(SMSM) for seismic analysis of "regular" highway bridges. The basic assumption behind the Single Mode Spectral Method is that for a bridge with no abrupt change of geometry, mass and stiffness along its length, the seismic response can be determined by considering only the fundamental mode of vibration of the bridge. According to ATC-6, regular bridges need to be analyzed twice in each of the transverse and longitudinal directions. One analysis is for a uniform unit load to determine the fundamental mode shape of the bridge, and the other for pseudo seismic loads to determine the design lateral loads. This leads to a space frame analysis in the transverse direction of the bridge. By developing two separate models (one for each direction), and incorporating substructuring techniques for bents, the analysis can be simplified. The ATC-6 procedure 1 is such an approach. In order to simplify the input phase, the user can link to the AutoCAD drafting package to prepare data interactively. Alternatively, formatted input files may be used.

Operates on PC DOS computers.

USER GUIDES: Orie, D., M. Saiidi and B. Douglas, "A Micro-CAD System for Seismic Design of Regular Highway Bridges," Civil Engineering Department, University of Nevada,Reno, Report No. CCEER 88-2, June 1988.

Orie, D., and M. Saiidi, "User's Manual for Micro-SARB, A Microcomputer Program for Seismic Analysis of Regular Highway Bridges," Civil Engineering Department,University of Nevada, Reno, Report No. CCEER 88-3, October 1988.

SEISAB . . . SEISMIC ANALYSIS OF BRIDGES

DEVELOPED BY:

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Sacramento, California 95827

SUMMARY: SEISAB was specifically developed for the seismic analysis of bridges. The overall objectives in developing SEISAB were to provide the practicing bridge engineer with a usable design tool and a vehicle for implementing the latest aseismic design methodologies into the bridge engineering profession. SEISAB contains both the single mode and multi-mode response spectrum techniques included in the current AASHTO Standard Specifications for Highway Bridges and in the "Seismic Design Guidelines for Highway Bridges," which has been adopted by AASHTO as a design guideline. SEISAB can be used to analyze simply supported or continuous deck girder-type bridges with no practical limitation on the number of spans or the number of columns at a bent. In addition, earthquake restrainer units may be placed between adjacent structural segments. Horizontal alignments composed of a combination of tangent and curved segments are easily described using alignment data taken directly from roadway plans. SEISAB has generating capabilities that will, with a minimum amount of input data, automatically provide a model consistent with the model currently being used to conduct dynamic analyses. Seismic loadings in the form of response spectra are stored in the system and may be easily referenced by the user. The central theme underlying the development of SEISAB was to provide the bridge designer with an effective means of user-program communication using a problem-oriented language developed specifically for the bridge engineer. User input data is thoroughly checked for syntax and consistency prior to conducting an analysis and numerous default values are assumed for data not entered by the user.

Operates on IBM mainframe and VAX computers.

USER GUIDE: "SEISAB-1 User Manual and Example Problems," Engineering Computer Corporation, Sacramento, California, January 1984.

DAMS

ADAP-88 . . . NONLINEAR EARTHQUAKE ANALYSIS OF CONCRETE ARCH DAMS

DEVELOPED BY:

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University of California, Berkeley

SUMMARY: The modeling and dynamic analysis of concrete arch dams, the impounded water and foundation rock, is an important step in the earthquake safety evaluation of such systems. A linear earthquake analysis assuming an arch dam is an elastic monolithic structure usually shows large tensile stresses that exceed the tensile strength of concrete. Because arch dams are constructed as cantilever monoliths, the joints between the monoliths cannot develop the tensile stress predicted in a linear analysis. In reality, the contraction joints are expected to open and close during an earthquake, releasing arch stresses and redistributing the internal forces.

ADAP-88 is a finite element analysis program for computing the earthquake response of arch dams including the nonlinear effect of contraction joint opening. The nonlinear joint elements are combined with shell, solid and fluid finite elements to model a complete arch dam system. Special consideration is given to resolving the stress distribution near the joints by using a refined mesh of solid elements. A numerical procedure for solving the equations of motion assumes that the nonlinearity in the model is restricted to the joints. The cantilever monoliths between contraction joints are modeled as linear substructures, resulting in a significant reduction of computation in the iterative solution of the nonlinear equations of motion. ADAP-88 includes a finite element mesh generator for typical arch dam geometries. The computer program RESVOR is

used to compute the added mass for the water impounded in the reservoir, assuming the fluid is incompressible.

Operates on VAX/Unix computers.

USER GUIDE: Mojtahedi, S., G.L. Fenves, and R.B. Reimer, "ADAP-88: A Computer Program for Nonlinear Earthquake Analysis of Concrete Arch Dams," Report No. UCB/SEMM- 92/11, Structural Engineering, Mechanics and Materials, Department of Civil Engineering, University of California, Berkeley, May 1992.

BASIC PROGRAMS FOR BLOCK THEORY

DEVELOPED BY:

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SUMMARY: In recent years block theory has been applied to the planning and design of surface and underground excavations. The object of this technology is to specify the critical joint blocks intersecting an excavation. It applies to rock engineering for excavations in hard rock where the movement of predefined blocks precipitate failure. A series of Block Theory programs help to find the critical key blocks and possibility of failure in all types of excavations. These were developed along with the theories outlined in the book, *Block Theory and Its Application to Rock Engineering,* by Richard E. Goodman and Gen-hua Shi, Prentice-Hall, 1985.

