

Chapter 16

Computer Applications in Seismic Design

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Abstract: This chapter surveys the state-of-the-art in computer applications in seismic design. The field of computer applications is rapidly changing. Therefore, a general overview of contemporary applications is provided with references to the relevant worldwide web site addresses. The ever-increasing reliance on computer applications requires a re-doubling of emphasis on sound engineering judgment by practicing professionals. Computers can enable us to perform engineering tasks we did not dream to be possible just a few years ago. Blind faith in computers, however, may produce results that are far less reliable than back of the envelope calculations by a seasoned engineer.

16.1 INTRODUCTION

This chapter provides a sampling of computer applications in seismic design at the time of this writing. No other field of science and technology moves forward faster than computer and communication technologies. Therefore, it is vital for the reader to examine the state of knowledge and practice at the time of his/her reading because significant advances may have occurred in between the time of writing this chapter and the time it is being read. To assist the reader in this task, we will point to relevant Internet resources in different parts of this chapter.

The builder's need for computational devices predates ancient Babylonian, Persian, and Greek empires. Over the ages, as the complexity of engineering concepts grew, it initially created *master craftsmen*: people who could design and build magnificent structures without an exact understanding of underlying mathematical principles but a fantastic ability to apply structural proportions found workable in nature. For example, it is said that the slenderness of the Pantheon columns were derived from studying the proportions of the human female leg-bones. The curves of many magnificent ancient domes were derived from the shape of wild mushroom crowns⁽¹⁶⁻¹⁾. Over many centuries, remarkable structures were built –without any precise mathematical formulation– that withstood the test of the time. These designs were based on what we now refer to as *sound engineering judgment*. The design-build practice that is now becoming prevalent in the United States and other advanced countries, was the only form of construction known for many centuries.

The next stage in engineering evolution brought about the *multidisciplinary masters*. People like Leonardo Davinci who was an

artist, architect and engineer at the same time exemplify this category. The growth of science and engineering knowledge in the 20th century made high degrees of specialization necessary and made multidisciplinary masters extinct. Today, not only we distinguish structural engineers from civil engineers but we further break down each field of expertise: structural designers, structural analysts, earthquake engineers, wind design engineers, cladding specialists, seismic isolation specialists, design ground motion specialists, etc. Therefore, we live in the era of *specialists*.

Specialization increases the depth of the knowledge but unfortunately reduces the breadth of it. The grand vision common to master builders and multidisciplinary masters are very difficult to find. At the same time the growth of computing hardware and software over the past two decades have been monumental. It is safe to say that all specialists now rely on computing facilities to the extent that was imaginable just a few years ago. The combined effect of reduction in the scope of knowledge (brought about by specialization) and heavy reliance on computational devices (caused by rapid growth of computing facilities) can be dangerous. Engineering has never been, or can be, a pure game of numbers. Engineering judgment is simply too important to be lost to blind faith in computing devices. There is a need for balance. We have to find ways of maximizing our use of computer technology without leaving our engineering judgment behind. Seismic design students must be trained to develop and to value a physical feeling for how buildings resist earthquake forces, why they survive them, and the cause of their failure. The best use of computer technology is only possible if respect for engineering judgment is nurtured and preserved.

IBC/NEHRP Design Parameters

Optional
 Show Name and Date/Time on Output
☒ Name Example
☐ Include Date and Time in Output

Select File Location
 Open File Selection Menu

Select Geographic Region
 Conterminous 48 States
 Alaska
 Hawaii
 Puerto Rico
 Culebra

Calculate MCE Spectrum
 Ground Motion
 MCE Ground Motion
 Calculate Ss and S1
 Select Soil Factor
 Calculate Spectrum
 View Spectrum

Output for All Calculations
 Example
 MCE Parameters - Conterminous 48 States
 Zip Code-91326 Central Latitude = 34.290201
 Central Longitude = -118.554266
 Data are based on the 0.01 deg grid set

Period (sec)	SA (%g)	Soil Factor of
0.2	211.9	1.0
1.0	075.5	1.0

USGS science for a changing world
 FEDERAL EMERGENCY MANAGEMENT AGENCY
 BUILDING SEISMIC SAFETY COUNCIL

Clear Selections Clear Output Clear All
 Save To File Print View Maps
 Opening Menu Exit Program

Figure 16-1. Seismic Hazard Map CD-ROM Supplement to IBC-2000

The computer revolution that started in the last quarter of the 20th century and is still accelerating today, has the potential of impacting human civilization more than the advent of printing by Gutenberg⁽¹⁶⁻²⁾. As will be noticed from reading this chapter, earthquake engineers are now achieving objectives that could not have been even imagined a short few years ago. A few examples would be illustrative. The probabilistic seismic hazard map of the entire United States for default site soil conditions is now readily available on the Internet and distributed as a part of the 2000 International Building Code (IBC-2000)⁽¹⁶⁻³⁾ as well as FEMA Guidelines for Seismic Rehabilitation of Existing Buildings^(16-4, 16-5). A companion CD-ROM to these documents allows the user to identify design spectral ordinates of any site by providing its latitude and longitude. For more approximate applications, providing a postal zip code also suffices! (Figure 16-1).

Instrumental Intensity maps for significant earthquakes in the southern California region are automatically produced by the *Trinet* and *Cube* networks. The *Cube* maps are instantaneously sent via e-mail to subscribers. *Trinet* shake maps may be viewed on the Internet (<http://www.Trinet.org>) within a few minutes after earthquakes (Figure 16-2). A click-able map for Southern California faults available at a web site (<http://www.scecdc.scec.org/faultmap.html>) permits users to point to any fault and obtain all relevant information (Figure 16-3).

In the field of loss estimation, emergency management and post-earthquake response, the GIS based HAZUS-99 software system⁽¹⁶⁻⁶⁾ developed under a grant from the Federal Emergency Management Agency (FEMA) has provided a new horizon to various casualty loss scenario and probabilistic analysis (Figures 16-4 and 16-5).

In seismic analysis and design of very complex structures, automotive and airplane proportioning and design software have been utilized to accommodate the sophisticated curvatures in the architectural and structural systems (Figure 16-6)⁽¹⁶⁻⁷⁾.

Detailed nonlinear finite element analysis techniques have been successfully utilized to predict the experimental behavior of proposed structural connections (Figures 16-7 and 16-8)⁽¹⁶⁻⁸⁾.

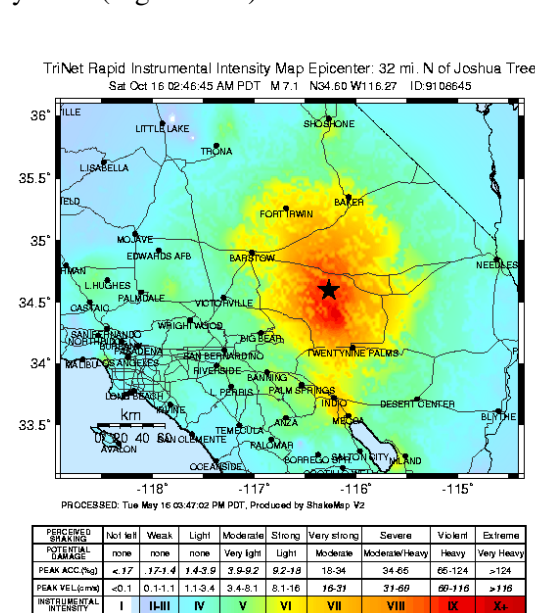


Figure16- 2. A TriNet Shake Map for the 1999 Hector Mines Earthquake in southern California (www.trinet.org).

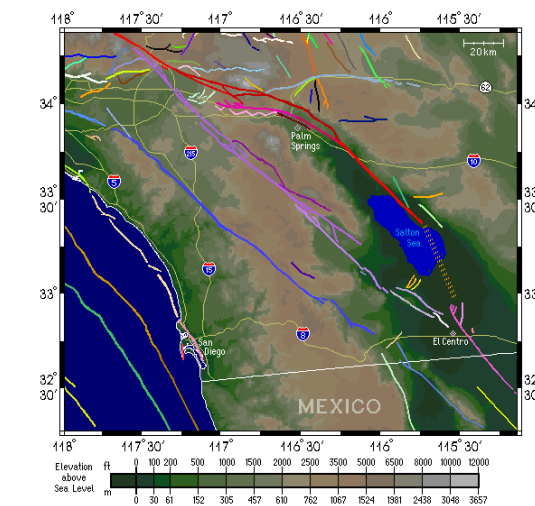


Figure 16-3. A click-able Fault Map Available on the Internet (www.scecdc.scec.org).

