the system designer to present the control and edit options in an organized, hierarchical way and provide the user with clear choices of the appropriate actions to invoke at any given stage of program execution. Interactive color graphics can present massive amounts of output data in a readily understood display, enable direct manipulation of 3D models, and greatly facilitate the entire input process. More intelligent interfaces are emerging, such as intelligent digitizers, natural language systems, and voice recognition/synthesis. While the first two are seen as readily acceptable extensions to current interactive techniques, voice recognition often draws skeptical reactions, due to the increased office noise generated.

The overall views of interactive analysis/design packages are that, while current analysis systems are well understood technologies that have matured to near-commerical quality, the design aspects of these systems need much more development. In particular, postprocessors that display deformed shapes or stress resultants of even simple three-dimensional models may become so cluttered with details as to obscure the significant physical interpretation of the analysis results. It is desirable to develop software mechanisms where the designer can set a "design focus" so that irrelevant/less significant results are filtered from the output display, thus allowing the designer to more clearly identify the actual behavior of his design. Also, preprocessors should be extended "upstream" to support preliminary layout and conceptual design activities. Systems should also be open to the other disciplines that contribute to the overall building project, such as architect/owner constraints, zoning requirements, and construction.

Questions associated with software portability and graphics standards appear to be getting resolved by the fact that hardware and operating systems vendors are starting to come to a consensus on various software standards. Prevailing opinion is that C and Fortran have become quite portable programming languages. Object-oriented supersets of C, such as C++, promise powerful programming environments. Unix has become a widely acceptable operating system. In the area of data bases, SQL has achieved widespread acceptance for engineering design applications. X-windows has been nearly universally accepted as the window interface system. While Phigs+ is expected to prevail over the fading GKS and Core graphics display languages, it may not remain the ultimate accepted approach by the early 1990's.

4.3 Recommendations

Five development goals for good software systems for seismic analysis and design of buildings have been identified:

o Software should be designed for **integration** with other activities in the structural design process as well as integration with other related disciplines. The effectiveness of this integration depends on how compact and complete the problem representation language can be. The various disciplines should be able to access the common database, and yet receive context-dependent descriptors of the same physical elements being modeled. For example, the structural analysis discipline should see a girder as a linear element having connectivity to its two end points, while the design software should receive additional information, such as lateral bracing conditions, cross section geometry, and connection details at its ends. The interface between design and drawings needs further innovation: one should be able to interactively design by computer and have the completed drawing as output.

o Software should be designed with an **open architecture** where **modularity** and **extensibility** are primary design objectives. When a user can attach his own modules to an existing software framework, he can customize the computer processes to support his own in-house accepted practices. Four particular areas where **accepted practices** can be identified are:

1. Modeling (e.g., choice of constitutive relations)
2. Preprocessing (e.g., choice of methods for defining input objects)
3. Analysis (e.g., choice of type of nonlinear analysis method)
4. Postprocessing (e.g., tools for setting an output focus and output style)

o Software should be as **portable** as possible. Portability of the programming language can be maximized by programming in **C** or **Fortran** in a **Unix** environment. Portability of graphics seems to rely on using **Phigs+** for displaying 3D graphics in **X-windows** screen displays.

o The software package should house a family of well-defined **development tools** from which the user can select, according to his research, design-practice, or educational needs:

1. I/O Tools
    - interactive type-in
    - on-line help
    - spreadsheets
    - command language
    - menu systems
    - interactive color graphics
    - intelligent digitizing
    - natural languages
    - voice recognition/synthesis
2. Analysis and Modeling Tools
    - equation solvers
    - eigenvalue extraction routines

  - optimization routines
  - design code modules
  - databases of standard sections
  - type of nonlinear analysis method

3. Data Management Tools (e.g., object oriented, relational, hierarchical, or network databases)
4. Artificial Intelligence Tools
  - knowledge based expert systems
  - symbolic programming
5. Instructional Tools
  - analysis modules
  - design modules

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SECTION 5
TECHNOLOGY TRANSFER

5.1 Introduction

The charge to the Working Group on Technology Transfer consisted of the following: What are the ways in which technology transfer -- research to practice and research to research (i.e., inter-university) -- can be improved? Can the needs and the concerns of practitioners be expressed more effectively and, if so, how? The use of advanced methods of analysis is creeping into civil engineering practice. Should attempts be made to expedite this process (are the methods useful; is it prudent to advocate them, etc.) and, if so, what can be done?

