# Engineering Overview of ACS SASSI NQA V4.3 Application to Seismic SSI Analysis of Safety-Related NPP Buildings

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## Part 5: Description of Advanced Options PRO and UPLIFT

**GP Technologies, Inc., Rochester, New York**



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# Day 3B Presentation Content:

1. Option PRO: Probabilistic Site Response and SSI Analysis (per ASCE 4-16)

2. Option UPLIFT: Nonlinear Foundation Uplift SSI Analysis (per JEAC 4601-2015)


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# 1. Option PRO: Probabilistic Site Response and SSI Analysis (per ASCE 4-16)



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# ASCE 4-16 Sect. 2 and 5.5 on PSRA and PSSIA

-The recent ASCE 4-16 standard provides an unique set of engineering guidance for modeling SSI uncertainties using physics-based probabilistic SSI models.

- *Probabilistic SSI analysis is a superior engineering approach, if correctly implemented by the analyst*. PSSIA represents the future. *The ASCE 4-16 based probabilistic SSI analysis provides a  solid physics-based modeling basis for improving the design-basis SSI analysis and the fragility calculations in next future*.

- Need of additional research projects and publications so that designers see differences between probabilistic and deterministic SSI results. Dual applications with both DSSIA and PSSIA useful.

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# ASCE 4-16 Probabilistic SSI Analysis (PSSIA)

*Based on the new ASCE 04-2016 recommendations*:

- *Probabilistic SSI analyses should be performed using at least 30 LHS randomized simulations.*

- For the ***design-level applications***, *probabilistic SSI responses should defined for the 80% non-exceedance probability (NEP)*.

- Probabilistic modeling should minimally include:
  - SEISMIC INPUT: GMRS/UHRS amplitude assumed to randomly varying (Methods 1 and 2).
  - SOIL PROFILE: Vs and D soil profiles
  - STRUCTURE: Effective stiffness and damping, as functions of stress/strain level in different parts of structure.



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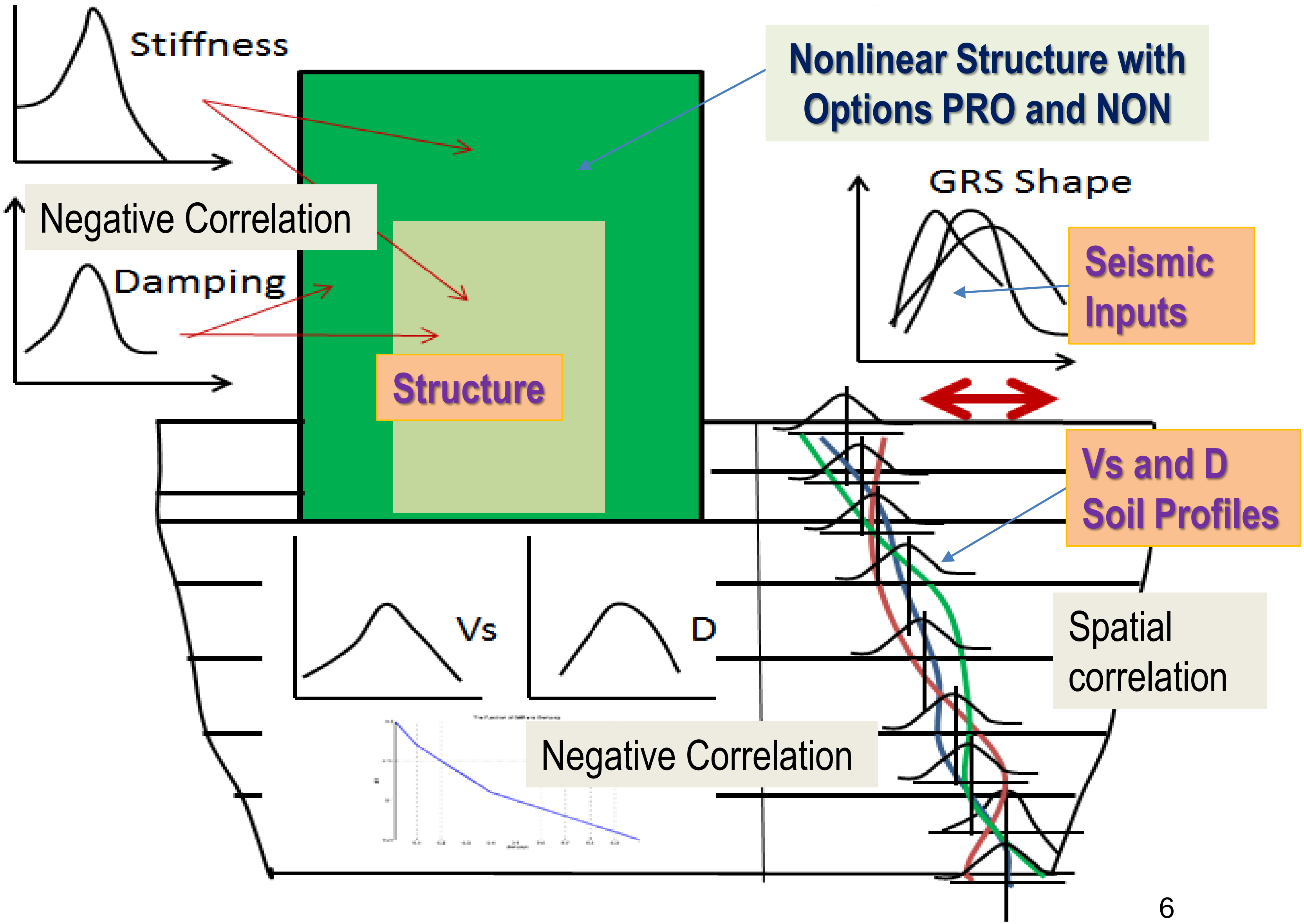
# ASCE 4-16 /ACS SASSI Option PRO Probabilistic SSI Simulation Approach



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# PSRA and PSSIA Computational Steps

1) **PREPARE SSI INPUTS:** Using *ACS SASSI PRO modules*, generate the input simulations *(ProEQUAKE, ProSITE, ProSOIL and ProHOUSE, ProNON, ProMOTION, ProSTRESS)*

2) **PERFORM SSI ANALYSIS:** Using the *ACS SASSI modules,* run in batch the ensembles of the simulated input files to compute the SSI responses (SITE, SITE, SOIL, HOUSE, ANALYS, MOTION, RELDISP, NONLINEAR, STRESS).

3) **POST-PROCESS SSI RESPONSES:** Using the *ACS SASSI PRO* modules, post-process statistically the ensembles of the simulated SSI responses *(ProSRSS, ProRESPONSE)*

*REMARK: The SSI input mean values which are deterministic quantities defined in the baseline files that are generated with the ACS SASSI UI commands, similar to deterministic SSI input values.*

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# Option PRO Modules for PSRA and PSSIA

| | | |
|---|---|---|
| Check_Site_Output.exe | Application | 10,378 KB |
| ProEquake.exe | Application | 1,970 KB |
| PROHOUSE.exe | Application | 9,270 KB |
| ProMotion.exe | Application | 695 KB |
| ProNon.exe | Application | 80 KB |
| ProResponse.exe | Application | 178 KB |
| ProSite.exe | Application | 9,651 KB |
| ProSoil.exe | Application | 9,079 KB |
| ProSRSS.exe | Application | 722 KB |
| ProStress.exe | Application | 37 KB |
| SITEPRO.exe | Application | 640 KB |
| Write_Site_Input.exe | Application | 25 KB |



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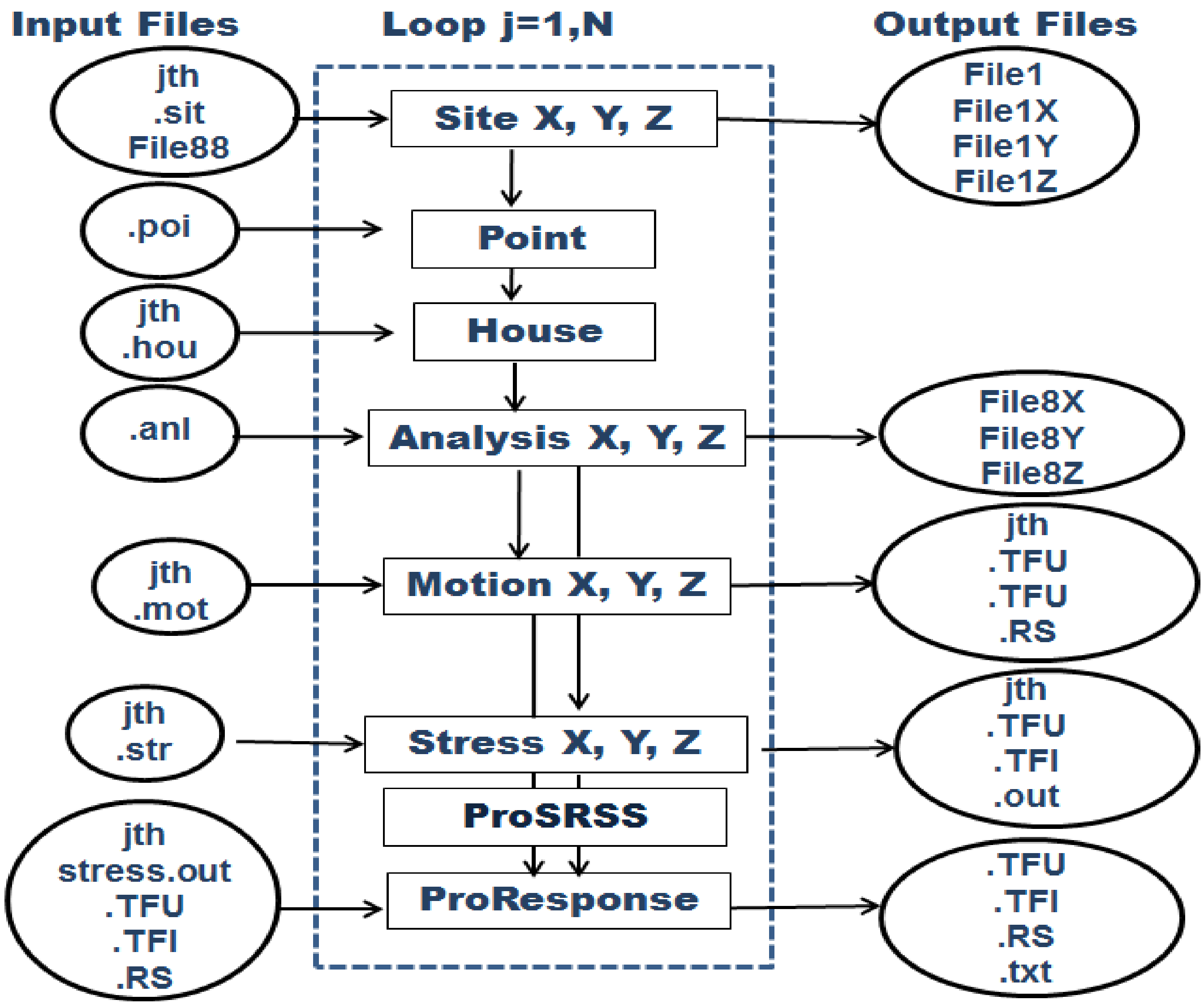
# Probabilistic SSI Analysis Simulations
## Using N LHS Samples



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# Probabilistic Simulation Using PRO Modules

**DET/ INPUT MEAN VALUES**
**Baseline Input Files (UI)**
**(BASELINE.ModuleExt)**

Generated with ACS SASSI UI Commands, similar to a deterministic SRA/SSI models.

*Using ACS SASSI main software.*

**PRO/ INPUT STATISTICS**
**GProModule Input Files (Text)**
**(GModuleExt.In)**

Generated with PRO Modules for user input text files.

*Using ACS SASSI option PRO software.*

**PRO MODULE INPUT SIMULATIONS**
**Simulated Input Files for ACS SASSI runs**
**(GModuleNameXXX.ModuleExt)**



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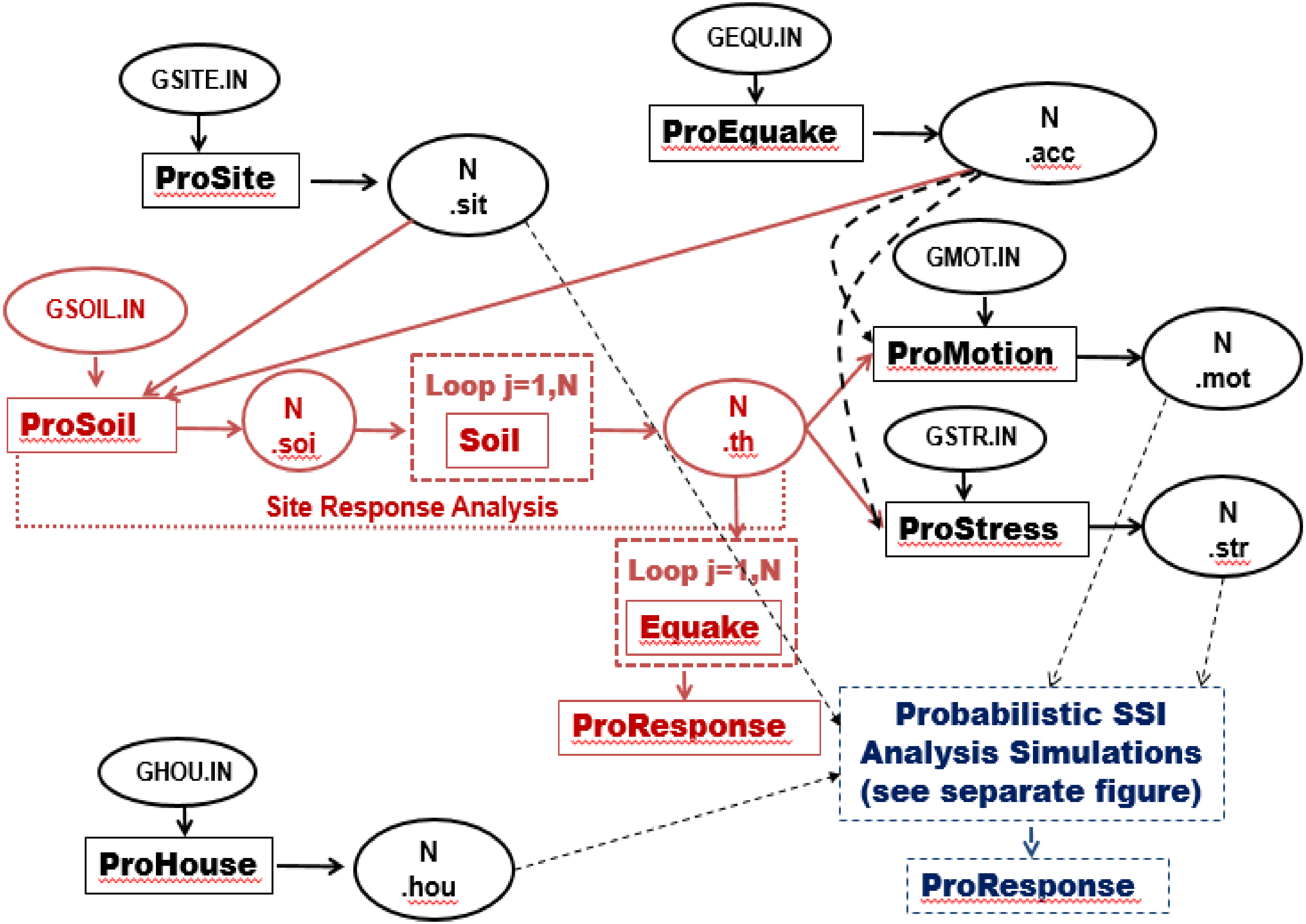
# Probabilistic SSI Input Simulations

## Using N LHS Samples

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# ProEQUAKE Module

The ProEQUAKE module simulates the LHS random samples for the probabilistic input GRS (the .rsi extension files) and, then, generates the spectrum-compatible input acceleration histories (the .acc extension files) to be used as inputs for probabilistic simulations. The response spectrum shape can be modeled as either a lognormal random variable or a lognormal random field. Both methods, Method 1 and Method 2 of the ASCE 4-2016 standard Section 5.5 are implemented in Option PRO.

ProEQUAKE uses a similar algorithm with EQUAKE for the simulation of the random spectrum-compatible input acceleration histories. The simulated acceleration histories are automatically baseline corrected. For each simulated acceleration the user can also get the ground velocity and displacement histories (the .vel and .dis extension files), the power spectral density (PSD) function (the .psd extension files) and the Fourier amplitude (the .fft extension files). For details see user manuals for EQUAKE.



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# ProSITE Module

The ProSITE module (Model 1 and Model 2) simulates the LHS random samples for the SITE module input (the .sit extension files). The ProSITE module generates the simulated low-strain soil Vs and D profiles. The Vs and D could be defined as statistical dependent random quantities. The Vs spatial correlation with depth can be included.

The soil profiles can be defined using two Gaussian continuous stochastic process models: i) Model 1, normal or lognormal random curves/fields, or ii) Model 2, mixture of long wavelength random curves/fields and short wavelength lognormal random curves/fields. Lognormal soil profiles can be obtained per user's option by an inverse probability transformation (for translation non-Gaussian processes). This is implemented to be made automatically at no effort for the users.

The Vs soil profiles can be also simulated using a non-homogeneous Poisson discrete stochastic process model (Toro, 1995).
For iterated soil profiles the .sit files generated by ProSITE and the FILE88 produced by SOIL runs are used as inputs for the SITE runs.


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# ProSOIL Module

The ProSOIL module is required for nonlinear probabilistic site response analysis. The ProSOIL module simulates the LHS random samples for the SOIL module input (the .soi files). The simulated soil shear modulus G and damping D curves are considered functions of the soil shear strain in each soil layer.

The Vs and D profiles are defined as statistical dependent random quantities. For nonlinear site response analysis the .soi files generated by ProSOIL will be used as inputs for the SOIL runs.

After each SOIL run, for PSSIA, the SITE module should be run with the "Nonlinear" option, so that the iterated soil properties from SOIL run written in FILE88 will be used by SITE and eventually by HOUSE for the embedded SSI models.



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# PSRA Batch Run Steps (See Examples)

## Prepare PSRA Inputs Steps:

Run ProEQUAKE Module to get input acceleration time histories ACCxxx.acc
Run ProSITE to get GSITExxx.sit
Run ProSOIL Module to get the nonlinear soil curve samples GSOILxxx.soi

## Sample SRA Analysis Steps:

Run SOIL Module (3 Runs for X, Y and Z)



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# PSRA Batch Example – ProEQUAKE and ProSITE

```
rem This batch is to do probabilistic site response analysis for a soil site.
rem  No soil nonlinear behavior is included. The UHRS input is defined at bedrock.
SET exe_path="C:/ACSV300/PRO/"
rem Part 1: Generate the probabilistic simulated inputs
rem ProEQUAKE:  Get the time histories for ProMOTION and ProSOIL

cd .\ProEquake\xdir
    %exe_path%Proequake.exe < GEQU-SOIL.IN
cd ..\ydir
    %exe_path%Proequake.exe < GEQU-SOIL.IN
cd ..\zdir
    %exe_path%Proequake.exe < GEQU-SOIL.IN
cd ..
cd ..

rem ProSITE:
cd .\ProSite
    %exe_path%Prosite.exe < gsite.in
cd  ..

rem ProSOIL: Soil
for %%j in (X Y Z) do (
    mkdir .\ProSoil\%%jdir\MEAN
    mkdir .\ProSoil\%%jdir\SampleD
    mkdir .\ProSoil\%%jdir\GumbelD
    mkdir .\ProSoil\%%jdir\LognormalD

    copy .\ProEquake\%%jdir\ACC*.ACC  .\ProSoil\%%jdir\ACC*.ACC
    copy .\ProSite\GSITE*.SIT  .\ProSoil\%%jdir\GSITE*.SIT
    copy .\inputs\SOIL.INP  .\ProSoil\%%jdir\SOIL.INP
    copy .\inputs\EQUAKE.INP  .\ProSoil\%%jdir\EQUAKE.INP
    copy .\inputs\Spectru.RS  .\ProSoil\%%jdir\Spectru.RS
    copy .\inputs\EQUAKE.EQU  .\ProSoil\%%jdir\PSRA.EQU
    copy .\inputs\samples_cases.txt  .\ProSoil\%%jdir\Samples_cases.txt
    copy .\ProResponse\RS*.IN .\ProSoil\%%jdir\*.IN
```

**ProEQUAKE and ProSITE are used to simulate probabilistic free-field accelerations and soil profiles - samples**



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# PSRA Batch Example – Use SOIL and EQUAKE

```
    cd .\ProSoil\%%jdir
        copy ..\BASELINE.soi  BASELINE.soi
        %exe_path%Prosoil.exe < gsoil.in
        FOR /F %%i IN (.\Samples_cases.txt) DO (
            copy GSOIL%%i.soi PSRA.soi
            rem  Run SOIL to compute free-field accelerations
            C:\ACSV300\EXEB\SOILB.exe < soil.inp
            copy PSRA.osoi gsoil%%i.osoi
            copy FILE88 FILE88-%%i
            copy ACC*.TH  ACC0*.TH%%i

            rem layer 1 acceleration. compute ARS using EQUAKE
            copy ACC001.TH  input-acc.acc
            C:\ACSV300\EXEB\EQUAKEB.exe < equake.inp
            copy input-acc.rso rso-l1.r%%i
            rem layer 7 acceleration. compute ARS using EQUAKE
            copy ACC007.TH  input-acc.acc
            C:\ACSV300\EXEB\EQUAKEB.exe < equake.inp
            copy input-acc.rso rso-l7.r%%i
            rem layer 14 acceleration. compute ARS using EQUAKE
            copy ACC014.TH  input-acc.acc
            C:\ACSV300\EXEB\EQUAKEB.exe < equake.inp
            copy input-acc.rso rso-l14.r%%i
        )
```

**SOIL and EQUAKE are used to compute simulated site response accelerations and ARS**



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# PSRA Batch Example – Use ProRESPONSE

```
        rem Compute probabilistic ARS using ProRESPONSE
        %exe_path%ProRESPONSE.exe < RS-MEAN.in
        copy *MEAN.RS  .\MEAN\*MEAN.RS
        copy *.out .\MEAN\*.out
        del *MEAN.RS *.out
        %exe_path%ProRESPONSE.exe < RS-SampleD.in
        copy *P*.RS  .\SampleD\*P*.RS
        copy *.out .\SampleD\*.out
        del *P*.RS *.out
        %exe_path%ProRESPONSE.exe < RS-GumbelD.in
        copy *P*.RS  .\GumbelD\*P*.RS
        copy *.out .\GumbelD\*.out
        del *P*.RS *.out
        %exe_path%ProRESPONSE.exe < RS-LognormalD.in
        copy *P*.RS  .\LognormalD\*P*.RS
        copy *.out .\LognormalD\*.out
        del *P*.RS *.out
    cd ..
    cd ..
)
```

**ProRESPONSE is used to compute probabilistic site response ARSC**



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# ProHOUSE Module

The ProHOUSE module (Option 1 for Structure and Option 2 for 2D Soil Models) simulates the LHS random samples for the HOUSE module input file (the .hou files).

The ProHOUSE Option 1 assumes that the structural effective stiffness (normalized to elastic stiffness) and damping are two statistically dependent random variables for each material selected by the user. The effective stiffness and damping values are different for different parts of the structure that have different shear deformation levels.

The ProHOUSE Option 2 simulates the iterated Vs and D for 2D layered soil models using 2D/2V stochastic field models.



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# PSSIA Batch Run Steps (See Examples)

## PSRA and PSSIA Inputs Steps:

Run ProEQUAKE Module to get input acceleration time histories ACCxxx.acc
Run ProSITE to get GSITExxx.sit
Run SITE Module to get the free-field simulation
Run Check_SITE_output Module to check if all the SITE module convergence.

NOTE: If some of the SITE samples are not convergent, then, the file "samples_cases.txt" will provide the list of the nonconverged samples. Otherwise, this file does not exist. Module Write_SITE_Input will write the final convergent SITE simulated input files.

Run ProSOIL Module to get the nonlinear soil curve samples GSOILxxx.soi
Run SOIL Module to get the in-column input acceleration histories ACCxxx.th
Run ProMOTION Module to get MOTION inputs GMOTIONxxx.mot
Run ProSTRESS Module to get MOTION inputs GSTRESSxxx.str
Run ProHOUSE Module to get House inputs HOUSExxx.hou

## Sample SSI Analysis Steps:

Run SITE Module (3 Runs for X, Y and Z)
Run POINT Module (1 Run)
Run HOUSE Module (1 Run)
Run ANALYS Module (1 Run for X, Y and Z
Run MOTION Module (3 Runs for X, Y and Z)
Run STRESS Module (3 Runs for X, Y and Z)
Run ProSRSS Module (1 Run for X, Y and Z)

## PSSIA Response Post-Processing Steps:

Run ProRESPONSE Module to compute mean TFU and TFI, and/or probabilistic level RS and STRESS responses:

- User options for computing mean or probability level responses.
- User options for computing probabilistic responses using: Sample distribution, Lognormal distribution or Gumbel distribution.



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# PSSIA Batch Run – Use ProEQUAKE

```
rem This batch is to do probabilistic SSI analysis of RB stick for a soil site
SET exe_path="C:/ACSV300/PRO/"
rem Part 1: Generate the probabilistic simulated inputs
rem ProEquake:  get the time histories for promotion and prosoil

cd .\ProEquake\xdir
    %exe_path%Proequake.exe < GEQU-SOIL.IN
cd ..\ydir
    %exe_path%Proequake.exe < GEQU-SOIL.IN
cd ..\zdir
    %exe_path%Proequake.exe < GEQU-SOIL.IN
cd ..
cd ..

rem ProMotion:  generate *.mot files
for %%k in (coh) do (
    for %%j in (X Y Z) do (
        mkdir .\ProMotion\%%k\%%jDIR
        copy .\ProEquake\%%jdir\ACC*.ACC  .\ProMotion\%%k\%%jDIR\ACC*.ACC
        copy .\ProMotion\GMOT.IN  .\ProMotion\%%k\%%jDIR\GMOT.IN
        copy .\ProMotion\%%k\BASELINE.mot  .\ProMotion\%%k\%%jDIR\BASELINE.mot

        cd .\ProMotion\%%k\%%jDIR
            %exe_path%ProMotion.exe < GMOT.IN
        cd ..
        cd ..
        cd ..
    )
)
rem ProStress:  generate *.str files
for %%k in (coh) do (
    for %%j in (X Y Z) do (
        mkdir .\ProStress\%%k\%%jDIR
        copy .\ProEquake\%%jdir\ACC*.ACC  .\ProStress\%%k\%%jDIR\ACC*.ACC
        copy .\ProStress\GSTRESS.IN .\ProStress\%%k\%%jDIR\GSTRESS.IN
        copy .\ProStress\%%k\BASELINE.str .\ProStress\%%k\%%jDIR\BASELINE.str
        cd .\ProStress\%%k\%%jDIR
            %exe_path%ProStress.exe < gstress.in
        cd ..
        cd ..
        cd ..
    )
```

**ProEQUAKE is used to generate probabilistic spectra and acceleration inputs**

**ProMOTION and ProSTRESS used to generate probabilistic seismic inputs for MOTION and STRESS**



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# PSSIA Batch Run – ProHOUSE and ProSITE

```
rem ProHouse: generate *.hou files
cd .\ProHouse\coh
    %exe_path%prohouse.exe < ghou.in
cd ..
cd ..


rem ProSite: generate *.sit files
copy .\inputs\SITE.INP  .\ProSite\SITE.INP
cd .\ProSite
    copy gsite.in wgsite.in
    %exe_path%prosite.exe < gsite.in
cd  ..
call check_linear_site.bat
cd .\ProSite
    %exe_path%Write_Site_Input.exe < wgsite.in
cd  ..

rem part 2:  Run Site, Point, House, analysis: Soil
mkdir Work
mkdir outputs\coh\XDIR
mkdir outputs\coh\YDIR
mkdir outputs\coh\ZDIR

copy .\inputs\SITE.INP  .\Work\SITE.INP
copy .\inputs\POINT.INP  .\Work\POINT.INP
copy .\inputs\HOUSE.INP  .\Work\HOUSE.INP
copy .\inputs\ANALYSIS.INP  .\Work\ANALYSIS.INP
copy .\inputs\MOTION.INP  .\Work\MOTION.INP
copy .\inputs\STRESS.INP  .\Work\STRESS.INP
copy .\ProHouse\coh\samples_cases.txt .\Work\samples_cases.txt

cd .\Work
FOR /F %%i IN (.\samples_cases.txt) DO (

    rem site: XDIR
    copy ..\ProSite\GSITE%%i-X.sit pssia.sit
    %exe_path%SITEPro.exe < site.inp
    copy FILE1 FILE1X
    copy pssia.osit ..\outputs\site%%iX.out
```

**ProHOUSE is used to simulate structure stiffness and damping**

**ProSITE used to simulate Vs and D soil profiles. Convergence is checked by Check_Linear_Site.bat**

```
SET exe_path="C:/ACSV300/PRO/"
cd .\PROSite

  FOR /F %%i IN (.\samples_cases.txt) DO (
    rem site
    copy GSITE%%i.sit pssia.sit
    %exe_path%SITEPro.exe < site.inp
    copy pssia.osit gsite%%i.osit
  )

  :start
  %exe_path%check_site_output.exe < gsite.in
  if exist samples_cases.txt (
    goto CONTINUE
  ) else (
    goto END
  )

  :CONTINUE
  FOR /F %%i IN (.\samples_cases.txt) DO (
    rem site
    copy gsite%%i.sit pssia.sit
    %exe_path%SITEPro.exe < site.inp
    copy pssia.osit gsite%%i.osit
    )
    del samples_cases.txt
    goto start
  :END

cd ..
```

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# PSSIA Batch Run – SSI Simulation Runs

```
rem site: YDIR
copy ..\ProSite\GSITE%%i-Y.sit pssia.sit
%exe_path%SITEPro.exe < site.inp
copy FILE1 FILE1Y
copy pssia.osit ..\outputs\site%%iY.out

rem site: ZDIR
copy ..\ProSite\GSITE%%i-Z.sit pssia.sit
%exe_path%SITEPro.exe < site.inp
copy FILE1 FILE1Z
copy pssia.osit ..\outputs\site%%iZ.out

rem point
copy ..\inputs\rb.poi pssia.poi
C:\ACSV300\EXEB\point3b.exe < point.inp
copy pssia.opoi ..\outputs\point%%i.out

    rem house
    copy ..\ProHouse\coh\house%%i.hou pssia.hou
    C:\ACSV300\EXEB\houseFSb.exe < house.inp
    copy pssia.ohou ..\outputs\coh\house%%i.out

    rem analysis
    copy ..\inputs\rb-%%k.anl pssia.anl
    C:\ACSV300\EXEB\analysFSb.exe < analysis.inp
    copy pssia.oanl ..\outputs\%%k\analysis%%i.out
    copy FILE8X ..\outputs\%%k\XDIR\FILE8_%%i
    copy FILE8Y ..\outputs\%%k\YDIR\FILE8_%%i
    copy FILE8Z ..\outputs\%%k\ZDIR\FILE8_%%i

    rem run motion and stress
    for %%j in (X Y Z) do (
        copy ..\ProMotion\%%k\%%jdir\gmotion%%i.mot pssia.mot
        copy FILE8%%j FILE8
        C:\ACSV300\exeb\motionb.exe < motion.inp
        copy *.tfi  ..\outputs\%%k\%%jDIR\*.i%%i
        copy *.tfu  ..\outputs\%%k\%%jDIR\*.u%%i
        copy *.RS  ..\outputs\%%k\%%jDIR\*.r%%i
        copy pssia.omot ..\outputs\%%k\%%jDIR\motion%%i.out
```

**ACS SASSI modules used for SSI batch runs for all simulations; SITE, POINT, HOUSE, ANALYS, MOTION**



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# PSSIA Batch Run – SSI Simulation Runs

```
                copy ..\ProStress\%%k\%%jdir\gstress%%i.str pssia.str
                C:\ACSV300\exeb\stressb.exe < stress.inp
                copy pssia.ostr ..\outputs\%%k\%%jDIR\stress.o%%i

                del *.tf* *.RS FILE8
            )
        del FILE8X FILE8Y FILE8Z FILE77 FILE78 FILE79
        )
    del FILE1* COO* *.o* *.ACC *.s* *.hou
    )
)
cd ..

call compute_srss_response.bat


pause
```

**ACS SASSI modules used for SSI batch runs for all simulations; STRESS**



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# PRO Post-Processing – ProSRSS & ProRESPONSE

```
SET exe_path="C:/ACSV300/PRO/"

rem run ProResponse
for %%k in (coh) do (
    mkdir .\outputs\%%k\SRSS\RS
    mkdir .\outputs\%%k\SRSS\STRESS

    mkdir .\outputs\%%k\SRSS\RS\MEAN
    mkdir .\outputs\%%k\SRSS\RS\SampleD
    mkdir .\outputs\%%k\SRSS\RS\GumbelD
    mkdir .\outputs\%%k\SRSS\RS\LognormalD

    mkdir .\outputs\%%k\SRSS\STRESS\MEAN
    mkdir .\outputs\%%k\SRSS\STRESS\SampleD
    mkdir .\outputs\%%k\SRSS\STRESS\GumbelD
    mkdir .\outputs\%%k\SRSS\STRESS\LognormalD

    REM  compute SRSS
    copy .\ProSRSS\*.IN .\outputs\%%k\*.IN
    copy .\ProSRSS\*.str .\outputs\%%k\*.str
    cd .\outputs\%%k
        %exe_path%ProSRSS.exe < SRSS-RS.in
        copy ProSRSS.out .\\SRSS\RS\ProSRSS.out
        %exe_path%ProSRSS.exe < SRSS-STRESS.in
        copy ProSRSS.out .\\SRSS\STRESS\ProSRSS.out
    cd ..
    cd ..

    rem transfer function
    for %%j in (X Y Z) do (
        copy .\ProResponse\%%jDIR\TF*.IN .\outputs\%%k\%%jDIR\*.IN
        cd .\outputs\%%k\%%jDIR
            %exe_path%ProResponse.exe < TFU-MEAN.in
            copy ProResponse.out ProResponse-TFU.out
            %exe_path%ProResponse.exe < TFI-MEAN.in
            copy ProResponse.out ProResponse-TFI.out
        cd ..
        cd ..
        cd ..

    )
```

**ProSRSS used for combining the maximum responses for ARS and stresses**

**ProRESPONSE used for computing mean ATF values (TFU, TFI)**



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# Post-Processing – ProRESPONSE for ARS

```
rem RS, STRESS
copy .\ProResponse\RS*.IN .\outputs\%%k\SRSS\RS\*.IN
copy .\ProResponse\STRESS*.IN .\outputs\%%k\SRSS\STRESS\*.IN
cd .\outputs\%%k\SRSS\RS

    %exe_path%ProResponse.exe < RS-MEAN.in
    copy *MEAN.RS  .\MEAN\*MEAN.RS
    copy ProResponse.out .\MEAN\ProResponse.out
    del *MEAN.RS ProResponse.out

    %exe_path%ProResponse.exe < RS-SampleD.in
    copy *P*.RS  .\SampleD\*P*.RS
    copy ProResponse.out .\SampleD\ProResponse.out
    del *P*.RS ProResponse.out

    %exe_path%ProResponse.exe < RS-GumbelD.in
    copy *P*.RS  .\GumbelD\*P*.RS
    copy ProResponse.out .\GumbelD\ProResponse.out
    del *P*.RS ProResponse.out

    %exe_path%ProResponse.exe < RS-LognormalD.in
    copy *P*.RS  .\LognormalD\*P*.RS
    copy ProResponse.out .\LognormalD\ProResponse.out
    del *P*.RS ProResponse.out

cd ..
```