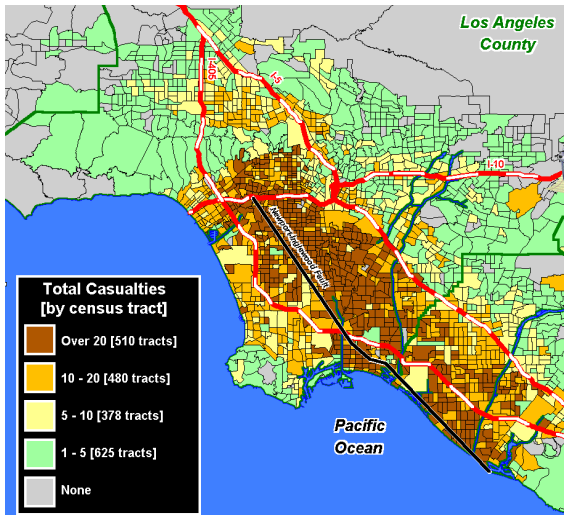


Figure 16-4. A HAZUS-99 casualty loss estimate for a scenario event in southern California.

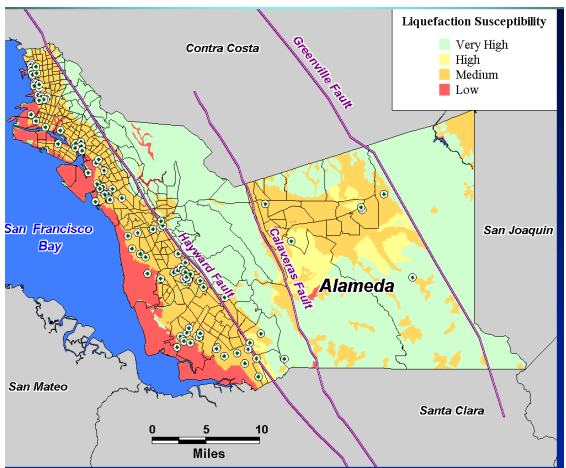


Figure 16-5. A HAZUS-99 analysis of liquefaction potential and dangers posed by hazardous material storage sites in Alameda county of California.

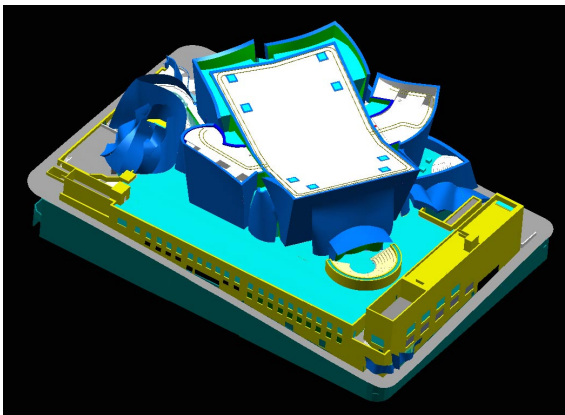


Figure 16-6. The Disney Concert Hall, under construction in Los Angeles, California was designed using CATIA, a software primarily used in automotive and airplane design applications.

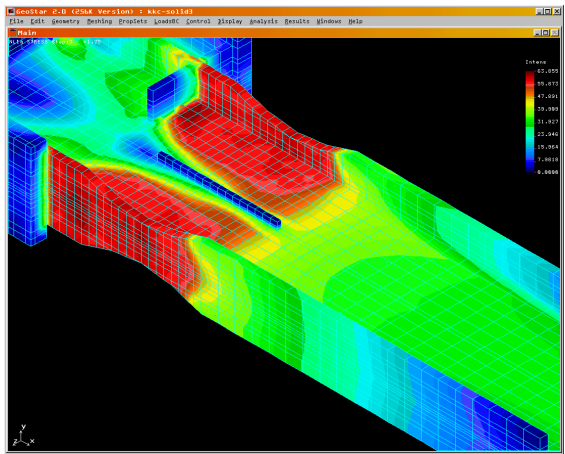


Figure 16-7. Nonlinear finite element analyses were instrumental in shaping a new SMRF connection for the UCLA Replacement Hospital under construction in Los Angeles, California.

Last, but not least, up-to-date literature searches can be conducted online. Therefore, seismic design engineers rarely need to “re-invent the wheel”. Now, it is not only always possible, but a necessity, to check the relevant information on the Internet before one starts to embark on an unfamiliar path. A few web sites of particular significance in this regard are listed in Table 16-1.

In short, computer applications have tremendously enhanced our capabilities in all facets of seismic design and construction. At

the same time, computer applications has to be balanced with sound engineering judgment and a true physical sense of seismic performance, for it to benefit –and not adversely affect– the safety and quality of the end product.

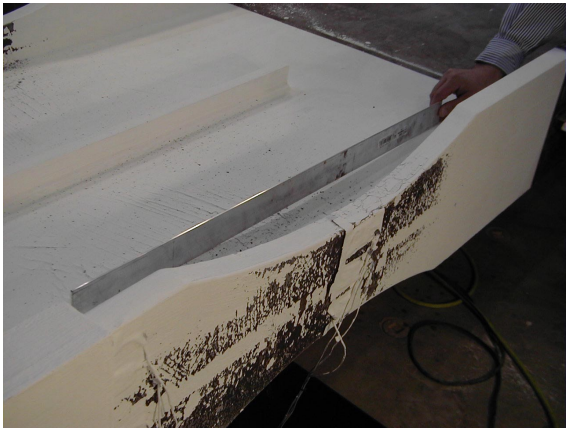


Figure 16-8. Full-scale testing confirms the findings of the compute model shown in Fig. 16-7.

Table 16-1. Important World-Wide-Web sites

Organization	Web Site Address
Earthquake Engineering Research Institute	http://www.eeri.org
Multidisciplinary Center for Earthquake Engineering Research	http://mceer.buffalo.edu
Mid-America Earthquake Center	http://mae.ce.uiuc.edu
Pacific Earthquake Engineering Research Center	http://peer.berkeley.edu
The Earthquake Hazards Mitigation Information Network	http://www.eqnet.org
Applied Technology Council	http://www.atcouncil.org
Trinet	http://www.trinet.org
Southern California Earthquake Center	http://www.scec.org
California Strong Motion Instrumentation Program (CSMIP)	http://www.consrv.ca.gov
USGS National Earthquake Information System	http://wwwneic.cr.usgs.gov
HAZUS User Group	http://www.hazus.org
Federal Emergency Management Agency	http://www.fema.gov

16.2 EARTHQUAKE RECORDS

A few short years ago, it was very difficult to get hold of a good collection of earthquake records for design. That is no longer the case. Naeim and Anderson⁽¹⁶⁻⁹⁾ have compiled a comprehensive list of design attributes of horizontal and vertical components of available ground motion for North and Central America as well as Hawaii. Once the desired design attributes are determined, it takes only a short visit to various web sites that contain large databases of earthquake records for various regions of the world. For example, for California records, the CSMIP web site provides time series as well as spectral ordinates of a variety of recorded ground motions (Figures 16-9 to 16-11).

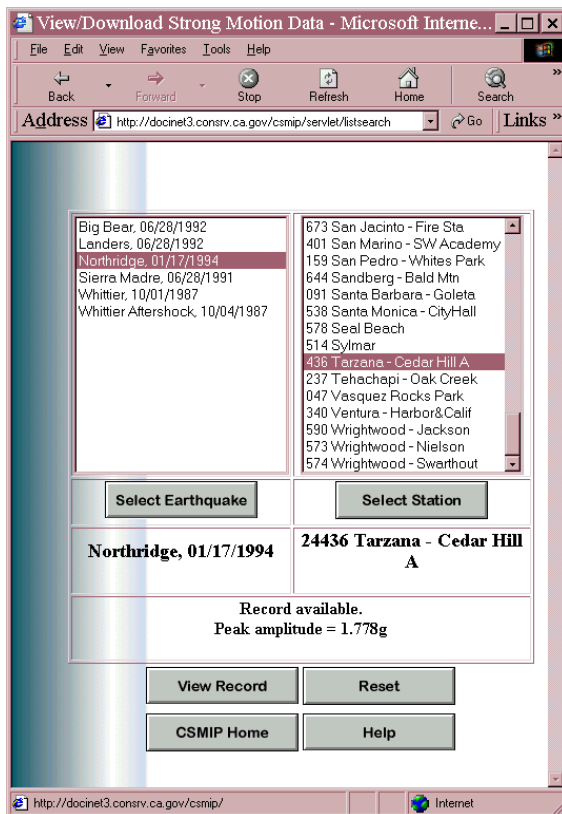


Figure 16-9. Selecting an earthquake record from the CSMIP web site.