The problem is limited in scope — to find the critical blocks created by intersections of discontinuities in a rock mass excavated along defined surfaces. Yet the problem is sufficiently difficult that a series of simplifying assumptions are adopted: (1) All joint surfaces are assumed to be perfectly planar. (2) Joint surfaces will be assumed to extend entirely through the volume of interest; that is, no discontinuities will terminate within the region of a key block. The implications are that all blocks are completely defined by preexisting joint surfaces so that no new cracking is entailed in the analysis of block movements. (3) Blocks defined by the system of joint faces are assumed to be rigid. This means that block deformation and distortion will not be introduced. The key-block problem is formulated entirely through geometry and topology. (4) Discontinuities and the excavation surfaces are assumed to be determined as input parameters. Block theory is developed on the basis of geometric information derived from structural geology and equilibrium calculations using simple statics. It is assumed that continuum mechanics is second in importance to the calculation and description of key blocks. Only block movement modes are to be considered.

The suite of programs included in the program package include, (1) Basic Programs for Block Theory: (1) General Key Blocks, (2) Stereographic Projections, (3) Stability Analysis, and (4) Tunnels and Shafts.

(1) Programs B02, B03, B10, B12, and B16 comprise General Key Blocks. B02 will compute all removable Joint Pyramids and give the corresponding modes of sliding for (a) a slope consisting of one free plane; (b) a convex slope; (c) a concave slope; and (d) all walls, edges and corners of an underground chamber. B03, based on the orientation of joints and free planes, will draw the general shapes of possibly removable blocks (potential key blocks) before excavation starts. The output block volume, the area of each face, and maximum distance are useful for computing the sliding force of key blocks, and the spacing and length of rock bolts. B10 will compute, for horizontal tunnels, inclined tunnels and vertical shafts, the angular intervals of Joint Pyramids. B10 gives the direction of the sliding force for each Joint Pyramid. The sliding force can be projected to the tunnel section plane and projected again to directions normal and tangential to the tunnel lining. Thus the sliding force can be transferred to the loading force on the tunnel lining. B12 can produce the tunnel shape. Preliminary estimation of the size of key or removable blocks for the determination of tunnel support and tunnel lining requirements. The program computes the Joint Pyramids that are both removable and have a mode of sliding. Different tunnel directions can be compared using this program. When a possible block face is exposed at the excavation or natural rock surface, B16 can be used to judge if this block is finite and draw the 3D view behind the rock surface. When a possible block face is exposed at the excavation or natural rock surface, program B16 can be used to judge if this block is finite and draw the 3D view behind the rock surface. The output block volume, the area of each face, and maximum distance are useful for computing the sliding forces of key blocks, and the spacing and length of rock bolts.

(2) The programs B05, B06, B07, B08, B13, B17, and B18 produce stereographic projection drawings to show the geometry of joints and other planes and to do the angle - related computation.

(3) Stability analysis is performed with programs B04, B09, B11, and B20. Programs for stability analysis with one, two or more joint sets. These programs display graphically all of the removable blocks of the input Joint Pyramid to reach the limit equilibrium condition, give the sliding modes for a definite resultant force. As the sliding mode changes, the sliding planes are changed. Different sliding plates have different friction angles, therefore the sliding forces have to be computed by different formulas. The positions of the resultant area relating to the friction loop will offer a global view of the stability for the changing resultants.

(4) Programs B25, B29, B30, and B01 are used to produce the tunnel shape, compare different tunnel directions, estimate the size of the maximum removable blocks for the determination of tunnel support and tunnel lining requirements, to compute the maximum sliding forces of all joint pyramids for a

tunnel, and to choose a safe tunnel direction in the design stage before excavation.

Operates on PC DOS computers.

USER GUIDE: Shi, Gen-hua and Goodman, Richard E., "Basic Programs for Block Theory, Department of Civil Engineering, University of California, Berkeley, August 1989.

REFERENCE: Goodman, R.E., and Gen-hua Shi, *Block Theory and Its Application to Rock Engineering,* Prentice-Hall, 1985 (OP)

EACD-3D . . . A COMPUTER PROGRAM FOR THREE-DIMENSIONAL EARTHQUAKE ANALYSIS OF CONCRETE DAMS

DEVELOPED BY:

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Department of Civil Engineering
University of California, Berkeley

SUMMARY: This program implements an analytical procedure for the three-dimensional earthquake response analysis of concrete dams which includes the effects of dam-water interaction and of alluvium and sediments usually present at the bottom, and possibly at the sides, of reservoirs.

The dam is idealized as an assemblage of finite elements. The main part of an arch dam is represented by thick shell finite elements. Three-dimensional solid elements are used to idealize a concrete gravity dam or a thick arch dam. The part of the dam near its junction with foundation rock is represented by transition elements designed to connect thick shell elements to three-dimensional solid elements idealizing the foundation rock. A very simplified idealization of the foundation rock is used. Only the foundation rock flexibility is considered, with the inertial and damping effects ignored. The absorptiveness of the alluvium, silt and other sedimentary materials at the bottom is characterized by a wave reflection coefficient. The reservoir is idealized as an assemblage of three-dimensional finite elements for the finite region of irregular geometry adjacent to the dam connected to an infinite uniform channel along the upstream direction.