A summary of the points raised is as follows:

We must examine what we are trying to transfer and who generates the software we wish to transfer.

Potential sources of software can be universities, public agencies, trade groups, or industry.

Many users of software are also software developers.

The NSF supported a series of workshops starting in 1971 on software transfer and related problems. Other agencies such as ONR have had similar activities to stimulate software transfer. In spite of these efforts there is still a serious software transfer problem.

A number of software transfer efforts have been started in the past such as NISEE, CEPA, COSMIC, STRUDL Users group, etc. Some of these still exist and some of these have disappeared.

Changes in technology have taken place which impact the transfer problem. We have progressed from a strictly punched card, batch, central-printer environment to one which includes graphics, interactive computing, and expert systems.

Some of the problems of transfer include: standards, documentation of programs, verification/certification (litigation), maintenance, user assistance, languages, complete programs vs. modules, transfer media (floppy disks, tape, modem, etc.), and graphics problems.

New technologies such as networks, high density information storage (optical disks) and special ROM chips containing programs must be taken into account.

The AISC (American Institute of Steel Construction) is sponsoring along with NSF and AISI (American Iron and Steel Institute) a project on computer formulation of the new AISC LRFD steel specification which will interface with computer programs. This may add another dimension to the possibilities for software transfer problem.

It is extremely difficult to develop a software research program and a widely-used software program at the same time.

It has been almost impossible to develop machine independent software. Widely used operating systems such as DOS, VMS, and UNIX may help somewhat.

There should be some provision for the death of programs. There are may obsolete programs which are still in use.

Because of inadequate transfer mechanisms, there are many redundant Ph.D. dissertations, however, some duplication is probably useful.

There is not sufficient motivation for transfer of software technology.

The need for Earthquake Engineering Technology is not well understood in many states. The purpose of computer utilization is insight, not just numbers, and computer graphics may help improve that insight.

Researchers should be willing to communicate with people in the profession.

Trained graduate students are one of the most effective means of transfer of technology. NSF-supported projects which extend at least three years instead of the two years which is typical now could improve the effectiveness of this source of transfer.

5.2 Issues and Ideas

The following is a summary of the ideas and issues discussed:

Although there are significant advances and developments in industry, particularly with respect to CAD-CAM and work stations which may lead university capabilities, there is still an important role for university research in algorithm development, new methods, innovative programming, AI and Expert Systems, graphics, and other areas.

Requirements for inter-university transfer of software for educational and research purposes is quite different than transfer of software to practicing users.

University research should aim at advanced future capabilities and not be constrained by current requirements.

Universities may not be good at, or probably should not get into, specific semi-commerical software development.

Industrial users should be prepared to maintain and/or verify software they work with.

Design databases should include portability among all disciplines involved and ideally should be used over the life of the structure both for maintenance and for management. This may be hard to achieve but should be a definite goal.

Small firms are currently getting some structural analysis programs but these are primarily 2-D programs. There is a serious need to transfer new software technology and capabilities to the broad practicing community more quickly than is now the case.

Use of graphics and advanced programs may be hampered by permit requirements and other barriers as Building Departments and other approving agencies may not accept output from these new technologies.

The availability of several microcomputers or several workstations in a design office can minimize the impact of one machine crashing because, if the programs and data are properly backed up, it is probably possible to shift to another device of the same type. This is an advantage compared to a central system crash.

Stronger efforts are needed to encourage practicing engineers to acquire and utilize software which is currently available to them.

Part of software technology transfer is in educating engineers in becoming aware of what is available to them in addition to just making software available.