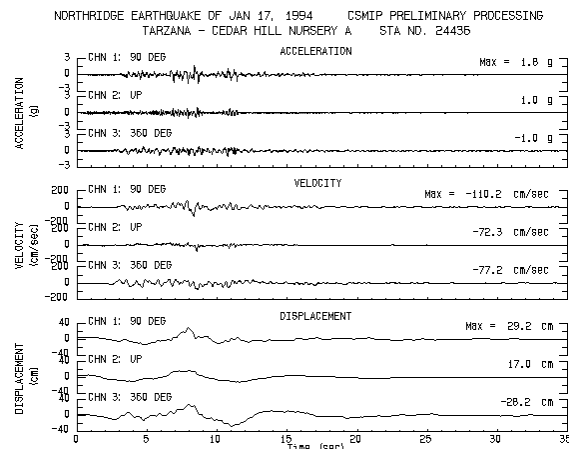


Figure 16-10. Time series for the earthquake record selected in Fig. 16-9 as displayed on the CSMIP web site.

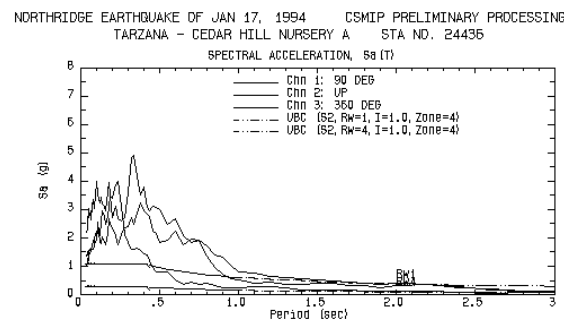


Figure 16-11. Response spectra for the earthquake record selected in Fig. 16-9 as displayed on the CSMIP web site.

16.3 MONITORING SEISMIC ACTIVITY

Besides click-able fault maps, seismocams (worldwide web pages connected directly to seismograms or to cameras focused on them) can be found in abundance on the Internet, some very serious work is being conducted in this area that could not possibly be performed without computer assistance. Perhaps the most significant of these experiments is being conducted by TriNet in Southern California.

TriNet is a multifunctional seismic network for earthquake research, monitoring and computerized alerts. TriNet is a cooperative

project between US Geological Survey, California Institute of Technology, and the Strong Motion Instrumentation Program of the California Division of Mines and Geology. The goals of TriNet are to provide data for research in engineering and earth sciences, emergency response applications and development of a seismic computerized alert network. The TriNet network features a dense recording of ground motions in all frequency bands, dense strong motion instrumentation with 150 broadband and 600 strong motion sensors all connected to a central processing system. The network can issue automatic post-earthquake intensity maps very quickly after an earthquake (see Figure 16-2).

16.4 SEISMIC HAZARD ANALYSIS

There are a variety of software systems with different levels of sophistication available in the marketplace. Arguably, the computer programs developed by the California geologist Dr. Thomas F. Blake (are among the most widely used at least in the western United States (<http://www.thomasfbake.com>). We will highlight Blake's programs as representative applications in this field.

The *EQSEARCH* program⁽¹⁶⁻¹⁰⁾ contains a searchable catalog of significant earthquakes in western United States dating back to 1880. Given a site latitude and longitude, soil conditions and the choice of attenuation relationship, the program reports historical events that have occurred within a given radius (or rectangle) around the site. The program then uses this information to estimate the peak ground accelerations observed at the site as well as a Gutenberg-Richter recurrence relationship for the site (see Figures 16-12 to 16-14).

The *EQFAULT* program⁽¹⁶⁻¹¹⁾ can be used to perform a deterministic seismic hazard analysis for a given site. The input information is similar to that of the previous program. *EQFAULT*, however, searches a three-dimensional database of earthquake faults and reports maximum magnitude associated with each fault and an

estimate of the corresponding maximum accelerations experienced at the site (Figures 16-15 and 16-16).

Figure 16-12. A typical *EQSEARCH* input screen

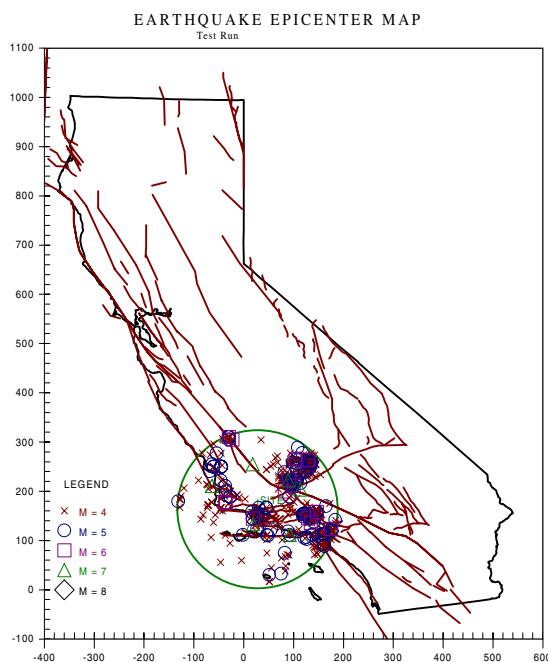


Figure 16-13. A typical epicenter map generated by *EQSEARCH*

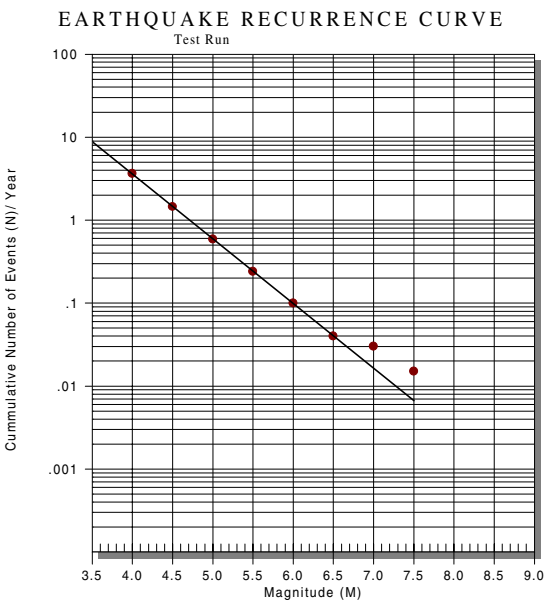


Figure 16-14. An earthquake recurrence curve generated by application of *EQSEARCH*

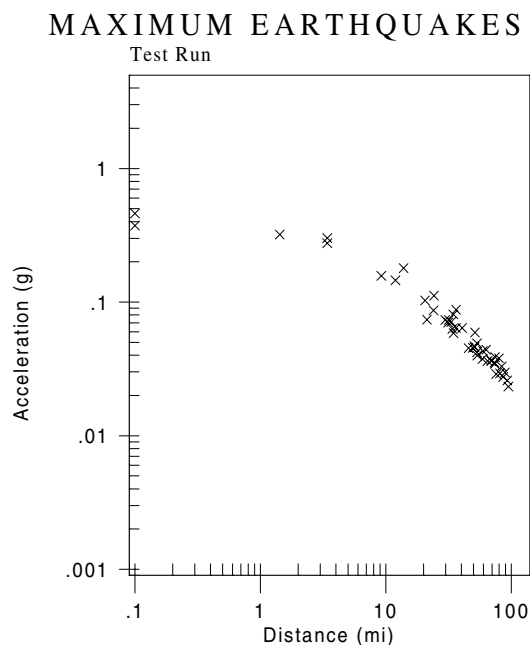


Figure 16-16. A site acceleration versus distance chart generated by *EQFAULT*

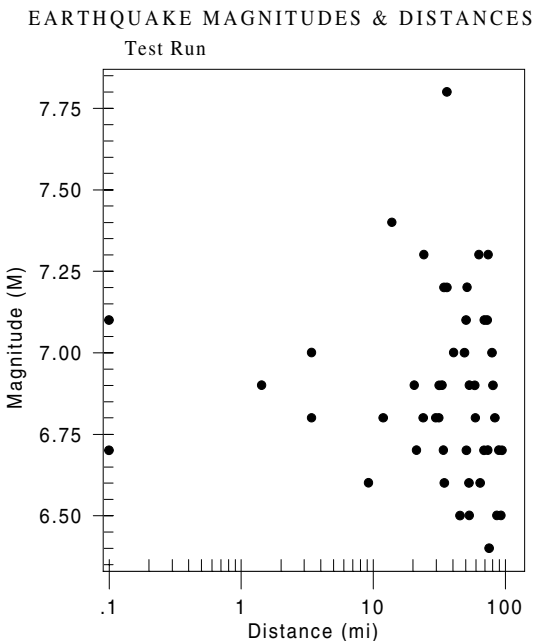


Figure 16-15. A plot of earthquake magnitudes and their corresponding distances from a given site generated by the *EQFAULT* program