**ProRESPONSE used for computing mean and probability-level ARS using Sample CFD, Gumbel and Lognormal distributions**



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# Post-Processing – ProRESPONSE for STRESS

```
    cd .\STRESS

        %exe_path%ProResponse.exe < STRESS-MEAN.in
        copy *MEAN.TXT  .\MEAN\*MEAN.TXT
        copy ProResponse.out .\MEAN\ProResponse.out
        del *MEAN.TXT ProResponse.out

        %exe_path%ProResponse.exe < STRESS-SampleD.in
        copy *P*.TXT  .\SampleD\*P*.TXT
        copy ProResponse.out .\SampleD\ProResponse.out
        del *P*.TXT ProResponse.out

        %exe_path%ProResponse.exe < STRESS-GumbelD.in
        copy *P*.TXT  .\GumbelD\*P*.TXT
        copy ProResponse.out .\GumbelD\ProResponse.out
        del *P*.TXT ProResponse.out

        %exe_path%ProResponse.exe < STRESS-LognormalD.in
        copy *P*.TXT  .\LognormalD\*P*.TXT
        copy ProResponse.out .\LognormalD\ProResponse.out
        del *P*.TXT ProResponse.out

    cd ..
    cd ..
    cd ..
    cd ..
)
```

**ProRESPONSE used for computing mean and probability-level element stress components using Sample CFD, Gumbel and Lognormal distributions**



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# Option PRO Modules.
# Input Guidance and Examples



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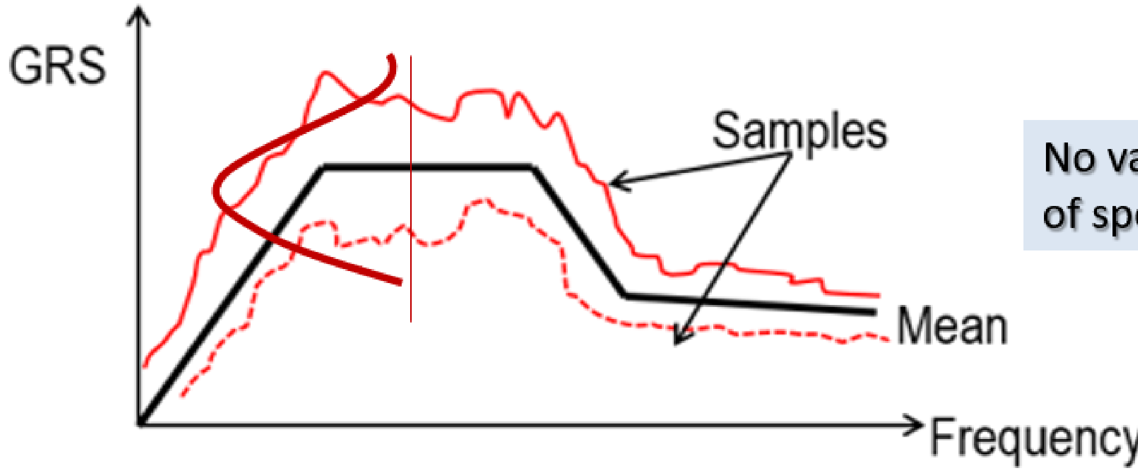
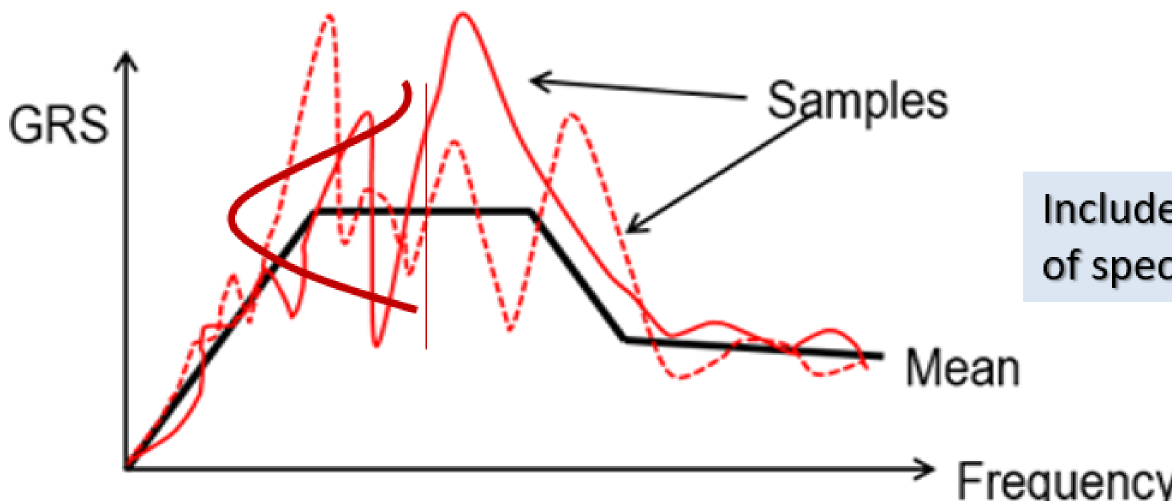
# Probabilistic Seismic Input Models

ASCE 04 Method 1




No variation of spectral shape

ASCE 04 Method 2




Include variation of spectral shape



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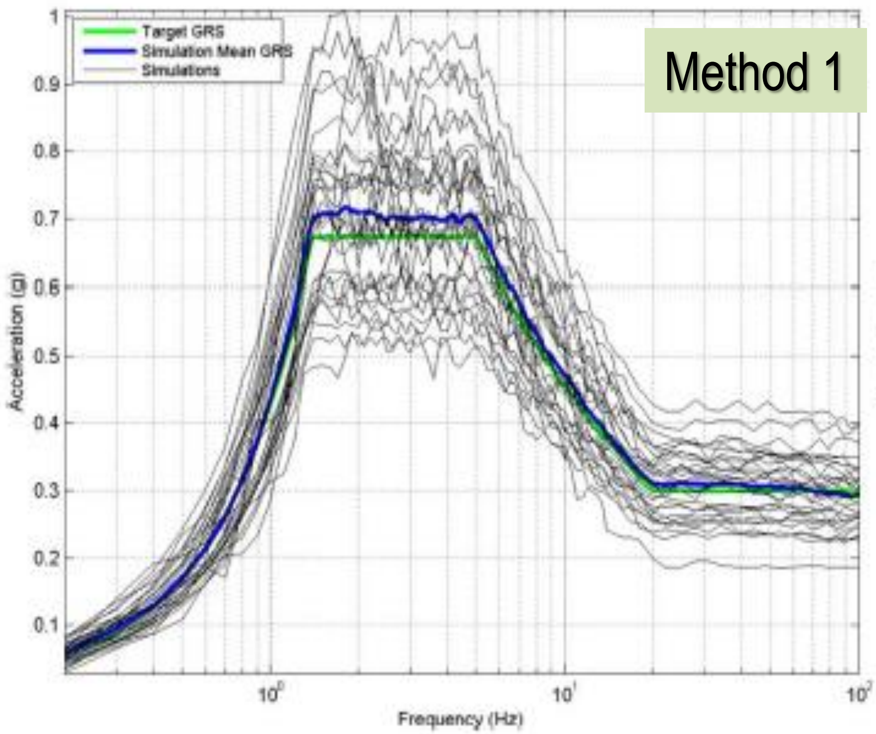
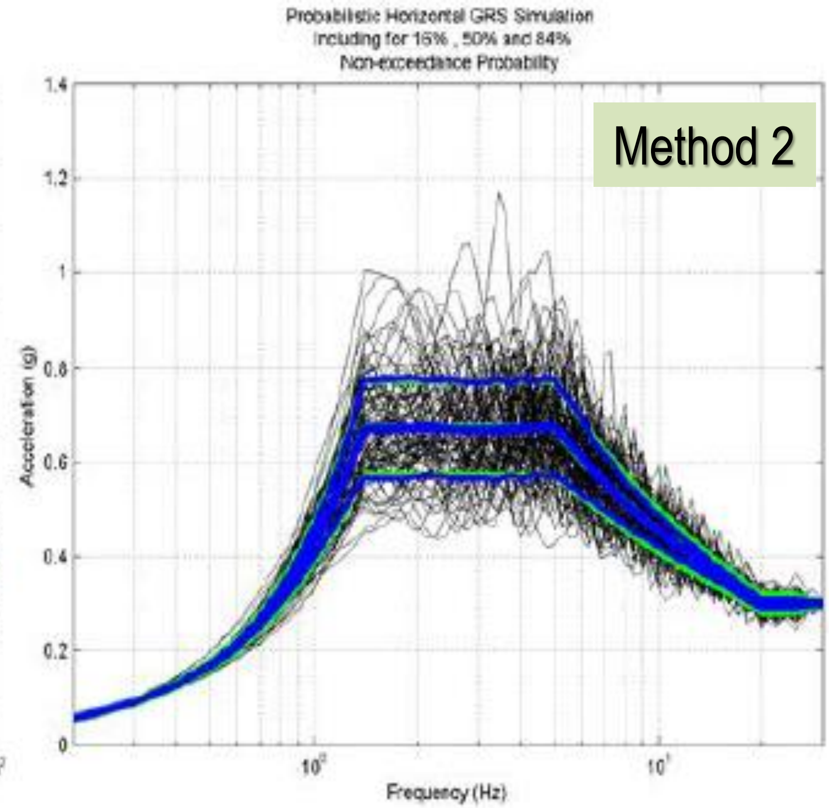
# ProEQUAKE for Probabilistic Seismic Input




Probabilistic GRS and Its Simulated GRS Samples using
ASCE 4 Methods 1 (left) and Method 2 (right)



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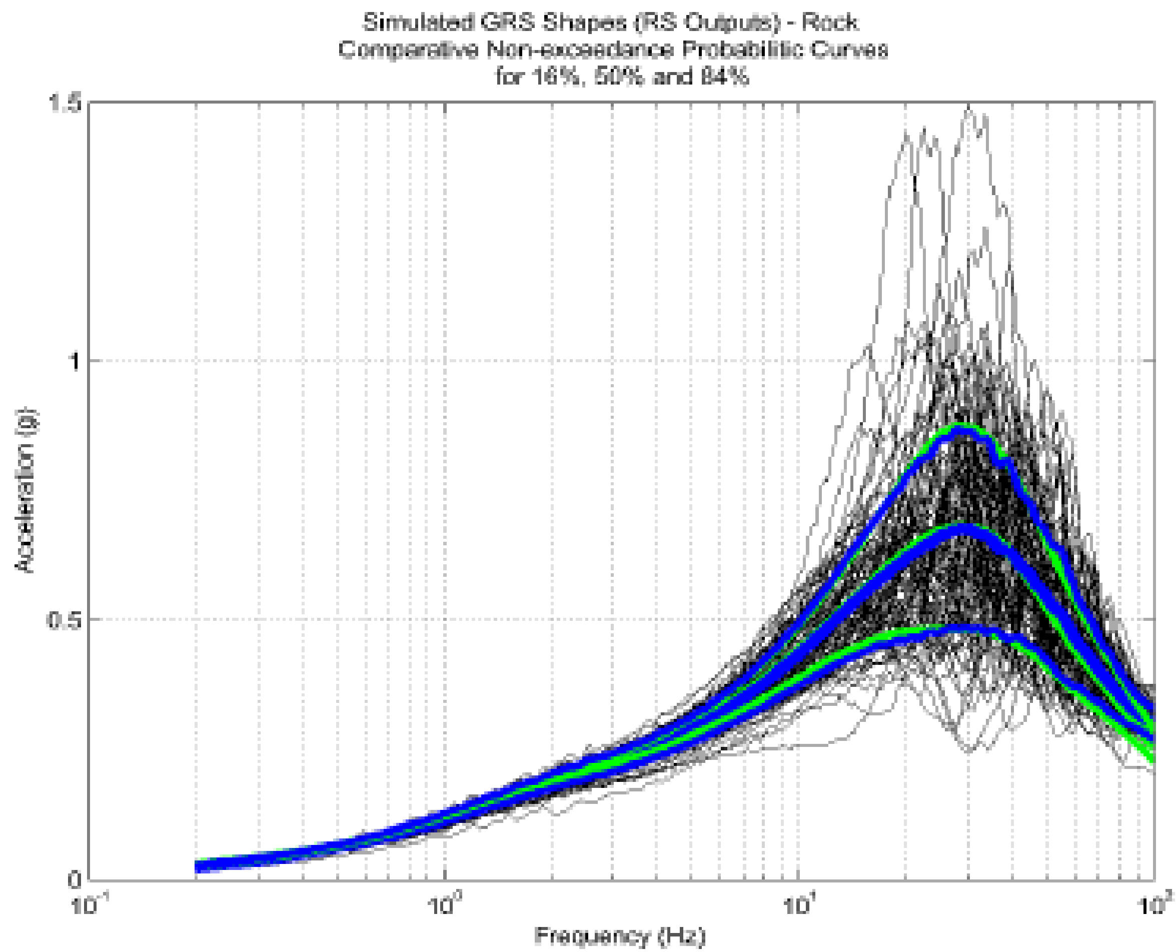
# Example for ProEQUAKE Input Parameters

## EXAMPLE 1: ROCK SITE - METHOD 2 WITH CONSTANT CORRELATION LENGTH

RSIXXX.RS
RSOXXX.RS
ACCXXX.acc

RSIXXX.RS
RSOXXX.RS
ACCXXX.acc
GEQUXXX.equ
GRSMEAN.RSI
0.05 32.2
15 0.005
100 12345 153414
0 1
26.0 135.0
0 0.3
10



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# GRS Amplitude Correlation for Different Frequencies

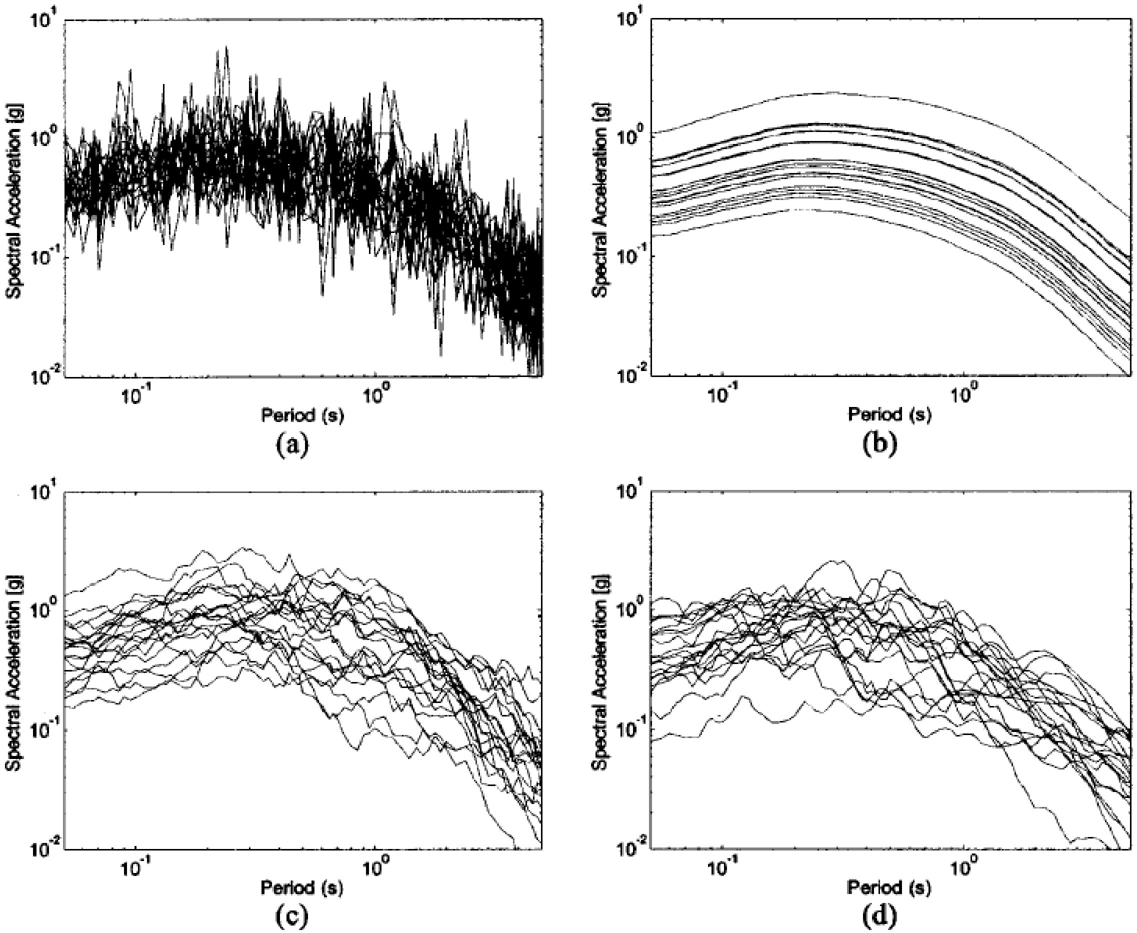


Figure 11. Samples of 20 response spectra from magnitude 6.5 earthquakes with a source-to-site distance of 8 km. The simulated spectra use means and variances from Abrahamson and Silva (1997). (a) Simulated spectra using correlation coefficients equal to zero between all periods. (b) Simulated spectra using correlation coefficients equal to one between all periods. (c) Simulated spectra using correlation coefficients from equation (9). (d) Real spectra from recorded ground motions with magnitude ≅6.5 and distance ≅ 8 km.

Cases with Differing Periods but the Same Orientation

When the two periods of interest differ, more complex functional forms are needed. The correlation between the $\varepsilon$ values of a single horizontal ground motion component at two differing periods is estimated by the function:

$$\rho_{\varepsilon_x,\varepsilon_x} = 1 - \cos\left(\frac{\pi}{2} - \left(0.359 + 0.163 I_{(T_{\min}<0.189)} \ln \frac{T_{\min}}{0.189}\right) \ln \frac{T_{\max}}{T_{\min}}\right), \quad (9)$$

where $I_{(T_{\min}<0.189)}$ is an indicator function equal to 1 if $T_{\min} < 0.189$ second and equal to 0 otherwise, implying that the form of the equation is simply $1 - \cos(a - b \ln(T_{\max}/T_{\min}))$ for periods larger than 0.189 sec. The variables $T_{\min}$ and $T_{\max}$ are used to denote the smaller and larger of the two periods of interest, respectively.

(Baker and Cornell, 2006)



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# ProEQUAKE Input Parameters

RSIXXX.RS
RSOXXX.RS
ACCXXX.acc
GEQUXXX.equ
GRSMEAN.RSI
0.05 32.2
15 0.005
100 12345 153414
0 1
26.0 135.0
0 0.3
10

Table 5.1 The ProEQUAKE Input File (GEQU.IN)

| Input File Line Number | Variable Name (Input in free format) | Definition of Input Variables | Variable Type |
|---|---|---|---|
| 1 | FRSI | Filenames for the simulated GRS inputs (ex. RSIxxx.RS) | Output |
| 2 | FRSO | Filenames for the computed GRS samples (ex. RS0xxx.RS | Output |
| 3 | FACC | Filenames for the computed acceleration histories (ex. ACCxxx.acc) | Output |
| 4 | FEQU | Filename for the simulated equ inputs (ex. GEQU001.equ) | Output/Input |
| 5 | FBASEL | Filename for the mean GRS amplitude (ex. BASELINE.RSI) | Input |
| 6 | DAMPING | Damping ratio for the GRS input (in percent) | Input |
| 6 | GRAVACC | Acceleration of gravity for ground velocity and displacement calculations | Input |
| 7 | DURATION | Duration of simulated acceleration histories (in seconds) | Input |
| 7 | TIMESTEP | Time step of simulated acceleration histories (in seconds) | Input |
| 8 | NSIMUL | Number of simulated seismic inputs for a single direction | Input |
| 8 | INITRSI | Initial SEED Random Number for RSIxxx.RS simulation | Input |
| 8 | INITACC | Initial SEED Random Number for ACCxxx.ACC simulation | Input |
| 9 | OPTMETH | Option for the Method used for GRS Simulation<br>= 0 for Method 2 in ASCE 04-2016 (Line 11 not needed)<br>= 1 for Method 1 in ASCE 04-2016 (Line 11 needed) | Input |
| 9 | DIR | Selected Input Direction:<br>= 0 for X<br>= 1 for Y<br>= 2 for Z | Input |
| 10 | F1 | 1st Frequency for calculation of the c.o.v. factor (in Hz) | Input |
| 10 | F2 | 2nd Frequency for calculation of the c.o.v. factor (in Hz) | Input |
| 11 | OPTCOR | Option for GRS shape correlation structure:<br>= 0 for frequency-independent correlation length (scalar)<br>= 1 for frequency-dependent correlation length (vector)<br>= 2 for full correlation matrix for GRS amplitudes (matrix) | Input |
| 11 | COV | Coefficient of variation of the GRS amplitudes | Input |
| 12 | SIGMA | For OPTCOR = 0 Correlation length value input | Input |
| 12 | SIGMAV | For OPTCOR = 1 Correlation length vector input | Input |
| 12 | CORRMAT | For OPTCOR =2 Correlation matrix file name input | Input |

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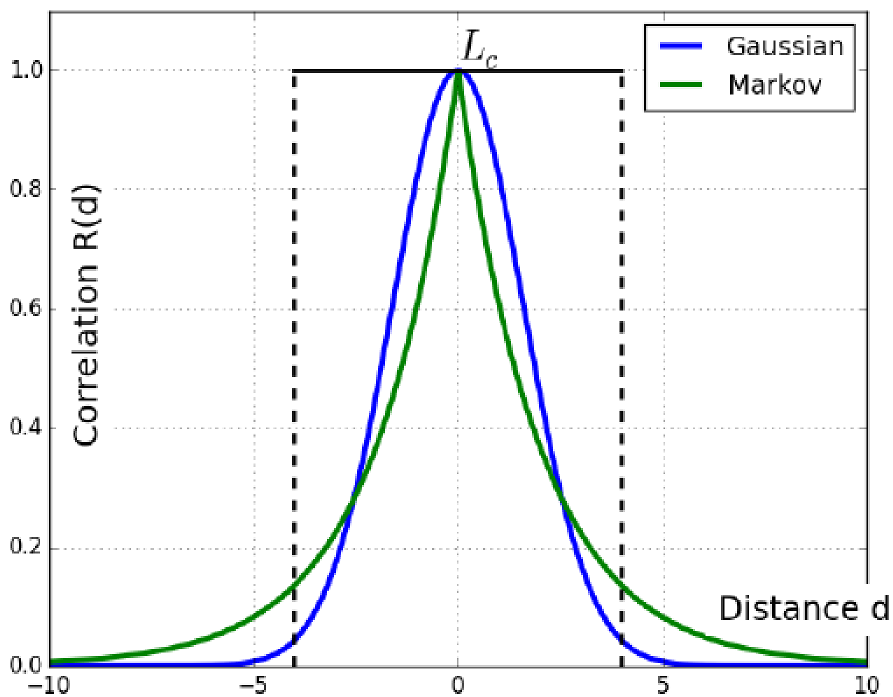
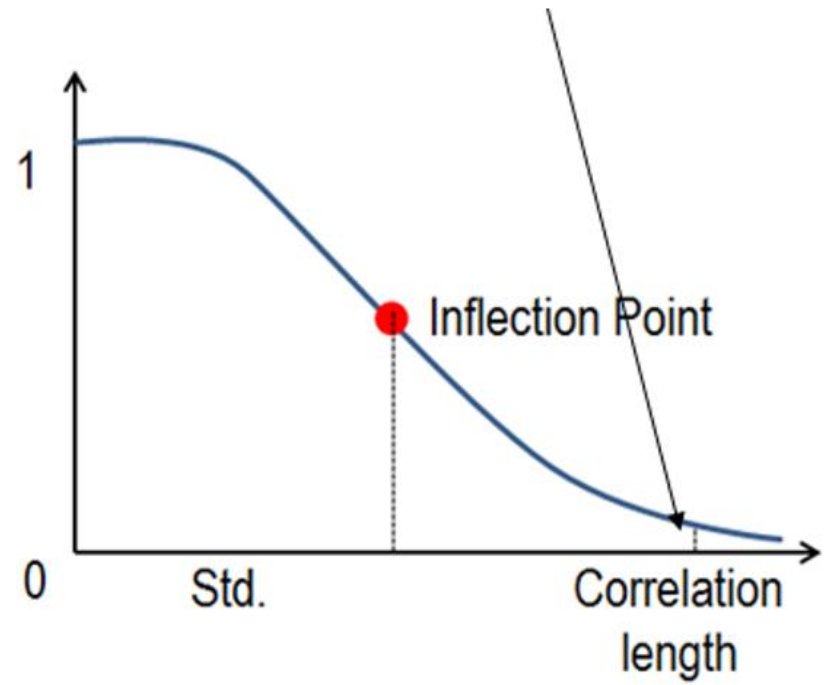
# Correlation Length -"Strong Correlation Distance"

$$L_C = \int_{-\infty}^{\infty} R_U(d)\,dd$$

$$R_U(d) = \exp\left[-\sqrt{\pi}\left(\frac{d}{L_C}\right)^2\right]$$

$$\boxed{R_U(d) = \exp\left[-2\left(\frac{d}{L_C}\right)\right]}$$



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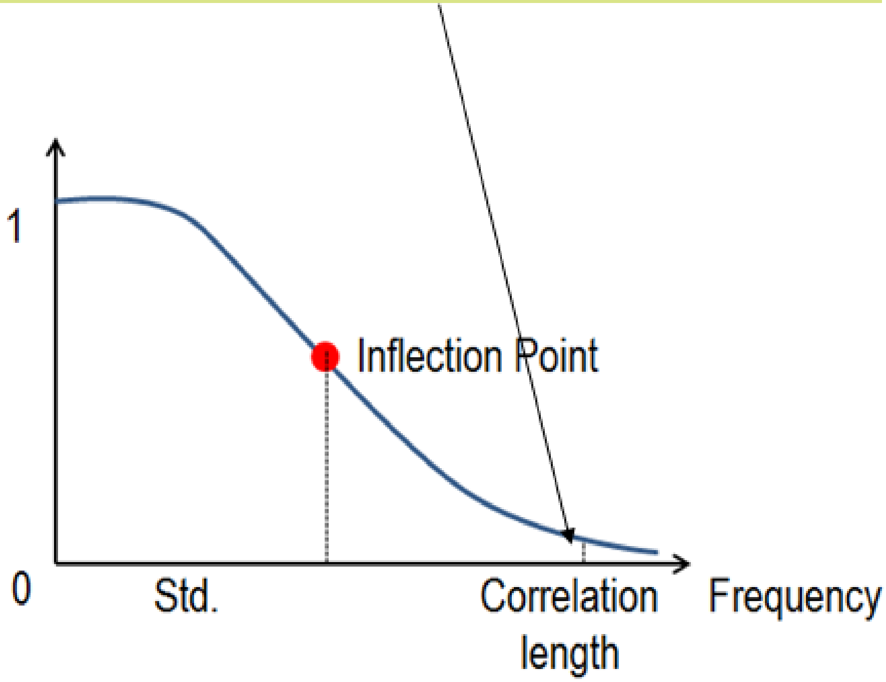
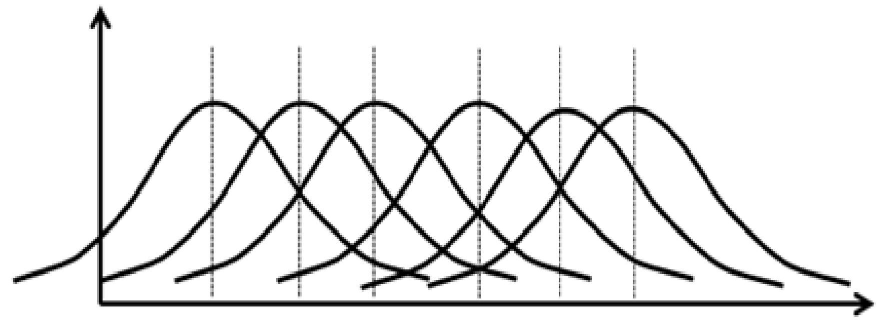
# Constant vs. Variable Correlation Lengths

**Correlation Length Definition**

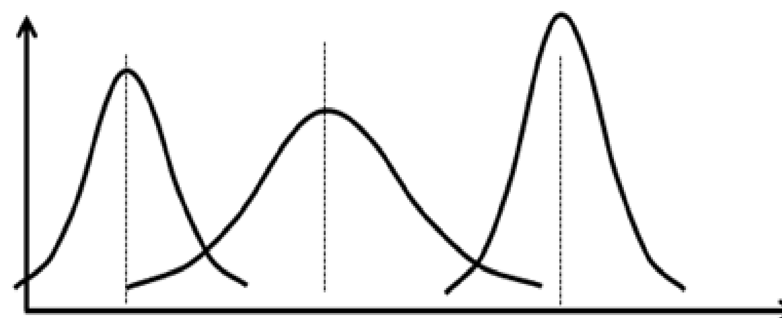



Variable correlation length or correlation matrix capture better the site response

**Constant vs. Variable Correlation Length**



Constant Correlation Length



Variable Correlation Length



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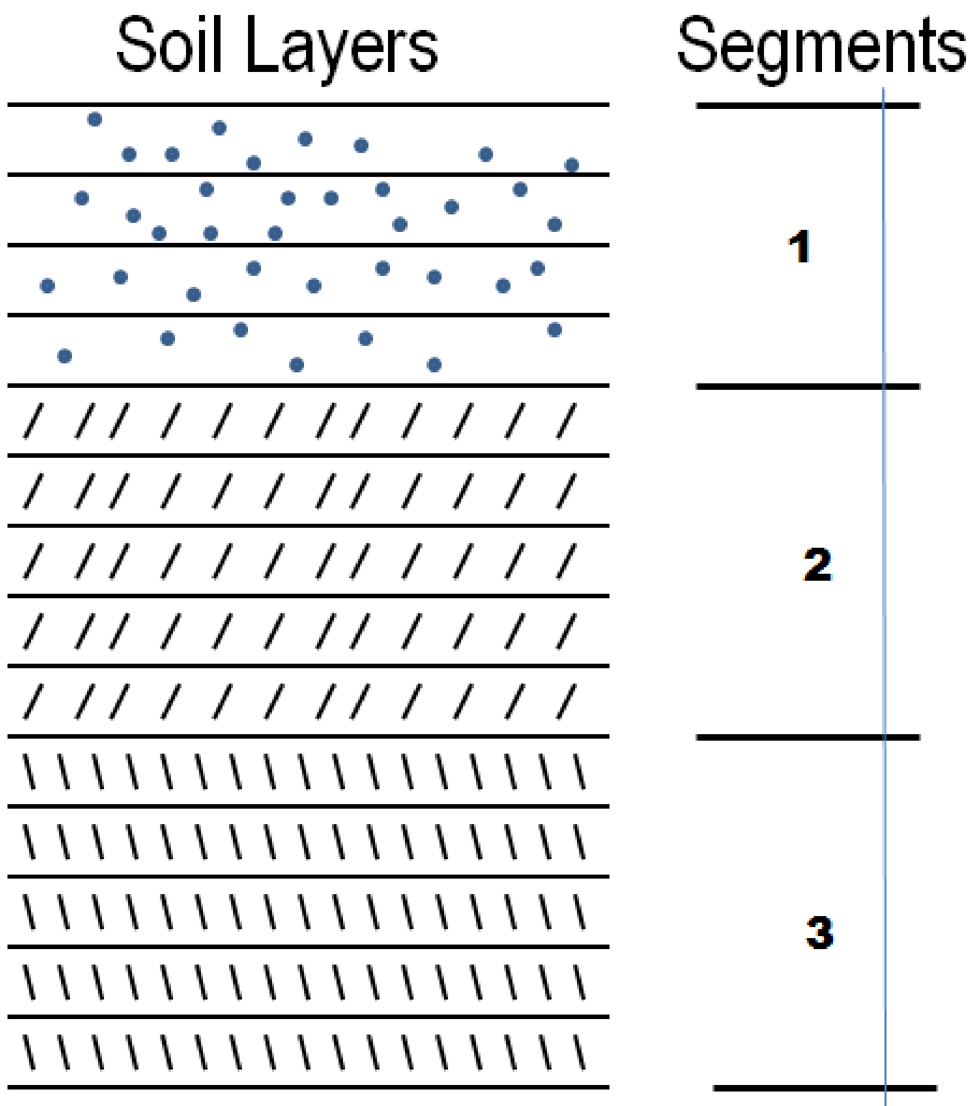
# Probabilistic Vs and D Soil Profile 1D Models Using Multiple Homogeneous Segments




Different statistical properties for different soil profile segments in depth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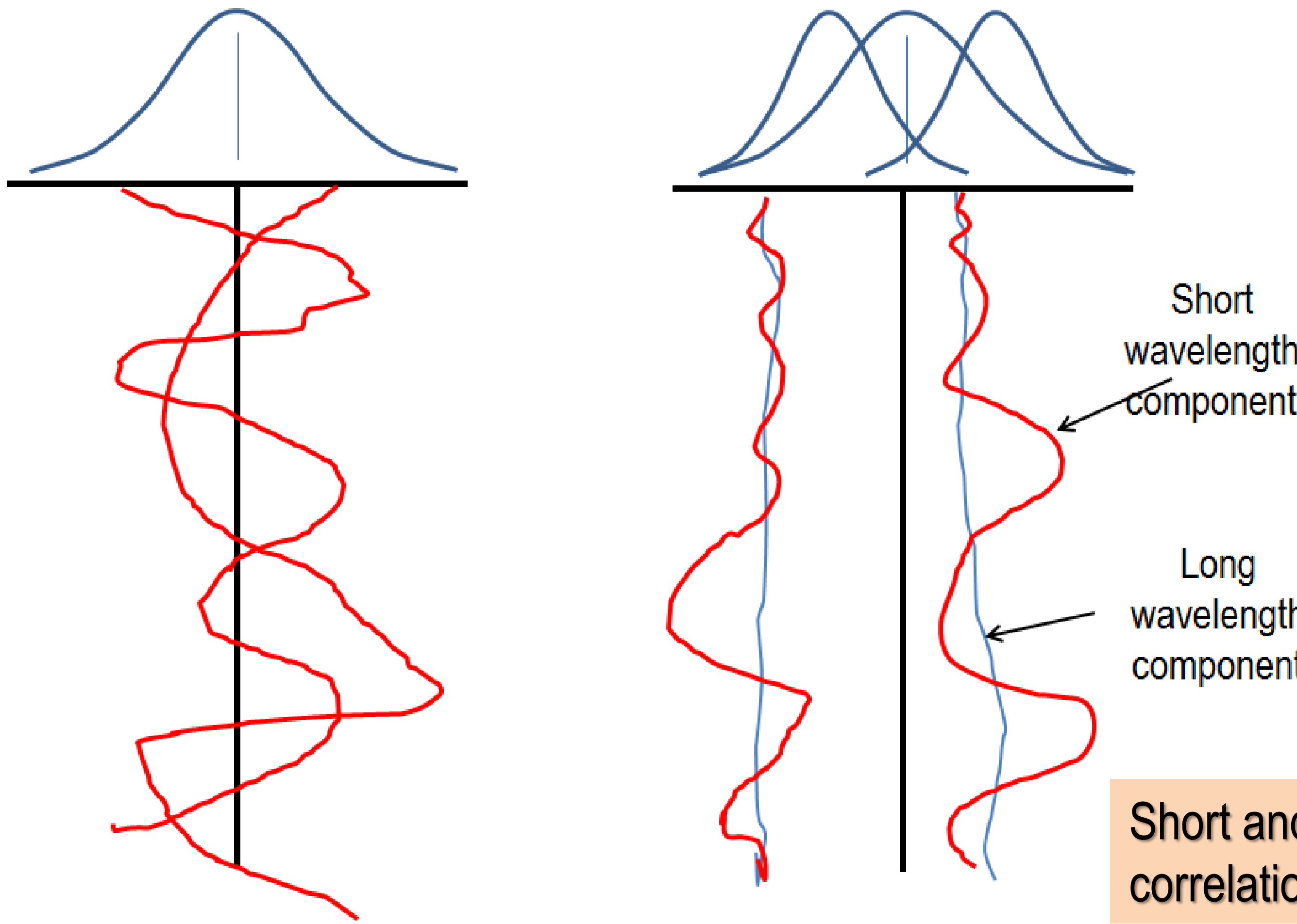
# Vs & D Profiles Using Continuous Process 1D Models. Two Variation Models, M1 and M2