A variety of possible conditions can be analyzed: (1) the dam-foundation-reservoir system can be symmetric or nonsymmetric; (2) the foundation rock supporting the dam can be rigid or flexible; (3) the extent of the reservoir can be infinite or finite; (4) compressibility of the water can be included or neglected; (5) any water level may be input, or the reservoir can be empty; (6) the bottom and side reservoir boundaries may be absorptive or rigid.

Operates on IBM mainframe computers.

USER GUIDE: Fok, K.-L., J. F. Hall, and A. K. Chopra, "EACD-3D, A Computer Program For Three-Dimensional Earthquake Analysis of Concrete Dams," Earthquake Engineering Research Center, Report No. UCB/EERC-86/09, University of California, Berkeley, July 1986.

EADAP . . . ENHANCED ARCH DAM ANALYSIS PROGRAM

DEVELOPED BY:

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University of California, Berkeley

SUMMARY: This enhanced and modified version of the ADAP program accounts for the hydrodynamic effects of the reservoir by calculating an equivalent added-mass matrix. Each component of the dam-foundation-reservoir system is idealized as an assemblage of finite elements of appropriate shapes and types. A thick shell element is used to represent the concrete arch, an eight node solid for the foundation rock, and 2D and 3D liquid elements for the reservoir. EADAP includes an automatic mesh generator that can handle a general three-centered arch dam of regular geometry. The mesh generator has been extended for arch dams built in U-shaped valleys, in addition to V-shaped cases. Temperature loads due to both uniform and linearly varying temperature changes throughout the dam thickness are supported. Linear dynamic analysis is accomplished using two types of mode superposition: response spectrum and response history. The results of the response spectrum analysis are the estimated maximum nodal displacements and the element stresses of the dam structure. The results of the step-by-step time integration response history analysis include the displacement and stress histories of the nodes and elements prescribed by the user, along with the maximum and minimum response values during the input earthquake time history.

Operates on VAX/Unix computers.

USER GUIDE: Ghanaat, Y., and R.W. Clough, "EADAP — Enhanced Arch Dam Analysis Program User's Manual," Report No. UCB/EERC-89/07, Earthquake Engineering Research Center, University of California, Berkeley, California, November 1989.

EAGD-84 . . . EARTHQUAKE ANALYSIS OF CONCRETE GRAVITY DAMS

DEVELOPED BY:

G. Fenves and A. K. Chopra
Department of Civil Engineering
University of California, Berkeley

SUMMARY: This program may be used to evaluate the response of concrete gravity dams to earthquakes, including the effects of dam-water-foundation rock interaction and of materials, such as alluvium and sediments, at the bottom of reservoirs.

The dam monolith is idealized as an assemblage of planar, four-node nonconforming finite elements. Energy dissipation in the dam concrete is represented by constant hysteretic damping. The water impounded in the reservoir is idealized as a fluid domain of constant depth and infinite length in the upstream direction. The absorptiveness of the reservoir bottom materials is characterized by a wave reflection coefficient. If the effects of dam-foundation rock interaction are to be included, the dynamic stiffness matrix for the region of the foundation rock appears in the equations of motion for the dam. This frequency-dependent stiffness matrix is defined with respect to the degrees-of-freedom of the nodal points at the dam base. The dam-foundation rock system may be assumed to be either in a state of generalized plane stress or plane strain.

Outputs from the program include hydrostatic loads; nodal point displacements and element stresses due to static loads; natural vibration frequencies and mode shapes of the dam (if the foundation rock is assumed to be rigid) or of an associated dam-foundation-rock system (if dam-foundation-rock interaction effects are included); the largest major principal stress and the smallest minor principal stress in each finite element and the times at which they occur.

Source code written in Fortran 4. Originally programmed for CDC computers.

USER GUIDE: Fenves, G., and A. K. Chopra, "EAGD-84, A Computer Program for Earthquake Analysis of Concrete Gravity Dams," Report No. UCB/EERC-84/11, Earthquake Engineering Research Center, University of California, Berkeley, August 1984.

EAGD-SLIDE . . . EARTHQUAKE ANALYSIS OF CONCRETE GRAVITY DAMS INCLUDING BASE SLIDING

DEVELOPED BY:

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University of California, Berkeley

SUMMARY: A numerical method has been implemented in a computer program, EAGD-SLIDE, to evaluate the earthquake response of concrete gravity dams, including sliding at the interface between the base of the dam and the foundation rock surface. The earthquake response of the dam is influenced by the interaction between the dam and the compressible water in the reservoir, by the interaction between the dam and foundation rock, and by the dam-foundation rock interface properties.