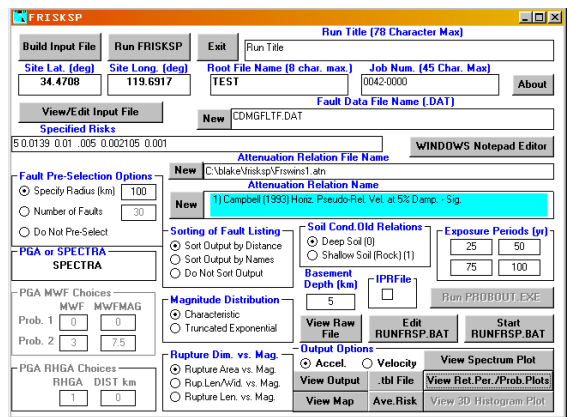


Figure 16-17. A typical input screen for the *FRISKSP* computer program

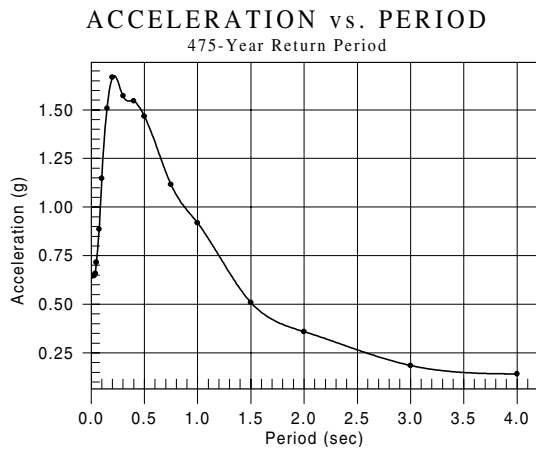


Figure 16-18. A probabilistic design spectrum generated by the FRISKSP computer program

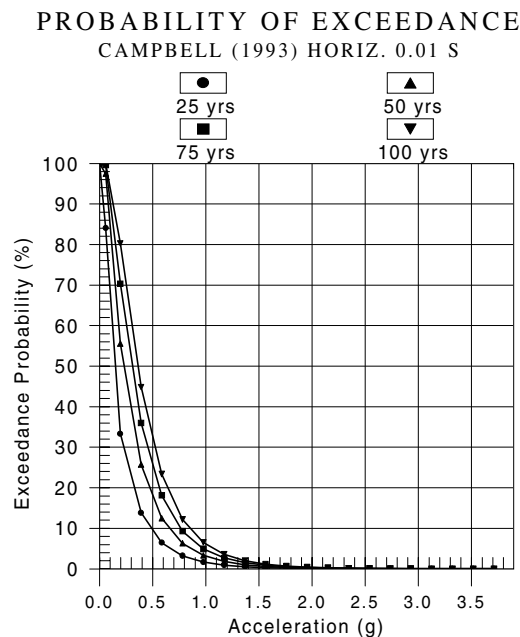


Figure 16-19. A typical probability of exceedance chart for peak ground acceleration generated by FRISKSP computer program

FRISKSP program⁽¹⁶⁻¹²⁾ is a more complicated software than the previous two and performs a probabilistic seismic hazard analysis for a given site and is capable of generating a set of probabilistic design spectra corresponding to the desired average return periods and dispersions (Figures 16-17 to 16-19). It is also capable of hazard de-aggregation

16.5 LOSS ESTIMATION, SCENARIO ANALYSIS AND PLANNING

The loss estimation methodology and application was revolutionized by release of the HAZUS-99 software system⁽¹⁶⁻⁶⁾, development of which was made possible through a concentrated and prolonged funding by the Federal Emergency Management Agency (FEMA).

HAZUS-99 was intended to provide local, state and regional officials with the tools necessary to plan and stimulate efforts to reduce risk from earthquakes and to prepare for emergency response and recovery from an earthquake. The program was also indented to provide the basis for assessment of nationwide risks of earthquake loss. HAZUS-99 can be used by a variety of users with needs ranging from simplified estimates that require minimal input to refined calculations of earthquake loss. Since it is totally built around a geographical information system (GIS) technology, its application and enhancement are rather straight forward.

The vision of earthquake loss estimation requires a methodology that is both flexible, accommodating the needs of a variety of different users and applications, and able to provide the uniformity of a standardized approach. The framework implemented in HAZUS-99 includes each of the components shown in Figure 16-20:

- Potential Earth Science Hazard (PESH)
- Inventory
- Direct Physical Damage
- Induced Physical Damage
- Direct Economic/Social Loss, and
- Indirect Economic Loss.

As indicated by arrows in Figure 16-20, HAZUS-99 modules are interdependent with output of some modules acting as input to others. In general, each of the components will be required for loss estimation. However, the degree of sophistication and associated cost will vary greatly by user and application.

Framing the earthquake loss estimation methodology as a collection of modules permits adding new modules (or improving models/data of existing modules) without reworking the entire methodology. Improvements may be made to adapt modules to local or regional needs or to incorporate new models and data.

The modular nature of the HAZUS-99 methodology permits a logical evolution of the methodology as research progresses and the state-of-the-art advances.

HAZUS-99 incorporates state-of-the-art models in the earthquake loss estimation methodology. For example, ground shaking

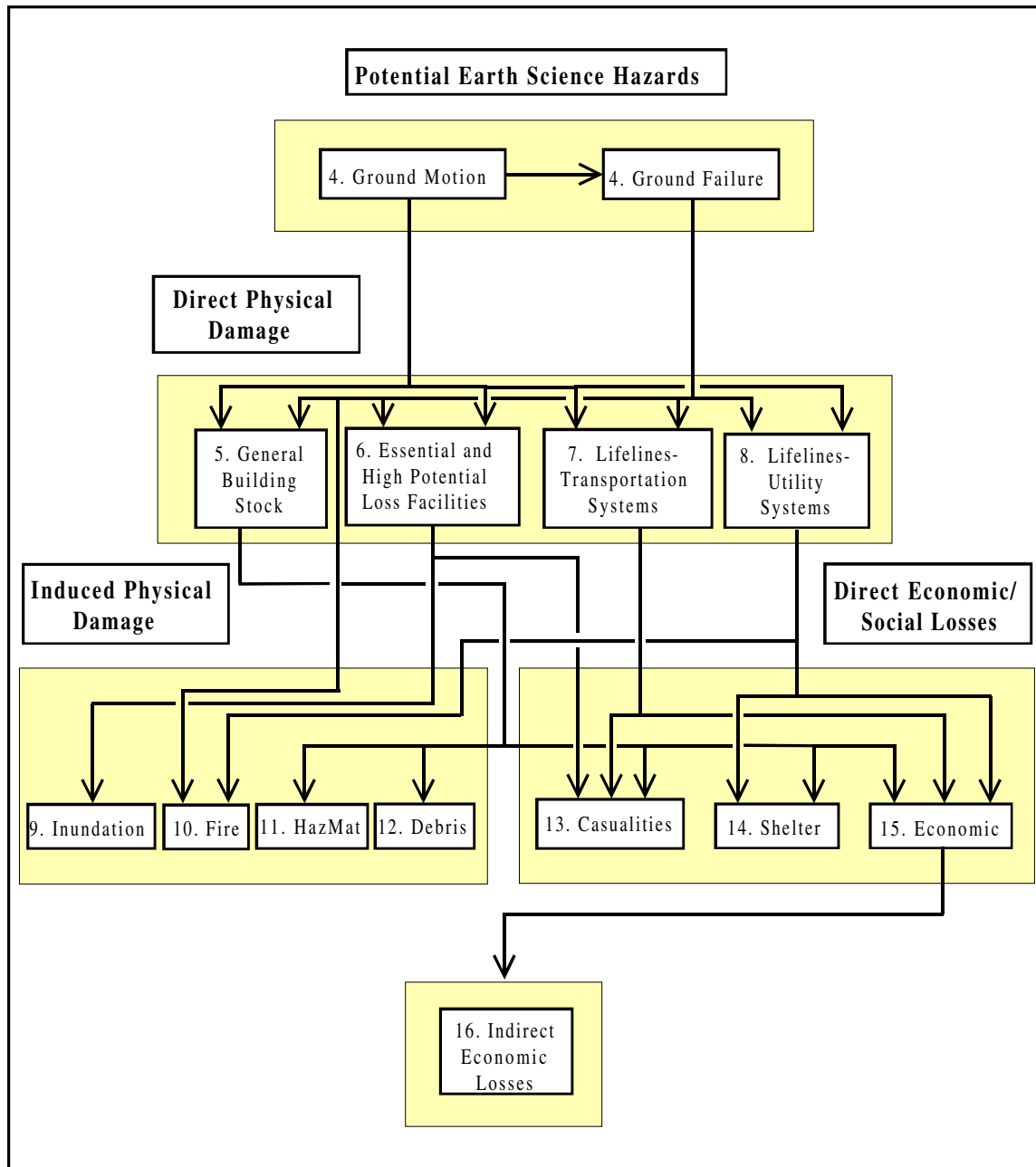


Figure 16-20. Flowchart of HAZUS-99 loss estimation methodology⁽¹⁶⁻⁶⁾

hazard and related damage functions are described in terms of spectral response rather than MMI. Modules include damage loss estimators not previously found in most studies, such as induced damage due to fire following earthquake and indirect economic losses. A nationally applicable scheme is developed for classifying buildings, structures and facilities.