Use of advanced computing capabilities, such as the large supercomputers, is not being adequately explored in the earthquake and structural engineering areas and increased research taking advantage of these capabilities should be promoted.

5.3 Recommendations

o There should be increased and early-on university-industry interaction in engineering software development.

o Work should be encouraged in setting improved goals (standards) and methods for transferability and portability of software.

o Communication should be improved in all directions.

o We need improved guidelines and emphasis on importance of documentation, both within the software and separate written documentation.

o Documentation requirements should be strengthened and enforced in NSF grants, but the increased cost of adequate documentation of research software must also be recognized by NSF.

o The use of proprietary components in public domain or semi-public domain software should be avoided as much as possible unless these have achieved a sort of industry-standard status.

o NSF should consider mechanisms to increase user awareness of software which could be available to users.

o NSF should help develop material for teaching short courses on software utilization and encourage and assist persons in offering these courses for practicing engineers and for university education.

o Increased use of shareware, Networks, BBS's, SIG's, etc., for small microcomputers should be encouraged for structural-earthquake programs.

o Increased efforts should be made to assure that software, graphics, etc., is brought to the attention of and shared among universities for educational purposes.

o Simplified PC-AT level structural analysis programs which utilize a high level of graphic input should be distributed free to high schools to encourage students to "play around with them" and possibly have their interest in pursuing engineering as a profession stimulated.

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APPENDIX A

NCEER PROJECT 86-6012
WORKSHOP ON SEISMIC COMPUTER ANALYSIS AND DESIGN OF BUILDINGS WITH INTERACTIVE GRAPHICS

to be held at Cornell University, Ithaca, NY
August 3-5, 1987

Program and Schedule

Mon., 8/3:	8:00 a.m.	Opening remarks: Dr. Robert L. Ketter, NCEER Director Objectives, Organization of working groups, Overview of facilities: Professors William McGuire and John F. Abel, Workshop Co-directors **140 Bard Hall**
	9:00-9:30 a.m.	Break **Hollister Hall Lobby**
	9:30 a.m.	Demonstrations of Cornell MicroVAX GPX and advanced programs, Computer-Aided Design Instructional Facility (CADIF) and Program of Computer Graphics **Hollister Hall/Rand Hall**
	noon	Lunch/Speaker on Interactive Graphics: Professor Donald P. Greenberg, Director, Program of Computer Graphics, Cornell University **Hollister Hall Lounge**
	1:30 p.m.	Demonstration of Cornell Micro VAX GPX and advanced programs, Computer-Aided Design Instructional Facility (CADIF) and Program of Computer Graphics **Hollister Hall/Rand Hall**
	4:00-4:30 p.m.	Break **Bard Hall Lobby**
	4:30 p.m.	Discussion of current and planned NCEER Computer Analysis Research **140 Bard Hall**
	evening	Hands-on use of programs, CADIF **Hollister Hall**
Tue., 8/4:	8:00 a.m.	Developments at selected universities Professor Edward L. Wilson, University of California, Berkeley Professor Young-Ji Park, State University of New York, Buffalo **405 Malott Hall**
	9:30-10:00 a.m.	**Break** **2nd Floor - Malott Hall**

	10:00 a.m.	Selected commercial developments Mr. Richard J. Clayton, Vice President, Thinking Machines Corporation Mr. Navin Amin and Mr. Mark Mulert, Skidmore, Owings and Merrill **405 Malott Hall**
	noon	Lunch **135 Emerson Hall**
	1:30 p.m.	Panel Discussion on Research Needs in Computer-Aided Earthquake Engineering **405 Malott Hall**
	3:00-3:30 p.m.	Break **2nd Floor - Malott Hall**
	3:30 p.m.	Panel Discussion on Hardware Innovations **405 Malott Hall**
	evening	Hands-on use of programs, CADIF **Hollister Hall**
Wed., 8/5:	8:00 a.m.	Panel Discussion on Software Innovations **405 Malott Hall**
	9:30-10:00 a.m.	Break **2nd Floor - Malott Hall**
	10:00 a.m.	Panel Discussion on Technology Transfer: Research to Practice and Research to Research **405 Malott**
	noon	Lunch meetings for working groups to formulate reports and recommendations **Rooms 224, 226, 321 and 405 Malott Hall**
	2:30-3:00 p.m.	Break **2nd Floor - Malott Hall**
	3:00 p.m.	Presentations by Working Groups; Discussion and Refinement **405 Malott Hall**
	evening	Working groups refine reports and recommendations **Townhouses**