The dam monolith is modeled by a finite element discretization with linear, elastic, orthotropic material behavior. The water in the reservoir is modeled as a continuum, and the hydrodynamic effects of the impounded reservoir are modeled by the two-dimensional wave equation. The effect of reservoir bottom materials is accounted for by the wave reflection coefficient. The foundation rock is modeled as a linear viscoelastic half-space. A friction model based on the Mohr-Coulomb law is used to approximate the force-displacement relationship at the interface. Base sliding is the only source of nonlinearity in the system. Rocking (or rigid body tipping) is not considered. Other nonlinearities, such as concrete cracking, opening and sliding of joints, and water cavitation are not represented in the model. The system is subjected to horizontal and vertical components of free-field earthquake ground motion acting at the base of the dam.

The analysis method uses the hybrid frequency-time domain procedure, which accounts for the nonlinear base sliding behavior of the dam and the frequency-dependent response of the impounded water and the flexible foundation rock, to solve the equations of motion. The program can be used to obtain stresses, displacements, and base sliding of gravity dams subjected to free-field ground motion.

Operates on Workstation Unix computers.

USER GUIDE: Chavez, Juan W. and Gregory L. Fenves, "EAGD-SLIDE: A Computer Program for the Earthquake Analysis of Concrete Gravity Dams Including Base Sliding," Structural Engineering, Mechanics and Materials, Department of Civil Engineering, University of California, Berkeley, Report No. UCB/SEMM-94/02, March, 1994.

TOWER . . . EARTHQUAKE ANALYSIS AND RESPONSE OF INTAKE-OUTLET TOWERS

DEVELOPED BY:

A. Goyal and A. K. Chopra
Department of Civil Engineering
University of California, Berkeley

SUMMARY: This program consists of a series of three programs for the earthquake response analysis of intake-outlet towers. The first, TOWERINF, evaluates the added mass associated with the hydrodynamic effect of the water surrounding an infinitely-long, uniform tower. The tower is restricted to cross sections with two axes of symmetry, and the added mass is computed for motion along an axis of symmetry. The second program, TOWERRZ, can be used to analyze axisymmetric towers with hollow circular cross section with radius varying arbitrarily over height, subjected to one or two components of ground motion. The effects of tower-water interaction, due to water surrounding the tower and contained inside the tower, and tower-foundation-soil interaction can be included independently or simultaneously. The third program, TOWER3D, is designed for the analysis of towers with arbitrary cross section but having two axes of symmetry, subjected to one component of ground motion. The

outputs from TOWERRZ and TOWER3D consist of the maximum responses—lateral displacements, shear force and bending moment—at selected locations along the height of the tower.

Operates on PC DOS computers.

USER GUIDE: Goyal, A., and A.K. Chopra, "Earthquake Analysis and Response of Intake-Outlet Towers," Report No. UCB/EERC-89/04, Earthquake Engineering Research Center, Berkeley, California, July 1989.

GEOTECHNICAL

APOLLO . . . ANALYSIS OF POTENTIAL LIQUEFACTION OF SOIL LAYERS FOR ONE-DIMENSIONAL SEEPAGE

DEVELOPED BY:

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Department of Civil Engineering
University of California, Berkeley

SUMMARY: This program incorporates a simplified procedure for one-dimensional analysis of generation and dissipation of pore water pressures in a sand deposit due to seismic excitation. The method of liquefaction analysis in APOLLO is outlined by the following steps: (1) By means of a dynamic response analysis of the soil deposit under investigation, time histories of shear stress developed by earthquake are determined at the various depths of interest; (2) For each depth in the soil profile, determine the equivalent uniform cyclic stress, the equivalent number of uniform stress cycles and the effective period of each stress cycle representing the induced stress history; (3) Determine from laboratory cyclic load test the relationships between the applied cyclic shear stresses and the number of stress cycles required to produce a condition of initial liquefaction under undrained conditions; (4) Determine the number of stress cycles required to cause initial liquefaction; (5) Determine rate of pore pressure build up for each elemental layer of the deposit; (6) From a knowledge of the coefficients of permeability and compressibility of the soil layers, determine the corresponding values of the coefficient of consolidation for the different layers; (7) Solve the governing differential equation for the known values of soil characteristics, pore pressure generation expressions and boundary conditions. Program APOLLO is used to solve this equation by an implicit finite difference method.

Source code written in Fortran 4. Originally programmed for CDC computers.

USER GUIDE: Martin, P. P., and H. B. Seed, "APOLLO, A Computer Program for the Analysis of Pore Pressure Generation and Dissipation in Horizontal Sand Layers During Cyclic or Earthquake Loading," Earthquake Engineering Research Center, Report No. UCB/EERC-78/21, October 1978.

CHARSOIL . . . CHARACTERISTICS METHOD APPLIED TO SOILS

DEVELOPED BY:

V. L. Streeter, E. B. Wylie, and F. E. Richart, Jr.
University of Michigan
Ann Arbor, Michigan 48104

PC Version by:

T. F. Blake, Newbury Park, California 91320

SUMMARY: CHARSOIL is an application of the method of characteristics for calculating one-dimensional dynamic behavior of soils. A constant thickness zoned soil may consist of layers each having specific properties, shear modulus, density, maximum shearing strength, and viscoelastic coefficient. Underlying the soil is a rock base which may be horizontal or inclined. Dynamic excitation of the soil is introduced at the rock-soil interface by shearing stresses produced by rock motions. At the upper surface of the soil a slab may be included to simulate the dynamic influence of the weight of a building. Response of the soil can be evaluated on the basis of elastic, viscoelastic, or nonlinear (Ramberg-Osgood) soil behavior and plastic slip can be included. Information printed out includes shear; velocity (and slip velocity); displacements (and slip displacements) at each section; acceleration of ground surface; and information for plotting a hysteretic shearing stress-shearing strain curve at any layer.