Short and large correlation lengths

**Model 1 (Simple)**

**Model 2 (Composite)**

(Popescu, 1996)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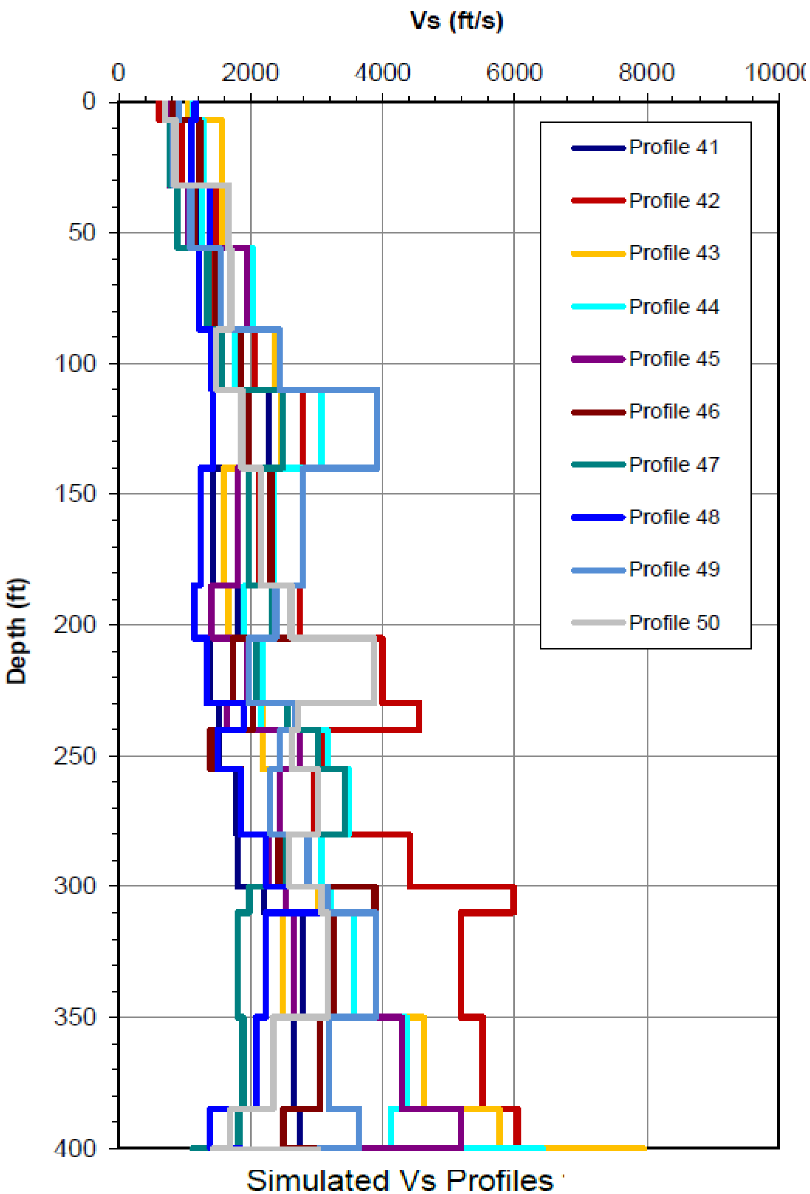
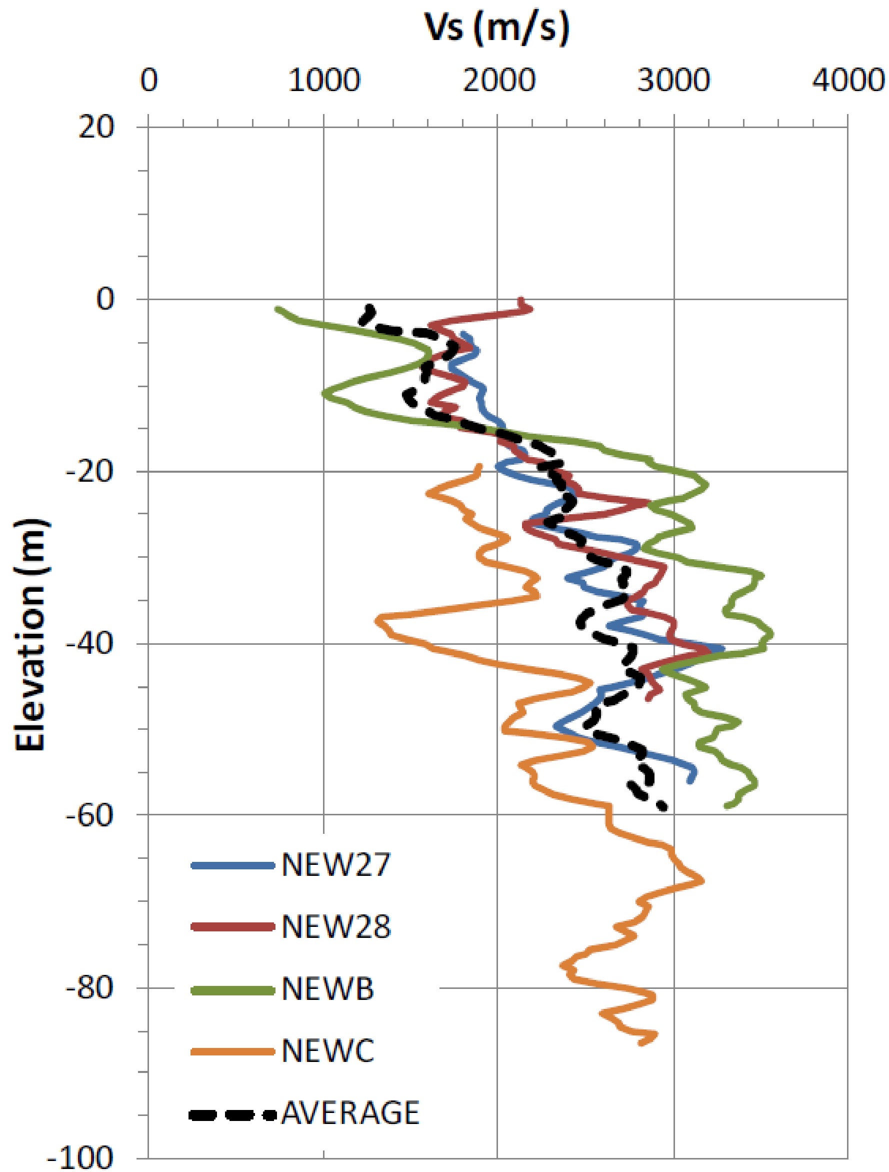
# Typical Probabilistic Vs Soil Profile Variations



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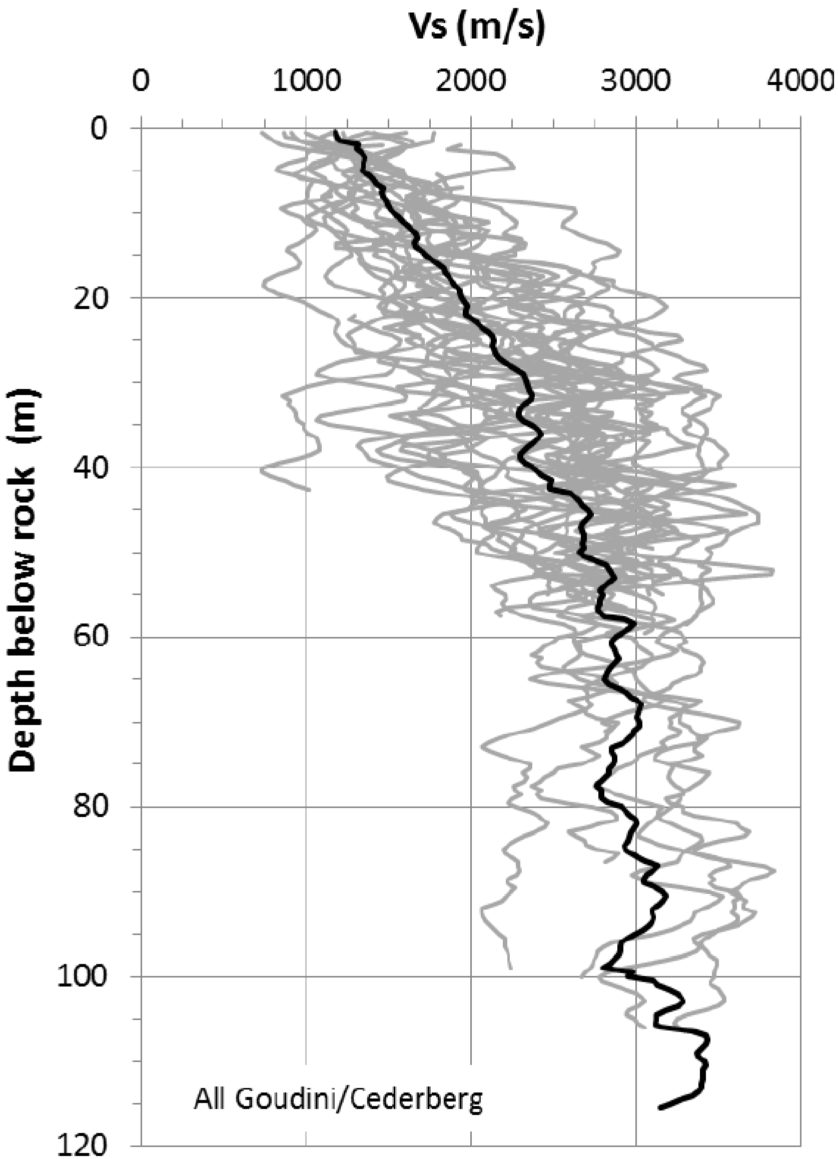
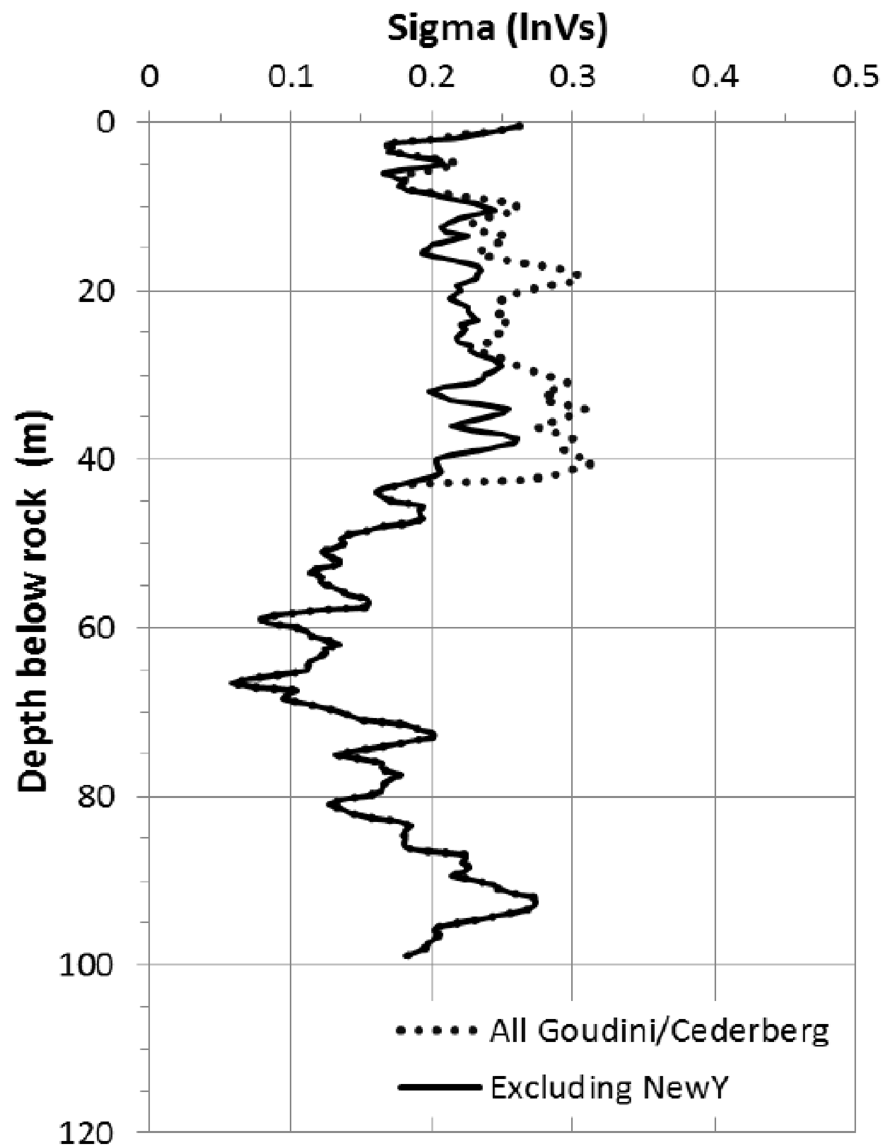
# Typical Probabilistic Vs Soil Profile Variations



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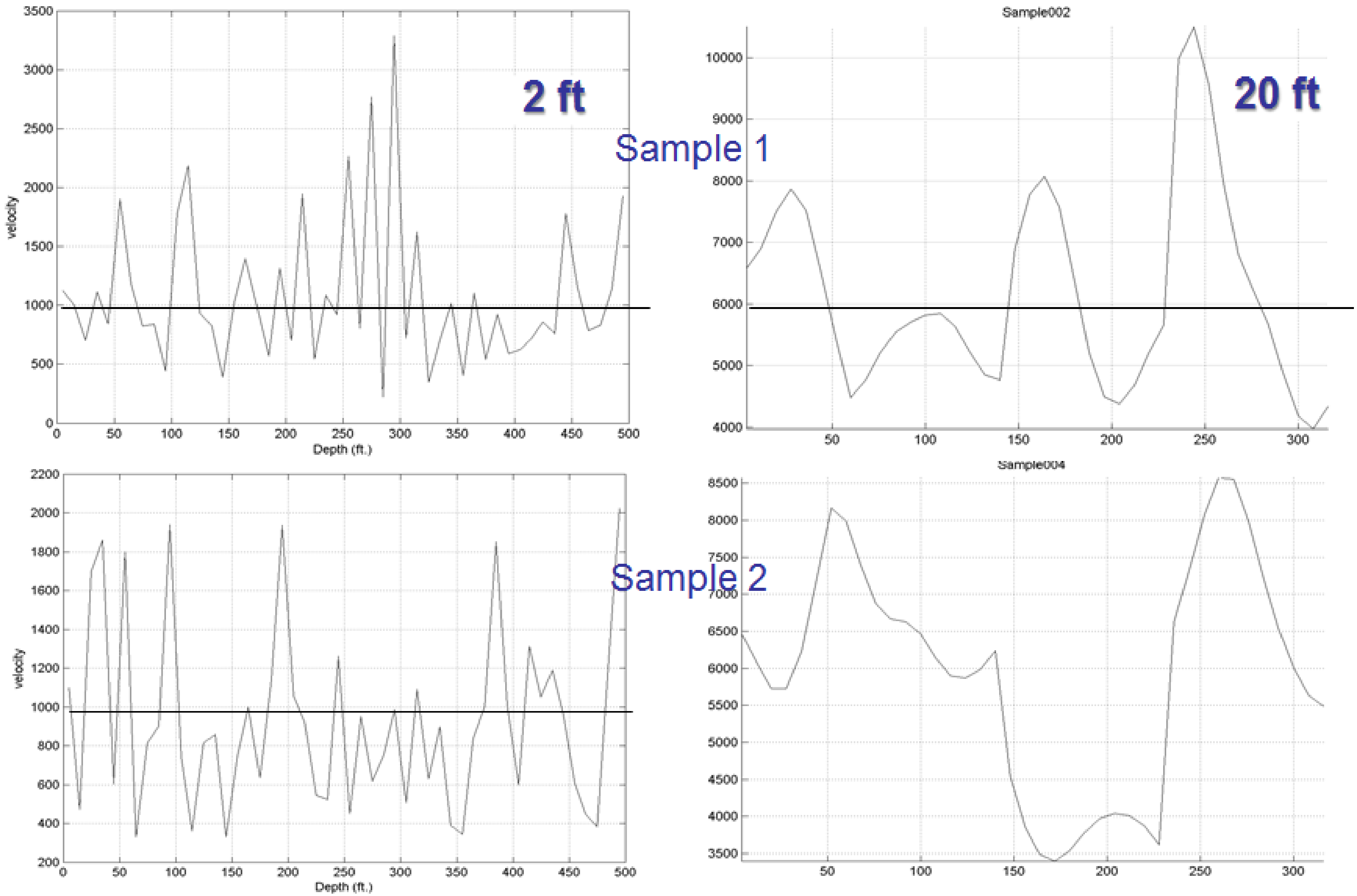
# Simulated Vs for 2ft & 20ft Correlation Lengths



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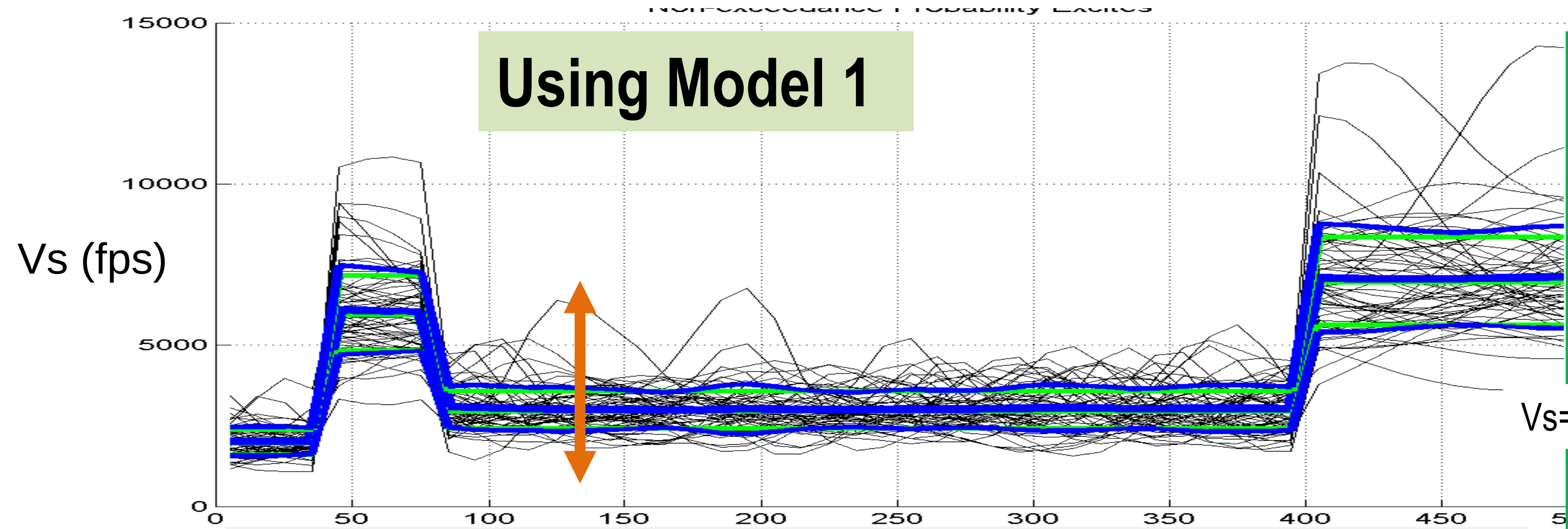
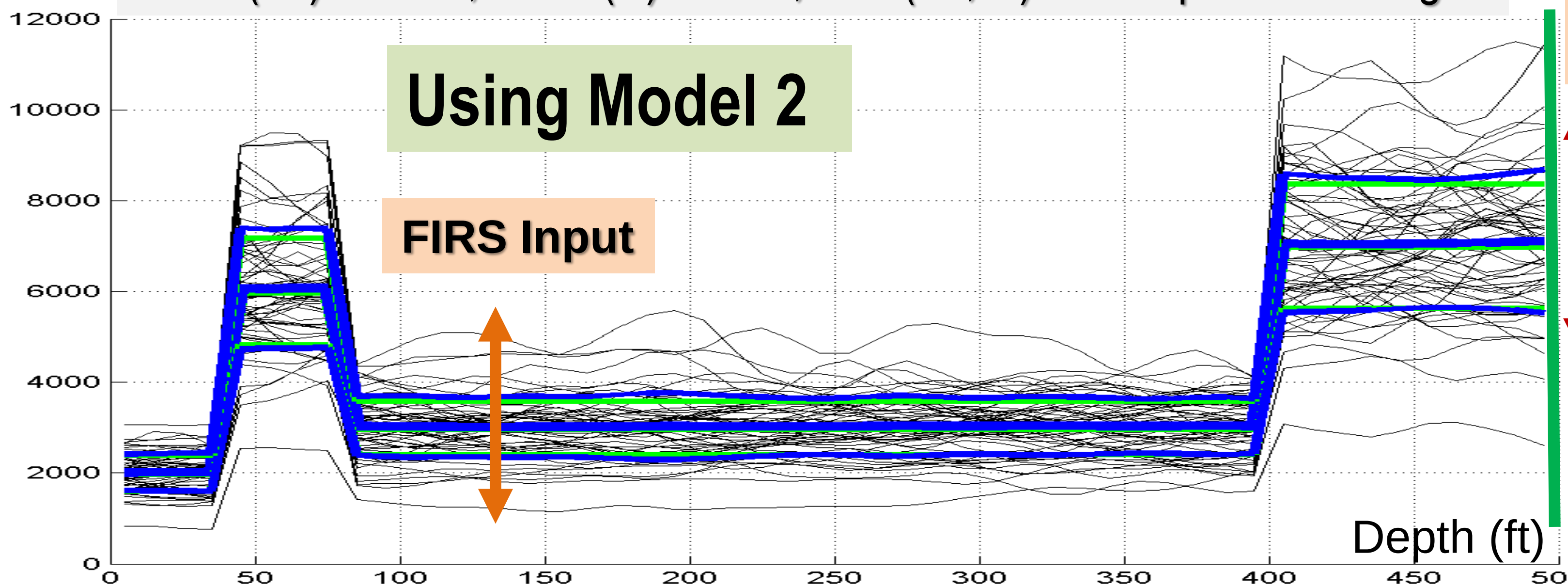
# ProSITE for Probabilistic Vs and D Soil Profiles




c.o.v. (Vs) = 20%, c.o.v. (D) = 30%, corr (Vs, D) =-0.40 plus corr. length

Mean UHRS Input

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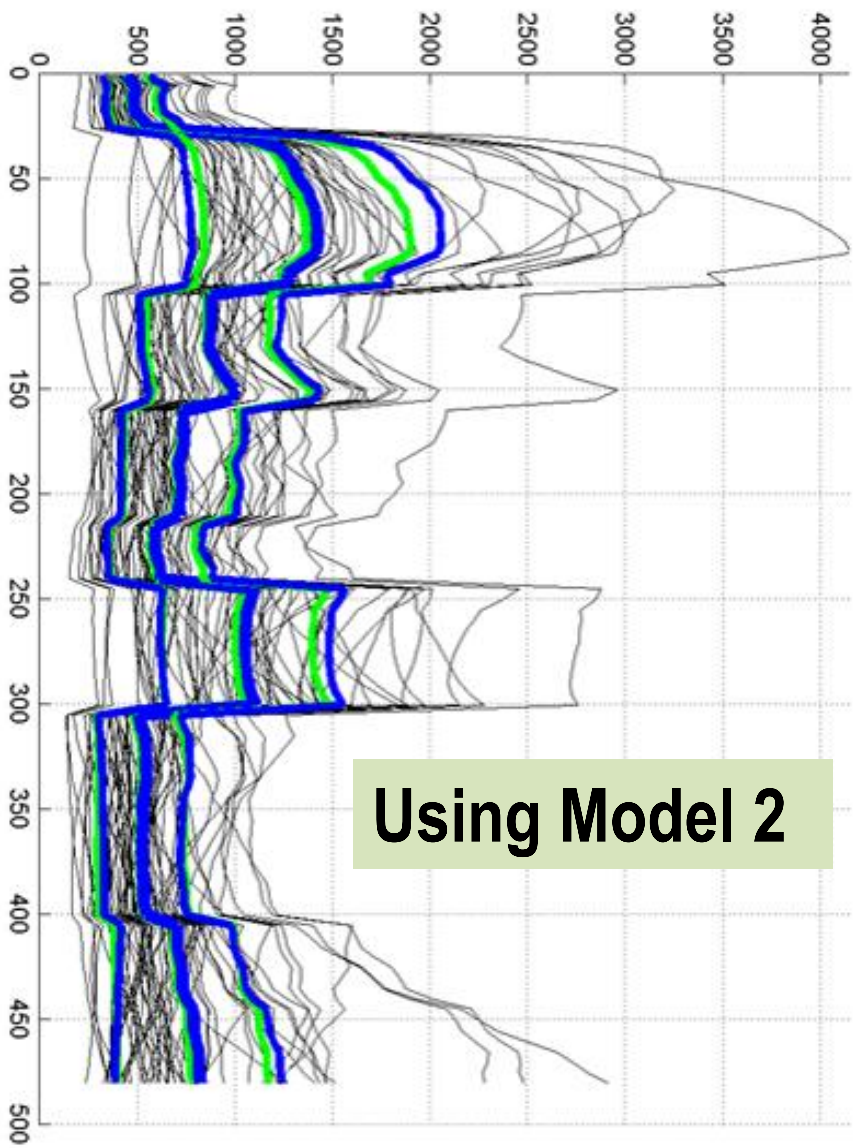
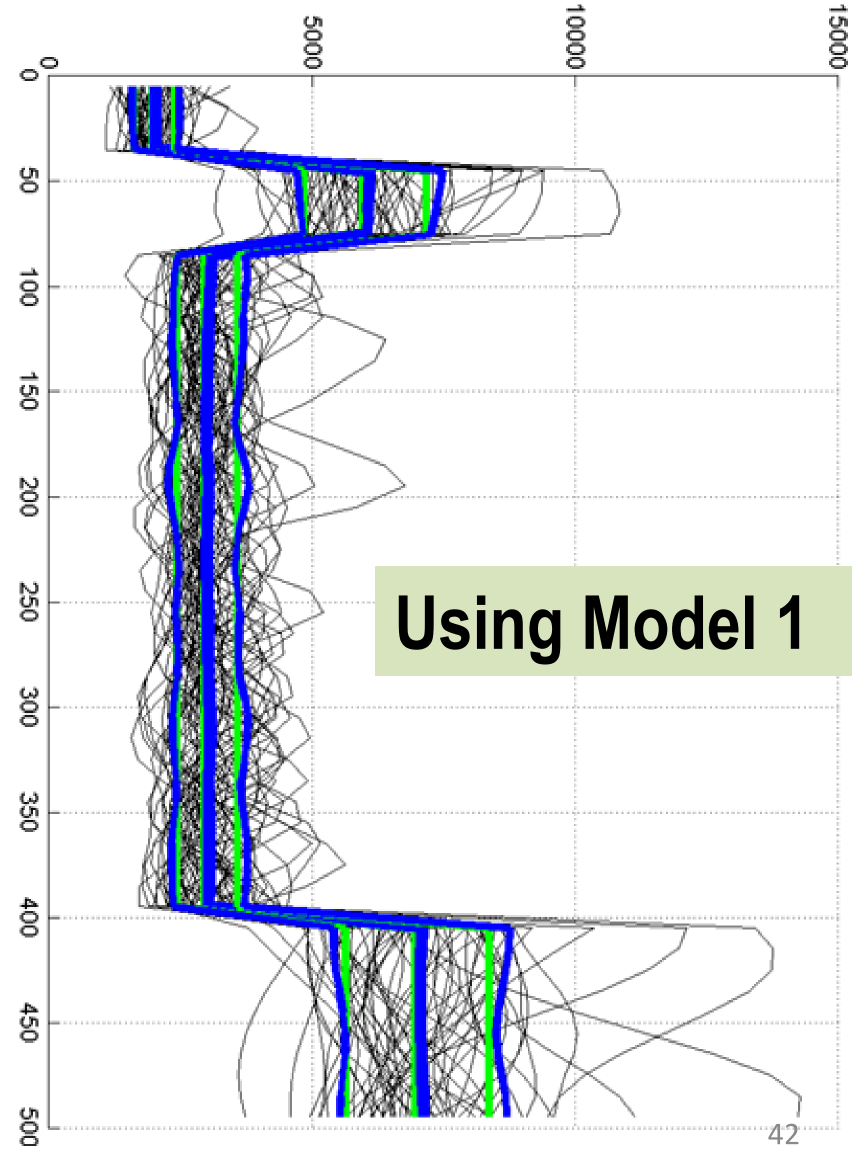
# Simulated Vs Profiles for Nonuniform Soils Using Continuous Process Models



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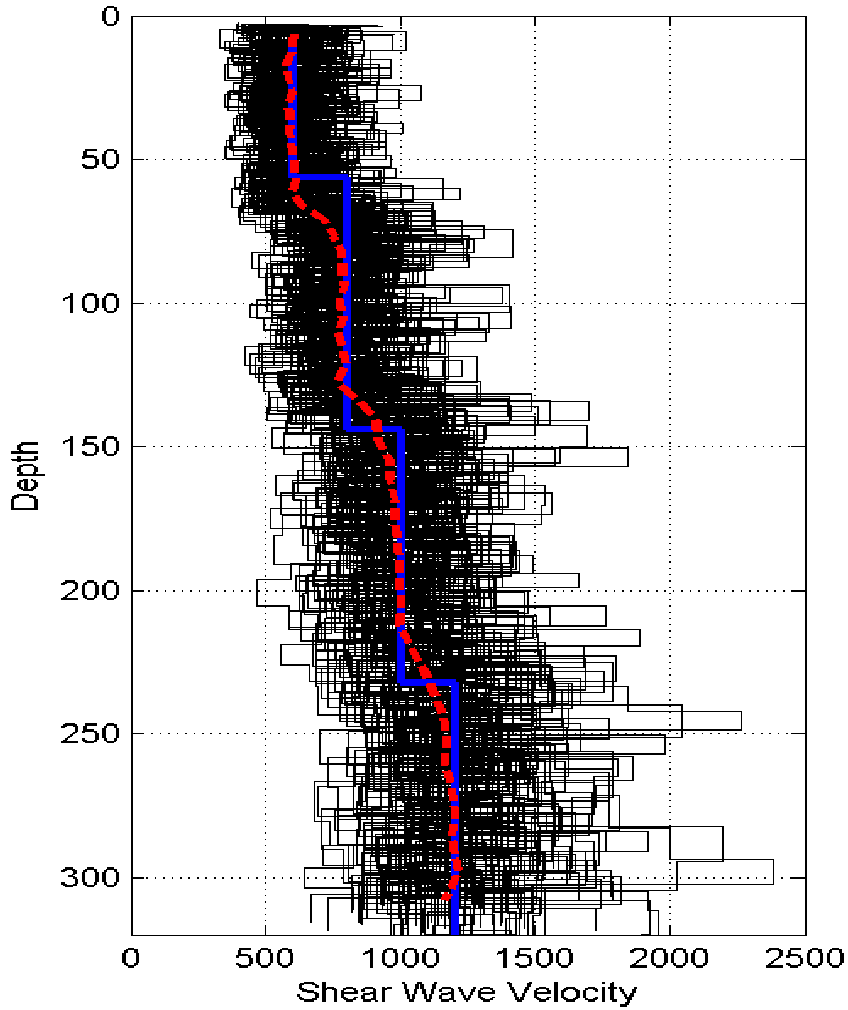
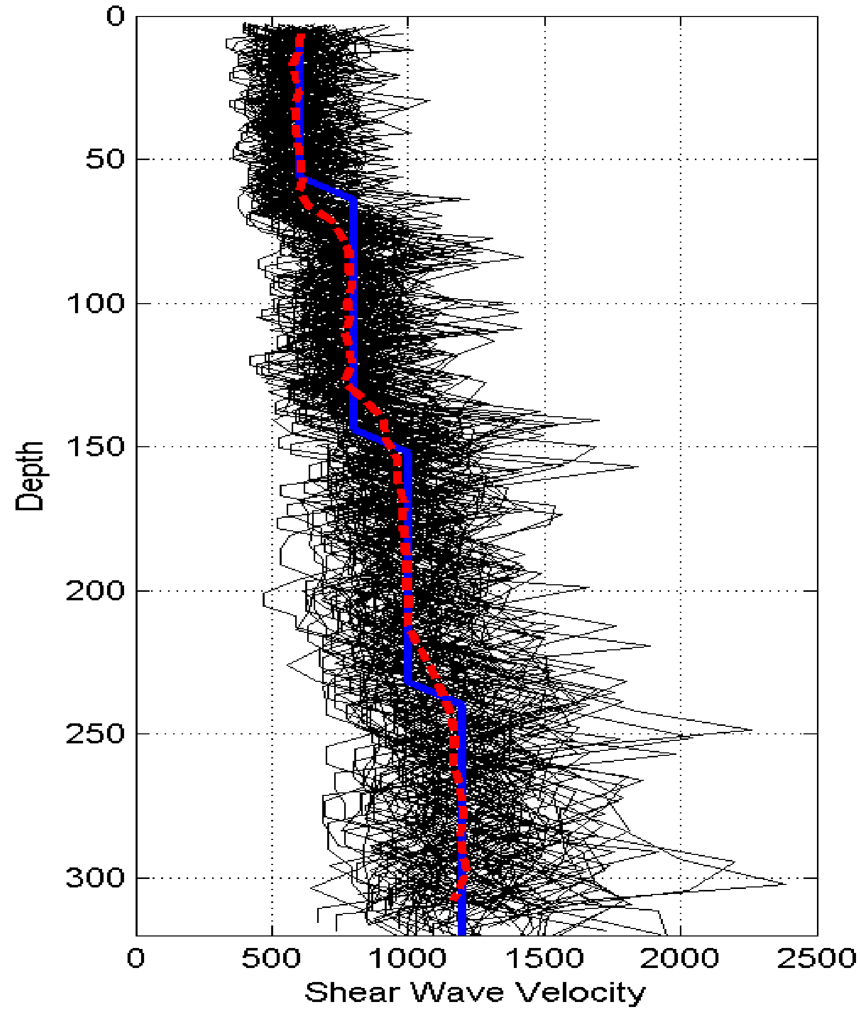
# Probabilistic Simulations of Soil Profiles Using Discrete Process Model, Model 3 (Toro's Model)




Toro, G. R. (1995). "Probabilistic models of site velocity profiles for generic and site-specific ground-motion amplification studies", Brookhaven National Laboratory.



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# Toro's Model (M3) If No Good Data Is Available

The Toro's model is a generic randomization of layer thicknesses (Toro, 1995) that results in a significant frequency shifts of peaks, and a decrease in in the amplitude of the motion site response spectral amplification. It was used in some past projects.