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August 3-5, 1987

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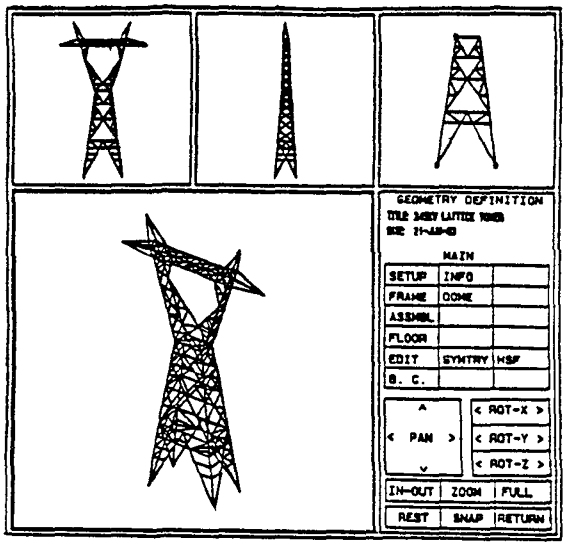
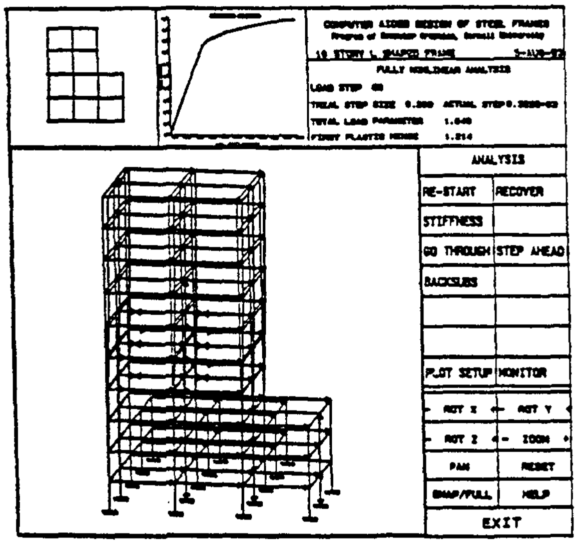
APPENDIX C



CU-PREPF

(Cornell University PREProcessor for Frames)

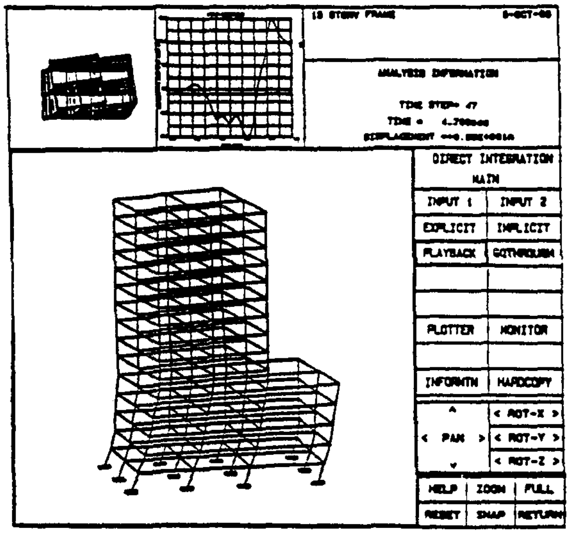
A fully interactive program for the definition of 2D and 3D framed structures: geometry, boundary conditions, member properties, and loads. Particular facilities are provided for steel frames, including AISC section tables. Used in graduate courses in steel design, matrix analysis course, student design projects at both graduate and undergraduate level. Demonstrations at all levels from freshman year up.