HAZUS-99 incorporates both deterministic (scenario earthquake) and probabilistic descriptions of spectral response. Alternatively, it accepts user-supplied maps of earthquake demand. The software also accepts externally supplied maps of earthquake ground shaking. The uncertainty in earthquake demand due to spatial variability of ground motion is addressed implicitly by the variability of damage probability matrices or fragility curves. Uncertainty in earthquake demand due to temporal variability (i.e., earthquake recurrence rate) or uncertainty in the magnitude of earthquake selected for scenario events may be readily evaluated by the users. Loss estimation using HAZUS-99 may be conducted on a regional or a national scale.

16.6 EERI/IAEE WORLDWIDE HOUSING ENCYCLOPEDIA PROJECT

Under the joint leadership of the Earthquake Engineering Research Institute (EERI) and the International Association of Earthquake Engineers (IAEE) and cooperation of engineers from over 70 countries an online encyclopedia of earthquake vulnerability of worldwide housing is under progress. This is a monumental task of immense practical consequences. By collecting and comparing various types of housing vulnerability across the globe and local techniques currently deployed for hazard mitigation, for the first time the sharing of experience and expertise may be exercised in a truly universal scale. The online version to be developed and published on the Internet can be of immense value to

governmental as well as nongovernmental agencies. It could be also used by funding agencies such as the World Bank in rational prioritization of investments in earthquake hazard reduction projects. The interested reader is referred to the EERI web site (<http://www.eeri.org>) for more information.

16.7 INSTRUMENTED BUILDING RESPONSE ANALYSIS

Seismic performance of instrumented buildings provide a vital link for critical evaluation of various theories, code provisions, and practices utilized in seismic design. Generally, there are two types of seismic instrumentation:

1. *Code Instrumentation* whereby according to mandates of the applicable building code, some significant structures are instrumented. Codes usually mandate a minimal level of instrumentation for buildings of certain height and/or complexity. The requirements are usually satisfied by installation of a tri-channel accelerometer at the base, mid-height, and roof of the building. Generally, in this type of application the various sensors are not time-synchronized.
2. *Extensive Instrumentation* whereby buildings are instrumented by installation of a relatively large number of sensors (usually between 10 to 30) throughout the plan and elevation of the structure. The sensor locations are designed to maximize post-earthquake understanding of building response. Dozens of buildings have been extensively instrumented by CSMIP and USGS agencies in California. The records of instrumented response may be downloaded from the Internet (see Table 16-1).

To illustrate the lessons that can be learned from studying seismic performance of instrumented structures, Naeim developed an interactive CD-ROM based information system (Figure 16-21)⁽¹⁶⁻¹³⁾. This information system

contains detailed information regarding performance of 20 extensively instrumented buildings during the 1994 Northridge earthquake. However, the database organization and the overall structure of the information system are readily expandable to include other buildings and/or other earthquakes. It provides facilities for manipulating instrument records in either frequency or time domain, combining and contrasting them, identification of predominant building frequencies, and generation of moving windows fast Fourier transform (FFT) functions to track possible structural damage by identifying significant shifts in predominate building periods.



Figure 16-22. A buckled penthouse brace documented for the building shown in Figure 16-21.

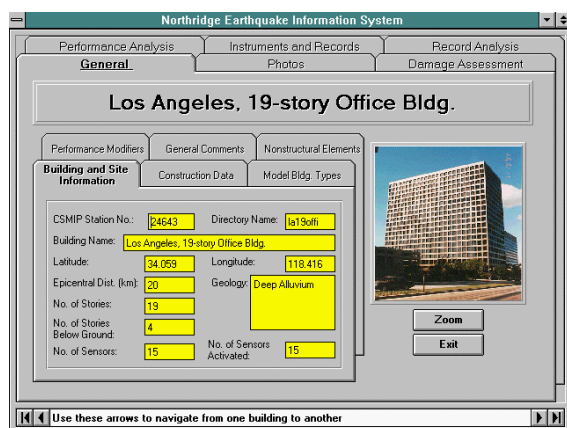


Figure 16-21. The main folder for one of the 20 buildings contained in the information system CD-ROM

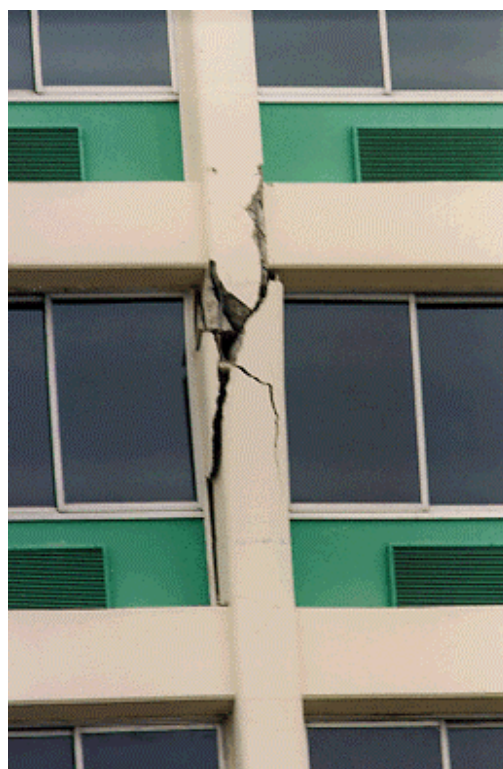


Figure 16-23. One of the damaged columns for a severely damaged building documented in the information system CD-ROM

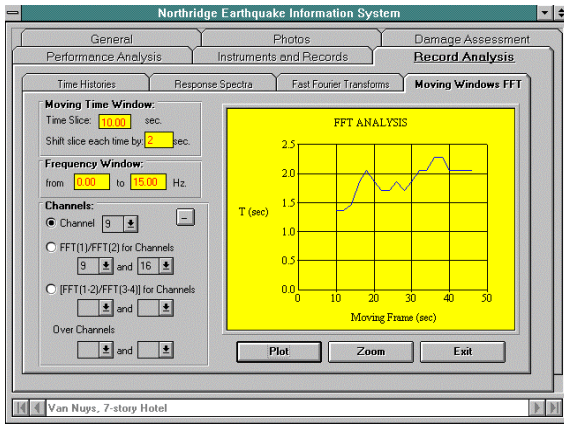


Figure 16-24. A moving-windows FFT plot generated for the building shown in Figure 16-23 using the information system utilities indicating a significant softening of the building due to damage. Horizontal axis in the plot shows the time and the vertical axis shows predominant building period as a function of time.

16.8 STRUCTURAL ANALYSIS AND DESIGN

Structural engineers have always been at the forefront of computer applications. The advancement of computer technology in terms of both hardware and software has vastly broadened the use of computers in seismic analysis and design. The advent of personal computers and availability of very sophisticated analysis software on this platform has further integrated computers into routine seismic analysis and design practices. The large scale finite element analysis programs that were available only on mainframe computers are now readily accessible on ordinary personal computers. As a matter of fact, interactive finite element analysis software has been even successfully ported on to some pocket calculators⁽¹⁶⁻¹⁴⁾.

Two and three-dimensional linear static analysis of structures has become so routine that it is hardly worth extended review in this chapter. It is fair to say, that the generally available competent software systems for performing these tasks could be primarily

distinguished based on their user interface, ease of use, and the extent to which graphical modeling of the structure has been made possible. The same observation is not necessarily true for linear dynamic analysis where the number of robust software systems that can properly model untypical cases without ill-conditioning and other similar problems is fairly limited.

Nonlinear analysis software systems, on the other hand, are in a revolutionary stage. They are undergoing rapid changes to accommodate the various practical needs that have become critical because of the rise in popularity of performance based design techniques (see Chapter 15) and application of technologies such as seismic isolation and energy dissipation devices (see Chapter 14).

A structure is said to exhibit nonlinear behavior when its response is not directly proportional to the applied load. Generally, three distinct types of nonlinearity may be distinguished:

1. *Material nonlinearities* account for the hysteretic behavior of the material. Their characteristics are derived from the constitutive stress-strain properties of the material. Commonly utilized material nonlinearity models include elastic-plastic, hyper-elastic, visco-elastic, or visco-plastic behaviors. The onset of nonlinear behavior (yielding) is governed by various yield criteria and their associated flow and hardening rules such as the Tresca and Von-Mises criteria. Depending on the material used in the structure, different yield criteria surfaces and yield to choose from. Example and surfaces are selected. Examples include the Hill's criterion for anisotropic materials and the Mohr-Coulomb, Drucker Prager, and Cam-clay criteria for soils and rock.
2. *Geometric nonlinearities* are the effects of large displacements on basic structural assumptions or on the equilibrium state. They include large deflections, P- Δ effects, and buckling.
3. *Boundary nonlinearities* model the behavior of elements in contact, but not connected to

each other. These are specified either by *gap* (compression only), *hook* (tension only), *sliders* (friction at point of contact) or *slide-line* (friction over line of contact) elements.