*USNRC Vladimir Graizer*, "Treasure Island Geotechnical Array Case Study for Site Response Analysis", 4th IASPEI/IAEE International Symposium: Effects of Surface Geology on Seismic Motion, UCSB, California, August 23–26,2011 states:

*"This type of randomization of layer thicknesses is possibly useful in the situations when site characterization is generic, for example in cases when detailed characterization from neighboring sites is applied to nearby location. Based on my tests, I do not recommend applying generic (Toro, 1995) type of layer thicknesses and S-wave velocity randomization in cases when layer and velocity profile are well determined (typical for many recent critical facilities requiring detailed P- and S-wave site characterization). I recommend applying randomization of velocity and layer thickness based on actual geologic and geotechnical measurements providing actual limits of variability."*



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# ProSITE Soil Profile Modeling and Simulation

A. Gaussian Continuous Process Model, Models 1 (simplified) and 2 (accurate)
B. Poisson Discrete Process Model, Model 3 (simplified, limited to power correlation)

**BLOCK A**

**OPTION INPUTS FOR METHOD SELECTION:**
**MODEL 1&2 (0) OR MODEL 3 (1)**

**BLOCK B.1**

**MODEL 1&2**

**BLOCK B.2**

**MODEL 3**


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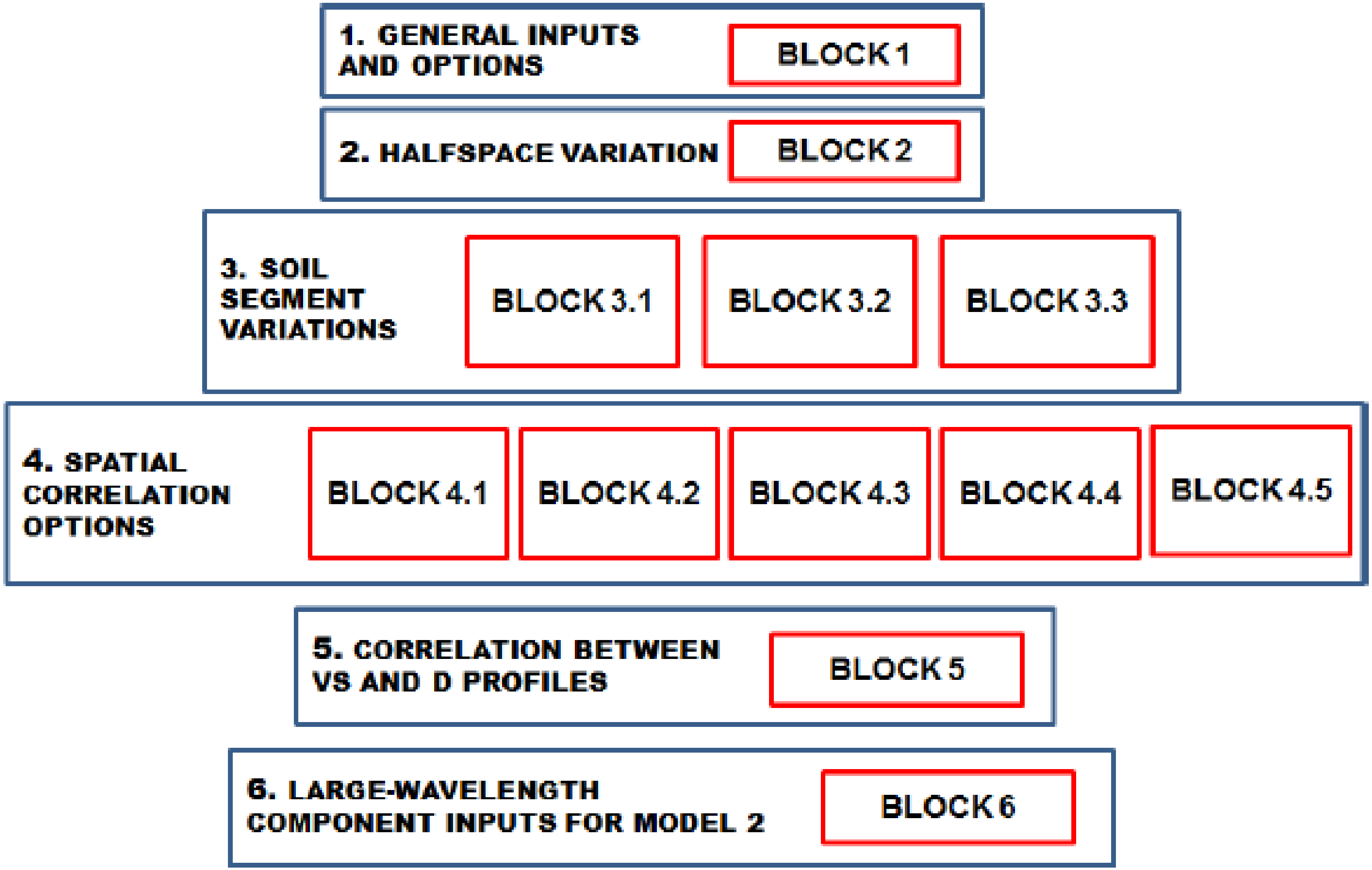
# ProSITE Input Blocks for Block B.1 Models 1 & 2




GSITE.IN Input File Data Block Structure



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# OPTVDCOR: Statistical Dependence for Vs and D

The OPTVDCOR variable controls the statistical dependence between the soil layer Vs and damping D values.

= 0 or 2. The options for values of 0 and 2 are straight forward.

= 1. For value of 1, the inverse statistical dependence is introduced based on the values that correspond to the same number of standard deviations from the mean values with changed sign.

= 3. For value of 3, the statistical dependence between Vs and D is included based a given, user-defined response function Vs = f(D).

=4. For value of 4, the statistical dependence is included by independently simulating the Vs and D sample values, and then pairing them, (Vs, D) in an inverse order (that corresponds to a rank correlation of -1.00).

***WARNING:*** *The OPTVDCOR = 1 option should be used only when Vs and D have normal distributions. If Vs and D have lognormal distributions, this option may produce too low damping values, as shown in Appendix 2.*



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# OPTSPCOR: Spatial Correlation for Vs and D

The OPTSPCOR variable controls the option for soil profile spatial correlation structure with depth.

For OPTSPCOR values o
= 0, 1 and 2, the correlation is defined either by a constant or a variable correlation length that is defined for a generic, analytical Gaussian spatial correlation function with an inflection point defined at the half of the correlation length value, as shown in (left plot).
= 3. For the OPTSPCOR value of 3, a more general model based directly on the spatial correlation matrix is considered. This soil profile correlation matrix should be determined based on the on-site Vs and D soil profile data or site response simulations.

The correlation length vector and correlation matrix should be input in a free format.


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# OPTPROFIL: Soil Profiles By Models 1 and 2

The OPTPROFIL variable controls the selection of the random field models for Vs and D soil profiles idealized by Gaussian Continuous Process Model, with Normal or Lognormal PDF. For the OPTPROFIL values
= 0 for Model 1, the Vs and D profiles are modeled as 1D random fields
= 1 for Model 2, the Vs and D profiles are modeled as a superposition of two 1D random fields with significantly different spatial correlation wavelength content. The first random field should have a long wavelength variation with depth, while the second random field should have a short wavelength variation. For the OPTSPCOR value of 1, user has to input in addition to the statistical parameters of the short-wavelength component profile, the statistical parameters of the long-wavelength profile in terms of coefficient of variation and correlation length for each soil profile segment.

The superposition model is useful to simulate "slow-varying" type of random fields, rather than "rapid-oscillatory" type of random fields. The selection of the correlation structure depends on the statistical evidence obtained from the on-site Vs soil profile data.


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# ProSITE Input Block Details for Block B.1

NSIMUL, OPTPDF, OPTVDCOR, OPTSPCOR, OPTPROFIL
FBASEL
FGSITE
NSEGM, OPTHS

**Block 1**

*IF OPTHS=0 AND OPTVDCOR=0,1,2 THEN*
COVHSVS, COVHSD

**Block 2.1**

*IF OPTHS=0 AND OPTVDCOR=3,4 THEN*
COVHSVS

**Block 2.2**

*IF OPTVDCOR=3 THEN*

*LOOP J=1,NSEGM*
NLAYSEG(J), COVVS(J), INSEEDVS(J)
NDATAFCT(J), INSEEDFCT(J)
*LOOP I=1, NDATAFCT(J)*
VSDAT(J,I), DDAT(J,I), VSNOISE(J,I)
*END LOOP I*
*END LOOP J*

**Block 3.1**

*IF OPTVDCOR=4 THEN*

*LOOP J=1,NSEGM*
NLAYSEG(J), COVVS(J), INSEEDVS(J)
RSMEANVS(J), RSCOVVS(J)
RSMEAND((J), RSCOVD(J)
*END LOOP J*

**Block 3.2**

*IF OPTVDCOR=0,1,2 THEN*

*LOOP J=1,NSEGM*
NLAYSEG(J), COVVS(J), INSEEDVS(J) ,
COVD(J), INSEEDD(J)
*END LOOP J*

**Block 3.3**

*IF OPTSPCOR=1 AND OPTVDCOR=0,1,2 THEN*

*LOOP J=1, NTLAYER*
CORLVS(J), CORLD(J)
*END LOOP J*

**Block 4.1**

*IF OPTSPCOR=1 AND OPTVDCOR=3,4 THEN*

*LOOP J=1, NTLAYER*
CORLVS(J)
*END LOOP J*

**Block 4.2**

*IF OPTSPCOR=3 THEN*

CORMAT *(CORRLELATION MATRIX FILE)*
*- IF OPTVDCOR=0,1,2: THEN*
*INPUT CORRELATION MATRICES FOR VS AND DAMPING FOR ALL LAYERS*
*- IF OPTVDCOR=3,4: THEN*
*INPUT CORRELATION MATRIX FOR VS*

**Block 4.3**

*IF OPTSPCOR=0,2 AND OPTVDCOR=3,4 THEN*

*LOOP J=1, NSEGM*
CORLVS(J)
*END LOOP J*

**Block 4.4**

*IF OPTSPCOR=0,2 AND OPTVDCOR=0,1,2 THEN*

*LOOP J=1, NSEGM*
CORLVS(J), CORLD(J)
*END LOOP J*

**Block 4.5**

*IF OPTVDCOR =0 THEN*
CORVSD

**Block 5**

*IF OPTPROFIL = 1 THEN*
*LOOP J=1, NSEGM*
COVMEANVS(J), CORLLWVS(J), COVMEAND(J), CORLLWD(J)
*END LOOP J*

**Block 6**

Figure 5.3 GSITE.IN File Input Data Description

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# ProSITE Input Parameters for Block 1 (M1, M2)

| Input BlockNumber | Input File Line Number Inside Each Block | Variable Name (Input file in free format) | Definition of Input Variables |
|---|---|---|---|
| **BLOCK A** | | | |
| | 1 | NOPTMETH | Option for selecting methods<br>= 0 for Models 1 or 2 simulation<br>= 1 for Model 3 simulation |
| **BLOCK B.1:** | **BLOCK 1 -- BLOCK 6** | | |
| **BLOCK 1** | | | |
| 1 | 1 | NSIMUL | Number of simulated seismic input files |
| 1 | 1 | OPTPDF | Option for probability distribution for Vs and D<br>= 0 for Normal distribution<br>= 1 for Lognormal distribution |
| 1 | 1 | OPTVDCOR | Statistical dependence between soil layer Vs and D<br>= 0 using a linear correlation coefficient<br>= 1 assuming inverse variation based an equal number of standard variations from mean value<br>= 2 assuming statistical independence<br>= 3 using given response function Vs=f(D) provided by the user<br>= 4 using inverse probability variation based on simulation of a statistical response function Vs=f(D), obtained for rank correlation is -1.0. |

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# ProSITE Input Parameters for Blocks 1 and 2

| | | | |
|---|---|---|---|
| 1 | 1 | OPTSPCOR | Spatial correlation structure with depth for Vs and D<br>= 0 for constant correlation length with depth (scalar)<br>= 1 for variable correlation length with depth (vector)<br>= 2 for infinite correlation length (perfect correlation with depth)<br>= 3 for using the spatial correlation matrix (matrix) |
| 1 | 1 | OPTPROFIL | Soil profile random field models for Vs and D<br>= 0 Model 1, using a 1D random field<br>= 1 Model 2, using a superposition of two random fields; a long-wavelength and a short-wavelength variation |
| 1 | 2 | FBASEL | Filename for the mean soil profile (ex. BASELINE.SIT) |
| 1 | 3 | FGSITE | Filenames of the simulated SITE inputs (ex. GSITExxx.sit) |
| 1 | 4 | NSEGM | Number of the soil profile segments |
| 1 | 4 | OPTHS | Option for the half-space layer random samples |
| | | | = 0 independent from soil above<br>= 1 full correlated with the soil layer above |
| **BLOCK 2** | Only for OPTHS=0 | | |
| 2.1, 2.2 | 1 | COVHSVS | Coefficient of variation for bedrock Vs |
| 2.1 | 1 | COVHSD | Coefficient of variation for bedrock D |



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# ProSITE Input Parameters for Block 3

| **BLOCK 3** | Start Loop J=1,NSEGM | | Loop over the number of soil layer segments |
|---|---|---|---|
| 3.1, 3.2, 3.3 | 1 Inside J Loop | NLAYSEG(J) | Number of layers in the segment (J) |
| 3.1, 3.2, 3.3 | 1 Inside J Loop | COVVS(J) | Coefficient of variation of Vs(J) |
| 3.1, 3.2, 3.3 | 1 Inside J Loop | INSEEDVS(J) | Initial SEED for Vs(J) |
| 3.3 | 1 Inside J Loop | COVD(J) | Coefficient of variation of D(J) |
| 3.3 | 1 Inside J Loop | INSEEDD(J) | Initial SEED for D(J) |
| 3.1 | 2 Inside J Loop | NDATAFCT(J) | Number of response function data |
| 3.1 | 2 Inside J Loop | ISEEDFCT(J) | Initial seed for response function noise |
| 3.2 | 2 Inside J Loop | RSMEANVS(J) | Mean Vs for simulation (to compute Vs=f(D) response function based on assuming a rank correlation = -1) |
| 3.2 | 2 Inside J Loop | RSCOVD(J) | Coefficient of variation of Vs for simulation (to compute Vs=f(D) function based on assuming a rank correlation = -1) |
| 3.1 | Start Loop I=1,NDATAFCT(J) | | Loop over Vs=f(D)+noise response surface data |
| 3.1 | 3 Inside J Loop/1 Inside I Loop | VSDAT(J,I) | Response function Vs data points |
| 3.1 | 3 Inside J Loop/1 Inside I Loop | DDAT(J,I) | Response function D data points |
| 3.1 | 3 Inside J Loop/1 Inside I Loop | VSNOISE(J,I) | Response function noise standard deviation |
| 3.1 | End Loop I=1,NDATAFCT(J) | | |
| 3.2 | 3 Inside J Loop | RSMEAND(J) | Mean D for simulation (to compute response function based on assuming a rank correlation = -1) |
| 3.2 | 3 Inside J Loop | RSCOVD(J) | Coefficient of variation of D for simulation (to compute response function based on assuming a rank correlation = -1) |
| | End Loop J=1,NSEGM | | |



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# ProSITE Input Parameters for Blocks 4, 5 and 6

| | | | |
|---|---|---|---|
| **BLOCK 4** | | | |
| 4.1, 4.2 | Start Loop J=1,NTLAYER | | Loop over the number of soil layers |
| 4.1,4.2 | 1 Inside J Loop | CORLVS(J) | Correlation length of Vs(J) |
| 4.1 | 1 Inside J Loop | CORLD(J) | Correlation length of D(J) |
| 4.1, 4.2 | End Loop J=1,NTLAYER | | |
| 4.3 | 1 | CORMAT | Correlation matrix file name |
| 4.4, 4.5 | Start Loop J=1,NSEGM | | |
| 4.4,4.5 | 1 Inside Loop J | CORLVS(J) | Correlation length of Vs(J) |
| 4.5 | 1 Inside Loop J | CORLD(J) | Correlation length of Damping D(J) |
| 4.4,4.5 | End of Loop J=1,NSEGM | | |
| **BLOCK 5** | | | |
| 5 | 1 | CORVSD | Correlation coefficient between Vs and D profiles |
| **BLOCK 6** | | | |
| | Start Loop J=1,NSEGM | | |
| 6 | 1 Inside Loop J | COVMEANVS(J) | Coefficient of variation of long-wavelength component Vs profile |
| 6 | 1 Inside Loop J | COVMEAND(J) | Coefficient of variation of long-wavelength component D profile |
| 6 | 1 Inside Loop J | CORLLWVS(J) | Correlation length of the long-wavelength component Vs profile |
| 6 | 1 Inside Loop J | CORLLWD(J) | Correlation length of the long-wavelength component D profile |
| 6 | End of Loop J=1,NSEGM | | |



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# Example for ProSITE Input Parameters

**EXAMPLE 1: SOIL SITE – MODEL 1 WITH 4 SEGMENTS, VS AND D PROFILES WITH CONSTANT CORRELATION LENGTH, LOGNORMAL DISTRIBUTIONS, INVERSE VARIATION STATISTICAL DEPENDENCE FOR VS AND D**

```
100 1 1 0 0
BASESITE.SIT
GSITEXXX.SIT
4 1
 7  0.20  222222  0.3   334522
11  0.20  313473  0.3   368953
11  0.20  513473  0.3   168953
11  0.20  118542  0.3   214345
40  40
40  40
40  40
40  40
```

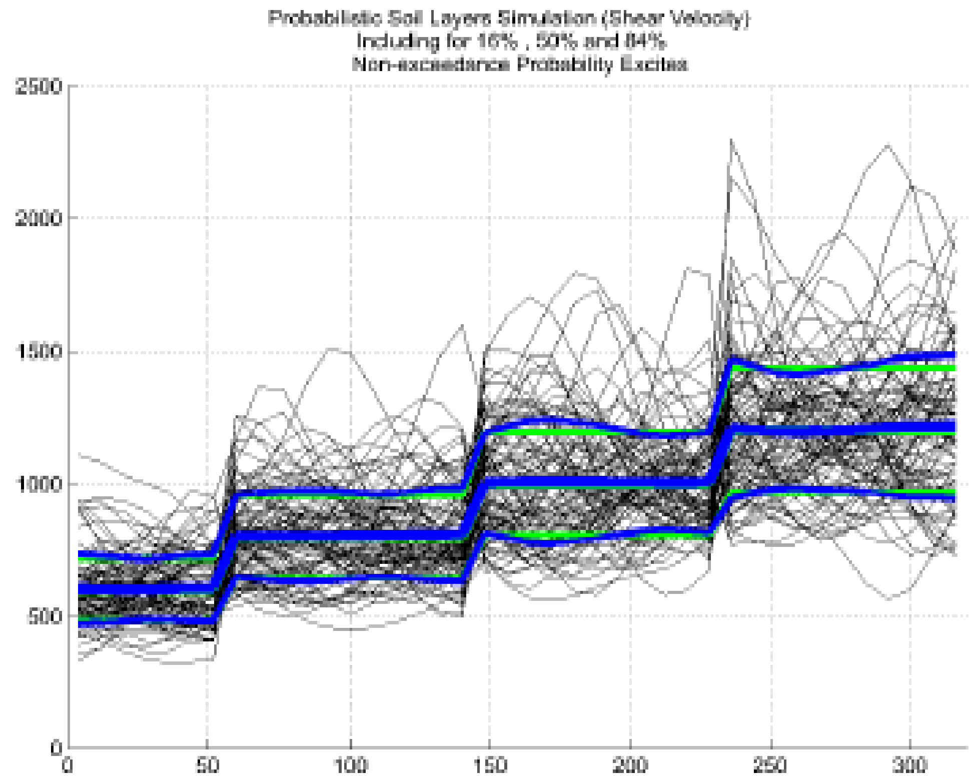


Figure A2.1 Shear Velocity Statistical Curves (Mean and Mean +/- Standard Deviation) and Simulated Samples (black); Computed Probability Curves based on Simulated Samples (blue line) are plotted Against Given Probability Curves (light green line)



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## EXAMPLE 1: SOIL SITE – MODEL 1 WITH 4 SEGMENTS, VS AND D PROFILES WITH CONSTANT CORRELATION LENGTH, LOGNORMAL DISTRIBUTIONS, INVERSE VARIATION STATISTICAL DEPENDENCE FOR VS AND D

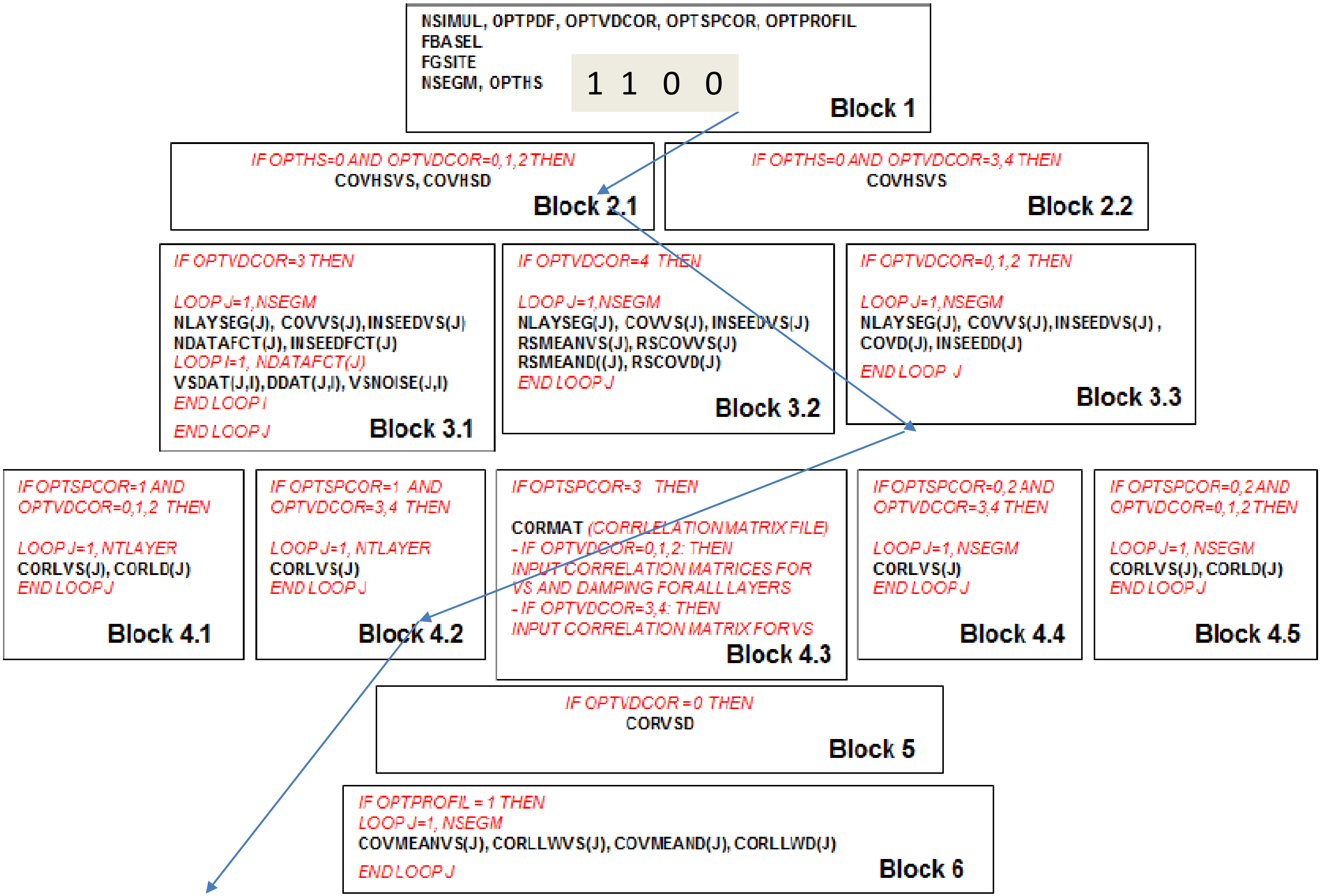
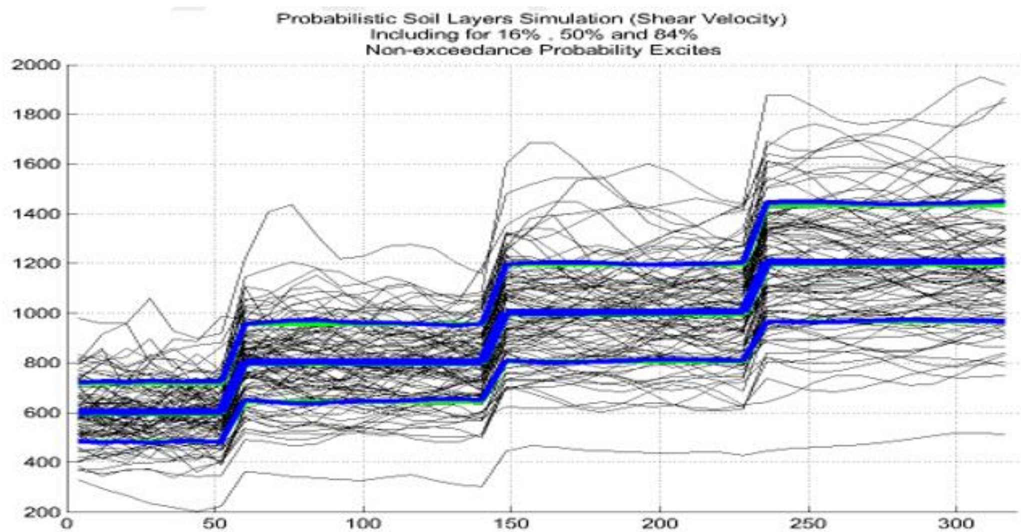
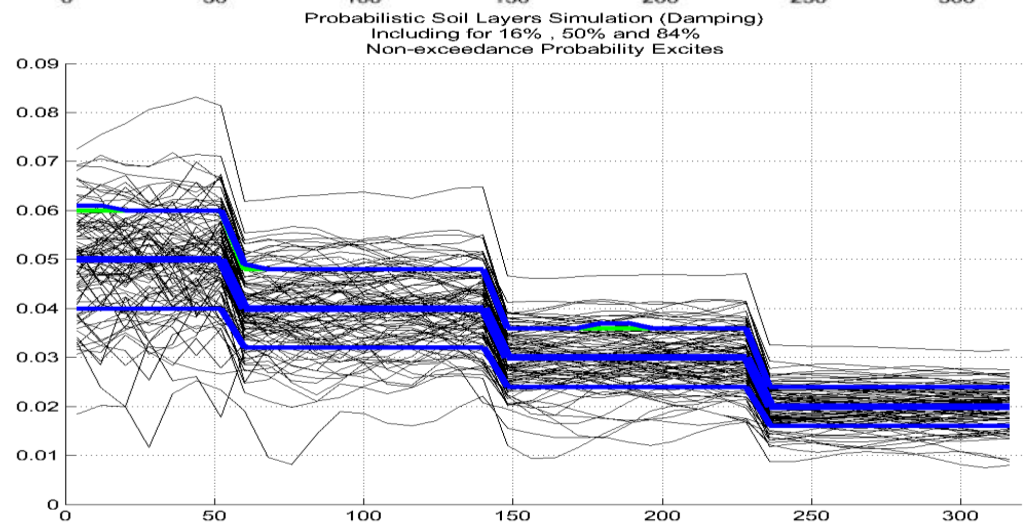



Figure 5.3 GSITE.IN File Input Data Description

# Example 9: Soil Site – Model 2 with 4 Segments, Vs and D Profiles with Constant Correlation Length, Lognormal Distributions, Inverse Variation Statistical Dependence for Vs and D

```
0
100 1 1  0  1
BASESITE.SIT
GSITEXXX.SIT
4  1
7  0.06 18542 0.06  32135
11 0.06 73322 0.06  52345
11 0.06 45621 0.06  67211
11 0.06 21854 0.06  14345
10. 10.0
20. 20.0
30. 30.0
40. 40.0
0.19 400.0  0.19  400.0
0.19 500.0  0.19  500.0
0.19 600.0  0.19  600.0
0.19 700.0  0.19  700.0
```

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## Example 9: Soil Site – Model 2 with 4 Segments, Vs and D Profiles with Constant Correlation Length, Lognormal Distributions, Inverse Variation Statistical Dependence for Vs and D

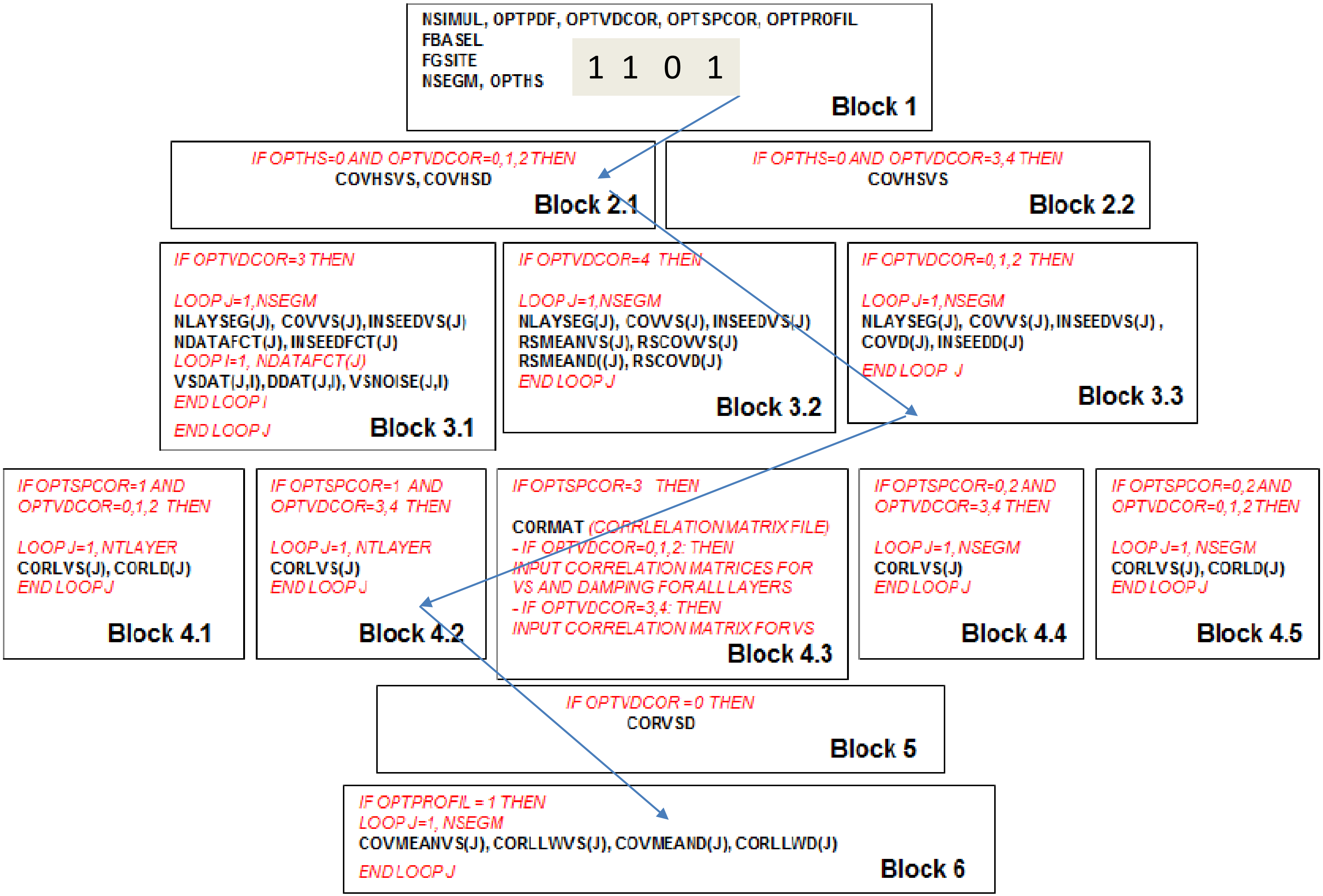


Figure 5.3 GSITE.IN File Input Data Description

# EXAMPLE 9: SOIL SITE – MODEL 2 WITH 4 SEGMENTS, VS AND D PROFILES WITH CONSTANT CORRELATION LENGTH, LOGNORMAL DISTRIBUTIONS, INVERSE VARIATION STATISTICAL DEPENDENCE FOR VS AND D

```
0
100 1 1  0  1
BASESITE.SIT
GSITEXXX.SIT
4  1
7  0.06 18542 0.06  32135
11 0.06 73322 0.06  52345
11 0.06 45621 0.06  67211
11 0.06 21854 0.06  14345
10. 10.0
20. 20.0
30. 30.0
40. 40.0
0.19 400.0  0.19  400.0
0.19 500.0  0.19  500.0
0.19 600.0  0.19  600.0
0.19 700.0  0.19  700.0
```

| Input BlockNumber | Input File Line Number Inside Each Block | Variable Name (Input file in free format) | Definition of Input Variables |
|---|---|---|---|
| **BLOCK A** | | | |
| | 1 | NOPTMETH | Option for selecting methods<br>= 0 for Models 1 or 2 simulation<br>= 1 for Model 3 simulation |
| **BLOCK B.1:** | **BLOCK 1 -- BLOCK 6** | | |
| **BLOCK 1** | | | |
| 1 | 1 | NSIMUL | Number of simulated seismic input files |
| 1 | 1 | OPTPDF | Option for probability distribution for Vs and D<br>= 0 for Normal distribution<br>= 1 for Lognormal distribution |
| 1 | 1 | OPTVDCOR | Statistical dependence between soil layer Vs and D<br>= 0 using a linear correlation coefficient<br>= 1 assuming inverse variation based an equal number of standard variations from mean value<br>= 2 assuming statistical independence<br>= 3 using given response function Vs=f(D) provided by the user<br>= 4 using inverse probability variation based on simulation of a statistical response function Vs=f(D), obtained for rank correlation is -1.0. |


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# Example 9: Soil Site – Model 2 with 4 Segments, Vs and D Profiles with Constant Correlation Length, Lognormal Distributions, Inverse Variation Statistical Dependence for Vs and D

```
0
100 1 1  0  1
BASESITE.SIT
GSITEXXX.SIT
4  1
7  0.06 18542 0.06  32135
11 0.06 73322 0.06  52345
11 0.06 45621 0.06  67211
11 0.06 21854 0.06  14345
10. 10.0
20. 20.0
30. 30.0
40. 40.0
0.19 400.0  0.19  400.0
0.19 500.0  0.19  500.0
0.19 600.0  0.19  600.0
0.19 700.0  0.19  700.0
```

| | | | |
|---|---|---|---|
| 1 | 1 | OPTSPCOR | Spatial correlation structure with depth for Vs and D<br>= 0 for constant correlation length with depth (scalar)<br>= 1 for variable correlation length with depth (vector)<br>= 2 for infinite correlation length (perfect correlation with depth)<br>= 3 for using the spatial correlation matrix (matrix) |
| 1 | 1 | OPTPROFIL | Soil profile random field models for Vs and D<br>= 0 Model 1, using a 1D random field<br>= 1 Model 2, using a superposition of two random fields; a long-wavelength and a short-wavelength variation |
| 1 | 2 | FBASEL | Filename for the mean soil profile (ex. BASELINE.SIT) |
| 1 | 3 | FGSITE | Filenames of the simulated SITE inputs (ex. GSITExxx.sit) |
| 1 | 4 | NSEGM | Number of the soil profile segments |
| 1 | 4 | OPTHS | Option for the half-space layer random samples |

| | | | |
|---|---|---|---|
| | | | = 0 independent from soil above<br>= 1 full correlated with the soil layer above |
| **BLOCK 2** | Only for OPTHS=0 | | |
| 2.1, 2.2 | 1 | COVHSVS | Coefficient of variation for bedrock Vs |
| 2.1 | 1 | COVHSD | Coefficient of variation for bedrock D |


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# Example 9: Soil Site – Model 2 with 4 Segments, Vs and D Profiles with Constant Correlation Length, Lognormal Distributions, Inverse Variation Statistical Dependence for Vs and D

```
0
100 1 1  0  1
BASESITE.SIT
GSITEXXX.SIT
4  1
7  0.06 18542 0.06  32135
11 0.06 73322 0.06  52345
11 0.06 45621 0.06  67211
11 0.06 21854 0.06  14345
10. 10.0
20. 20.0
30. 30.0
40. 40.0
0.19 400.0  0.19  400.0
0.19 500.0  0.19  500.0
0.19 600.0  0.19  600.0
0.19 700.0  0.19  700.0
```

| **BLOCK 3** | Start Loop J=1,NSEGM | | Loop over the number of soil layer segments |
|---|---|---|---|
| 3.1, 3.2, 3.3 | 1 Inside J Loop | NLAYSEG(J) | Number of layers in the segment (J) |
| 3.1, 3.2, 3.3 | 1 Inside J Loop | COVVS(J) | Coefficient of variation of Vs(J) |
| 3.1, 3.2, 3.3 | 1 Inside J Loop | INSEEDVS(J) | Initial SEED for Vs(J) |
| 3.3 | 1 Inside J Loop | COVD(J) | Coefficient of variation of D(J) |
| 3.3 | 1 Inside J Loop | INSEEDD(J) | Initial SEED for D(J) |
| 3.1 | 2 Inside J Loop | NDATAFCT(J) | Number of response function data |
| 3.1 | 2 Inside J Loop | ISEEDFCT(J) | Initial seed for response function noise |
| 3.2 | 2 Inside J Loop | RSMEANVS(J) | Mean Vs for simulation (to compute Vs=f(D) response function based on assuming a rank correlation = -1) |
| 3.2 | 2 Inside J Loop | RSCOVD(J) | Coefficient of variation of Vs for simulation (to compute Vs=f(D) function based on assuming a rank correlation = -1) |
| 3.1 | Start Loop I=1,NDATAFCT(J) | | Loop over Vs=f(D)+noise response surface data |
| 3.1 | 3 Inside J Loop/1 Inside I Loop | VSDAT(J,I) | Response function Vs data points |
| 3.1 | 3 Inside J Loop/1 Inside I Loop | DDAT(J,I) | Response function D data points |
| 3.1 | 3 Inside J Loop/1 Inside I Loop | VSNOISE(J,I) | Response function noise standard deviation |
| 3.1 | End Loop I=1,NDATAFCT(J) | | |
| 3.2 | 3 Inside J Loop | RSMEAND(J) | Mean D for simulation (to compute response function based on assuming a rank correlation = -1) |
| 3.2 | 3 Inside J Loop | RSCOVD(J) | Coefficient of variation of D for simulation (to compute response function based on assuming a rank correlation = -1) |
| | End Loop J=1,NSEGM | | |