CU-STAND

(Cornell University STatic frame ANalysis and Design)

A fully interactive program for the analysis and design of statically loaded 2D and 3D steel framed structures defined by CU-PREPF. Analysis options are linear elastic, geometric nonlinear, material nonlinear, and both geometric and material nonlinear. Integrated graphical postprocessing (moment diagrams, deflected shapes, response curves, curve plotting, etc.) and printed output. Design options include AISC LRFD specification formulas for reviewing and refining trial designs. Used in same courses as CU-PREPF with emphasis on graduate and senior level design courses.



CU-QUAND

(Cornell University EarthQUake ANalysis and Design)

A fully interactive program for the earthquake resistant design of 2D and 3D steel framed structures defined by CU-PREPF. Analysis options include equivalent static loads, modal analysis (time history or response spectrum), and direct time history analysis. Design checks include ATC, UBC, and AISC LRFD formulas. Integrated graphical postprocessing. Used primarily in graduate course in structural dynamics.

APPENDIX D

DISSEMINATION POLICY ON SOFTWARE FOR STATIC AND SEISMIC NONLINEAR ANALYSIS AND DESIGN OF 3D BUILDING STRUCTURES

W. McGuire and J. F. Abel, Cornell University
July 20, 1987

During previous and current research at Cornell University, a variety of linear and nonlinear methods and interactive-graphic programs for the static and dynamic analysis and design of building structures have been developed. Aspects of the work have been or are being sponsored by the National Science Foundation, the National Center for Earthquake Engineering Research, various units of Cornell University, and a few private companies. The intent of the principal investigators is to disseminate the results of this work not only by scholarly and professional publication but also by sharing access to the software with designers and other researchers.

There are two classifications of structural engineering computer programs that emanate from this research:

I. Design and educational programs. These are generally workstation-based, interactive graphical programs which employ the commercial graphics package which is the current standard of Cornell's Computer-Aided Design Instructional Facility (CADIF). The present (1987) standard package utilized is HOOPS, produced by Flying Moose Systems and Graphics, Ltd.*, of Ithaca, New York. The present computer programs in this category are currently being converted to operate on DEC GPX workstations under the VMS operating system, and are CU-PREPF, CU-STAND, and CU-QUAND. Although the latter two programs embody some design capabilities, including portions of AISC and other codes, they must be considered only demonstrations of design approaches because all aspects of the codes are not necessarily included.

II. Research programs. These are generally interactive graphical programs, employing possibly nonstandard graphics software and/or hardware, which are continually evolving to enable examination of new ideas, techniques, algorithms, and approaches for analysis, design, and the study of structural behavior. These programs typically operate at Cornell's Program of Computer Graphics and/or Cornell's Center for Theory and Simulation in Science and Engineering.

It is expected that, in the future, as progress is made in the research (Category II), software resulting from this effort will enrich and supplement the design and educational programs (Category I).

The portions of both classsifications of software which have been developed in the Cornell research will be shared with universities and nonprofit research organizations at basically the cost of reproduction and distribution. Moreover, the portions of the Category I software which have been

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* Flying Moose Systems and Graphics, Ltd., is now called Ithaca Software.

developed in the Cornell structural engineering research will be shared with engineering design companies under the same terms. Obviously, any portions of the software which are commercial products or which have not been developed in this research cannot be transferred on the same basis; instead, these portions must be replaced by the recipient with software of equivalent functionality, or procurement of these portions must be separately arranged with the owners of this software.

General Disclaimers and Policies

A number of policies and disclaimers are relevant to both categories of software.

First, all the software is research-oriented code devised by graduate students and university staff (as opposed to robust, commercial software created by professional programmers). The work is innovative, but although the staff and graduate students are skilled, the software may not be "clean," has not been thoroughly debugged through field testing, and is usually only minimally documented. Therefore, there are absolutely no warranties of function, accuracy, or performance of any software distributed.

