NONLIN and EQ-Tools
Software for Earthquake Engineering Education

Finley A. Charney, Ph.D., P.E., Virginia Tech, Department of Civil and Environmental Engineering
NONLIN: Version 8.0

- Nonlinear Dynamic Analysis of SDOF Systems
- Incremental Dynamic Analysis of SDOF
- Nonlinear Dynamic Analysis of Simple MDOF Systems
- Elastic and Inelastic Response Spectrum Analysis
- Fourier Amplitude Spectrum Analysis
- Modal Analysis of Simple Proportionally Damped Systems
- Modal Analysis of Simple Non-proportionally Damped Systems

Items in **BOLD** indicate significant updates since Version 7
SDOF Analysis Tools

New degrading Strength and Stiffness model (Sivaselvan and Reinhorn)
Properties set interactively. Properties can be “tested” before use.
SDOF Analysis Tools: IDA

Incremental Dynamic Analysis
Incremental Dynamic Analysis

ID Method: Multiple Ground Motions

Available Earthquakes:
- OAKW1H2.ACC
- PACOMA1.ACC
- PACOMA2.ACC
- PARK1130.ACC
- PULSE1.ACC
- SR_MONC2.ACC
- S_MONIC1.ACC
- S_MONIC2.ACC
- SANFERN1.ACC
- SANFERN2.ACC

Selected Earthquakes:
- 49C71Y1.ACC: 1.031, 0.280
- KERN1.ACC: 1.872, 0.281
- LOMA1.ACC: 0.543, 0.150
- NRITE1.ACC: 0.331, 0.300
- PARK640.ACC: 1.897, 0.450
- S_MONIC1.ACC: 1.39, 1.006

Scaling Parameters:
- Target Accel., g: 0.500
- Target Period, s: 0.554
- Target Damping: 5.00
- Target Multiplier: 2.00
- No. of Increments: 10

System Properties (Used for Analysis):
- 150.000 k:
- 50.000 k:
- 20.000 k:
- 15.000 k:
- 15.08 k:
- Stiffness Kg

Ductility Limit:
- Damage Factor: 0.40
- Non-Degradation:

NonLIN and EQ-Tools
Incremental Dynamic Analysis (2)

Multiple Ground Motions or Multiple Structural Parameters
Incremental Dynamic Analysis (3)

Automatic Ground Motion Scaling
Incremental Dynamic Analysis (4)

Multiple Response Parameters
New Multi-Story Model

Nonlin Version 8.00: untitled

RJM Frame Models (VERSION: 1.20)

Structure Type

Include Nonstructural Elements

Structure Properties

STORY 1  STORY 2  STORY 3
NONSTRUCTURAL
New Multi-Story Model (2)

Degrading Strength and Stiffness Properties
New Multi-Story Model (3)

Structural and Nonstructural Properties

[Diagram showing structure types and properties]

Instructional Material Complementing FEMA P-751, Design Examples
New Multi-Story Model (4)

Nonlinear Viscous Dampers
New Multi-Story Model (5)
New Multi-Story Model (6)

Earthquakes in Series
New Multi-Story Model (7)

Earthquakes in Parallel

NONLIN Version 8.00: untitled

Earthquake Assembly Tool

Detailed Summary

- Northridge Earthquake
  - Santa Monica City Hall Grounds
  - January 17, 1994 04:31 PST
  - Corrected Accelerogram, Channel 1, 90 Degrees, Comp GNSA0530
  - Source NSE, UC Berkeley, California

- Number of Points: 3000
- Digitization Interval: 0.02 sec
- Duration: 60.0000 sec

- Acceleration
  - Maximum = 0.7524 g
  - Minimum = -0.8827 g
- Velocity
  - Maximum = 41.751 cm/sec
  - Minimum = -30.123 cm/sec
- Displacement
  - Maximum = 7.652 cm
  - Minimum = -14.316 cm