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# Example 9: Soil Site – Model 2 with 4 Segments, Vs and D Profiles with Constant Correlation Length, Lognormal Distributions, Inverse Variation Statistical Dependence for Vs and D

```
0
100 1 1  0  1
BASESITE.SIT
GSITEXXX.SIT
4  1
7  0.06 18542 0.06  32135
11 0.06 73322 0.06  52345
11 0.06 45621 0.06  67211
11 0.06 21854 0.06  14345
10. 10.0
20. 20.0
30. 30.0
40. 40.0
0.19 400.0  0.19  400.0
0.19 500.0  0.19  500.0
0.19 600.0  0.19  600.0
0.19 700.0  0.19  700.0
```

| | | | |
|---|---|---|---|
| **BLOCK 4** | | | |
| 4.1, 4.2 | Start Loop J=1,NTLAYER | | Loop over the number of soil layers |
| 4.1,4.2 | 1 Inside J Loop | CORLVS(J) | Correlation length of Vs(J) |
| 4.1 | 1 Inside J Loop | CORLD(J) | Correlation length of D(J) |
| 4.1, 4.2 | End Loop J=1,NTLAYER | | |
| 4.3 | 1 | CORMAT | Correlation matrix file name |
| 4.4, 4.5 | Start Loop J=1,NSEGM | | |
| 4.4,4.5 | 1 Inside Loop J | CORLVS(J) | Correlation length of Vs(J) |
| 4.5 | 1 Inside Loop J | CORLD(J) | Correlation length of Damping D(J) |
| 4.4,4.5 | End of Loop J=1,NSEGM | | |
| **BLOCK 5** | | | |
| 5 | 1 | CORVSD | Correlation coefficient between Vs and D profiles |
| **BLOCK 6** | | | |


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# Example 10: Layer Thickness and VS Simulation by using Discrete Process Model

1
100 1 1 34521
BASESITE.SIT
GSITEXXX.SIT
1.98 10.86 -0.89 20
3.9 0.75 0.5 0.2 93152

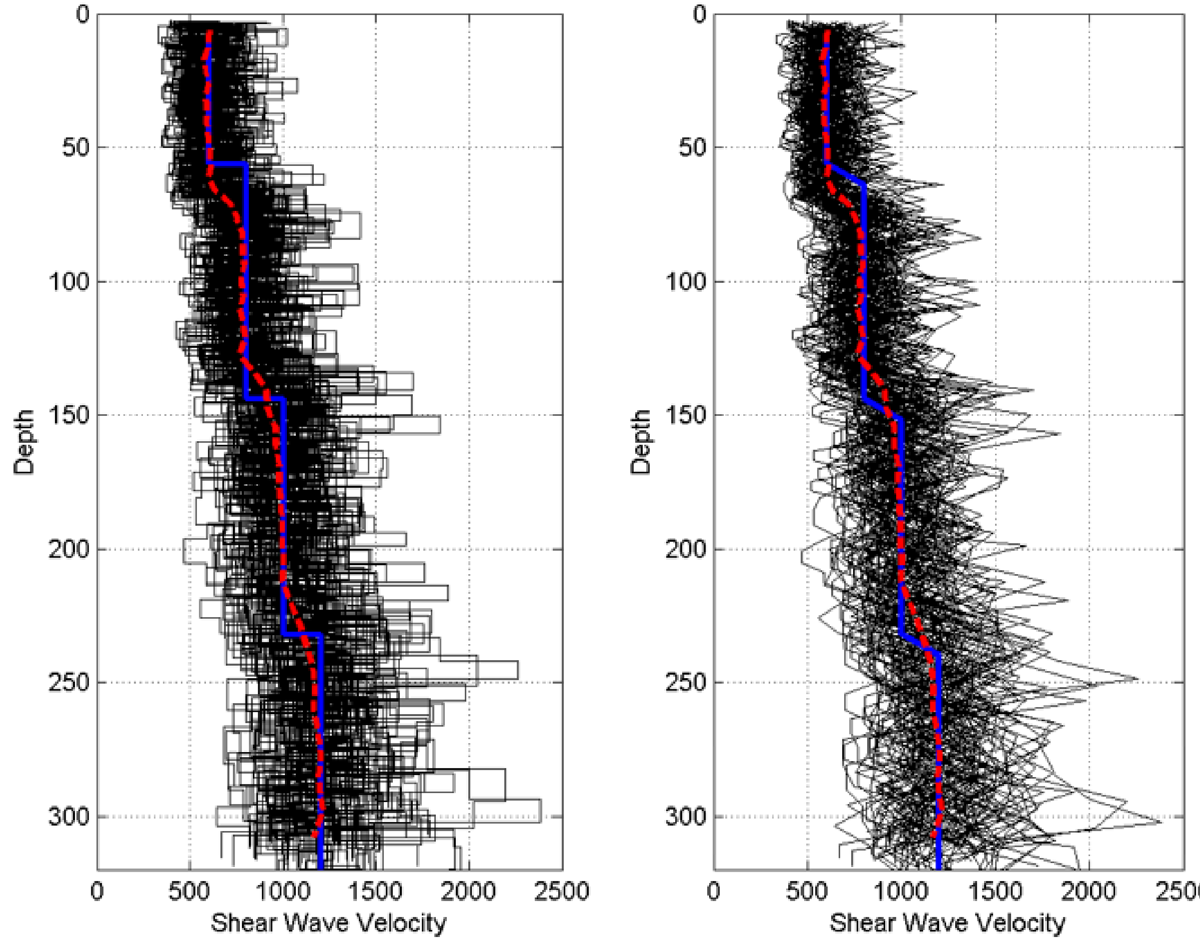


Figure A2.19 Thickness and Vs Mean Curves (red dotted) and Simulated Samples (black); Computed Probability Curves based on Input line (blue line) are plotted

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# ProSITE Input Parameters for Block 2 (M3)

| BLOCK B.2 | | | |
|---|---|---|---|
| | 1 | NSIMUL | Number of simulated seismic input files |
| | 1 | MOPTDVS | The option for simulating thickness and vs<br>= 0 only for simulating thickness<br>= 1 simulating both thickness and vs |
| | 1 | NLAYTHK | The number of layering to start simulation |
| | 1 | XTHKSEED | The initial seed number |
| | 2 | FBASEL | Filename for the mean soil profile (ex. BASELINE.SIT) |
| | 3 | FGSITE | Filenames for the simulated SITE inputs(ex. GSITExxx.sit) |
| | 4 | AX | Coefficient parameter of the fitted model |
| | 4 | BX | Initial parameter of the fitted model |
| | 4 | CX | Exponent parameter of the fitted model |
| | 4 | FMAX | Maximum frequency number |
| | If MOPTDVS=1 | | |
| | 5 | DELTA | The parameter to change in correlation with depth |
| | 5 | P0 | Correlation coefficient at surface level |
| | 5 | P200 | Correlation coefficient at 200m depth level |
| | 5 | XCOV | c.o.v. for simulating VS |
| | 5 | XVSEED | Initial seed number for simulating VS |

Layer thickness variation

Vs values variation



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# ProSOIL Simulation of Soil Material Behavior

```
NMAT2CUR, NSEGM, NSIMUL, NDIR, MOPT
FBASEL
FGSOIL
FGSITE
                                        Block 1
```

```
Loop J=1, NTCURVE
    SEEDMAT(J)
END LOOP J
                                        Block 2
```

```
Loop I=1, NTYPE
    NCURV(I), NDATA(I), CORL(I), GCOV(I), DCOV(I)
    Loop J=1, NDATA(I)
        SCALE(I,J))
    END LOOP J
END LOOP I
                                        Block 3
```

```
IF MOPT=1, THEN
    DMAX
ENDIF
                                        Block 4
```



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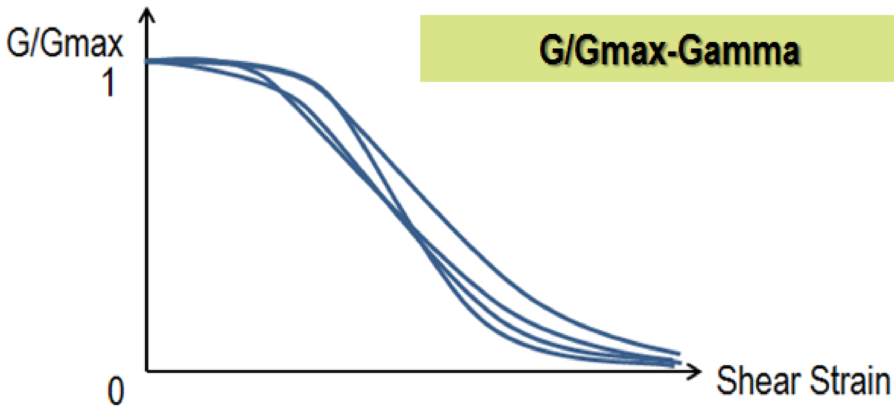
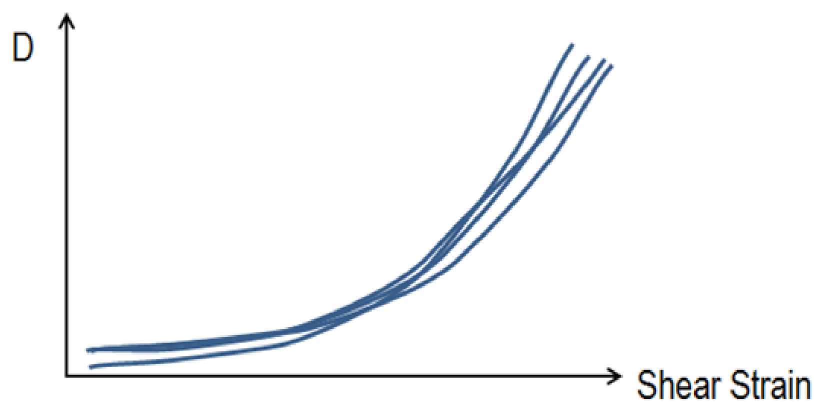
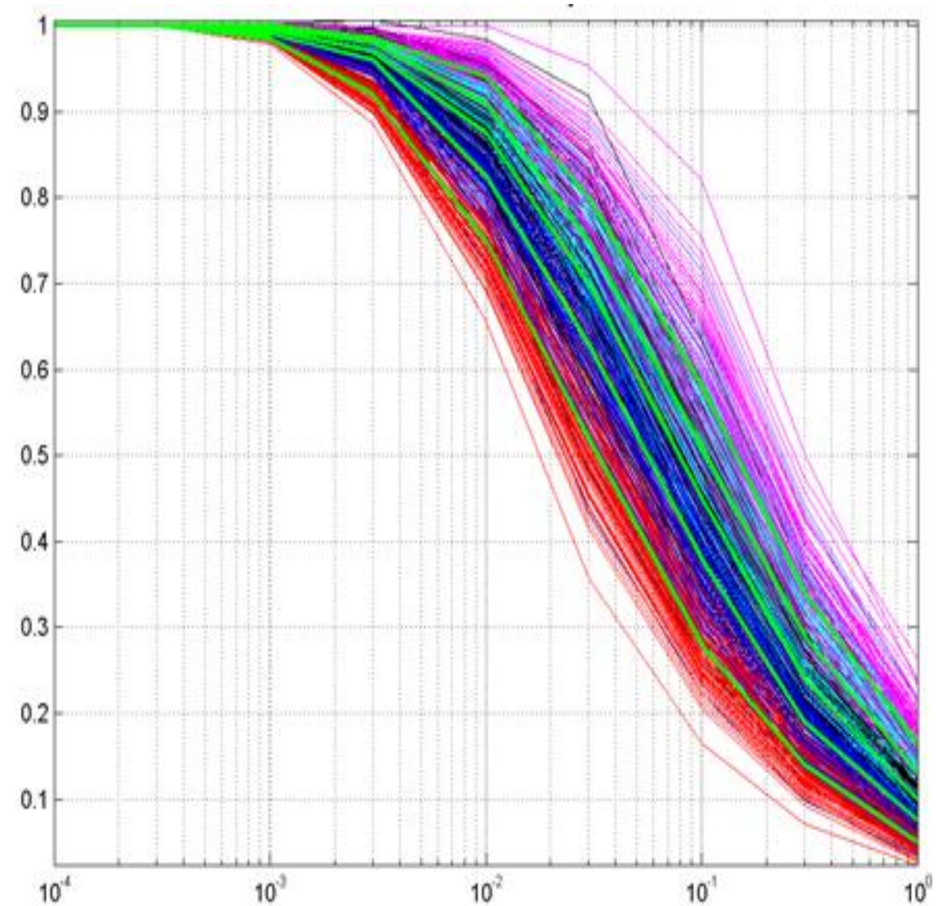
# ProSOIL Simulation of Soil Material Behavior

G/Gmax-Gamma




D-Gamma



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# ProSOIL Input Parameters for Blocks 1 and 2

| Input BlockNumber | Input File Line Number Inside Each Block | Variable Name (Input file in free format) | Definition of Input Variables |
|---|---|---|---|
| **BLOCK 1** | | | |
| 1 | 1 | NMAT2CUR | Number of soil material curves (this is twice than number of materials) |
| 1 | 1 | NSEGM | Number of the soil profile segments (or number of sets of multiple soil layers above half-space) |
| 1 | 1 | NSIMUL | Number of simulations |
| 1 | 1 | NDIR | Seismic input direction<br>= 0 horizontal (uses Vs)<br>= 1 vertical (uses Vp) |
| 1 | 1 | MOPT | Option to cut-off D-GAMMA curve<br>= 0 No cut-off<br>=1 Cut-off |
| 1 | 2 | FBASEL | Filename for the mean soil profile (ex. BASELINE.SOI) |
| 1 | 3 | FGSOIL | Filenames for the simulated SOIL inputs (ex. GSOILxxx.sit) |
| 1 | 4 | FGSITE | Filenames for the simulated SITE inputs (ex. GSITExxx.sit) |
| **BLOCK 2** | Start Loop J=1, NMAT2CUR | | |
| | 1 Inside of I Loop | SEEDMAT(J) | Seed number of material curve (J) |
| | End Loop J=1, NMAT2CUR | | |



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# ProSOIL Input Parameters for Blocks 3 and 4

| | | | |
|---|---|---|---|
| **BLOCK 3** | Start Loop I=1, NSEGM | | |
| | 1 Inside of I Loop | NCURV(I) | Number of material curves for soil segment (i) |
| | 1 Inside of I Loop | NDATA(I) | Number of data points for material curvesin segment (i) |
| | 1 Inside of I Loop | CORL(I) | Correlation length for segment (i) |
| | 1 Inside of I Loop | GCOV(I) | Coefficient of variation for the low-strain shear modulus for segment (i) |
| | 1 Inside of I Loop | DCOV(I) | Coefficient of variation for the low-strain damping for segment (i) |
| | Start Loop K=1, NDATA(I) | | |
| | 1 Inside of K Loop | SCALE(I,K) | Reduction factor for the coefficients of variations as a function of the soil shear strain |
| | End Loop K=1, NDATA(I) | | |
| | End Loop I=1, NSEGM | | |
| **BLOCK 4** | If MOPT = 1 | | |
| | DMAX | | Max value to cut-off D-Gamma curve |



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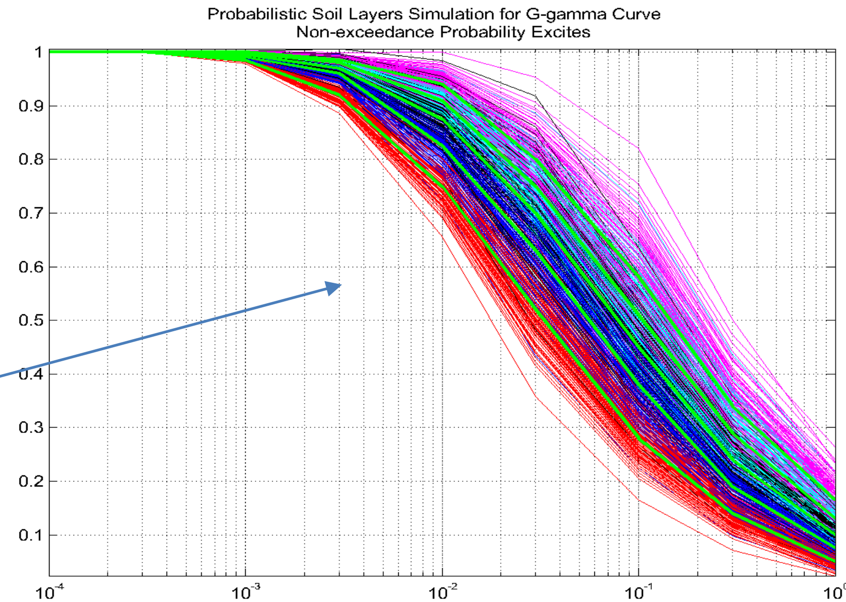
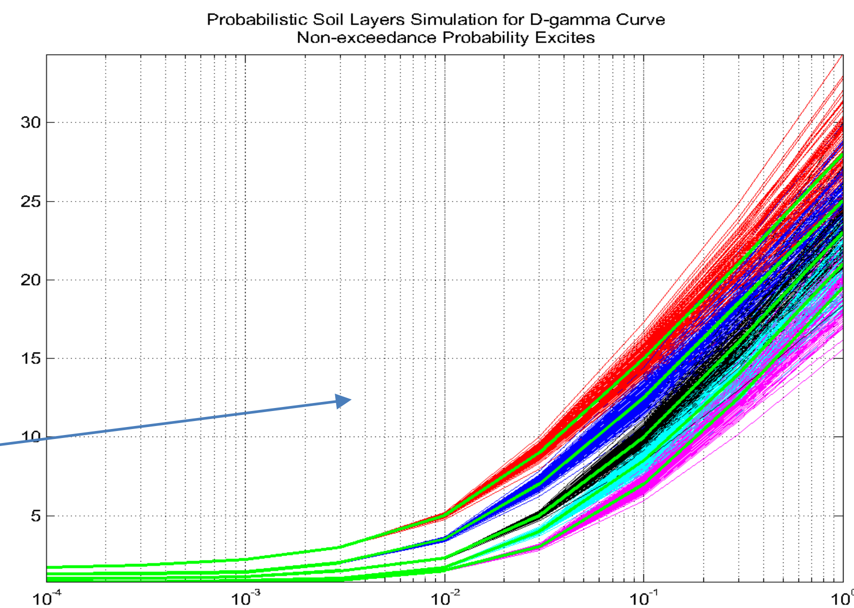
# EXAMPLE 1: 3 SOIL LAYERING MATERIAL CURVES

```
10 3 100 0 0
BASESOIL.soi
GSOILXXX.soi
GSITEXXX.SIT
12345
12313
34212
34345
57322
34556
78434
45667
56734
89832
5 9  4.0  0.40  0.15
0
0
0.005
0.03
0.1
0.25
0.33
0.4
0.5
3 9  4.0  0.40  0.15
0
0
0.0025
0.01
0.05
0.15
0.33
0.4
0.5
2 9 4.0  0.40  0.15
0
0
0.0025
0.01
0.05
0.15
0.33
0.4
0.5
```



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# EXAMPLE 1: 3 SOIL LAYERING MATERIAL CURVES

```
10 3 100 0 0
BASESOIL.soi
GSOILXXX.soi
GSITEXXX.SIT
12345
12313
34212
34345
57322
34556
78434
45667
56734
89832
5 9  4.0  0.40  0.15
0
0
0.005
0.03
0.1
0.25
0.33
0.4
0.5
3 9  4.0  0.40  0.15
0
0
0.0025
0.01
0.05
0.15
0.33
0.4
0.5
2 9 4.0  0.40  0.15
0
0
0.0025
0.01
0.05
0.15
0.33
0.4
0.5
```

1

2

3

| | | | |
|---|---|---|---|
| **BLOCK 3** | Start Loop I=1, NSEGM | | |
| | 1 Inside of I Loop | NCURV(I) | Number of material curves for soil segment (i) |
| | 1 Inside of I Loop | NDATA(I) | Number of data points for material curvesin segment (i) |
| | 1 Inside of I Loop | CORL(I) | Correlation length for segment (i) |
| | 1 Inside of I Loop | GCOV(I) | Coefficient of variation for the low-strain shear modulus for segment (i) |
| | 1 Inside of I Loop | DCOV(I) | Coefficient of variation for the low-strain damping for segment (i) |
| | Start Loop K=1, NDATA(I) | | |
| | 1 Inside of K Loop | SCALE(I,K) | Reduction factor for the coefficients of variations as a function of the soil shear strain |
| | End Loop K=1, NDATA(I) | | |
| | End Loop I=1, NSEGM | | |
| **BLOCK 4** | If MOPT = 1 | | |
| | DMAX | | Max value to cut-off D-Gamma curve |



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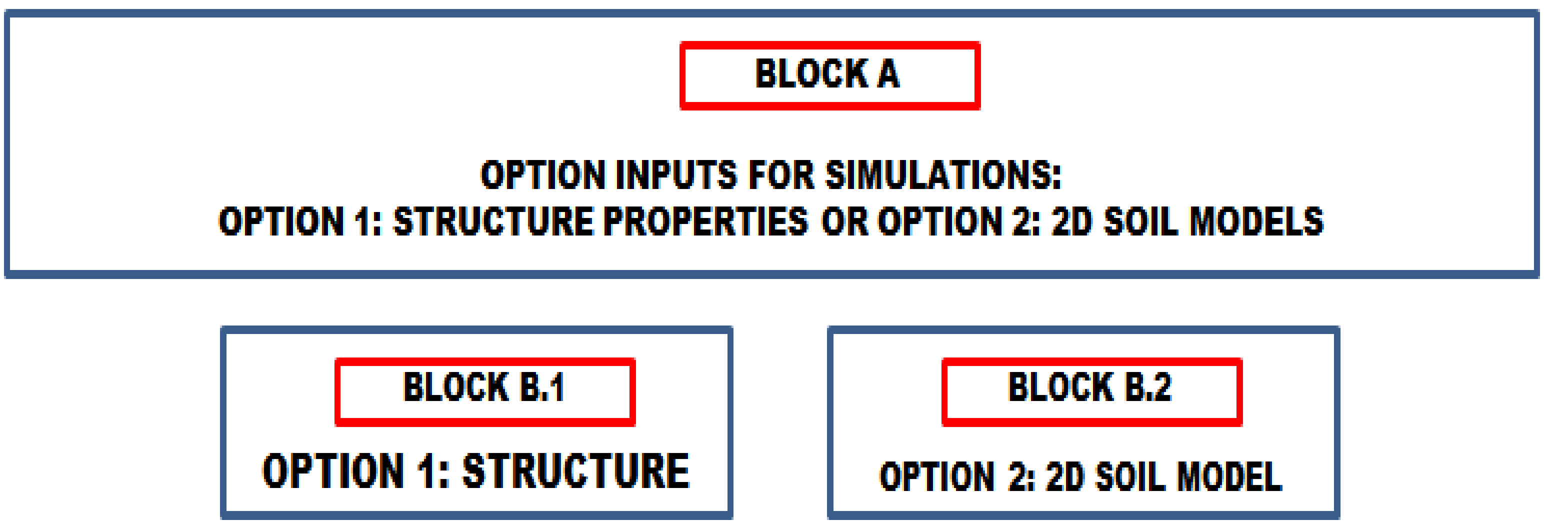
# ProHOUSE for Structure (or Soil) Properties

This ProHOUSE Module has two optional inputs:

- Option 1: For 2D or 3D structure FE models, input the structure effective stiffness and damping per element group, or
- Option 2: For 2D soil models, input Vs and D soil profiles with random variations in both vertical and horizontal directions.

The first line of the input file ‘GHOU.IN’ lists the option: 0 for 3D simulations and 1 for 2D simulations.



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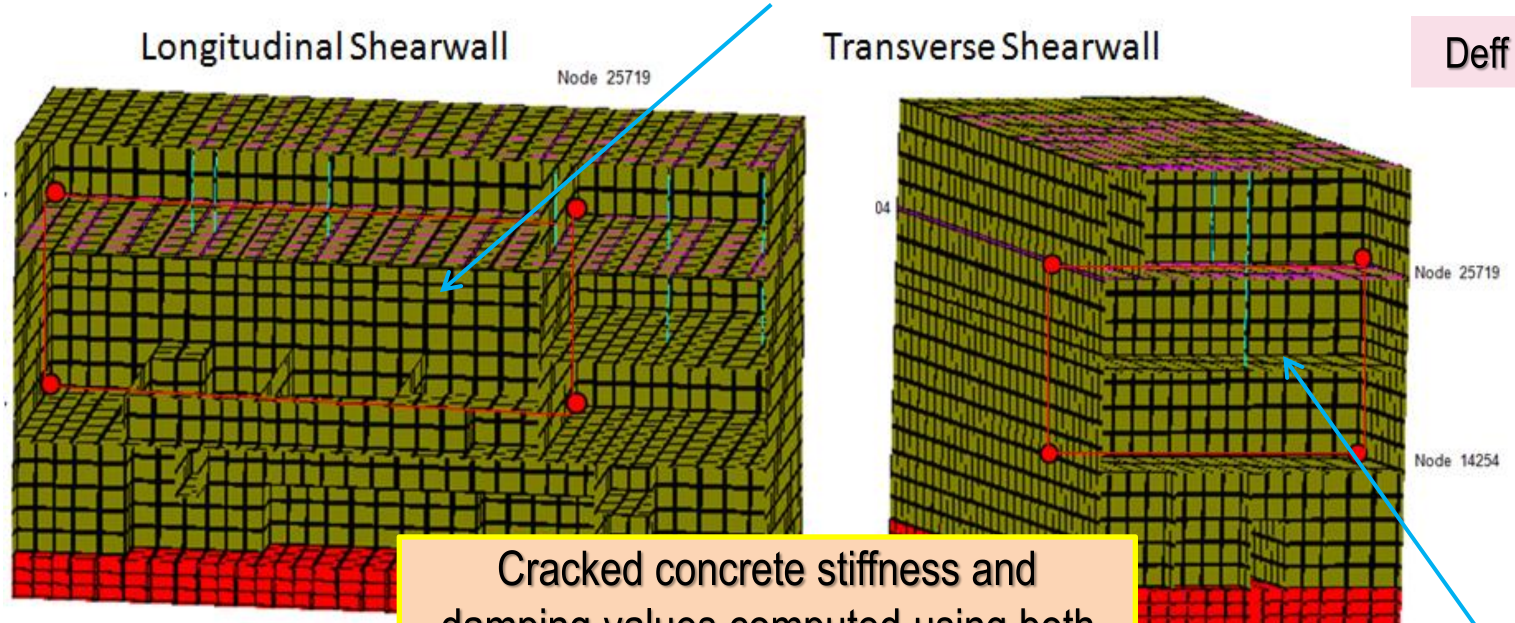
# Option 1: Probabilistic Structural Models; Effective Stiffness and Damping *Depend on Wall Strain Levels*

- Keff/Kel and Deff variables should defined by user *for each element group.*
- Effective stiffness ratio Keff/Kelastic and damping ratio, Deff, should be modeled as *statistically dependent* random variables. They can be considered *negatively correlated*, or Deff defined as a *response function* of Keff/Kelastic based on experimental tests.




Cracked concrete stiffness and damping values computed using both Option PRO and NON capabilities.

Deff = f (Keff/Kelastic)

| Stiff | Damp |
|---|---|
| 0.01 | 0.20 |
| 0.10 | 0.17 |
| 0.20 | 0.15 |
| 0.30 | 0.13 |
| 0.40 | 0.11 |
| 0.50 | 0.10 |
| 0.60 | 0.09 |
| 0.70 | 0.08 |
| 0.80 | 0.07 |
| 0.90 | 0.06 |
| 1.00 | 0.05 |

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# Effective Wall Stiffness and Damping Can Be Computed with Option NON as Function of *Shear Strain*

An accurate approach for the low-rise concrete shearwall structures for estimating the effective stiffness and effective damping for each simulation due to the in-plane shear deformation is based on the Option NON that computes automatically these parameters based on the physical behavior of the concrete structure walls.

If Option NON is used, the initial values of the effective stiffness and effective damping for all concrete elements should be based on the uncracked concrete behavior that is 1.00 (uncracked elastic modulus) and 4% damping ratio.

ProNON should be used to simulate probabilistic BBCs for the concrete wall shear deformation.


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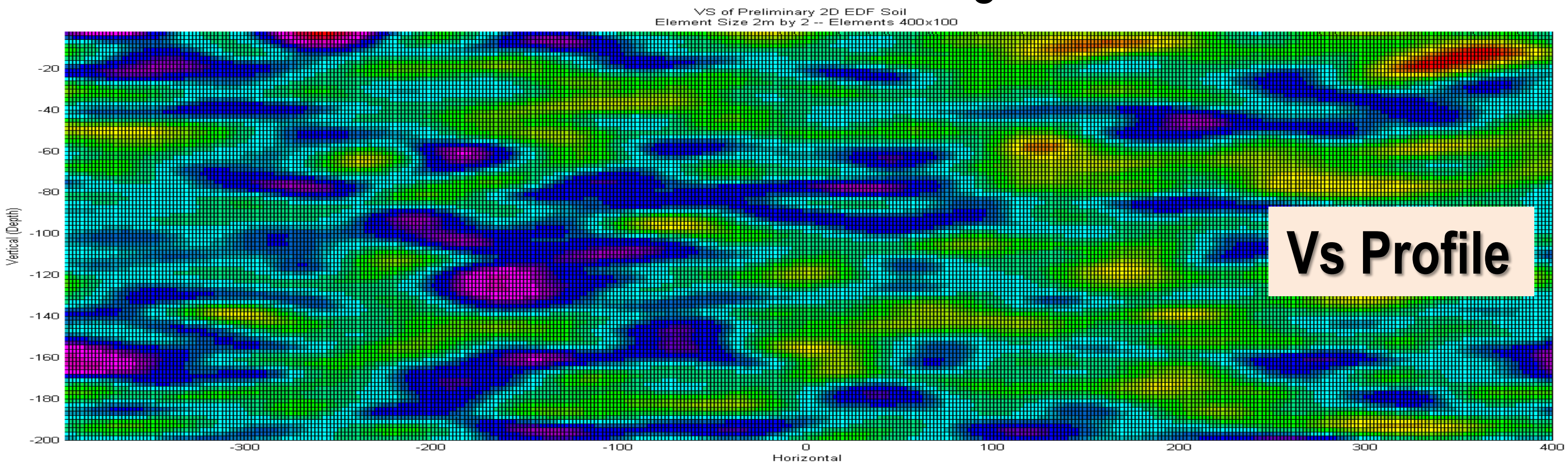
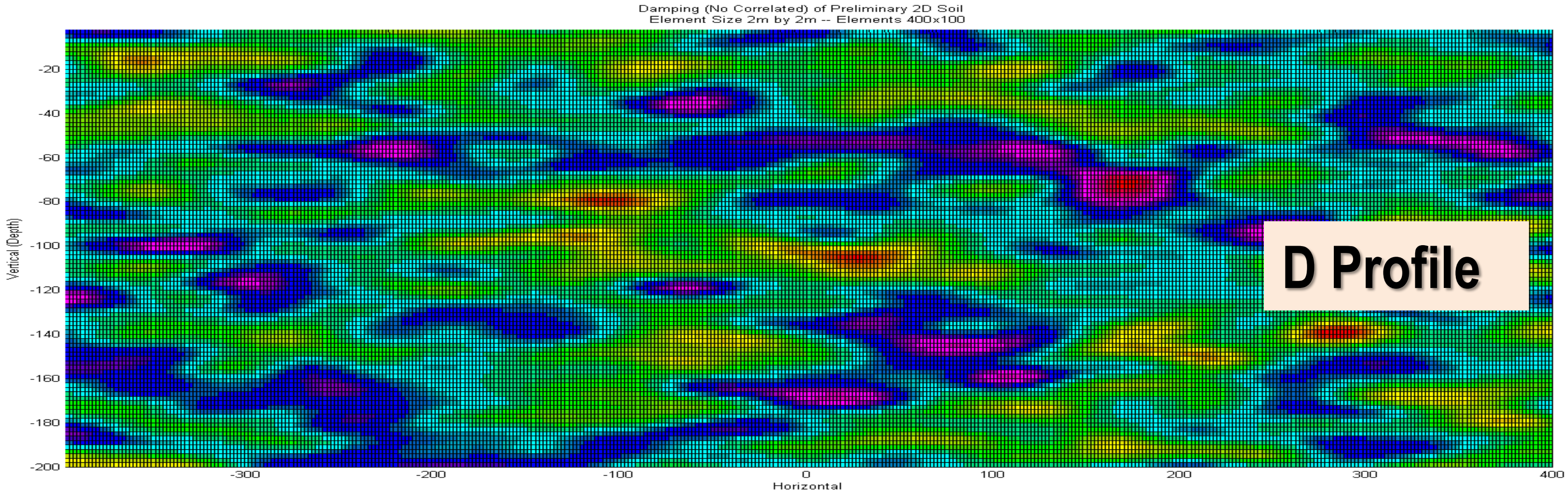
# Option 2: Simulated Vs and D Soil Profiles for Uniform Deep Soil Deposit

Vs and D Simulation for Correlation Lengths of 60m x 10m

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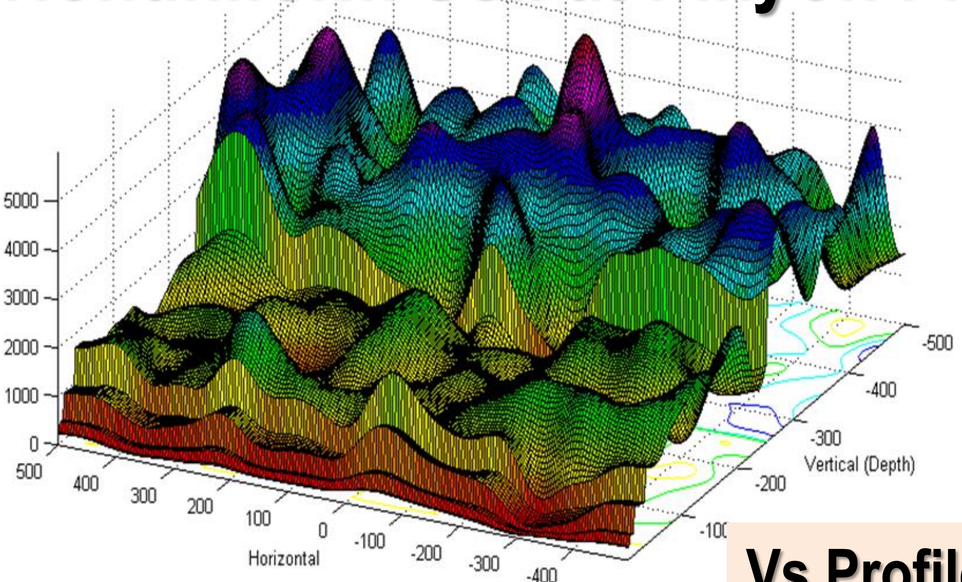
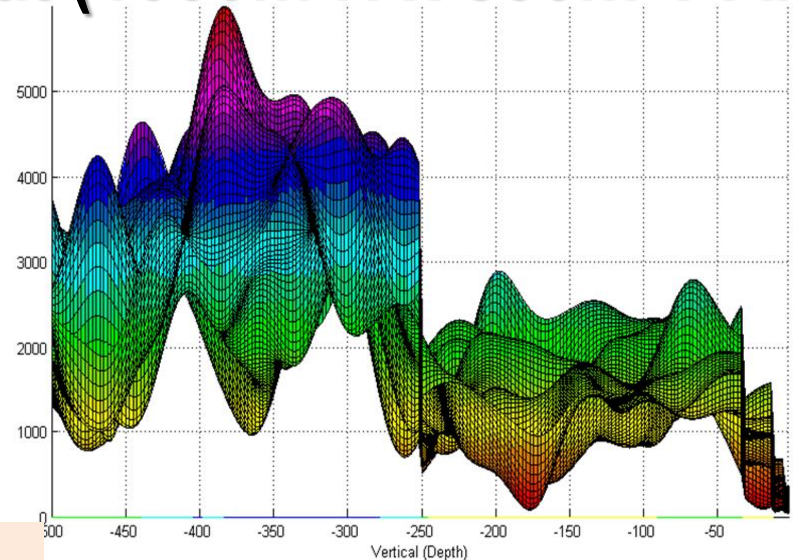
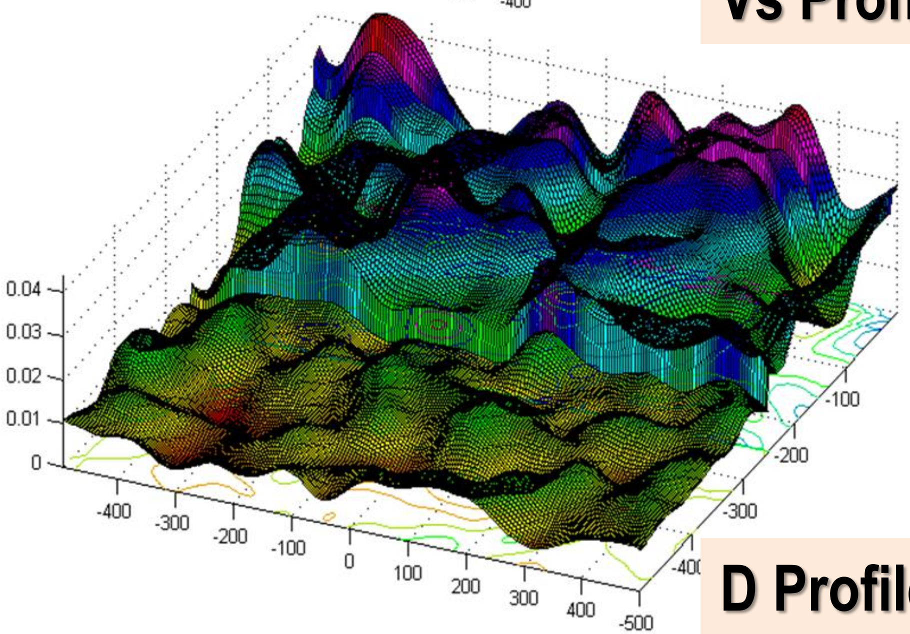
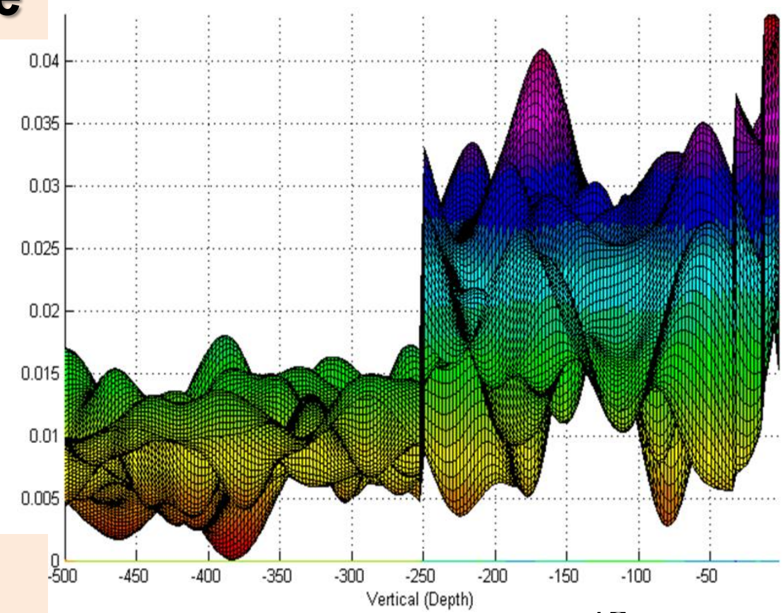
# Probabilistic Simulations Vs and D Soil Profiles for Nonuniform Soil at Pinyon Flat (1000m H x 500m V Area)