Generally speaking, computer programs used in seismic analysis and design can be classified into two main categories: *general-purpose* and the *special-purpose* structural analysis software.

General-purpose analysis programs are not specifically designed for seismic analysis and design but can certainly be used for this purpose. There are many general-purpose analysis programs that can analyze structures with any or all of the above mentioned non-linearities. The example⁽¹⁶⁻¹⁵⁾ presented in Figure 16-25 shows the analysis of an anchored cylindrical storage tank under reversed seismic loading. As the walls of the storage tank are made of very thin plates of steel, the deformations of the walls due to hydrodynamic loads are large. Also in many cases, the buckling of the walls of such tanks are preceded by yielding of the steel. Thus, both material and geometric non-linearities are involved in the analysis. For unanchored tanks⁽¹⁶⁻¹⁵⁾, the problem becomes more complex with participation of the uplifting of the base plate from the foundation in dissipating energy during an earthquake. In such cases, the analysis program must also include contact non-linearities as shown in Figure 16-26. Thus, for such seismic analyses, a general-purpose program is needed.

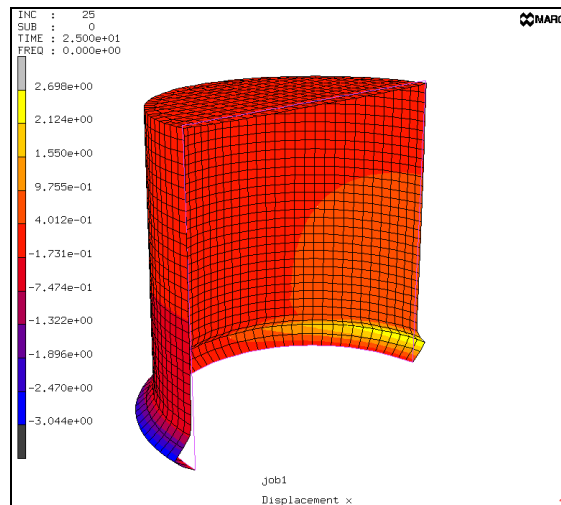
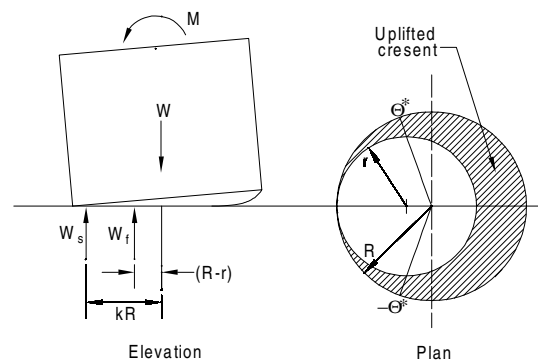


Figure 16-25. Buckling of an anchored cylindrical storage tank subject to reversed hydrodynamic pressures during an earthquake. MARC⁽¹⁶⁻¹⁶⁾ was used in the analysis.

Because of the practical utility that special purpose software systems provide, their use is more widespread than the general-purpose software. A practicing engineer is usually better served by using a special purpose software tailored to handle the specific type of project at hand rather than using a general purpose software to tackle all kinds of projects. In addition general-purpose programs by their nature are more complex and difficult to master. Therefore, training engineering staff on the use of specialty software tends to be less burdensome. General-purpose programs also tend to be more costly in terms of initial purchase and subsequent maintenance.



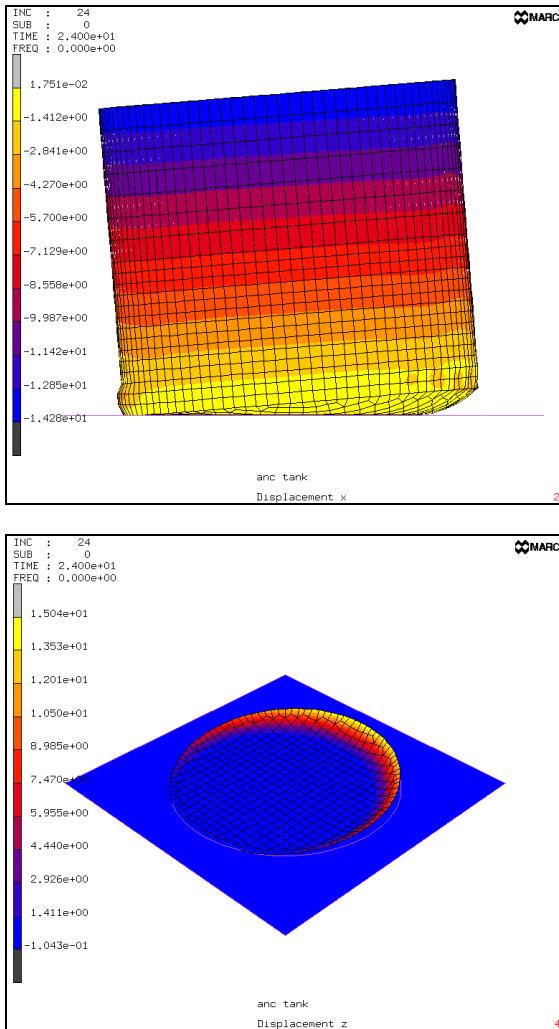


Figure 16-26. Buckling and uplifting of an unanchored cylindrical storage tank under seismic loads. Shown at the bottom is the base plate of the tank uplifting from its rigid foundation due to the hydrodynamic pressures on the vertical walls of the tank. The resisting moment is due to fluid pressure causes the unique crescent shape of the uplifted portion of the base plate of the tank. MARC was used in the analysis.

Seismic design of complex projects often involves application of both general purpose and special purpose software. For example, the design of the Staples Center sports arena in Los Angeles⁽¹⁶⁻¹⁷⁾, The Eiffel Tower II in Las Vegas⁽¹⁶⁻¹⁸⁾ and seismic correction of the Royce Hall⁽¹⁶⁻¹⁹⁾ all necessitated application of a variety of software from both groups of computer programs (see Figures 16-27, 16-28, and 16-29).



Figure 16-27. The roof truss of the Staples Center was analyzed using the RISA-3D computer program. Shear walls were analyzed using SAP-2000. Special software was developed to pass information from various programs to each other.



Figure 16-28. Royce Hall seismic rehabilitation design utilized SAP-90 computer program in conjunction with BIAx and other nonlinear analysis software. Specialty software was developed for cross-platforms communications.

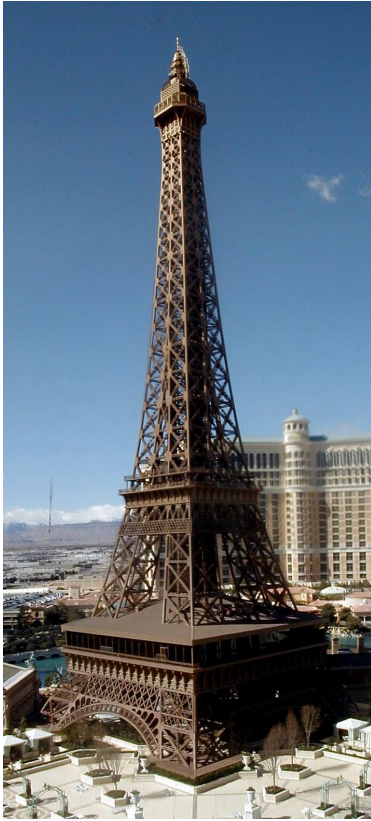


Figure 16-29. Eiffel Tower II in Las Vegas was analyzed and designed using SAP-2000. Nonlinear buckling analyses for temperature effects and fire scenarios were conducted using the ROBOT software system

Commonly used general-purpose analysis software include *SAP-2000*⁽¹⁶⁻²⁰⁾, *ADINA*⁽¹⁶⁻²¹⁾, *NASTRAN*⁽¹⁶⁻²²⁾, *ALGOR*⁽¹⁶⁻²³⁾, *ABAQUS*⁽¹⁶⁻²⁴⁾, *COSMOS/M*⁽¹⁶⁻²⁵⁾, *ANSYS*⁽¹⁶⁻²⁶⁾ and *MARC*⁽¹⁶⁻¹⁶⁾. The features and capabilities of these systems are so rapidly changing that a comparative discussion of their feature in a textbook like this could be counterproductive.

In addition to the above-named proprietary software systems, there are a variety of programs available in the public domain. These are generally programs motivated by academic research and are made available by various universities and research institutions. *NONSAP*⁽¹⁶⁻²⁷⁾ and *ANSR*⁽¹⁶⁻²⁸⁾ are examples of public domain general purpose computer programs.