Originally programmed for CDC computers, also operates on PC DOS computers.

USER GUIDE: Streeter, V. L., E. B. Wylie, and F. E. Richart, Jr., "CHARSOIL Characteristics Method Applied to Soils," March 25, 1974.

REFERENCE: Streeter, V. L., E. B. Wylie, E. Benjamin, and F. E. Richart, Jr., "Soil Motion Computations by Characteristics Method," Journal of the Geotechnical Engineering Division, ASCE, Vol. 100, No. GT3, March 1974, pp. 247-263.

CUMLIQ . . . EVALUATION OF POTENTIAL FOR LIQUEFACTION OF A SOIL DEPOSIT USING RANDOM VIBRATION PROCEDURES

DEVELOPED BY:

N. C. Donovan
Dames and Moore, San Francisco, California

PC Version by:

T. F. Blake, Newbury Park, California 91320

SUMMARY: The purpose of this program is to estimate the potential for seismic liquefaction using known field and laboratory data of soils in combination with general statistical parameters of earthquakes. The program is designed to perform the operation according to the mathematical procedure described in "A Stochastic Approach to the Seismic Liquefaction Problem," by N.C. Donovan, published in the *Proceedings of the First International Conference of Applications of Statistics and Probability to Soil and Structural Engineering,* Hong Kong, 1971, pp 514–535. A check on the applicability of the method was made by recomputing the 34 cases of liquefaction and non-liquefaction reported by Seed and Peacock (1970). The agreement between the analytical evaluations and the field observations was excellent.

Originally programmed for CDC computers, also operates on PC DOS computers.

USER GUIDE: Donovan, N. C., "Evaluation of Potential for Liquefaction of a Soil Deposit Using Random Vibration Procedures," July 1974.

FLUSH . . . A COMPUTER PROGRAM FOR SEISMIC SOIL-STRUCTURE INTERACTION ANALYSIS

DEVELOPED BY:

J. Lysmer
Department of Civil Engineering
University of California, Berkeley

PC version by N. Deng, San Francisco

SUMMARY: The computer program FLUSH is a further development of the complex response finite element program LUSH (Lysmer et al., 1974). The new program is considerably faster than LUSH and it includes a large number of new features which make the program more efficient and versatile. The program is now in its sixth version and provides a complete tool for seismic soil-structure interaction analysis by complex response method.

The FLUSH program includes the following features:

1. Plane strain quadrilateral elements for modeling of soils and structures.
2. Beam elements for modelling of structures.
3. Multiple nonlinear soil properties for equivalent linear analysis. This allows for different damping in each element.
4. An approximate 3-D ability which makes it possible to perform certain structure-soil-structure interaction analyses at essentially the same cost as 2-D analysis.
5. Transmitting boundaries which greatly reduce the number of elements required and eliminates the need to perform several analyses to ensure that the finite element boundaries are placed far enough away from the structures.
6. A new out-of-core equation solver which reduces core-size problems.

7. Internal deconvolution. This feature eliminates the need to perform an independent site response analysis for determination of the rigid base motions.
8. Convenient file handling features which provide restart ability and a permanent record for later recover of details of the solution.
9. Printed, plotted or stored output time histories of acceleration and bending moments.
10. Computation of maximum shear forces in beam elements.
11. Printed or stored acceleration velocity response spectra.
12. Plotting of Fourier amplification functions.
13. Optional baseline correction of input and output motions.
14. Several additional features which improve the efficiency, utility and clarity of the program (Optional RMS method for strain computations, new interpolation scheme, etc.).

Originally programmed for CDC computers, also operates on IBM mainframe computers and PC DOS computers. License agreement required.

USER GUIDE: Lysmer, J., Udaka, T., Tsai, C.F., Seed, H.B., "FLUSH—A Computer Program for Approximate 3-D Analysis of Soil-structure Interaction Problems, Earthquake Engineering Research Center, Report No. UCB/EERC-75/30, University of California, Berkeley, November 1975.

GADFLEA . . . ANALYSIS OF PORE PRESSURE GENERATION AND DISSIPATION DURING CYCLIC OR EARTHQUAKE LOADING

DEVELOPED BY:

J. R. Booker, M. S. Rahman, and H. B. Seed
Department of Civil Engineering
University of California, Berkeley

PC Version by:

T. F. Blake, Newbury Park, California 91320

SUMMARY: In recent years there has been considerable progress in the development of tests and test procedures for determining quantitative measurement of the stress conditions which lead to soil liquefaction. This development has been accompanied by developments in the methods of analysis which use these test results to evaluate the liquefaction potential of soil deposits in the field. These methods provide a useful basis for assessing probable site performance for prescribed earthquake performance. In this finite element program the pore pressure generating effects of cyclic loading are incorporated into a dissipation analysis by the introduction of a source term, under one-dimensional conditions.