**Vs Profile**






**D Profile**



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# Armenian NPP Project Used 2D Probabilistic Soil Models

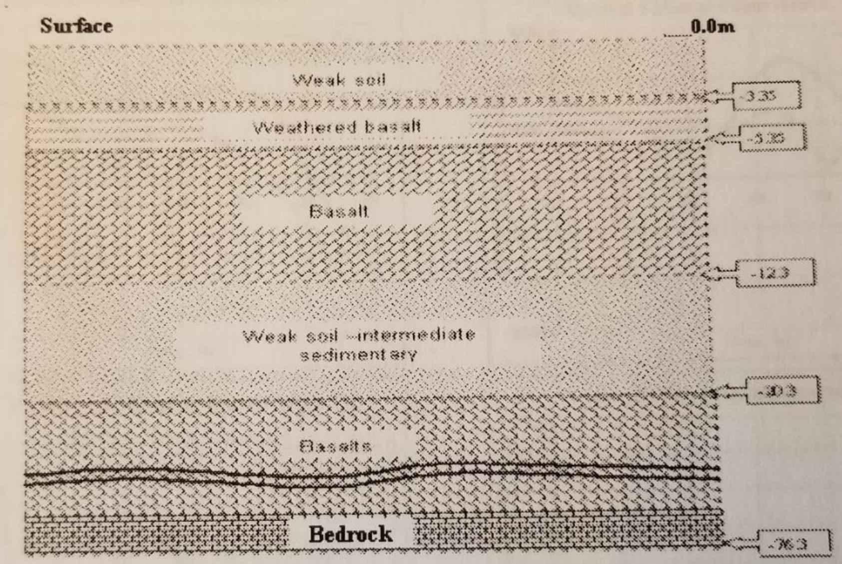


Figure 6. Layered soil profile under the Armenian Nuclear Power Plant (ANPP)

**Spatially Correlated Vs Profiles. Simos and Costantino (1997).**

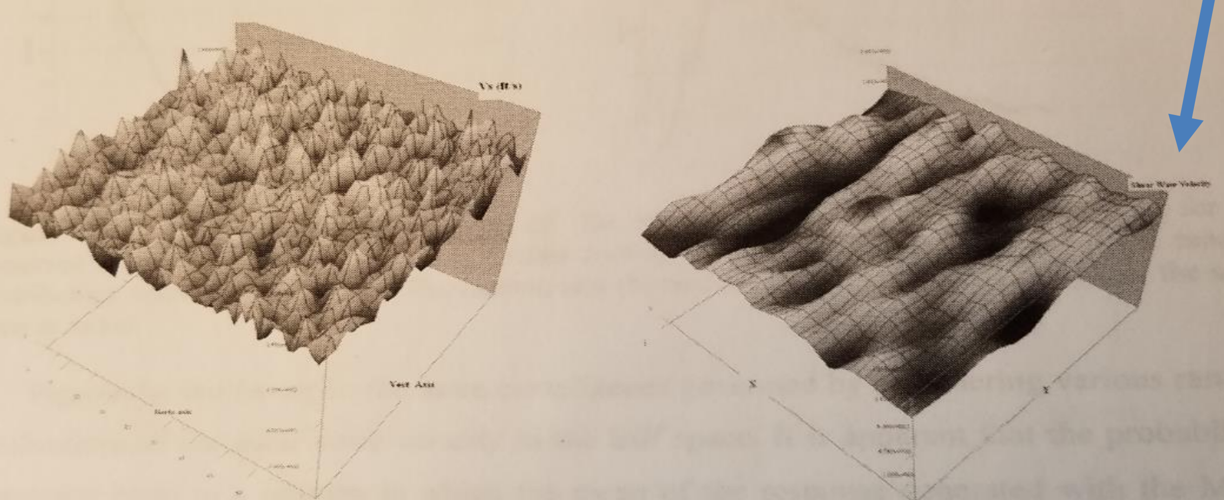

Figure 3. (a) Randomized shear wave velocity in half space domain of Figure 2 without special correlation and (b) resulting shear wave spatial distribution after cross-correlation procedures have been introduced in the randomized field shown in (a).



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# ProHOUSE Input for Option 1 (Block B.1)

```
NMODGRP, NSIMUL, OPTCOR, IEMB
IF IEMB = 1 THEN    FGSITE
FBASEL
FGHOU
                                        Block 1
```

```
LOOP J=1,NMODGRP
    JGROUP(J), NTYPE(J), NMAT(J), SEEDST(J)
    IF NTYPE(J) =1  THEN
        LOOP N=1, NMAT(J)
            JNVAR(J,N),  STFMEAN(J,N), STFCOV(J,N)
        END LOOP N
    IF NTYPE(J) =2  THEN
        LOOP N=1, NMAT(J)
            JNVAR(J,N),  VPMEAN(J,N), VPCOV(J,N) ),  VSMEAN(J,N), VSCOV(J,N)
        END LOOP N
    IF NTYPE(J) = 3  THEN
        LOOP N=1, NMAT(J)
            JNVAR(J,N),  XMEAN(J,N), XCOV(J,N) ),  YMEAN(J,N), YCOV(J,N) ,
            ZMEAN(J,N), ZCOV(J,N) ),  XXMEAN(J,N), XXCOV(J,N) ),
            YYMEAN(J,N), YYCOV(J,N),  ZZMEAN(J,N), ZZCOV(J,N)
        END LOOP N
                                        Block 2
```

```
IF OPTCOR ≤ 1  THEN   SEEDD(J)
    LOOP N=1, NMAT(J)
        DGMEAN(J,N),  DCOV(J,N)
    END LOOP  N
END LOOP J
                                        Block 3.1
```

```
IF OPTCOR = 2  THEN   NDATA(J)
    LOOP K=1, NDATA(J)
        SRATIO(J,K),  DRATIO(J,K)
    END LOOP  K
END LOOP J
                                        Block 3.2
```

```
IF OPTCOR = 0
CORRSTD
                                        Block 4
```



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# NMODGRP Variable for Material Randomization

The NMODGRP variable is the number of material groups used by the analyst to define the statistical dependency status between different materials. It should be noted that different materials in the same or different element groups can be either statistically independent or perfectly correlated. The material groups includes a number of subsets of materials that are statistically independent.

For example, if an element group has five materials which are considered all statistically independent, then, all these five materials belong to the same single material group. If all five materials are considered perfectly correlated, then, each material has to be defined in a separate group with the same SEEDST number. Each material group includes a single material. If the SEEDST number is not the same between different material groups, then, the material groups are statistically independent. Thus, the SEEDST number is used to control the statistical dependency, independent or perfectly correlated, between material groups. It should be noted that the materials should not necessarily belong to the same element group.



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# OPTCOR Variable for Statistical Dependence Between Stiffness and Damping Variations

The ProHOUSE module includes three options to handle the dependency between the effective stiffness reduction and the damping increase. These options are controlled by the OPTCOR input variable.

The four dependency options between the stiffness reduction and the damping correspond to:

1) correlated variables (Blocks 3.1 and 4),
2) independent variables (Block 3.1), and
3) damping is a function of stiffness reduction (Block 3.2).


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# ProHOUSE Input Parameters for Option 1, Block 1

| Input BlockNumber | Input File Line Number Inside Each Block | Variable Name (Input file in free format) | Definition of Input Variables |
|---|---|---|---|
| **BLOCK A** | | | |
| 1 | 1 | OPTDIM | Dimension selection:<br>=0 Structure Material Properies<br>=1 2D Soil Model Vs and D Properties |
| **BLOCK B.1:** | | | |
| **BLOCK 1** | | | |
| 1 | 1 | NMODGRP | Number of element groups that are modified (groups can be repeated for different independent materials) |
| 1 | 1 | NSIMUL | Number of simulations |
| 1 | 1 | OPTCOR | Option for statistical dependency between stiffness reduction and damping<br>= 0 Correlated random variables<br>= 1 Independent random variables<br>= 2 Deterministic functional dependence; damping is a function of stiffness reduction |
| 1 | 1 | IEMB | Model option:<br>0 = surface model<br>1 = embedded model |
| | | | |
| 1 | 2 (for IEMB=1) | FGSITE | SITE simulated files (GSITExxx.sit) |
| 1 | 2 (for IEMB=0) or 3 (for IEMB=1) | FBASEL | Baseline input file (BASELINE.HOU) |
| 1 | 3 (for IEMB=0) or 4 (for IEMB=1) | FGHOU | HOUSE simulated files (GHOUxxx.hou) |

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# ProHOUSE Input Parameters for Option 1, Block 2

| | | | |
|---|---|---|---|
| **BLOCK 2** | Start Loop J=1,NMODGRP | | |
| 2 | 1 Inside of J Loop | JGROUP(J) | Number of the element group |
| 2 | 1 Inside of J Loop | NTYPE(J) | Element property type:<br>1 = Concrete type property, E materials<br>2 = Soil type property, Vp and Vs<br>3 = Spring properties |
| 2 | 1 Inside of J Loop | NMAT(J) | Number of materials in JGROUP(J) that use the same SEEDST(J); fully correlated |
| 2 | 1 Inside of J Loop | SEEDST(J) | Seed number for stiffness simulation |
| 2 | Start Loop N=1,NMAT(J) | | |
| 2 | 1 Inside of N Loop If NTYPE(J) = 1 | JNVAR(J,N) | "E" Material number for JGROUP(J) |
| 2 | | STFMEAN(J,N) | Stiffness reduction factor mean for JNVAR(J) |
| 2 | | STFCOV(J,N) | Stiffness reduction factor coefficient of variation for JNVAR(J) |
| | 1 Inside of N Loop If NTYPE(J) = 2 | JNVAR(J,N) | "Soil Property" number for JGROUP(J) |
| | | VPMEAN(J,N) | VP reduction factor mean for JNVAR(J) |
| | | VPCOV(J,N) | VP reduction factor coefficient of variation for JNVAR(J) |


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# ProHOUSE Input Parameters for Option 1, Block 2

| | | | |
|---|---|---|---|
| | | VSMEAN(J,N) | VS reduction factor mean for JNVAR(J) |
| | | VSCOV(J,N) | VS reduction factor coefficient of variation for JNVAR(J) |
| | 1 Inside of N Loop<br>If NTYPE(J) = 3 | JNVAR(J,N) | "Spring Property" number for JGROUP(J) |
| | | XMEAN(J,N) | X Stiffness reduction factor mean for JNVAR(J) |
| | | XCOV(J,N) | X Stiffness reduction factor coefficient of variation for JNVAR(J) |
| | | YMEAN(J,N) | Y Stiffness reduction factor mean for JNVAR(J) |
| | | YCOV(J,N) | Y Stiffness reduction factor coefficient of variation for JNVAR(J) |
| | | ZMEAN(J,N) | Z Stiffness reduction factor mean for JNVAR(J) |
| | | ZCOV(J,N) | Z Stiffness reduction factor coefficient of variation for JNVAR(J) |
| | | XXMEAN(J,N) | XX Stiffness reduction factor mean for JNVAR(J) |
| | | XXCOV(J,N) | XX Stiffness reduction factor coefficient of variation for JNVAR(J) |
| | | YYMEAN(J,N) | YY Stiffness reduction factor mean for JNVAR(J) |
| | | YYCOV(J,N) | YY Stiffness reduction factor coefficient of variation for JNVAR(J) |
| | | ZZMEAN(J,N) | ZZ Stiffness reduction factor mean for JNVAR(J) |
| | | ZZCOV(J,N) | ZZ Stiffness reduction factor coefficient of variation for JNVAR(J) |
| | End Loop N=1,NMAT(J) | | |



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# ProHOUSE Input Parameters for Option 1, Block 3

| | | | |
|---|---|---|---|
| **BLOCK 3** | | | |
| 3.1 | 1 | SEEDD(J) | Seed number for the damping simulation |
| 3.1 | Start Loop N=1,NMAT(J) | | |
| 3.1 | 1 Inside N Loop | DMEAN(J,N) | Damping mean for JNVAR(J) |
| 3.1 | 1 Inside N Loop | DCOV(J,N) | Damping coefficient of variation for JNVAR(J) |
| 3.1 | End Loop N=1,NMAT(J) | | |
| 3.2 | 1 | NDATA(J) | Number of data points for damping as a function of stiffness reduction factor (<100) |
| 3.2 | Start Loop K=1,NDATA(J) | | |
| 3.2 | 1 Inside K Loop | STRESF(J,K) | Stiffness value at data points |
| 3.2 | 1 Inside K Loop | DRESF(J,K) | Damping value at data points |
| 3.2 | End Loop K=1,NDATA(J) | | |
| 3.1,.3.2 | End Loop J=1, NMODGRP | | |
| **BLOCK 4** | | | |
| | 1 | CORRSTD | Correlation between stiffness reduction factor and damping |



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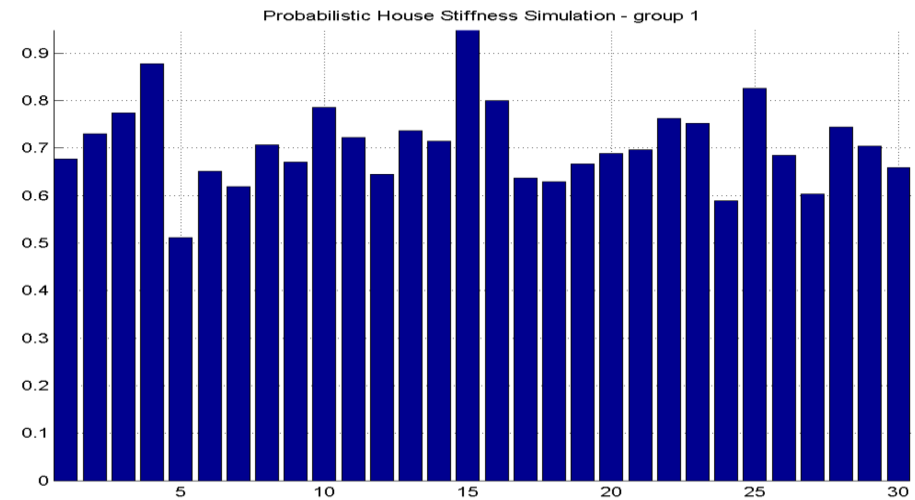
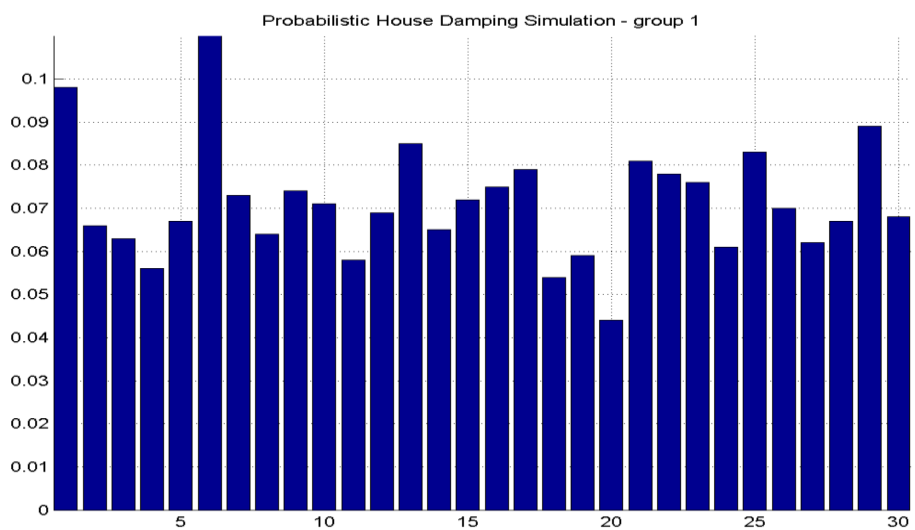
# EXAMPLE 3: EMBEDDED SSI MODEL WITH SOIL PROPERTIES, SINGLE ELEMENT GROUP, STIFFNESS REDUCTION FACTOR (SRF) AND DAMPING D ARE STATISTICALLY CORRELATED WITH C.C. = - 0.80

```
0
3 30  0  1
GSITEXXX.SIT
BASELINE.hou
HOUSEXXX.hou
2 1 1 34511
1  0.7  0.1
56789
0.07  0.15
3 1 1 13451
1  0.9  0.1
15289
0.04  0.15
5 1 1 10951
1  0.9  0.1
64578
0.03  0.15
-0.8
```





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# Example 3: Embedded SSI Model with Soil Properties, Single Element Group, Stiffness Reduction Factor (SRF) and Damping D are Statistically Correlated with C.C. = - 0.80

```
0
3 30  0  1
GSITEXXX.SIT
BASELINE.hou
HOUSEXXX.hou
2 1 1 34511
1  0.7  0.1
56789
0.07  0.15
3 1 1 13451
1  0.9  0.1
15289
0.04  0.15
5 1 1 10951
1  0.9  0.1
64578
0.03  0.15
-0.8
```

**Block 1**

NMODGRP, NSIMUL, OPTCOR, IEMB
*IF IEMB = 1 THEN* FGSITE
FBASEL
FGHOU

3 30 0 1

**Block 2**

*LOOP J=1,NMODGRP*
JGROUP(J), NTYPE(J), NMAT(J), SEEDST(J)
*IF NTYPE(J) =1 THEN*
*LOOP N=1, NMAT(J)*
JNVAR(J,N), STFMEAN(J,N), STFCOV(J,N)
*END LOOP N*
*IF NTYPE(J) =2 THEN*
*LOOP N=1, NMAT(J)*
JNVAR(J,N), VPMEAN(J,N), VPCOV(J,N) ), VSMEAN(J,N), VSCOV(J,N)
*END LOOP N*
*IF NTYPE(J) = 3 THEN*
*LOOP N=1, NMAT(J)*
JNVAR(J,N), XMEAN(J,N), XCOV(J,N) ), YMEAN(J,N), YCOV(J,N) ,
ZMEAN(J,N), ZCOV(J,N) ), XXMEAN(J,N), XXCOV(J,N) ),
YYMEAN(J,N), YYCOV(J,N), ZZMEAN(J,N), ZZCOV(J,N)
*END LOOP N*

**Block 3.1**

*IF OPTCOR ≤ 1 THEN* SEEDD(J)
*LOOP N=1, NMAT(J)*
DGMEAN(J,N), DCOV(J,N)
*END LOOP N*
*END LOOP J*

**Block 3.2**

*IF OPTCOR = 2 THEN* NDATA(J)
*LOOP K=1, NDATA(J)*
SRATIO(J,K), DRATIO(J,K)
*END LOOP K*
*END LOOP J*

**Block 4**

*IF OPTCOR = 0*
CORRSTD



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# Example 3: Embedded SSI Model with Soil Properties, Single Element Group, Stiffness Reduction Factor (SRF) and Damping D are Statistically Correlated with C.C. = - 0.80

```
0
3 30  0  1
GSITEXXX.SIT
BASELINE.hou
HOUSEXXX.hou
2 1 1 34511
1  0.7  0.1
56789
0.07  0.15
3 1 1 13451
1  0.9  0.1
15289
0.04  0.15
5 1 1 10951
1  0.9  0.1
64578
0.03  0.15
-0.8
```

| | | | |
|---|---|---|---|
| **BLOCK 2** | Start Loop J=1,NMODGRP | | |
| 2 | 1 Inside of J Loop | JGROUP(J) | Number of the element group |
| 2 | 1 Inside of J Loop | NTYPE(J) | Element property type:<br>1 = Concrete type property, E materials<br>2 = Soil type property, Vp and Vs<br>3 = Spring properties |
| 2 | 1 Inside of J Loop | NMAT(J) | Number of materials in JGROUP(J) that use the same SEEDST(J); fully correlated |
| 2 | 1 Inside of J Loop | SEEDST(J) | Seed number for stiffness simulation |
| 2 | Start Loop N=1,NMAT(J) | | |
| 2 | 1 Inside of N Loop | JNVAR(J,N) | "E" Material number for JGROUP(J) |
| 2 | If NTYPE(J) = 1 | STFMEAN(J,N) | Stiffness reduction factor mean for JNVAR(J) |
| 2 | | STFCOV(J,N) | Stiffness reduction factor coefficient of variation for JNVAR(J) |
| **BLOCK 3** | | | |
| 3.1 | 1 | SEEDD(J) | Seed number for the damping simulation |
| 3.1 | Start Loop N=1,NMAT(J) | | |
| 3.1 | 1 Inside N Loop | DMEAN(J,N) | Damping mean for JNVAR(J) |
| 3.1 | 1 Inside N Loop | DCOV(J,N) | Damping coefficient of variation for JNVAR(J) |
| 3.1 | End Loop N=1,NMAT(J) | | |
| 3.2 | 1 | NDATA(J) | Number of data points for damping as a function of stiffness reduction factor (<100) |
| 3.2 | Start Loop K=1,NDATA(J) | | |
| 3.2 | 1 Inside K Loop | STRESF(J,K) | Stiffness value at data points |
| 3.2 | 1 Inside K Loop | DRESF(J,K) | Damping value at data points |
| 3.2 | End Loop K=1,NDATA(J) | | |
| 3.1,.3.2 | End Loop J=1, NMODGRP | | |
| **BLOCK 4** | | | |
| | 1 | CORRSTD | Correlation between stiffness reduction factor and damping |



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# ProHOUSE Input for Option 2, Block B.2

NSIMUL, OPTCOR , OPTDIST
FBASEL
FGHOU

**Block 1**

VSHCOLL, VSVCOLL, VSCOV, VS_SEED
DPHCOLL, DPVCOLL, DPCOV, DP_SEED

**Block 2**

*IF OPTCOR = 1*
CORRSTD

**Block 3**


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# ProHOUSE Input for Option 2, Block B.2

| Input Block Number | Input File Line Number Inside Each Block | Variable Name (Input file in free format) | Definition of Input Variables |
|---|---|---|---|
| **BLOCK A** | | | |
| **1** | 1 | OPTDIM | Dimension selection:<br>=0 Structure Material Properties<br>=1 2D Soil Model Vs and D Properties |
| **BLOCK B.2** | | | |
| **BLOCK 1** | | | |
| 1 | 1 | NSIMUL | Number of simulations |
| | 1 | OPTCOR | Option for correlation between shear velocity and damping<br>= 0 Correlated<br>= 1 No Correlated |
| 1 | 1 | OPTDIST | Option for Distribution which simulated outputs must follow<br>= 0 Normal Distribution<br>= 1Lognormal Distribution |
| | | | |
| 1 | 2 | FBASEL | Baseline input file (BASELINE.HOU) |
| 1 | 3 | FGHOU | HOUSE simulated files (GHOUxxx.hou) |
| **BLOCK 2** | | | |
| 2 | 1 | VSHCOLL | Correlation Length of Horizontal for Vs |
| 2 | 1 | VSVCOLL | Correlation Length of Vertical for Vs |
| 2 | 1 | VSCOV | coefficient of variation for Vs |
| 2 | 1 | VS_SEED | InitialSeed number for Vs simulation |
| 2 | 2 | DPHCOLL | Correlation Length of Horizontal for Damping |
| 2 | 2 | DPVCOLL | Correlation Length of Vertical for Damping |
| 2 | 2 | DPCOV | coefficient of variation for Damping |
| 2 | 2 | DP_SEED | InitialSeed number for Damping simulation |
| **BLOCK 3** | | | |
| 3 | 1 | CORRSTD | Correlation between shear velocity reduction factor and damping |


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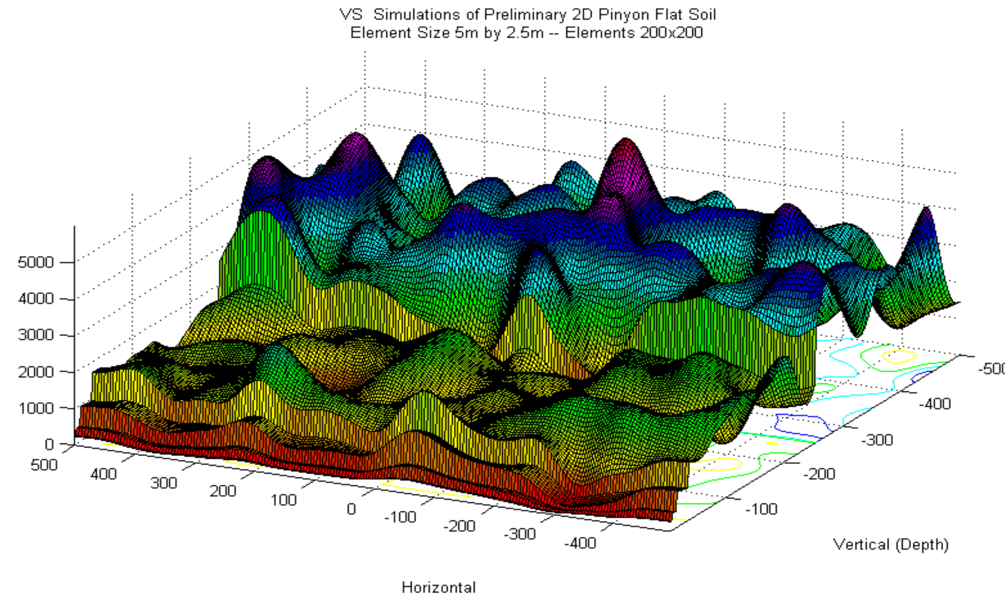
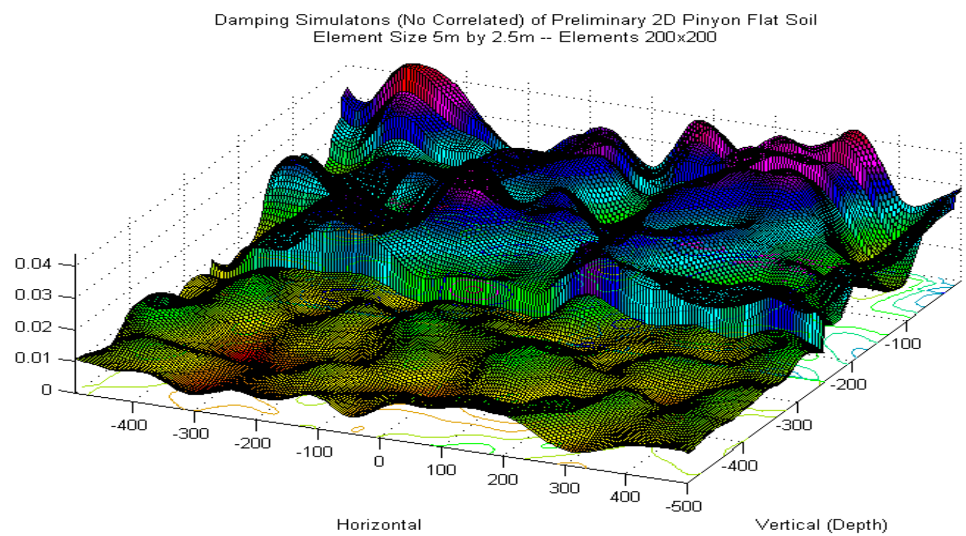
# Example 4: For 2D Layered Soil Model: Simulated Soil Shear Velocity Vs and Damping D As Gaussian Stochastic Fields With Separated Spatial Correlation Structure for Horizontal and Vertical Directions, and Negatively Inter-Correlated

1
60 0 0
BASELINE.HOU
Soil2DXXX.HOU
50 25 0.3 18556
50 25 0.3 85256
-0.6

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# Example 4: For 2D Layered Soil Model: Simulated Soil Shear Velocity Vs and Damping D As Gaussian Stochastic Fields With Separated Spatial Correlation Structure for Horizontal and Vertical Directions, and Negatively Inter-Correlated

1
60 0 0
BASELINE.HOU
Soil2DXXX.HOU
50 25 0.3 18556
50 25 0.3 85256
-0.6

| Input Block Number | Input File Line Number Inside Each Block | Variable Name (Input file in free format) | Definition of Input Variables |
|---|---|---|---|
| **BLOCK A** | | | |
| 1 | 1 | OPTDIM | Dimension selection:<br>=0 Structure Material Properties<br>=1 2D Soil Model Vs and D Properties |
| **BLOCK B.2** | | | |
| **BLOCK 1** | | | |
| 1 | 1 | NSIMUL | Number of simulations |
| | 1 | OPTCOR | Option for correlation between shear velocity and damping<br>= 0 Correlated<br>= 1 No Correlated |
| 1 | 1 | OPTDIST | Option for Distribution which simulated outputs must follow<br>= 0 Normal Distribution<br>= 1Lognormal Distribution |
| | | | |
| 1 | 2 | FBASEL | Baseline input file (BASELINE.HOU) |
| 1 | 3 | FGHOU | HOUSE simulated files (GHOUxxx.hou) |
| **BLOCK 2** | | | |
| 2 | 1 | VSHCOLL | Correlation Length of Horizontal for Vs |
| 2 | 1 | VSVCOLL | Correlation Length of Vertical for Vs |
| 2 | 1 | VSCOV | coefficient of variation for Vs |
| 2 | 1 | VS_SEED | InitialSeed number for Vs simulation |
| 2 | 2 | DPHCOLL | Correlation Length of Horizontal for Damping |
| 2 | 2 | DPVCOLL | Correlation Length of Vertical for Damping |
| 2 | 2 | DPCOV | coefficient of variation for Damping |
| 2 | 2 | DP_SEED | InitialSeed number for Damping simulation |
| **BLOCK 3** | | | |
| 3 | 1 | CORRSTD | Correlation between shear velocity reduction factor and damping |

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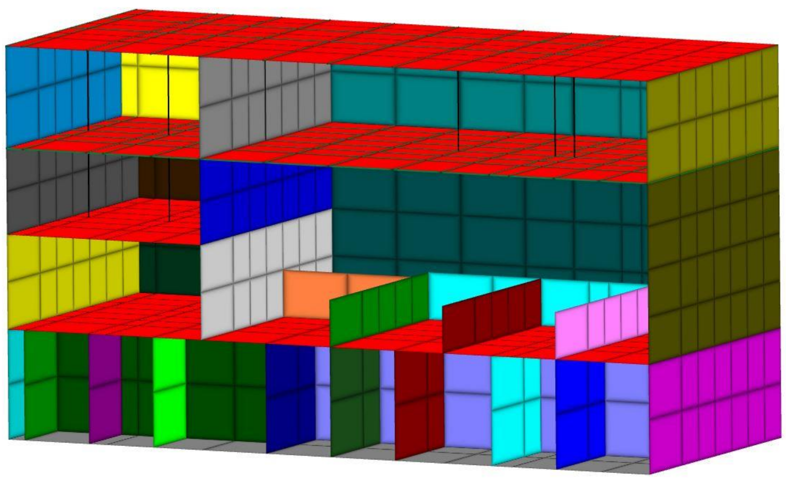
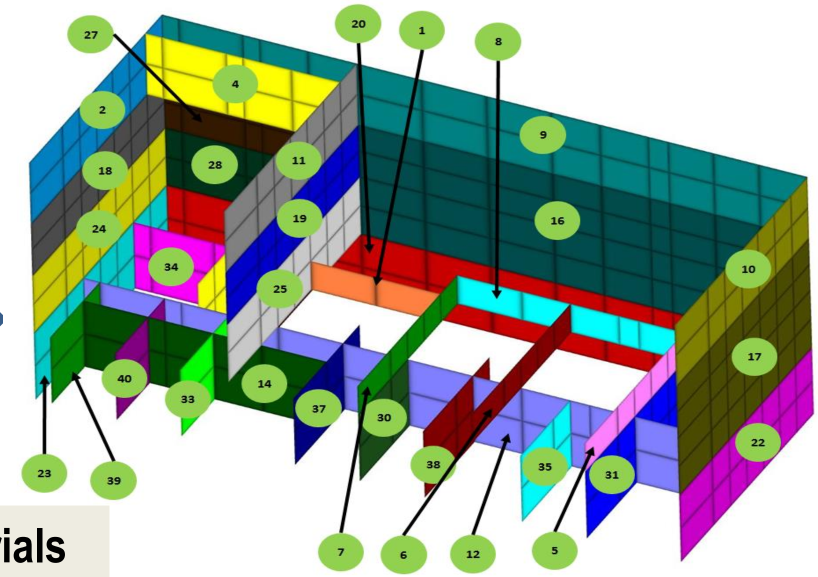
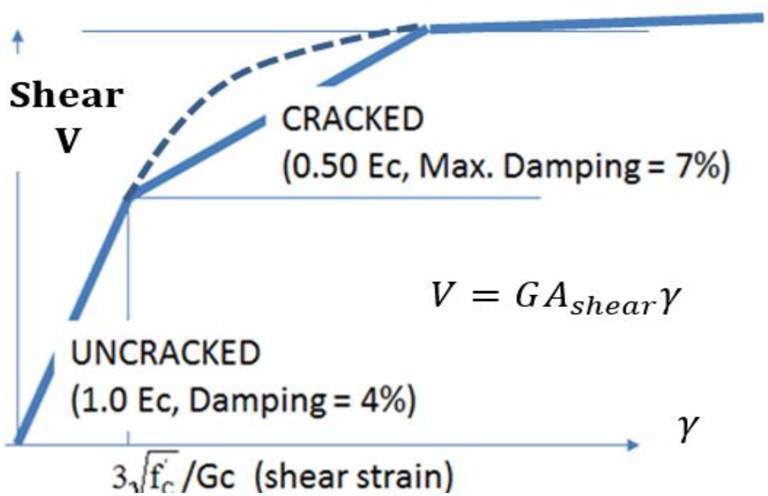
# ProNON Simulates Randomized BBCs for Option NON