Special-purpose programs, developed for analysis and design of building structures, are

often used in seismic analysis and design of buildings. They are generally faster and provide information that could be more readily applied to design purposes. Perhaps the most popular building seismic analysis software is *ETABS*⁽¹⁶⁻²⁹⁾. Currently a commercial software developed and maintained by Computers and Structures, Inc. of Berkeley, California, *ETABS* has its roots in public-domain versions of *TABS*, *TABS-80* and *ETABS* developed at the University of California at Berkeley, during the 1970s. The current commercial version of the program, however, is a very powerful and user-friendly program and has little in common with its old university developed predecessors.

A handful of public-domain programs are used extensively in nonlinear seismic analysis of structures. Perhaps the most widely used among this class of programs is *DRAIN-2DX*⁽¹⁶⁻³⁰⁾ which is widely used in both professional and research applications (Figure 16-30).

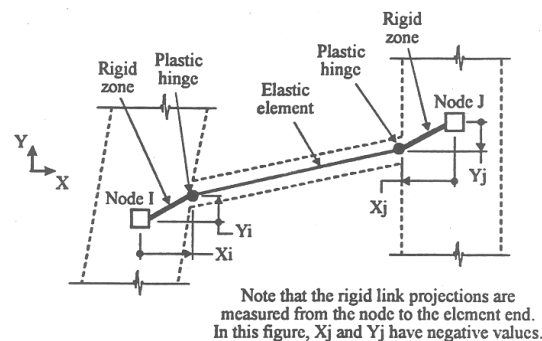


Figure 16-30. A DRAIN-2D nonlinear beam element

The success of *DRAIN-2DX* has resulted in the development of an entire family of *DRAIN* programs such as *DRAIN-3DX*⁽¹⁶⁻³¹⁾, and *DRAIN-BUILDING*⁽¹⁶⁻³²⁾. Various hysteretic models are implemented in the *DRAIN* family of programs (Figure 16-31) where the slope of the unloading branch is based on the previous maximum plastic hinge rotation. All plastic deformation effects including the effects of degrading stiffness can now be modeled.

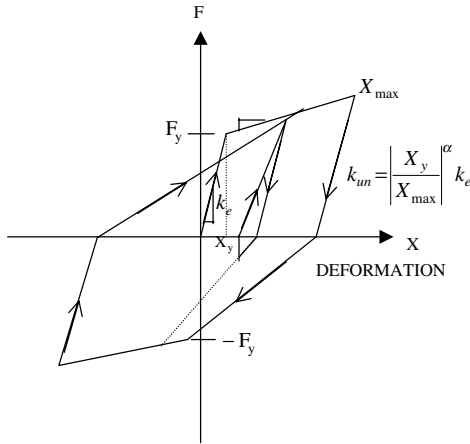


Figure 16-31. Modified Takeda Model⁽¹⁶⁻³³⁾ is one of the hysteretic behavior models implemented in the DRAIN and IDARC family of programs

A very promising development recently incorporated in the DRAIN family of programs is the incorporation of fiber elements (Figure 16-32) that allow modeling of various behavior states occurring at the same cross section of a beam or column element.

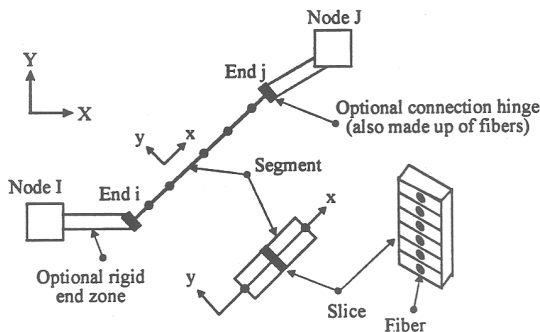


Figure 16-32. A typical beam modeled by fiber elements

IDARC is another family of very powerful public-domain computer programs developed and maintained at the University of Buffalo. The original IDARC⁽¹⁶⁻³⁴⁾ was developed for damage analysis of reinforced concrete structures. The IDARC family of programs^(16-35 to 6-37), however, can now be used for nonlinear analysis of steel structures as well⁽¹⁶⁻³⁹⁾.

A major difference between IDARC and DRAIN families of programs, is in the

construction of the inelastic element stiffness matrices. DRAIN programs use a concentrated plasticity model where the inelastic deformation is concentrated at the locations of plastic joints. The individual member stiffness matrix in IDARC is constructed based on a flexibility approach. This permits modeling of plasticity distributed along the length of the member. Concentrated plasticity models are generally better for modeling steel structures while distributed plasticity models (Figure 16-33) more accurately represent the response of reinforced concrete members (Figure 16-34).

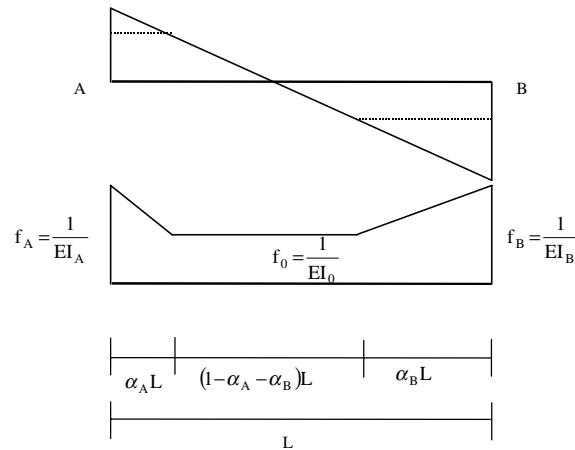


Figure 16-33. A distributed plasticity/flexibility model

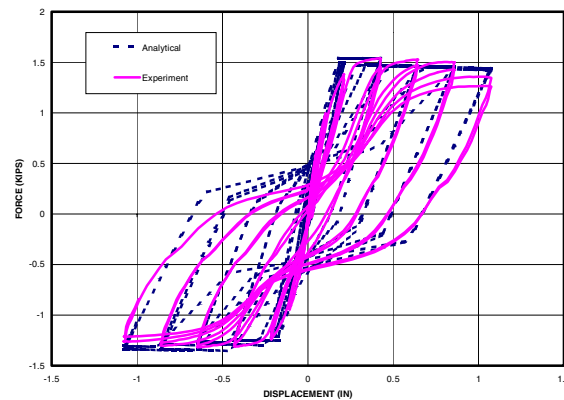


Figure 16-34. Analytical (using the distributed flexibility model) and experimental results compared for cyclic tests on a cantilever concrete column

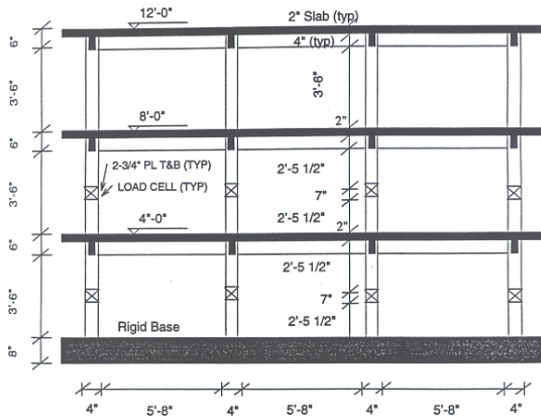
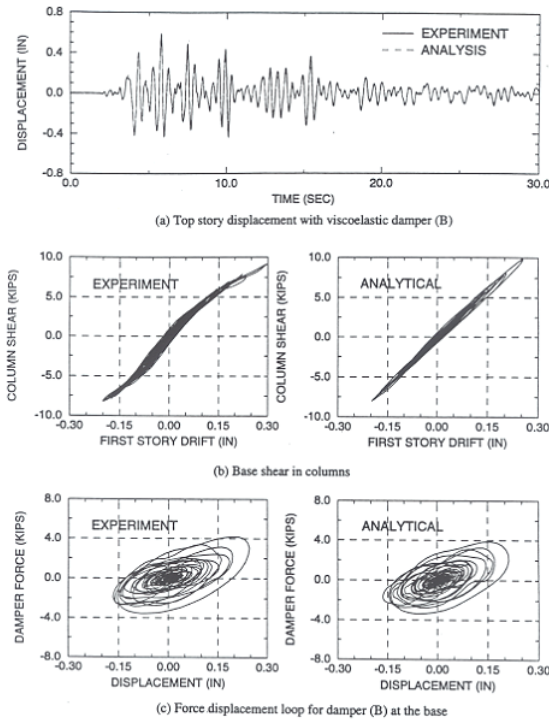


Figure 16-35. Model of a three-story building

Figure 16-36. Comparison of Analytical Responses with Experiment for model shown in Fig. 16-33⁽¹⁶⁻³⁸⁾.

The correlation among the analytical predictions and observed performance has been continuously improving. For example, Figure 16-35 shows the model of a three story building tested at the University at Buffalo. Diagonal brace dampers were added between floors as a retrofit alternative. As indicated by Figure 16-

36 the analytical and experimental results are in good agreement. Blind predictions of actual seismic response by analytical means, however, have not generally been as successful.