GADFLEA has been used to analyze a wide range of problems such as (1) the generation and dissipation of pore pressure in horizontally stratified soil deposit subjected to earthquake loading, (2) the use of gravel drains to stabilize potentially liquefiable soil deposits, (3) the generation and dissipation of pore pressure in earth and rock-fill dams subjected to earthquake loading, (4) the generation and dissipation of pore pressure in marine deposits subjected to wave action, and (5) the potential for liquefaction under offshore structures subjected to storm loading.

Originally programmed for CDC computers, also operates on PC DOS computers.

USER GUIDE: Booker, J. R., M. S. Rahman, and H. B. Seed, "GADFLEA—A Computer Program for the Analysis of Pore Pressure Generation and Dissipation During Cyclic or Earthquake Loading," Earthquake Engineering Research Center, Report No. UCB/EERC-76/24, University of California, Berkeley, October 1978.

LASS-II . . . LIQUEFACTION ANALYSIS OF SATURATED SOIL DEPOSITS

LASS-III . . . SEISMIC RESPONSE AND LIQUEFACTION OF LAYERED GROUND UNDER MULTIDIRECTIONAL SHAKING

DEVELOPED BY:

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Department of Civil Engineering, University of Illinois at
Urbana-Champaign, Urbana, Illinois 61801

SUMMARY: LASS-II analyzes seismic response and liquefaction of horizontally layered saturated solids. The saturated soil below the water table is modeled as a coupled two - phase medium with solid granular skeleton and pore water as the constituent materials. Coupling between these two phases is taken into account. The pore water is allowed to flow with respect to granular solid and this process is assumed to be governed by Darcy flow law with the coefficient of permeability as the material constant. Above the water table, soil is modeled as one phase solid. A nonlinear material model is used in the program which includes yielding, failure, volume change characteristics, cyclic effects and criteria for initial and final liquefaction.

Two different material models are used for the behavior of soil before and after initial liquefaction. All the material parameters needed for the material model used in this program can be determined from routine laboratory tests. Cyclic tests are not required for this model.

Damping is not included as an independent parameter in the model. Two effective damping mechanisms are inherently included: hysteretic and dissipative damping.

LASS-III analyzes seismic response and liquefaction of horizontally layered ground subjected to multidirectional shaking. The saturated sand below the water table is modeled as a coupled two phase medium. The two phases are the porous deformable granular solid and the pore water. A nonlinear material model is used to represent the behavior of sand under cyclic biaxial shear stress.

A vertical column of the horizontally layered ground is divided into a number of layer elements. At each nodal plane separating two adjacent layer elements there are four displacement degrees of freedom: three components of displacement of granular solid and the vertical displacement of pore water. The stress state for the solid portion consists of two horizontal shear stresses and effective pressure. Effective pressures at each element are monitored for initial liquefaction and complete liquefaction. When the liquefaction criterion is satisfied the element properties are modified accordingly. After completion of earthquake the program provides an option for analyzing dissipation of pore pressures.

Outputs from the program are controlled by the user who may request all or some of the following information: time histories of accelerations; velocities and displacements; time histories of shear stresses; effective pressures and pore pressures; maxima of the preceding quantities; liquefaction time history and response spectra.

Source code written in Fortran 4. Originally programmed for CDC computers.

USER GUIDES: Ghaboussi, J., and S. U. Dikmen, "LASS-II, Computer Program for Seismic Response and Liquefaction of Horizontally Layered Sands," Report No. UILU- ENG-77-2010, University of Illinois at Urbana-Champaign, June 1977.

Ghaboussi, J., and S. U. Dikmen, "LASS-III, Computer Program for Seismic Response and Liquefaction of Layered Ground Under Multidirectional Shaking," Report No. UILU-ENG-2012, University of Illinois at Urbana-Champaign, July 1979.

LUSH2 . . . COMPLEX RESPONSE ANALYSIS of SOIL-STRUCTURE SYSTEMS BY THE FINITE ELEMENT METHOD

DEVELOPED BY:

J. Lysmer, T. Udaka, H. B. Seed and R. Hwang
Department of Civil Engineering
University of California, Berkeley

SUMMARY: The program finds the complete response of a plane finite element model representing a soil-structure system. The program differs from more conventional finite element programs in that it, in an appropriate manner, takes into account the strong nonlinear effects which occur in soil masses subjected to strong earthquake motions. This is achieved by a combination of an equivalent linear method and the complex response method. The latter method makes it possible to work with different damping in each element and to consider higher frequencies than most other methods of dynamic analysis.

The input motion is assumed to be specified as acceleration time histories at a rigid boundary of the finite element model, usually the base, and different time histories may be specified for the horizontal and vertical components of the input motion. The solutions for the two components are found independently but may be added by an auxiliary program, COMBINE, which is included with LUSH2.

The basic output from LUSH is the time history of motion of all nodal points of the system. These time histories may be printed, or plotted as time histories of displacement or accelerations or in the form of acceleration and velocity spectra.

Source code written in Fortran 4. Originally programmed for CDC computers.