Second, the working assumption for this software dissemination is that the arrangement is viewed as a sharing of source code among engineering experts. Therefore, it is assumed that the recipients are experts who can understand the code in detail and may choose to use, modify, emulate, and/or incorporate the code to create their own software for which they take full responsibility. In other words, it is assumed that the software made available will not be naively employed as "black boxes."

Third, the software has not been designed for transportability. Most of the engineering research software is coded in Fortran-77; however, because DEC VAX/VMS is the usual programming environment, some extensions to standard Fortran-77 are often employed. Portions of the programs are coded in C or Pascal. Category II programs employing nonstructural graphics software and/or hardware may be difficult to port to other environments.

Fourth, upon request, source code will be provided on a mutually convenient medium (e.g., tape, diskette). Also provided will be any external documentation which would normally be created as part of the development of the code, in a format usually used by the graduate student developers. Other available documentation includes theses, papers, and research reports relevant to the software.

Fifth, it is not possible to provide on-site support for installation. Moreover, it is also not possible to provide any software maintenance in the current commercial sense of the phrase. That is, there will be no formal, automatic, contractual updating or modification of software after transfer. Of course, for as long as the Cornell researchers continue to use and develop a program, versions subsequent to that initially provided may be requested. Although comments and suggestions regarding the software are welcome, it is not possible to respond to requests for debugging or enhancement of a program after it is provided.

Finally, a recipient of a program must provide in writing a statement agreeing: (a) not to transfer the program outside of the institution or company; (b) not to sell the program to any person, institution, or company; and (c) to acknowledge the origin and sponsorship of the program should it be used to produce any open-literature publication, and to provide one copy of such publications to the transferrers. For the purposes of this statement, the term "program" shall mean either a program received under this policy and used essentially as received, or a program developed by the institution or company but substantially based on source code shared under this policy. The appropriate origin and sponsorship mentioned in (c) above will be provided to the recipient at the time of transfer or sharing.

Policies Particular to Catgory I

The educational and design programs in Category I employ the commercial graphics system called HOOPS. The owners of HOOPS, Flying Moose Systems and Graphics, Ltd.*, have agreed to the following policies or restrictions.

1. Copies of these programs may be distributed to educational institutions with only executable nonlinkable binary copies of the HOOPS routines used in those programs. The recipients may purchase full HOOPS licences, maintenance, and support at standard Flying Moose educational prices, which are and will remain substantially below the commercial prices for the same.

2. Copies of these programs may be distributed to recipients which are not educational institutions with only executable nonlinkable binary copies of the HOOPS routines used in those programs. The recipients may purchase full HOOPS licences, maintenance, and support at standard Flying Moose commerical prices.

Policies Particular to Category II

Researchers from NCEER universities and nonprofit research organizations will be able to have access to the facilities of Cornell's Program of Computer Graphics. Because space is limited at this facility, this access will need to be scheduled well in advanced on a case-by-case basis. One possible mechanism for this access will be for a project to place one graduate student or postdoctoral scholar in that facility for a period of a few weeks or months. The basic per person current cost for both Cornell or visiting researchers at the facility is $1,500 per month; this covers amortization and maintenance of equipment, system operation, and supplies. It provides for unrestricted use of the facilities. That is, there is no specific time limit on use of hardware; rather, access is limited by courteous and reasonable sharing by all facility participants. Details appropriate to each particular collaboration or sharing of this nature will need to be worked out on an individual basis.

Cornell's Program of Computer Graphics has recently submitted a proposal to the National Science Foundation for the development of visualization and graphical tools associated with the performance and steering of supercomputer simulations. Should this proposal be funded, the graphical systems and visualization software developed within the project for engineering and scientific computing will be available to users of National Supercomputing Facilities.

The Program of Computer Graphics is connected by a fibre-optic link to Cornell's National Supercomputer Facility, the Center for Theory and Simulation in Science and Engineering (the "Theory Center").

Access to the Theory Center facilities is available both locally and over networks through the standard policies set by the Center and by the National Science Foundation. Moreover, it is anticipated that the National Center for Earthquake Engineering Research will arrange for a block grant of supercomputer time for NCEER projects.