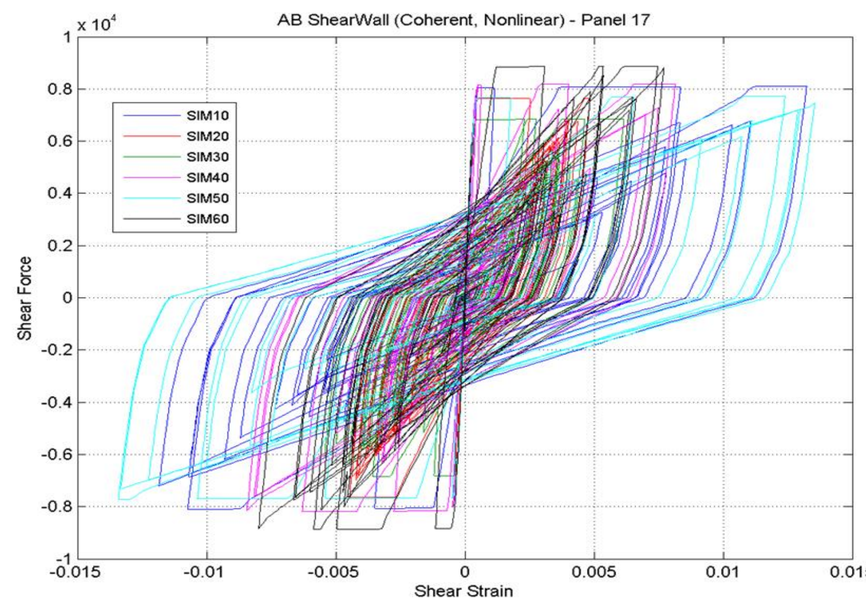





**Structure is split in wall panels with different materials**

**ProNON Automatically Generates BBCs**

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# ProNON for BBC Simulations for Option NON

| Input File Line Number | Variable Name (Input in free format) | Definition of Input Variables | Variable Type |
|---|---|---|---|
| 1 | NSIMUL | Number of simulations | Input |
| 1 | XM | Mean of Uncertainty Scale Factor | Input |
| 1 | XCOV | C.O.V of Uncertainty Scale Factor ( | Input |
| 1 | ISEED | Initial Seed Number of Uncertainty Scale Factor | Input |
| 2 | FBASEL | Baseline input file (BASELINE.EQL) | Input |
| 3 | FGEQL | Simulated input samples for the nonlinear runs (.eql extension) | Output |
| 4 | FBASEH | Baseline hou input file (BASELINE.HOU) | Input |
| 5 | FGHOU | Simulated input *.HOU files (.hou extension) | Input |
| 6 | NOPT | Option to set the maximum of strain (0=use maximum of simulations, 1=users define) | Input |
| 7 | XSTRAIN | Maximum of strain (if NOPT = 1) | Input |



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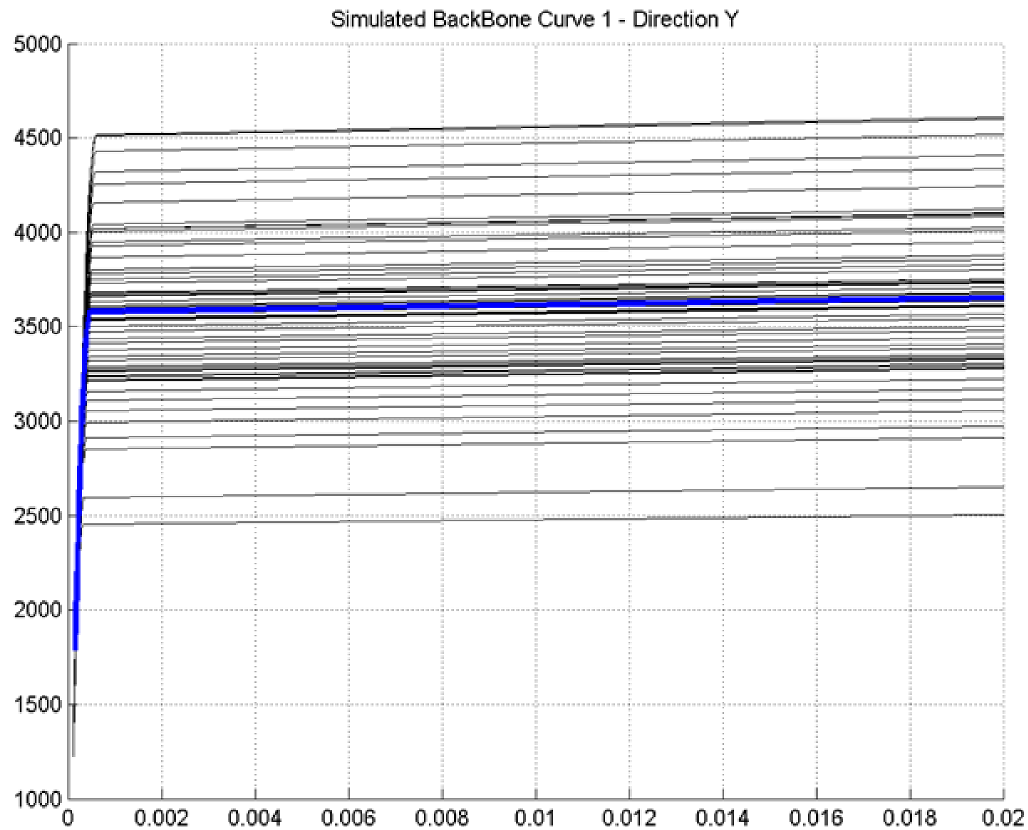
# EXAMPLE 1. Simulation of Wall Panel BBCs

60 1 0.15 34522
BASELINE.EQL
GNONXXX.EQL
BASELINE.HOU
HOUSEXXX.HOU
1
0.02



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# ProMOTION Input Parameters

Table 5.6ProMOTION Input File (GMOT.IN)

| Input File Line Number | Variable Name (Input in free format) | Definition of Input Variables | Variable Type |
|---|---|---|---|
| 1 | NSIMUL | Number of simulations | Input |
| 1 | NOPT | Option to Scale Time History (0=No, 1=Yes) | Input |
| 2 | FINACC | Input acceleration file names (.acc extension) | Input |
| 3 | FBASEL | Baseline input file (BASELINE.MOT) | Input |
| 4 | FGMOT | Simulated input samples for the MOTION runs (.mot extension) | Output |
| 5 | XM | Meanof Uncertainty Scale Factor (if NOPT=1) | Input |
| 5 | XCOV | C.O.V of Uncertainty Scale Factor (if NOPT=1) | Input |
| 5 | ISEED | Initial SeedNumberof Uncertainty Scale Factor (if NOPT=1) | Input |


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# ProSTRESS Input Parameters

Table 5.7ProSTRESS Input File (GSTR.IN)

| Input File Line Number | Variable Name (Input in free format) | Definition of Input Variables | Variable Type |
|---|---|---|---|
| 1 | NSIMUL | Number of simulations | Input |
| 1 | NOPT | Option to Scale Time History (0=No, 1=Yes) | Input |
| 2 | FINACC | Input acceleration file names (.acc extension) | Input |
| 3 | FBASEL | Baseline input file (BASELINE.STR) | Input |
| 4 | FGSTR | Simulated input samples for the STRESS runs (.str extension) | Output |
| 5 | XM | Meanof Uncertainty Scale Factor (if NOPT=1) | Input |
| 5 | XCOV | C.O.V of Uncertainty Scale Factor (if NOPT=1) | Input |
| 5 | ISEED | Initial SeedNumberof Uncertainty Scale Factor (if NOPT=1) | Input |


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# ProSRSS Input Parameters

```
NSIM, NRESP, OPTOUT
                                        Block 1
```

```
IF OPTOUT = 0 THEN
Loop J=1:NRESP
     FIN(J)
  END LOOP J
                                        Block 2.1
```

```
IF OPTOUT = 1, 2 THEN
 FSTR
Loop J=1:NRESP
     FIN(J)
  END LOOP J
                                        Block 2.2
```



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| Input Block Number | Input File Line Number Inside Each Block | Variable Name (Input file in free format) | Definition of Input Variables |
|---|---|---|---|
| **BLOCK 1** | | | |
| 1 | 1 | NSIM | Number of simulations |
| 1 | 1 | NRESP | Number of generic response files |
| 1 | 1 | OPTOUT | Option for response type to be computed<br>= 0 Acceleration response spectra (extension..rxxx)<br>= 1 Stress/forces in structural elements (extension .oxxx) |
| **BLOCK 2** | | | |
| 2.1 | Start Loop J=1,NRESP | | |
| 2.1 | 1 Inside Loop J | FIN(J) | Acceleration response spectra |
| 2.1 | End Loop J=1,NRESP | | |
| 2.2 | 1 | FSTR | Stress input (*.str), RDISP input (*.rdi) |
| 2.2 | Start Loop J=1,NRESP | | |
| 2.2 | 1 Inside Loop J | FIN(J) | Stress outputs, relative displacement outputs |
| 2.2 | End Loop J=1,NRESP | | |

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# Example of ProSRSS Input Parameters

## Example 1:

The example input files are in the folder called .\Examples\ProSRSS\Ex1. The input filename is SRSS-RS.IN. This case is used to combine nodal SRSS for 3 directories X, Y, Z.

The text content of the GSOIL.IN is

```
30 9 0
00001TR_X01.rXXX
00001TR_Y01.rXXX
00001TR_Z01.rXXX
00151TR_X01.rXXX
00151TR_Y01.rXXX
00151TR_Z01.rXXX
00158TR_X01.rXXX
00158TR_Y01.rXXX
00158TR_Z01.rXXX
```

## Example 2:

The example input files are in the folder called .\Examples\ProSRSS\Ex2. The input filename is SRSS-STRESS.IN. This case is used to combine stress SRSS for 3 directories X, Y, Z.

The text content of the GSOIL.IN is

```
60 1 1
STRESS.STR
STRESS.OXXX
```


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# ProRESPONSE Input Parameter Loops

| Block 1 |
|---|
| NOPTINP, NOPTOUT |

**Block 2.1**

*IF NOPTOPT =0 THEN*
NSIM, NFINP
*LOOP J=1,NFINP*
FINP(J)
*END LOOP J*

**Block 2.2**

*IF NOPT=1 THEN*
NSIM, NFINP, IDTYPE, NPROB
*LOOP K=1,NPROB*
PROBVAL(J)
*END OF LOOP K*
*LOOP J=1,NFINP*
FINP(J)
*END OF LOOP J*

Figure 5.7 GRESP.IN Data Description


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# ProRESPONSE Input Parameters

Table 5.8 ProRESPONSE Input File (GRESP.IN)

| Input BlockNum ber | Input File Line Number Inside Each Block | Variable Name (Input file in free format) | Definition of Input Variables |
|---|---|---|---|
| **BLOCK 1** | | | |
| 1 | 1 | NOPTINP | Options for inputs:<br>= 0 Acceleration response spectra (extension .rxxx files)<br>= 1 Uninterpolated transfer functions (extension .uxxx files)<br>= 2 Interpolated transfer functions(extension .ixxx files)<br>= 3 Maximum stress output (extension .oxxx files) |
| 1 | 1 | NOPTOUT | Options for outputs:<br>= 0 Mean response will be computed<br>= 1 Probability level response to be computed |
| **BLOCK 2** | | | |
| 2.1, 2.2 | 1 | NSIM | Number of simulations |
| 2.1,2.2 | 1 | NFINP | Number of generic simulated response files to be used as inputs for ProRESPONSE |
| 2.2 | 1 | IDTYPE | Probability distribution type |



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# ProRESPONSE Input Parameters (Continuation)

| | | | |
|---|---|---|---|
| | | | 0 = Sample distribution (using sample CDF)<br>1 = Lognormal distribution<br>2 = Gumbel distribution |
| 2.2 | 1 | NPROB | Number of probability levels |
| 2.2 | Start Loop K=1,NPROB | | |
| 2.2 | 1 Inside Loop K | PROBVAL(J) | Non-exceedance probability (NEP)for computing probabilistic SSI responses (for P1, P2, P3….) |
| 2.2 | End Loop K=1,NPROB | | |
| 2.1,2.2 | Start Loop J=1,NFINP | | |
| 2.1,2.2 | 1 Inside Loop J | FINP(J) | Generic input file name for simulated response files to be used as inputs by ProRESPONSE |
| 2.1,2.2 | End of Loop J=1,NFINP | | |


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# Example of ProRESPONSE Input Parameters

The text content of the RS-MEAN.IN is

0 0
30 3
00001TR_X01.rXXX
00151TR_X01.rXXX
00158TR_X01.rXXX

The text content of the GumbelD.IN is

0 1
30 3 2 2
0.8 0.95
00001TR_X01.rXXX
00151TR_X01.rXXX
00158TR_X01.rXXX

The text content of the LognormalD.IN is

0 1
30 3 1 2
0.8 0.95
00001TR_X01.rXXX
00151TR_X01.rXXX
00158TR_X01.rXXX

The text content of the SampleD.IN is

0 1
30 3 0 2
0.8 0.95
00001TR_X01.rXXX
00151TR_X01.rXXX
00158TR_X01.rXXX

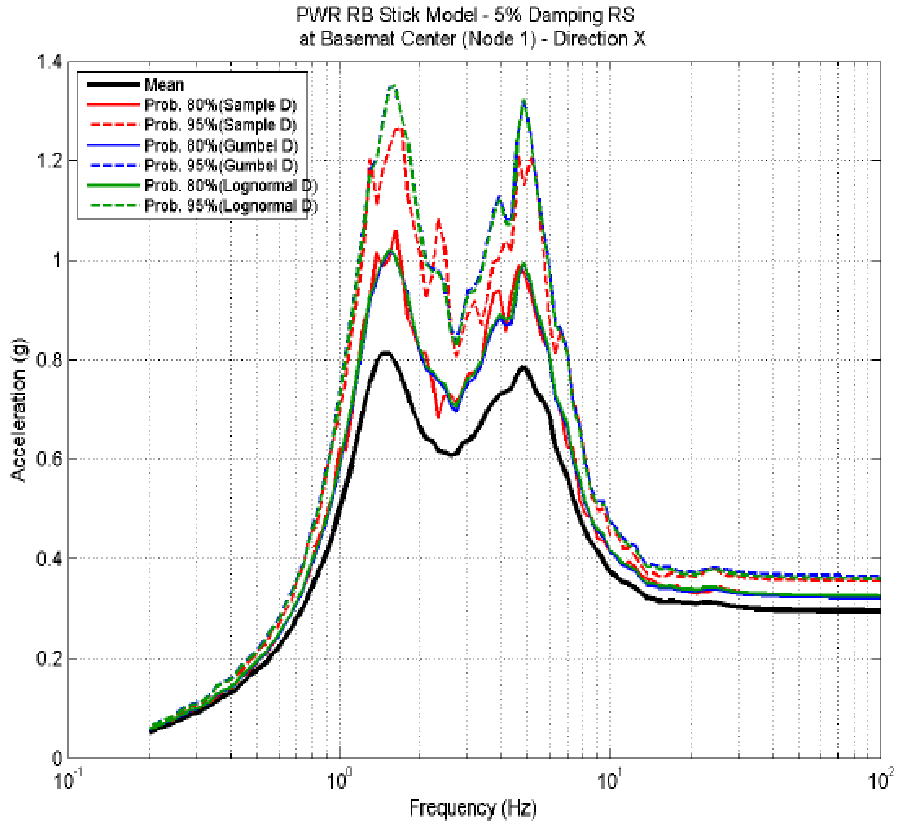


Figure A8.1Node 1 RS Probability Level Curves for Mean, and 80% and 95% NEP



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# Example of ProRESPONSE Input Parameters

The text content of the RS-MEAN.IN is

3 0
60 1
stress.oXXX

The text content of the GumbelD.IN is

3 1
60 1 2 2
0.8 0.95
stress.oXXX

The text content of the LognormalD.IN is

3 1
60 1 1 2
0.8 0.95
stress.oXXX

The text content of the SampleD.IN is

3 1
60 1 0 2
0.8 0.95
stress.oXXX

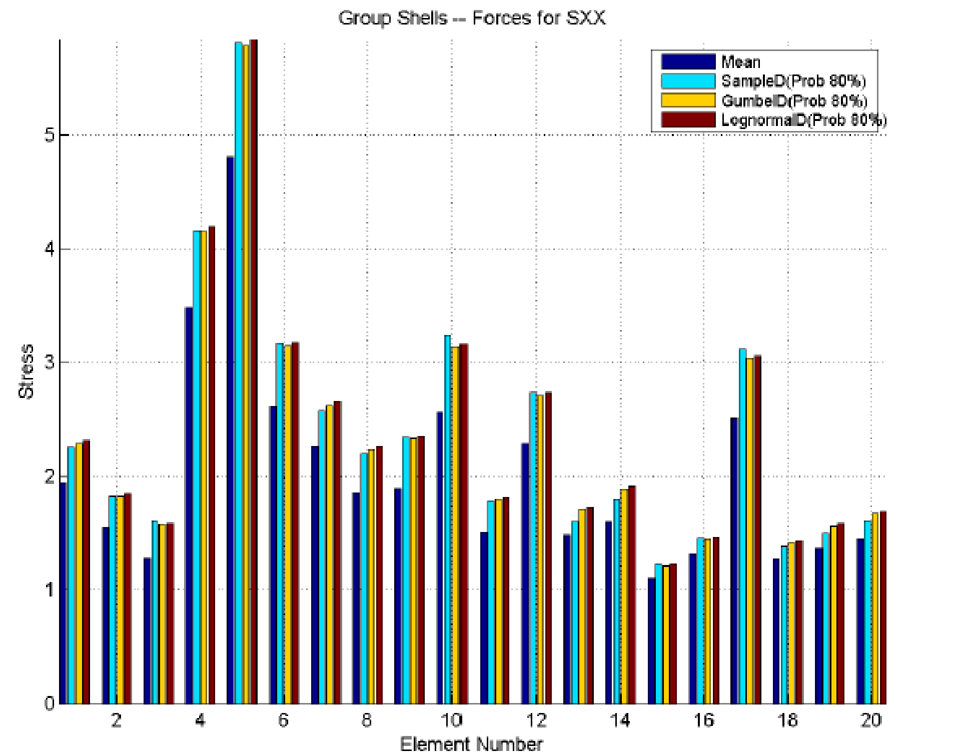


Figure A8.6 Probabilistic Maximum SXX Stress with 80% and 95% NEP



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# See Example files and V&V for PSRA and PSSIA


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# Option UPLIFT:

# Foundation Uplift SSI Analysis

(Nonlinear uplift approach is developed based on the JEAC 4601-2015 standard Section 3.5.5.4 and App. 3.6 recommendations)


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# JEAC 4601-2015 Section 3.5.5.4 and App. 3.6

The JEAC 4601-2015 standard [1] recommends two nonlinear uplift approaches applicable based on the basemat uplift severity:

1) A simplified nonlinear uplift approach (Method 1) applicable if the basemat surface contact ratio is in the 65%-75% range, and

2) A refined nonlinear dynamic uplift approach (Method 2) applicable if the surface contact ratio is in the 50%-65% range



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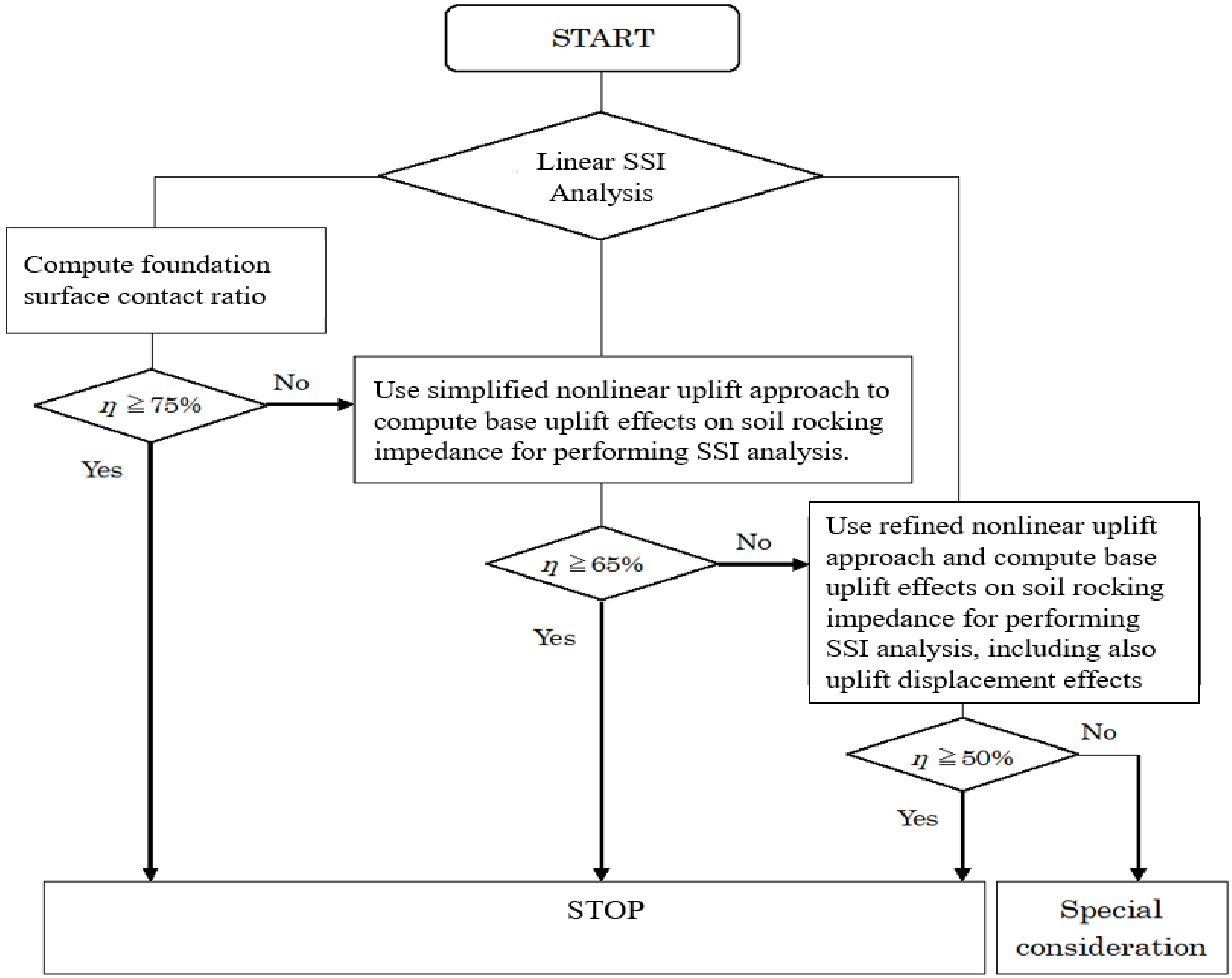
# JEAC 4601 Contact Ratio Criteria for Seismic Uplift SSI Analysis



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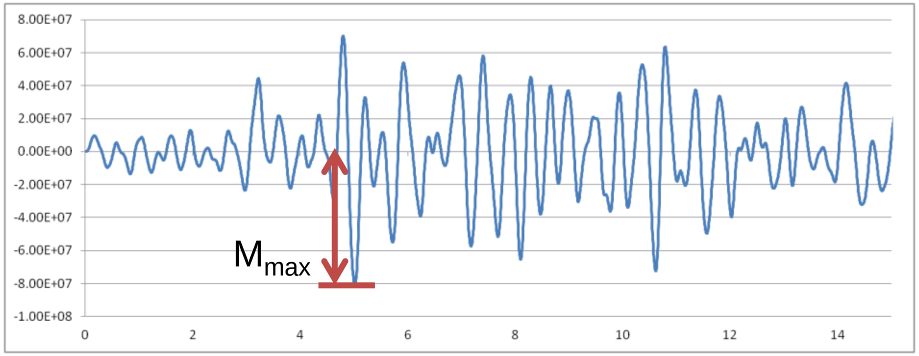
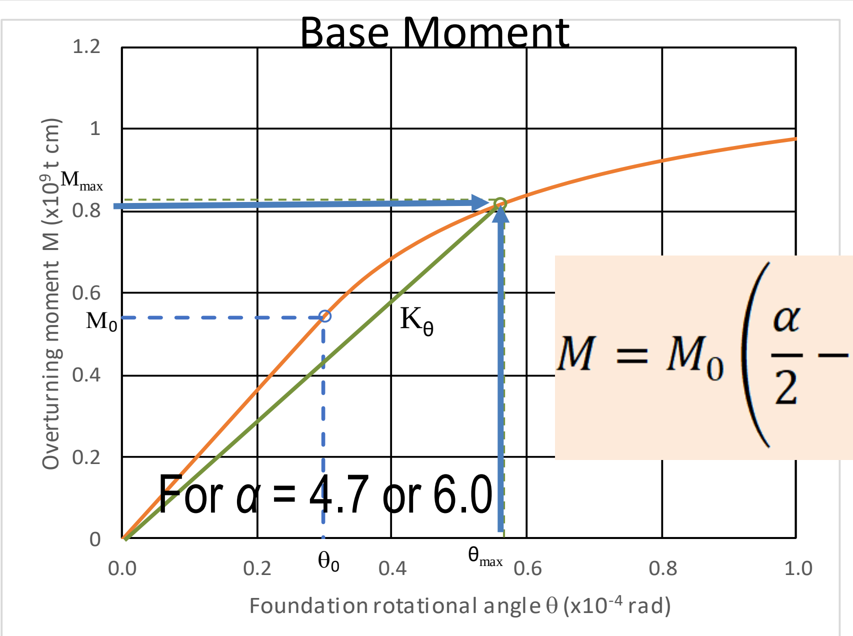
# Contact Surface Ratio is above 65%

# 1) *Simpler Approach* for Uplift (Multistep SSI Analysis)



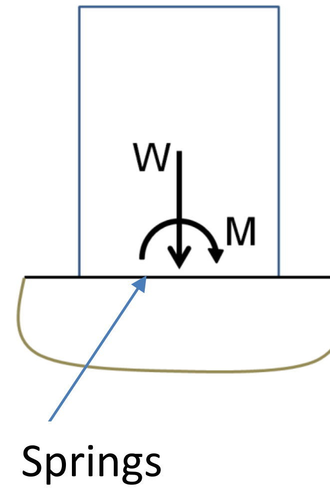




**M-θ Uplift Curve (Given)**

M(t) calculated from linear SSI by cut at base $M_{max}$

**For Sticks** $M_0 = \dfrac{W\,L}{\alpha}$

where: $W$ = weight
$L$ = foundation mat width
$\alpha$ = 6.0 for linear distribution, 4.7 for rigid foundation)




$$K_\theta = \frac{M_0}{\theta_0} \Rightarrow \theta_0 = \frac{M_0}{K_\theta^0}$$

$$M = M_0\left(\frac{\alpha}{2} - \frac{\alpha-2}{2}\left(\frac{\theta_0}{\theta}\right)^{\frac{2}{\alpha-2}}\right)$$

**Contact Ratio**

$$\eta = \frac{2\alpha}{\alpha-2}\left(\frac{1}{2} - \frac{M_{max}}{WL}\right)$$

Compute $$\theta = \left(\frac{M_0\,\frac{\alpha-2}{2}}{M_0\,\frac{\alpha}{2} - M}\right)^{\frac{\alpha-2}{2}} \theta_0$$

Compute new rotational K ech and repeat linearized SSI analysis



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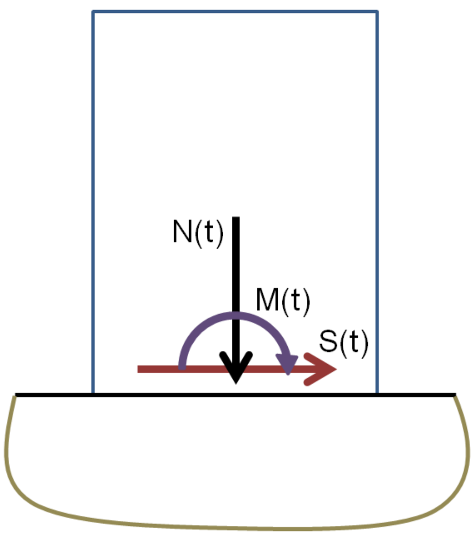
# Contact Surface Ratio is above 50%
# 1) *Refined Approach* (Multistep SSI Analysis)




Surface SSI Model

- Includes coupling between the basemat vertical uplift motion and its rocking motion
- Contact ratio given as a function of time which

$$\eta(t) = \left(\frac{\theta(t)}{\theta_0}\right)^{\frac{2}{\alpha-2}}$$

- Compute the base center displacements u(t), v(t), and θ(t) for one horizontal direction X or Y by solving ordinary differential equations (ODE)

$$\begin{bmatrix} S(t) \\ N(t) \\ M(t) \end{bmatrix} = \begin{bmatrix} K_H(t) & 0 & 0 \\ 0 & K_V(t) & K_{V\theta}(t) \\ 0 & K_{\theta V}(t) & K_\theta(t) \end{bmatrix} \begin{Bmatrix} w(t) \\ v(t) \\ \theta(t) \end{Bmatrix} + \begin{bmatrix} C_H(t) & 0 & 0 \\ 0 & C_V(t) & 0 \\ 0 & 0 & C_\theta(t) \end{bmatrix} \begin{Bmatrix} \dot{u}(t) \\ \dot{v}(t) \\ \dot{\theta}(t) \end{Bmatrix}$$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# ACS SASSI Option UPLIFT Modules

The ACS SASSI Option UPLIFT SSI analysis capability is implemented based on three specialized software modules:

1) *UPLIFT_3DFEM* module – Computes threshold moments, Mx, My

2) *GLOBAL_IMP* module – Computes global impedance for dominant frequency

3) *UPLIFT_JEAC_4601_2015* – Integrates base motion differential equation

The three UPLIFT modules can be efficiently run without the user intervention based on the batch run files provided with Demo 17. Demo 17 includes UPLIFT SSI case studies for a surface 3DFEM RB and a Stick/SR model, and for an embedded 3DFEM RB model.


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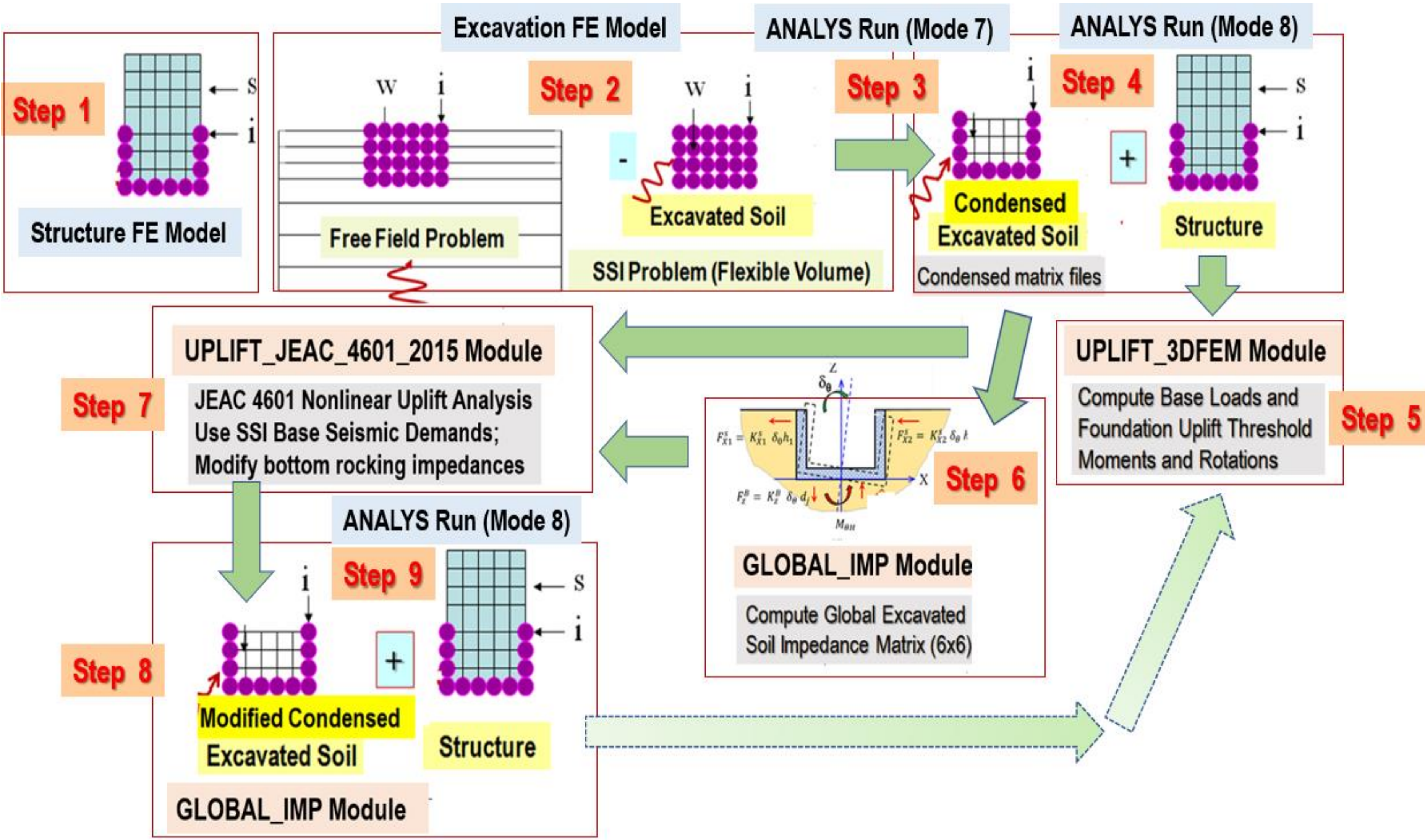
# ACS SASSI Uplift SSI Approach for Embedded Structures Based on JEAC 4601-2015



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For the *surface* structures, the computational efforts are significantly reduced, since the Steps 2 and 3 are not required, and Step 4 reduces to direct ANALYS “Initiation” (Mode1) run.

For the surface models, there is no need to compute the condensed soil impedance matrix, which is a computationally intensive step.

For the *embedded* structures, two options are available:

1) *2-Step Uplift Analysis* (2SUA) using *Modified* model is *Stage 1* (for IEMBL=1) and then *Design-condition* model in *Stage 2* (IEMBL=2).

2) *1-Step Uplift Analysis* (1SUA) using *Design-condition* model(IEMBL=3)

*The 2-Step uplift SSI analysis (2SUA) is consistent with the current practice in Japan.*



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# 2-Step Uplift SSI Analysis for Embedded Models

*Stage 1 for IEMB=1.* Use the *Modified embedded SSI model* with no lateral connecting springs or with very low stiffnesses (created using MERGESOIL) to simulate soil separation at the side-soil interface to compute the soil reaction parameters $\alpha$ for X and Y directions (using the UPLIFT_3DFEM module only, up to Step 5 in Figure 2), and

*Stage 2 for IEMBL=2.* Use the *Design-condition embedded SSI model* with the soil reaction parameters $\alpha$ computed in Stage 1 to perform an uplift SSI analysis (using the UPLIFT_3DFEM, GLOBAL_IMP and UPLIFT_JEAC_4601 modules, including all 8 steps in Figure 2)



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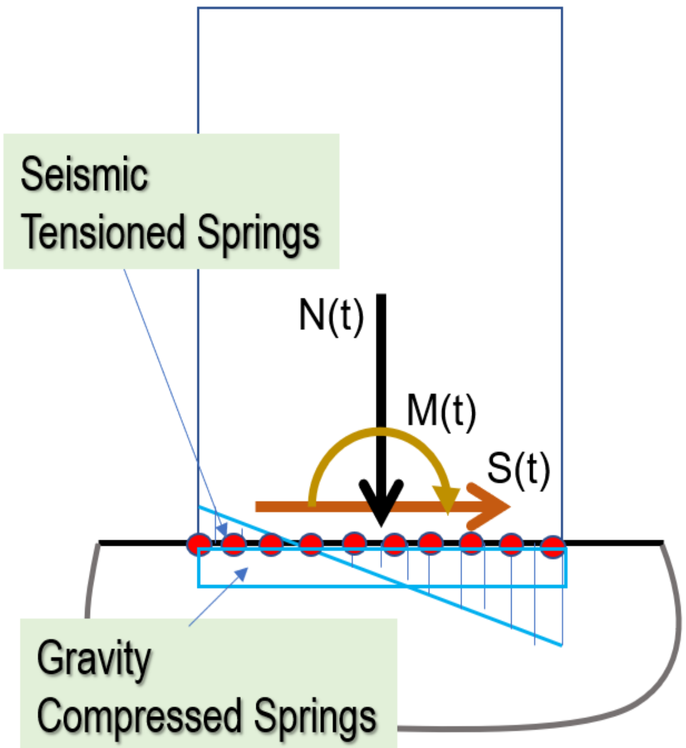
# Computation of Base Threshold Moments Under Gravity (Static) and Seismic (Dynamic) Loads

**UPLIFT_3DFEM Module**

$$\eta = \frac{A_{contact}}{A_{total}}$$ is computed based on the springs in tension

$$\gamma = \left| \frac{F^{static}}{F^{dynamic}_{max\ tension}} \right|$$ Force scaling coefficients




$$M_0 = \sum_j \left(F_j^{static} + \gamma F_j^{dynamic}\right) \cdot d_j$$

is computed for no-tensile springs

$\theta_0$ is computed by linear regression

*Critical spring* based on the no-tension force criterion corresponds to the *minimum spring scale factor*.