16.9 CONCLUSION

Computers are inseparable from contemporary seismic design. While advances in computer technology have broadened the range of problems that can be handled by earthquake engineers, they have had the unfortunate side-effect of downplaying the importance of sound engineering judgment.

Although vital to current seismic design practice, computer use if not subordinated to design experience and engineering judgment, is nothing but a recipe for disaster.

REFERENCES

- 16-1 Pearce, P. (1980), *Structure in Nature Is a Strategy for Design*, The MIT Press, Massachusetts Institute of Technology, Cambridge, MA.
- 16-2 Naeim, F. (1998), "Internet Frontiers for Earthquake Engineering Design and Education", *Proceedings of the 6th National Conference on Earthquake Engineering*, Earthquake Engineering Research Institute, Seattle, WA.
- 16-3 International Code Council (2000), *International Building Code*, March.
- 16-4 Federal Emergency Management Agency (1997), *NEHRP Guidelines for the Seismic Rehabilitation of Buildings*, FEMA-273, Washington, D.C.
- 16-5 Federal Emergency Management Agency (1997), *NEHRP Commentary on the Guidelines for the Seismic Rehabilitation of Buildings*, FEMA-274, Washington, D.C.
- 16-6 Federal Emergency Management Agency (1999), *HAZUS – FEMA's Tool for Estimating Potential Losses from Natural Disasters*, CD-ROM set, Washington, DC.
- 16-7 Naeim, F., Martin, J.A., Jr., Gong, V., Norton, G., Schindler, B.S., Scambellurri, M. and Rahman, M.A. (1999), "Structural Analysis and Design of the Walt Disney Concert Hall, Los Angeles," *Proceedings of the 1999 SEOAC Annual Convention*, Santa Barbara, CA.
- 16-8 Naeim, F., Patel, K., Tu, K.C., Saiidi, M., Itani, A., and Anderson, J.C. (2000), "A New Rigid Connection for Heavy Beams and Columns in Steel

- Moment Resisting Frames,” *Proceedings of the 5th Conference on Tall Buildings in Seismic Regions*, Los Angeles, CA.
- 16-9 Naeim, F. and Anderson, J.C. (1996), *Design Classification of Horizontal and Vertical Earthquake Ground Motion (1933-1994)*, Report No. 7738-96, John A. Martin & Associates, Inc., Los Angeles, CA.
- 16-10 Blake, T.F. (2000), *EQSEARCH: A Computer Program for the Estimation of Peak Acceleration from California Historical Earthquake Catalogs*, Version 3.0, Thomas F. Blake Computer Services and Software, Thousand Oaks, CA. (<http://www.thomasfbake.com>)
- 16-11 Blake, T.F. (2000), *EQFAULT: A Computer Program for the Deterministic Estimation of Peak Acceleration using Three-Dimensional California Faults as Earthquake Sources*, Version 3.0, Thomas F. Blake Computer Services and Software, Thousand Oaks, CA.
- 16-12 Blake, T.F. (2000), *FRISKSP: A Computer Program for the Probabilistic Estimation of Peak Acceleration and Uniform Hazard Spectra using Three-Dimensional California Faults as Earthquake Sources*, Version 4.0, Thomas F. Blake Computer Services and Software, Thousand Oaks, CA.
- 16-13 Naeim, F. (1997), *Performance of Instrumented Buildings During the January 17, 1994 Northridge Earthquake -- An Interactive Information System --*, Report No. 97-7530.68, John A. Martin & Associates, Inc., Los Angeles.
- 16-14 Naeim, F. (1991), “Interactive Finite Element Analysis on a Pocket Calculator,” *Computers and Structures*, Pergamon Press, Vol. 41, No. 2, Oxford.
- 16-15 Bhatia, H. (1997), *Seismic Analysis and Retrofit of Cylindrical Liquid Storage Tanks*, Ph.D. Dissertation, University of California, Irvine.
- 16-16 MARC Analysis Research Corporation (2000), *The MSC/MARC Software System*, (<http://www.marc.com>)
- 16-17 Martin, J.A., Jr. and Naeim, F. (2000), *Structural analysis and Design of the Staples Center*, ASG-ASCE 6th Annual Symposium, University of Southern California, Los Angeles, January.
- 16-18 Naeim, F. (2000), *Eiffel Tower II: Re-engineering a Landmark*, Invited Lecture, North American Steel Construction Conference, Las Vegas, February.
- 16-19 Naeim, F. (1997), *UCLA Royce Hall: Anatomy of An Award Winning Seismic Correction*, Annual Convention, American Concrete Institute, April.
- 16-20 Computers and Structures, Inc. (2000), *SAP2000 Integrated Finite Element Analysis and Design of Structures*, Berkeley, CA. (<http://www.csiberkeley.com>)
- 16-21 ADINA R&D, Inc. (2000), *The ADINA System*, (<http://www.adina.com>)
- 16-22 MSC Software Corporation (2000), *The MSC/NASTRAN Software System*, (<http://www.mssoftware.com>).
- 16-23 ALGOR Corporation (2000), *ALGOR Virtual Prototyping Solutions for Mechanical Engineers*, (<http://www.algor.com>).
- 16-24 Hibbitt, Karlsson & Sorensen, Inc. (2000), *The ABACUS Software System*, (<http://www.hks.com>).
- 16-25 Structural Analysis and Research Corporation (2000), *The COSMOS/M Software System*, (<http://www.srac.com>).
- 16-26 ANSYS Inc. (2000), *The ANSYS/Structural Software System*, (<http://www.ansys.com>).
- 16-27 Bathe, K.J., E.L. Wilson and R.H. Iding (1974), *NONSAP – A Structural Analysis Program for Static and Dynamic Response of Nonlinear Systems*, Structural Engineering Lab, Report No. UCB/SESM-74/3, Department of Civil Engineering, University of California, Berkeley, California.
- 16-28 Mondkar, D.P. and Powell, G.H., (1975), *ANSR-I General Purpose Program for Analysis of Nonlinear Structural Response*, EERC report No. 75-37.
- 16-29 Computers and Structures, Inc. (2000), *ETABS Linear & Nonlinear Static & Dynamic Analysis & Design of Building Systems*, (<http://www.csiberkeley.com>)
- 16-30 Prakash, V., Powell, G.H., and Filippou, F.C. (1992), *DRAIN-2DX: Base Program User Guide*, Report NO. UCB/SEMM-92/29 Department of Civil Engineering, University of California, Berkeley.
- 16-31 Prakash, V., Powell G.H., Campbell S.D., and Filippou F.C. (1992), *DRAIN-3DX Preliminary Element User Guide*, Report, Department of Civil Engineering, University of California, Berkeley, CA. December.
- 16-32 Prakash, V., Powell G.H., and Filippou F.C. (1992) *DRAIN-BUILDING Base Program User Guide*, Report No. UCB/SEMM-92/31.
- 16-33 Takeda, T., Sozen, M.A., and Nielsen, N.N., (1970), “Reinforced Concrete Response to Simulated Earthquakes,” *Proceedings*, ASCE, Vol. 96, No. ST12.
- 16-34 Park, Y.J., Reinhorn, A.M., and Kunnath, S.K., (1987), *IDARC: Inelastic damage analysis of reinforced concrete frame -- shear-wall structures*, Tech. Report NCEER-87-0008, State Univ. of New York at Buffalo, N.Y.
- 16-35 Valles, R.E., Reinhorn, A.M., Kunnath, S.K., Li, C., and Madan, A. (1996), *IDARC2D: A Computer Program for the Inelastic Damage Analysis of Buildings*, Tech. Report NCEER-96-0010, State Univ. of New York at Buffalo. (<http://civil.eng.buffalo.edu/idarc2d50/>)

- 16-36 Lobo, R.F., (1994), *Inelastic Dynamic Analysis of Reinforced Concrete Structures in Three Dimensions*, Ph.D. Dissertation. University at Buffalo, NY.
- 16-37 Lobo, R.F. and Naeim, F. (1998), *JAMA-IDARC-3D: A Computer Program for the Three Dimensional Inelastic Analysis of Building Structures*, John A. Martin and Associates, Inc., Los Angeles, CA.
- 16-38 Lobo, R.F., Bracci, J.M., Shen, K.L., Reinhorn, A.M., Soong, T.T., (1993), *Inelastic Response of Reinforced Concrete Structures with Viscoelastic Braces*, Technical Report NCEER-93-0006, National Center for Earthquake Engineering Research, SUNY/Buffalo.
- 16-39 Naeim, F., Skliros, K., Reinhorn, A.M., and Sivaselvan, M.V. (2000), *Effects of Hysteretic Deterioration Characteristics on Seismic Response of Moment Resisting Steel Structures*, A report to the SAC Joint Venture, Report No. 2000/8428, John A. Martin and Associates, Inc., Los Angeles, CA.