Assembly Parameters

- Earthquake Record: Include
  - 49OLYI.ACC: Yes
  - PARK130.ACC: Yes
  - NRDGE2.ACC: Yes
  - S_MONIC2.ACC: Yes
  - MEXCIT2.ACC: Yes

- Scale Factor: 1.00
New Nonproportional Damping Tool

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EQ-TOOLS: Version 3.0

- Ground Motion Search Engine
- Ground Motion History Analysis
- Linear Response Spectrum Analysis
- Fourier Amplitude Analysis
- 2D and 3D Ground Motion Evaluation Tools
- Ground Motion Scaling
- Ground Motion Attenuation Relationships
- Site Response Tools

Items in **BOLD** indicate significant updates since Version 2
Response Spectrum Tool

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FEMA and NEHRP
Horizontal Components Tool

Instructional Material Complementing FEMA P-751, Design Examples
Horizontal Components Tool (2)

2D Acceleration History

2D Orbit Spectrum
Ground Motion Attenuation Relationships

• Older (Project 97) relationships and newer PEER

• NGA Relationships
  • Abrahamson and Silva
  • Boore and Atkinson
  • Campbell and Bozorgnia
  • Chiou and Youngs
  • Idriss

Relationships may be used as targets for scaling

Conditional mean spectra development
Site Response Analysis Tool

Based on program “Waves” by J.D. Hart

[Image of Site Response Analysis Control Information]

- Time Domain Procedure for Site Response:
  - Linear Earthquake Response Analysis
  - Equivalent Linear Iterative Earthquake Response Analysis
  - Nonlinear Earthquake Response Analysis (Constant Time Step)
  - Nonlinear Earthquake Response Analysis (variable Time Step)

- Input and Analysis Units:
  - Unit Type: U.S., Metric
  - Length Units: inches, feet
  - Force Units: pounds, kilopounds

- Common Analysis Control Information:
  - Number of layer elements in site model: 10
  - Integration time step (seconds): 0.01
  - Scale factor for input acceleration data: 1.0
  - Maximum number of analysis iterations
  - Effective strain factor
  - Convergence tolerance (%) for dynamic soil properties
  - Maximum # of unloadings in Ramberg-Osgood Soil Elements
  - Maximum # of steps with a given time step before time step is increased
  - Equilibrium Tolerance
  - Accuracy Tolerance

- Damping Index:
  - Equivalent modal damping
  - Damping with control in two modes
  - Second control mode

- Energy Balance:
  - Skip Computations
  - Include Computations

- Integration Constants:
  - Newmark-Wilson integration constant, Gamma: 0.5
  - Newmark-Wilson integration constant, Beta: 0.25
  - Newmark-Wilson integration constant, Theta: 1.0

- Submerged Layer Parameters:
  - Number of first submerged layer
  - Unit weight of water
  - Coefficient of lateral earth pressure
Modified ground motion may be saved for further analysis in EQ-Tools
Access to Programs Through NEES Hub

• NONLIN and EQ-Tools are available as online tools through NEEShub: http://nees.org/

• Users must register with NEEShub before using the tools.

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Access to Programs Through NEES Hub (3)
Access to Programs Through NEES Hub (4)
Questions
NONLIN and EQ-Tools
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Degrading Stiffness and Strength Model

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Incremental Dynamic Analysis
Instructional Material Complementing FEMA P-751, Design Examples

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Title slide.
This presentation provides some of the key features of the educational computer programs NONLIN and EQ-Tools. These programs were developed by Dr. Finley Charney. Most of the funding for development of the programs was provided by FEMA. The programs are available from NEES Hub as described at the end of the presentation.

NOTE: It would beneficial for the instructor to demonstrate the programs “Live” during the presentation.