USER GUIDE: Lysmer, J., T. Udaka, H. B. Seed, and R. Hwang, "LUSH - A Computer Program for Complex Response Analysis of Soil-Structure Systems," Earthquake Engineering Research Center, Report No. UCB/EERC-74/4, University of California, Berkeley, April 1974.

MASH . . . NONLINEAR ANALYSIS OF VERTICALLY PROPAGATING SHEAR WAVES IN HORIZONTALLY LAYERED DEPOSITS

DEVELOPED BY:

P. P. Martin and H. B. Seed
Department of Civil Engineering
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SUMMARY: The computer program MASH is designed to solve the dynamic response of a deposit of horizontal soil layers. A deposit is discretized into a string of one-dimensional constant strain finite elements with masses lumped at the nodes. An implicit formulation of the time-stepping cubic inertia algorithm is used to integrate the equations of motion. This procedure has been found to be advantageous when used with nonlinear materials. The soil material may be either viscoelastic, or nonlinear with rate independent damping. The nonlinear soil model incorporated in the program is the Davidenkov model, wherein stresses are expressed as functions of strains. Laboratory measurement of the variation of the secant modulus with cyclic strain amplitude defines the parameters used in the model.

Inputs to the program include soil properties, base acceleration, time history and, optionally, pore pressure buildup during the earthquake (from program APOLLO). Outputs include the maxima of accelerations, stresses and strains within each element and response spectra.

Source code written in Fortran 4. Originally programmed for CDC computers.

USER GUIDE: Martin, P. P. and H. B. Seed, "MASH - A Computer Program for the Nonlinear Analysis of Vertically Propagating Shear Waves in Horizontally Layered Deposits," University of California, Earthquake Engineering Research Center, Report No. UCB/EERC-78/23, October, 1978.

QUAD4M . . . SEISMIC RESPONSE OF SOIL STRUCTURES USING FINITE ELEMENT PROCEDURES INCORPORATING A COMPLIANT BASE

DEVELOPED BY:

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University of California, Davis; 1994.

SUMMARY: The finite element method of analysis is a widely used computational procedure for the solution of problems in continuum mechanics, as well as in many other fields. The procedure has been found very powerful for modeling the seismic response of soil deposits and earth structures. Programs to solve such response have been written using time domain solutions as well as frequency domain solutions in the past 30 years.

QUAD4 (Idriss, Lysmer, Hwang, and Seed, 1973) was written as a two-dimensional, time domain solution to dynamic soil response. It incorporated for the first time independent damping in each element in the continuum.

QUAD4M incorporates into QUAD4 a transmitting base so that the half-space beneath a mesh can be modeled, and the need to assume a rigid foundation can be eliminated. The shear and compression wave velocities and the unit weight for the material underlying the mesh can be entered, and the response of the mesh on top of that half-space can now be modeled with greater accuracy.

In addition, seismic coefficients have been added in this version of the program. This feature is particularly useful in deformation analyses. The program also has a restart capability. The acceleration, velocity, and displacement are stored for the restart so that the program continues as if no interruption had occurred. This feature is useful for changing material properties during the shaking event.

Finally, QUAD4M incorporates a new method for the formulation of damping matrices which results in a significant reduction of the damping of higher frequencies commonly associated with the use of a Rayleigh damping formulation.

Operates on PC-DOS and PC-Windows on an IBM or 100 percent IBM compatible, with a 486 or higher processor.

USER GUIDE: Hudson, M., Idriss, I.M. and Beikae, Mohsen, "QUAD4M: A Computer Program to Evaluate the Seismic Response of Soil Structures Using Finite Element Procedures and Incorporating a Compliant Base," Center for Geotechnical Modeling, Department of Civil & Environmental Engineering, University of California, Davis, California, May 1994.

RASSUEL . . . RELIABILITY ANALYSIS OF SOIL SLOPES UNDER EARTHQUAKE LOADING

DEVELOPED BY:

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SUMMARY: This computer program is used to assess the reliability of soil slopes under earthquake loading. A pseudo-static slope stability analysis is performed. Significant uncertainties in material and seismic parameters are recognized, and probabilistic tools are introduced for their description and amelioration.

The safety of the slope is measured in terms of its probability of failure (or its complement, reliability) rather than the customary factor of safety. Numerical values of the probability are obtained through a Monte Carlo simulation of failure. Three types of earthquake source can be examined by the program: (a) point source, which models a known single earthquake source; (b) line source, which models a single known fault; and (c) area source, which simulates an ill-defined seismic threat.

Operates on IBM mainframe computers.

USER GUIDE: Grivas, D. A., "Program RASSUEL - Reliability Analysis of Soil Slopes Under Earthquake Loading," Department of Civil Engineering, Report No. CE-78-6, Rensselaer Polytechnic Institute, Troy, New York, December 1978.

SASSI . . . 3D DYNAMIC SOIL-STRUCTURE INTERACTION ANALYSIS

DEVELOPED BY:

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SUMMARY: SASSI is a package of interrelated computer programs which together form a practical system for two- and three-dimensional finite element analysis of a wide range of dynamic soil-structure interaction problems involving horizontally layered sites. The dynamic excitation may consist of dynamic forces acting on the structure(s) or a seismic environment defined in terms of inclined body waves or surface waves. The free-field is assumed to consist of horizontal viscoelastic layers over a uniform halfspace. Local irregularities such as backfill must be modeled as being part of the structure(s). The latter may be modeled by solid elements, beam elements or plate elements. Each element may have each own stiffness and damping characteristics.