NONLIN was originally developed for the Earthquake Engineering part of the FEMA Multihazard building Design Summer Institute (MBDSI) that was held for many years at the Emergency Management Institute in Emmitsburg, Maryland. The program proved to be very effective in teaching the basic concepts of structural dynamics, and is included on the CD for that purpose. The companion program, EQ-Tools, was also developed for the MBDSI. The MBDSI training course was discontinued in 2002, but both NONLIN and EQ-Tools have been continuously updated.
NONLIN provides tools for linear or nonlinear response history analysis of Single Degree of Freedom (SDOF) systems. A large variety of loading functions are available, including dozens of pre-recorded ground motions. In addition to the original bi-linear model, the latest version of the program provides a sophisticated degrading stiffness and strength model.
For the degrading model, the parameters can be set and then exercised interactively before using in the analysis.
NONLIN also offers Incremental Dynamic Analysis (IDA). IDA analysis is useful in research, and is utilized heavily in the FEMA P-695 Methodology.
This screen shows the basic IDA analysis window, together with results from an IDA analysis of a single structure subjected to six different ground motions.
In addition to running multiple ground motion IDA, one can select a single ground motion and test the influence on a variation of structural parameters (e.g. damping).
In IDA analysis it is necessary to scale the ground motions, and this is done automatically by the program (using single point spectrum matching).
Various response parameters (damage measures) can be used to assess the performance of the structure.
One of the key features of the new version of NONLIN is a simple MDOF model.
As with the SDOF model, degrading strength and stiffness properties may be set.
Nonstructural properties (to represent gravity framing or other components) may be included in the analysis.
The program also has the capability to model added damping, including nonlinear viscous damping.
This screen shows the behavior of a selected nonlinear viscous damper.
The structure may be subjected to a single earthquake or to a series of earthquakes (representing a main shock followed by aftershocks).
A structure can also be evaluated for a suite of ground motions, as in ASCE 7 Chapter 16.
NONLIN also provides an interesting new tool to study the dynamic behavior of a structure with nonclassical (nonproportional) damping. The animated mode shapes are particularly interesting, as the change in phase along the height can be easily seen. Note: This tool for illustrating nonproportional damping is separate from the MDOF tool shown in slide 14, which is limited to a maximum 3 stories.
The following slides describe some of the features of the new version of EQ-Tools.
One of the main features of EQ-Tools is to evaluate ground motion acceleration records. A large number of records is provided with the program, and suites of records can be developed using a variety of search parameters.
This slide illustrates the results of the ground motion record plotting tool, comparing the ground acceleration, velocity, and displacement histories of six recorded ground motions.
The program provides the capability to plot Fourier Amplitude spectra of the ground motions. The small plots on the bottom allow a “traveling” FFT in which the change in frequency content can be determined as a time window is passed through the record.
The program has a large variety or response spectrum plotting tools, including the tripartite spectrum shown here. Ground motion spectra, average spectra, and code spectra can be plotted simultaneously.
The two horizontal components can be plotted together vs time, or as an X-Y plot. Polar spectra (two rotated components plus geomean at a selected period) are also provided.
This is a close up view of the X-Y plot and the polar spectra plot.
EQ-Tools provides a large number of ground motion scaling tools. Dozens of scaling options are available, including a method that satisfies the requirements given in ASCE 7-05 and ASCE 7-10.
A key feature on EQ-Tools is the ability to plot a variety of ground motion attenuation relationships. More than a dozen such relationships are available.
This screen shows the results of a computation that produces a variety of ground motion spectra based on the Abrahamson-Silva relationship. Different spectra are provided for different Magnitude measures (ranging from 5 to 9).
EQ-Tools also provides the capability to perform site analysis, wherein the effect of a soil profile can be investigated. The base of the soil layer is shaken with a given ground motion record, and new acceleration histories and spectra are provided at each soil layer. Both linear and nonlinear soil can be modeled.
This slide shows the results of a site analysis.
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Access to NONLIN and EQ-Tools is provided by NEES-Hub. (This slide needs to be completed)
NEEShub Screen showing the dropdown Tools menu.
NEEShub Screen showing NONLIN “Launc Tool” option.
NONLIN running within the NEEShub online environment.
A slide to prompt questions from the participants.