The basic analytical method used is the complex response method, which works in the frequency domain, and the flexible volume method of substructuring. The latter allows for multiple structures and implies that only the structure(s) and the excavated soil need to be modeled by finite elements.

The SASSI system includes many restart features which makes it efficient in a design environment. For example, solutions for a new seismic environment or a changed structure can be obtained without rerunning all of the programs of the system.

Three versions of the program are currently available from NISEE: an IBM mainframe version, a partly vectorized Cray version, and an IBM RISC 6000 version. Potential users should be warned that experience has shown that conversion to other systems is nontrivial and that some experience is required to be able to take full advantage of the flexibility and efficiencies of the system.

License agreement required. Discounts do not apply to this program.

USER GUIDES: Lysmer, J., Ostadan, F., Tabatabaie, M., Vahdani, S., Tajirian, F., "SASSI - A System for Analysis of Soil-Structure Interaction," Department of Civil Engineering, University of California Berkeley, California, and Bechtel Power Corporation, San Francisco, California, July 1988.

SHAKE91 . . . EQUIVALENT LINEAR SEISMIC RESPONSE ANALYSES OF HORIZONTALLY LAYERED SOIL DEPOSITS

DEVELOPED BY:

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MODIFIED BY:

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SUMMARY: The SHAKE program has been by far the most widely used program for computing the seismic response of horizontally layered soil deposits. The program computes the response of a semi-infinite horizontally layered soil deposit overlying a uniform half-space subjected to vertically propagating shear waves. The analysis is done in the frequency domain, and, therefore, for any set of properties, it is a linear analysis. An iterative procedure is used to account for the nonlinear behavior of the soils. The object motion (i.e., the motion that is considered to be known) can be specified at the top of any sublayer within the soil profile or at the corresponding outcrop.

The main modifications incorporated in SHAKE91 include the following:

- The number of sublayers was increased from 20 to 50; this should permit a more accurate respresentation of deeper and/or softer soil deposits.
- All built-in modulus reduction and damping relationships were removed. These relationships are now specified by the user.
- The maximum shear velocity or the maximum modulus are now specified for each sublayer; again these are part of the input and therefore the program no longer calculates modulus values as a function of either confining pressure or shear strength.
- Object motion is now read from a separate file.
- Other clean-up include: renumbering of options, elimination of infrequently used options, user specified periods for calculating spectral ordinates.

Development of these program enhancements was supported by the National Institute of Standards.

Machine version available: PC DOS

USER GUIDES: Idriss, I.M., and Sun, J.I., "User's Manual for SHAKE91," Department of Civil & Environmental Engineering, University of California, Davis, California, November 1992.

Schnabel, P.B., J. Lysmer, and H.B. Seed, : "SHAKE - A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites," Earthquake Engineering Research Center, Report No. UCB/EERC-72/12. University of California, Berkeley, December 1972.

STABL . . . ANALYSIS OF GENERAL SLOPE STABILITY PROBLEMS

DEVELOPED BY:

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SUMMARY: STABL is a computer program for the general solution of slope stability problems by a two-dimensional limiting equilibrium method. The calculation of the factor of safety against instability of a slope is performed by a method of slices. The particular method employed in STABL is an adaptation of the Modified Bishop method. The adaptation of this method allows the analysis of trial failure surfaces other than those of circular shape.

STABL features unique random techniques for general potential failure surfaces for subsequent determination of the more critical surfaces and their corresponding factors of safety. One technique generates circular surfaces; another, surfaces of sliding block character; and, a third, more general irregular surfaces of random shape. The means for defining a specific trial failure surface and analyzing it are also provided.

The program can handle slope profiles having multiple slope ground surfaces. Any arrangement of subsurface soil types having different soil properties can be specified. Pore pressures may be related to a steady state flow domain, related to the overburden, or specified within zones. Surcharge boundary loads and pseudostatic earthquake loadings are also considered.

Source code in Fortran 4. Originally programmed for CDC computers.

USER GUIDES: Siegel, R. A., "Computer Analysis of General Slope Stability Problems," Joint Highway Research Project, Report No. JHRP-75-8, Project No C-36-36K, File NO 6-14-11, Purdue University, West Lafayette, Indiana, June 1975.

Siegel, R. A., "STABL User's Manual," Joint Highway Research Project, Report No. JHRP-75-9, Project No. C-36-36K, File No. 6-14-11, Purdue University, West Lafayette, Indiana, June 1975.

WAVES . . . SEISMIC RESPONSE OF HORIZONTALLY LAYERED SOIL DEPOSITS

DEVELOPED BY:

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SUMMARY: WAVES is a special purpose computer program for computing the dynamic characteristics and seismic response of horizontally layered soil deposits. The soil site is discretized into a finite element mesh of one-dimensional shear elements. The WAVES program takes advantage of the tri-diagonal nature of the one-dimensional equilibrium equations by implementing an extremely