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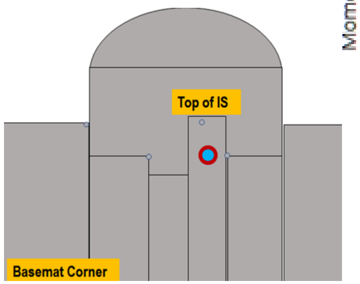
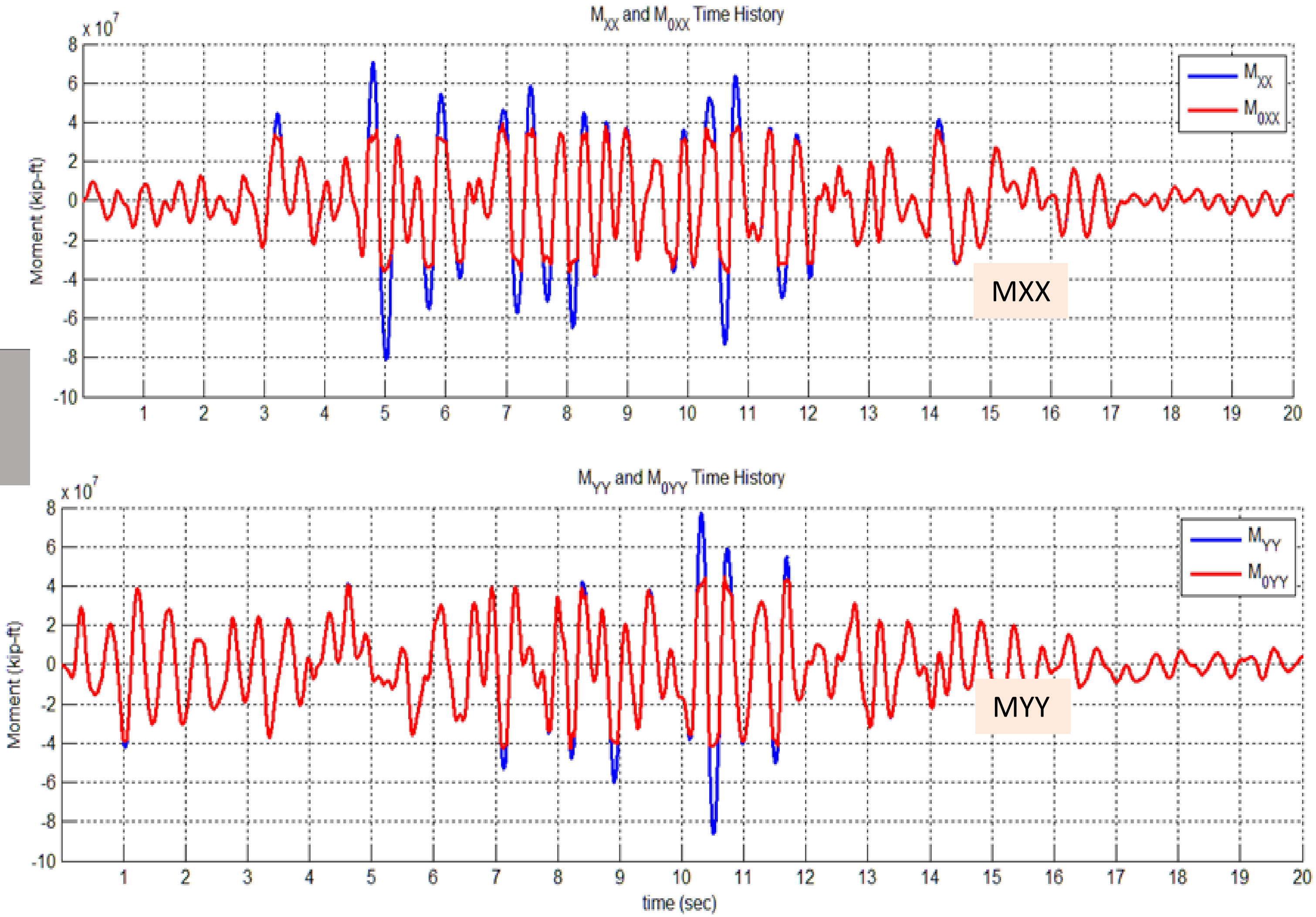
# Nonlinear Uplift Limit Base Moments (Mo) for X and Y Directions

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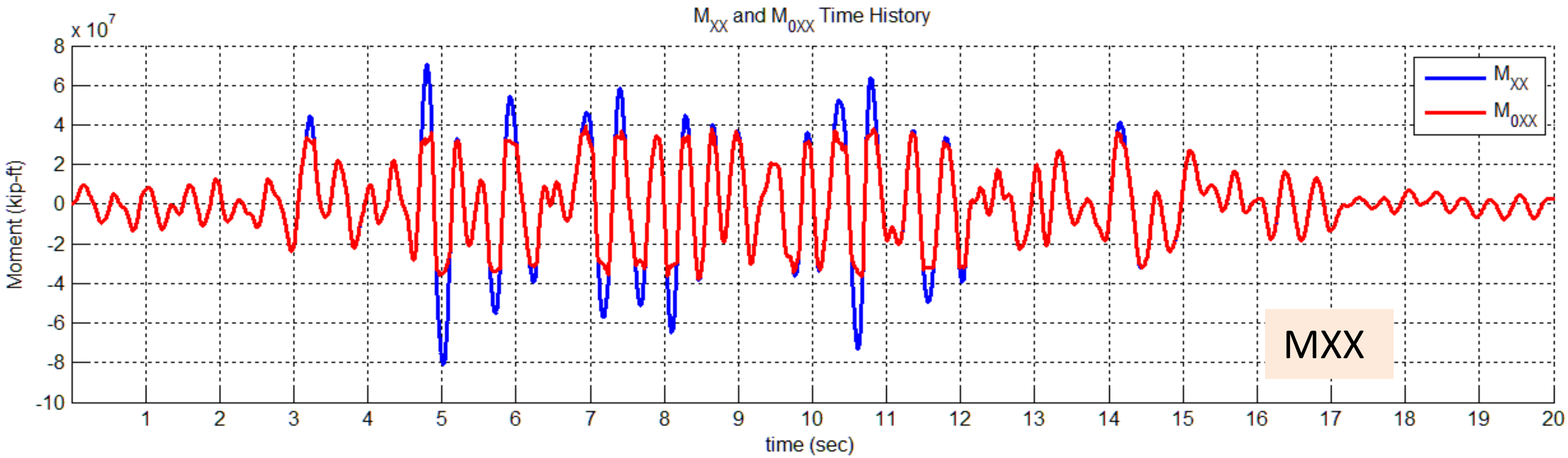
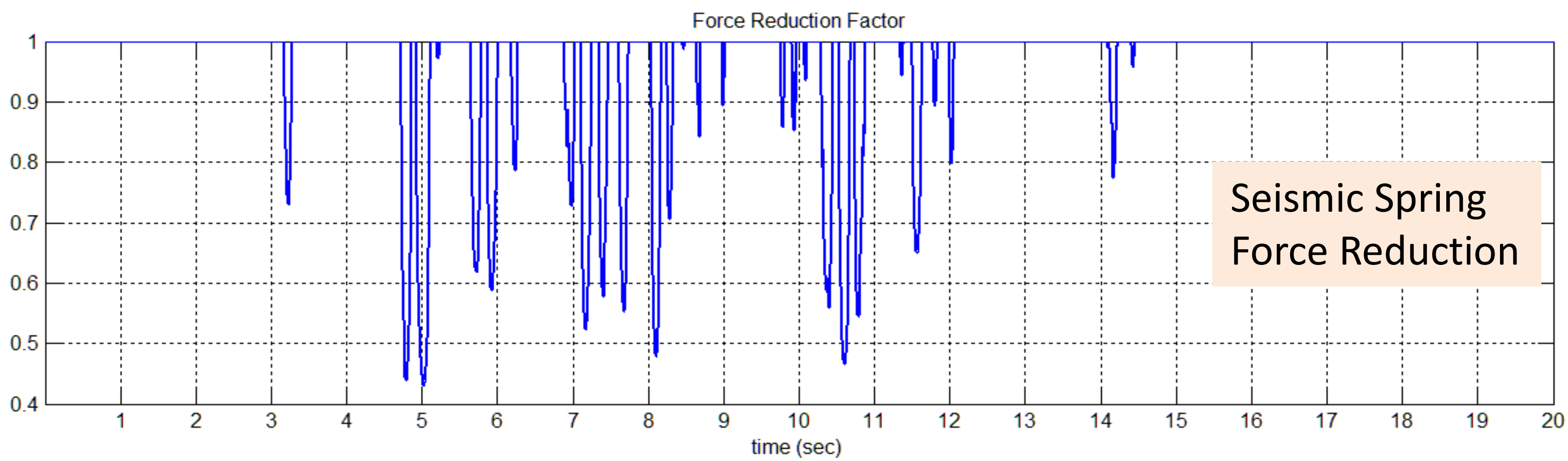
# Computing Uplift Limit Moment MoXX Using Contact Spring Forces for S+G Effects

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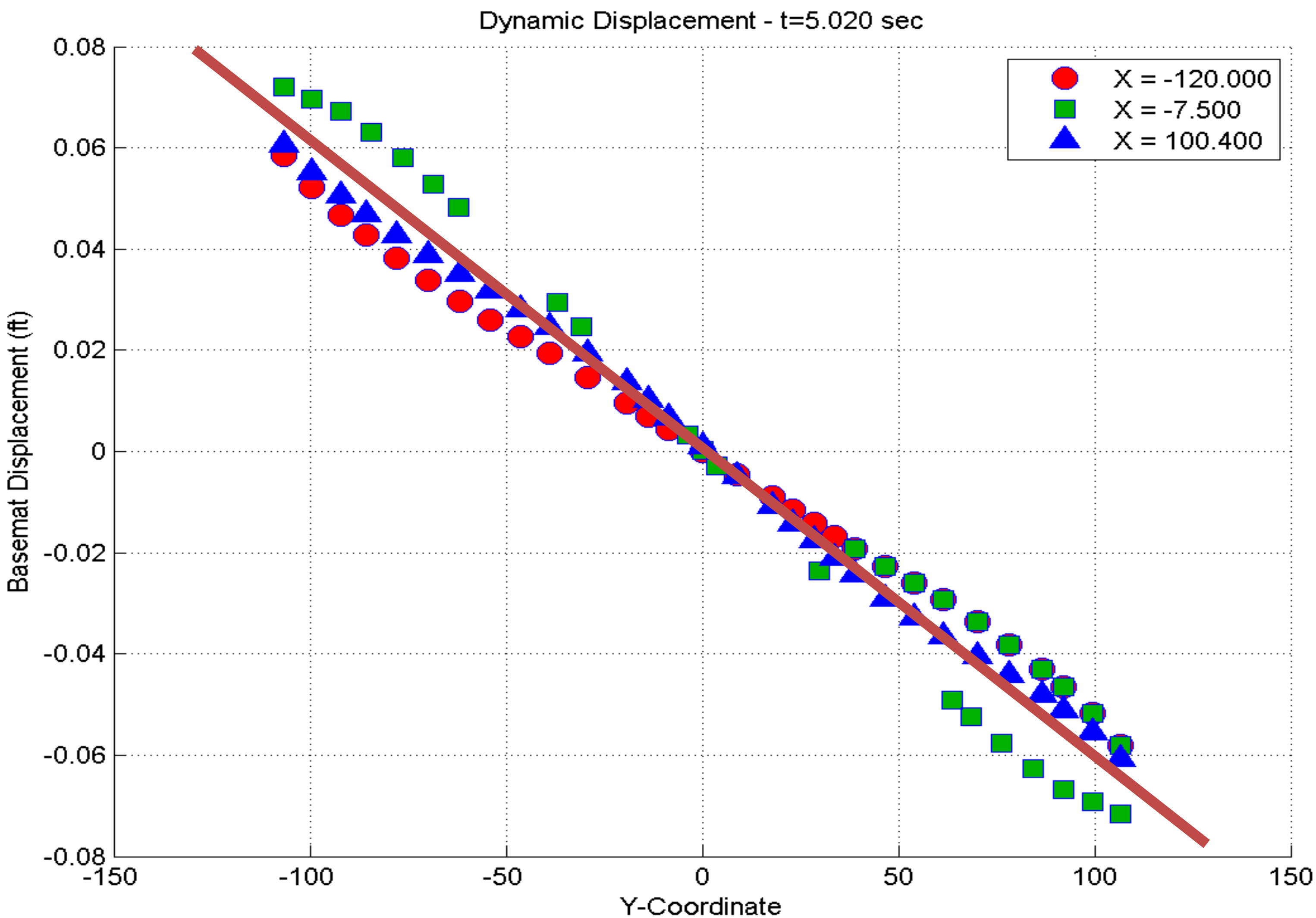
# Base Rocking Displacement for Transverse Y-Direction for Largest Uplift at Time 5.02 sec.



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# Nonlinear Uplift Analysis by Solving Base Motion ODE Equations with Time Varying Coefficients

$$\begin{bmatrix} N \\ S_x \\ S_y \\ M_{xx} \\ M_{yy} \end{bmatrix} = \begin{bmatrix} K_v & 0 & 0 & K_{v,xx} & K_{v,yy} \\ 0 & K_x & 0 & 0 & K_{x,yy} \\ 0 & 0 & K_y & K_{y,xx} & 0 \\ K_{xx,v} & 0 & K_{y,xx} & K_{xx} & 0 \\ K_{yy,v} & K_{x,yy} & 0 & 0 & K_{yy} \end{bmatrix} \begin{bmatrix} v \\ x \\ y \\ \theta_{xx} \\ \theta_{yy} \end{bmatrix} + \begin{bmatrix} C_v & 0 & 0 & 0 & 0 \\ 0 & C_x & 0 & 0 & 0 \\ 0 & 0 & C_y & 0 & 0 \\ 0 & 0 & 0 & C_{xx} & 0 \\ 0 & 0 & 0 & 0 & C_{yy} \end{bmatrix} \begin{bmatrix} \dot{v} \\ \dot{x} \\ \dot{y} \\ \dot{\theta}_{xx} \\ \dot{\theta}_{yy} \end{bmatrix}$$

$$\eta(t) = \left(\frac{\theta(t)}{\theta_0}\right)^{\frac{2}{\alpha-2}}$$

**Stiffness**

$$K_V(t) = \eta(t)^{\beta} K_V(0)$$

$$K_{V\theta}(t) = \frac{1-\eta(t)}{2} L \cdot K_V(t)$$

$$K_\theta(t) = \frac{M(t) - K_{V\theta}(t) \cdot v(t)}{\theta(t)}$$

**Damping**

$$C_V(t) = C_V(0) \cdot \eta(t)^{\frac{\alpha}{2}}$$

$$C_{V\theta} = 0$$

$$C_\theta = C_\theta(0) \cdot \eta(t)^{\frac{\alpha}{2}}$$

Uplift produces reductions of vertical and rocking soil impedances plus their coupling



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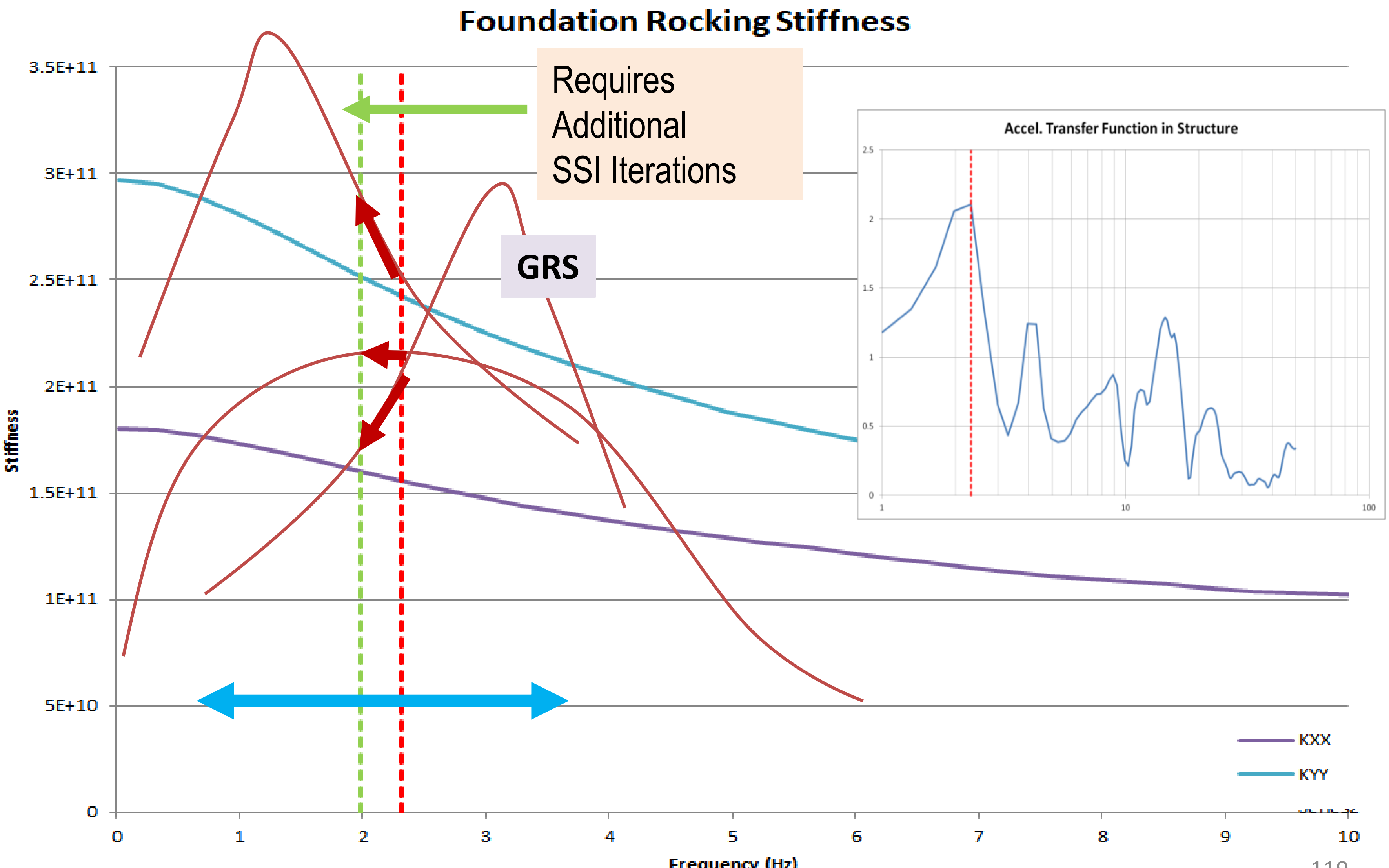
# Slight Frequency Shift for Soil Rocking and Vertical Impedances Due to Nonlinear Uplift Effect



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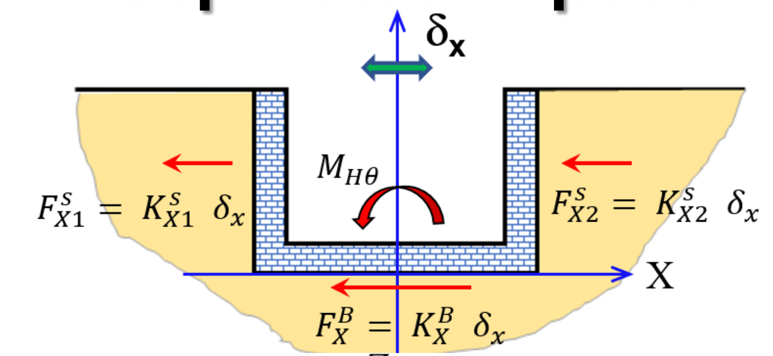
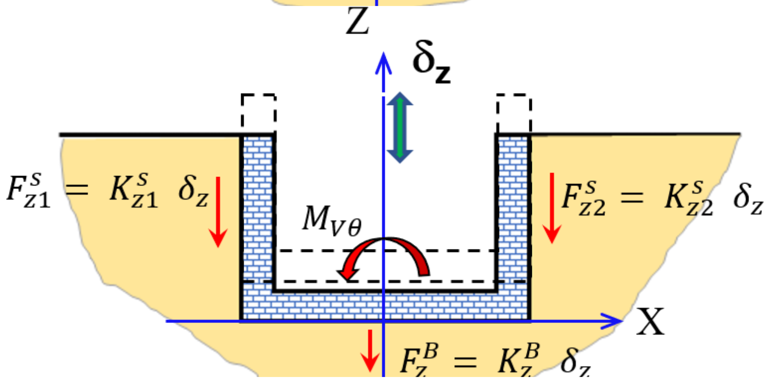
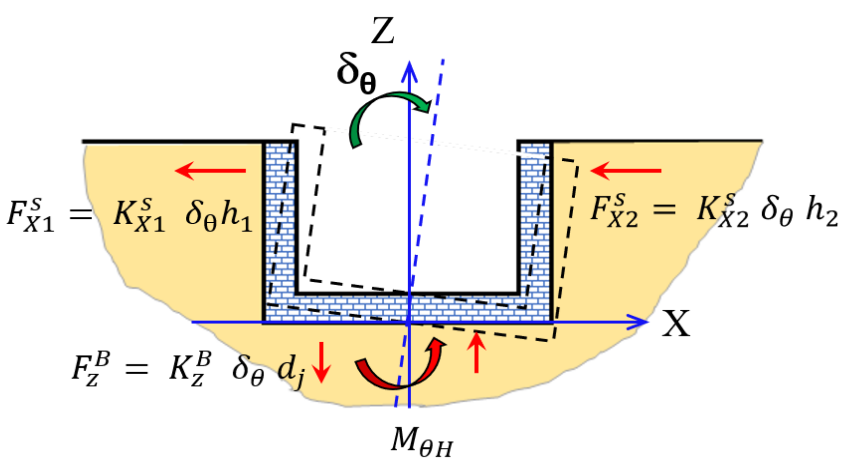
# Application to Embedded Structures Using Separated Impedances for Bottom and Side Soil




$$K_H = \sum_j (\gamma_{BX} K^B_{Xj} + \gamma_{SX} K^S_{Xj})$$

Only bottom soil impedance is reduced

$$K_{H\theta} = \sum_j \gamma_{SX} K^S_{Xj} h_j$$

$$\mathrm{K}(\eta) = \mathrm{K}^{\mathrm{B}}(\eta) + \mathrm{K}^{\mathrm{S}}$$

$$K_V = \sum_j (\gamma_{BZ} K^B_{Zj} + \gamma_{SZ} K^S_{Zj})$$

$$K_{V\theta} = \sum_j \gamma_{SZ} K^S_{Zj} h_j$$

Includes stiffness reduction factors for the local soil impedances computed based on the “condensed” excavation impedance matrix (ANALYS “Condense Impedance” Option)

$$K_\theta = \sum_j (K^B_{\theta j} + K^S_{\theta j})$$

$$K_{\theta H} = \sum_j K^S_{\theta Hj}$$



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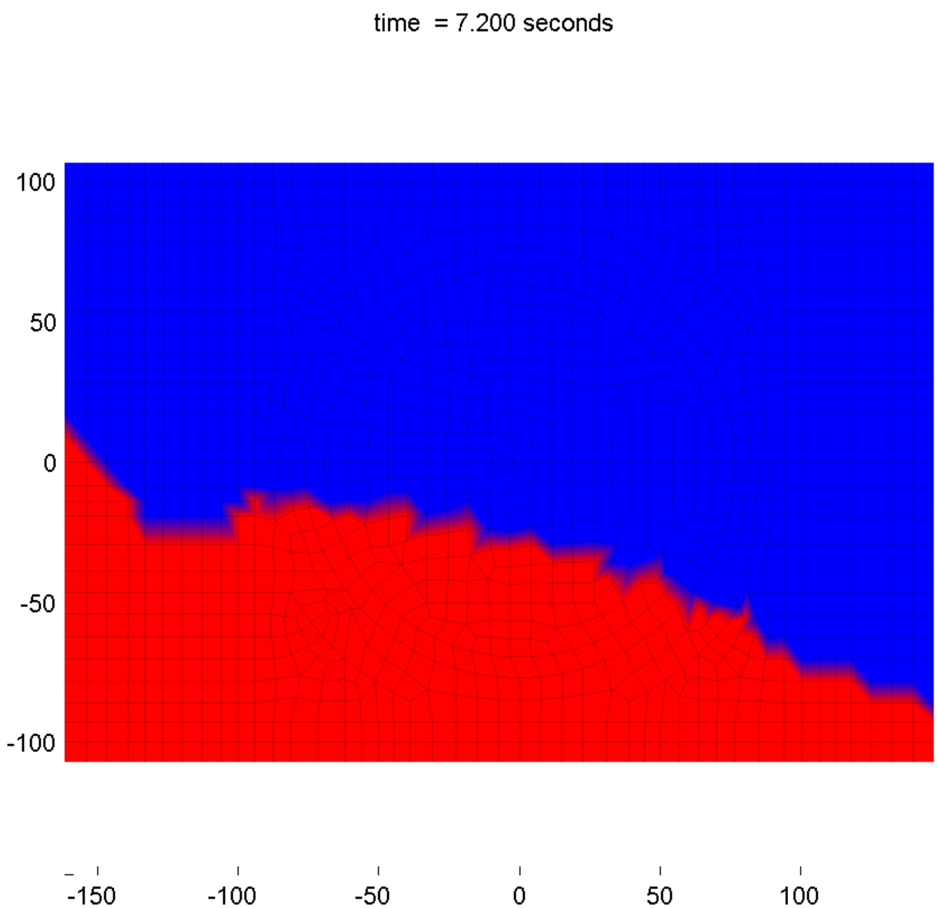
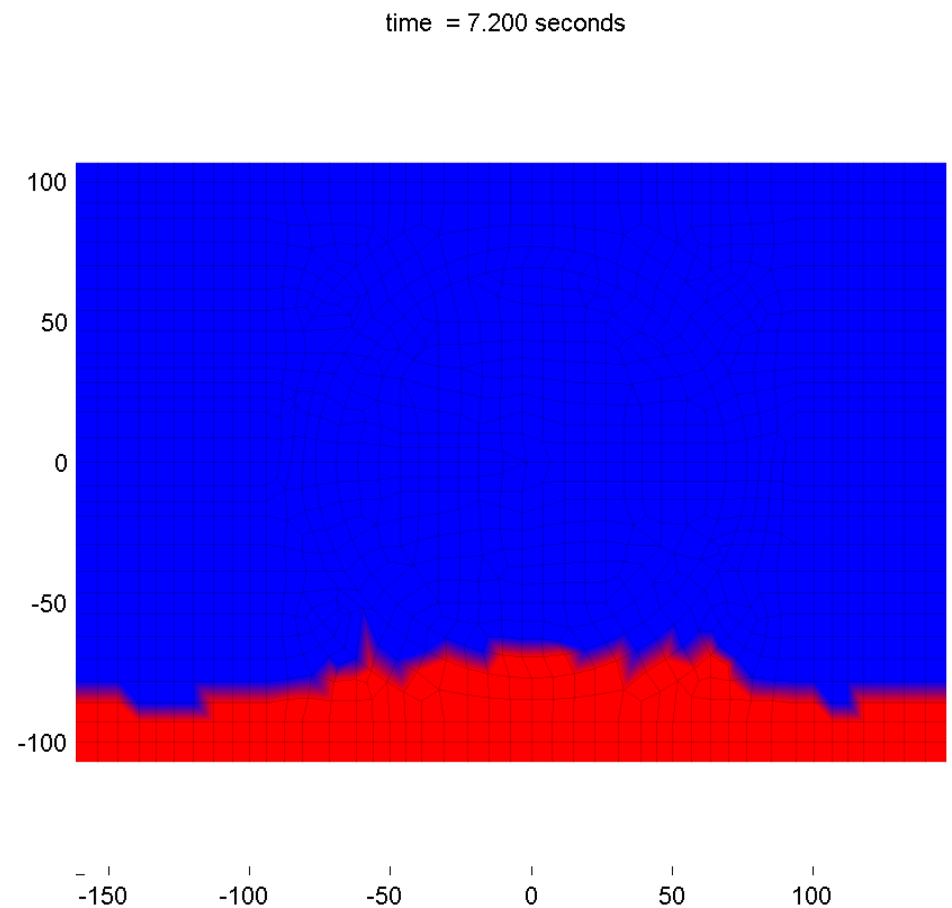
# Contact Surface for Large Uplift at Time 7.20 Sec.




XYZ Input




YDIR Input Only



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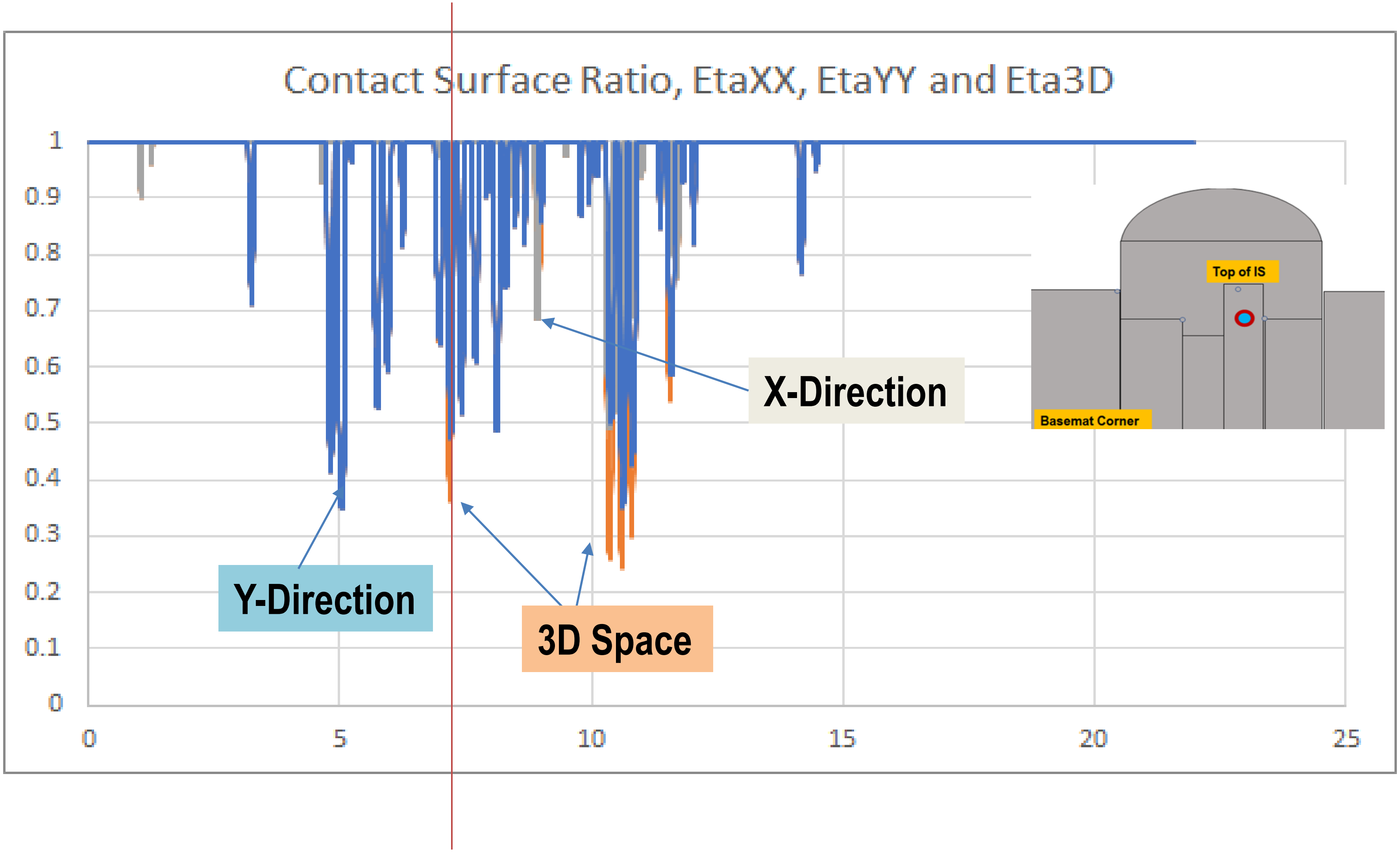
# Contact Surfaces for X (Longitudinal) and Y (Transversal) Directions and Combined for 1.4g



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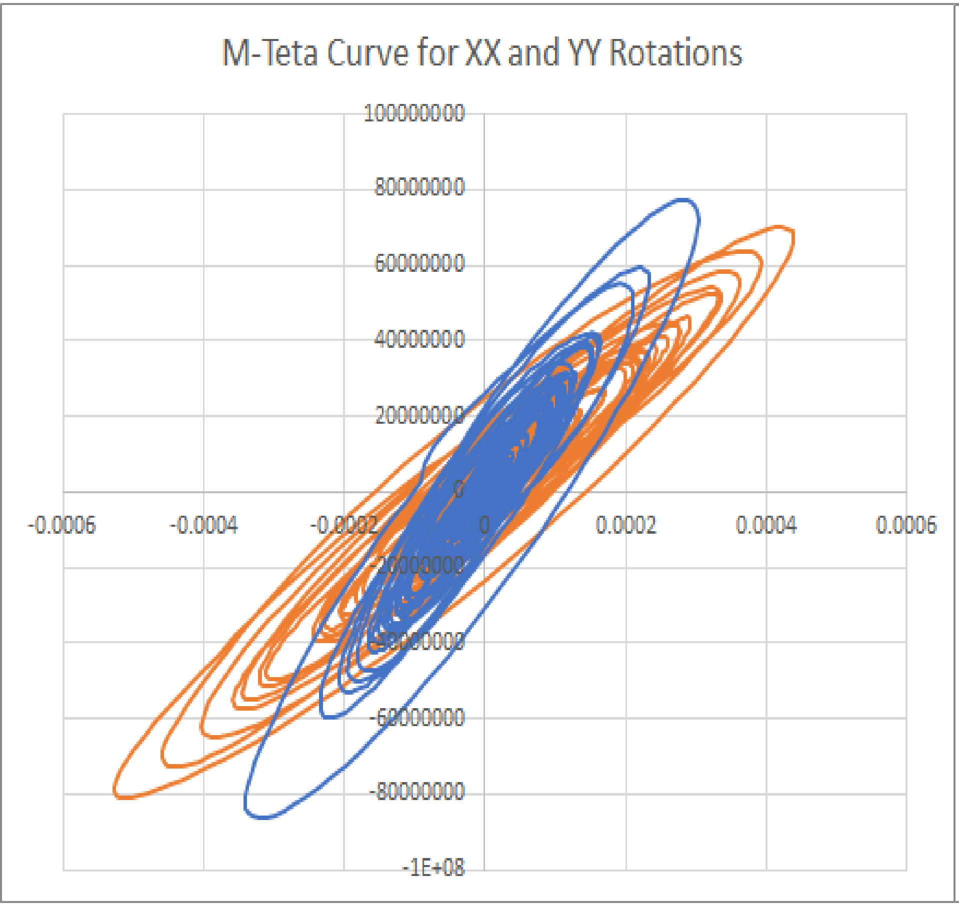
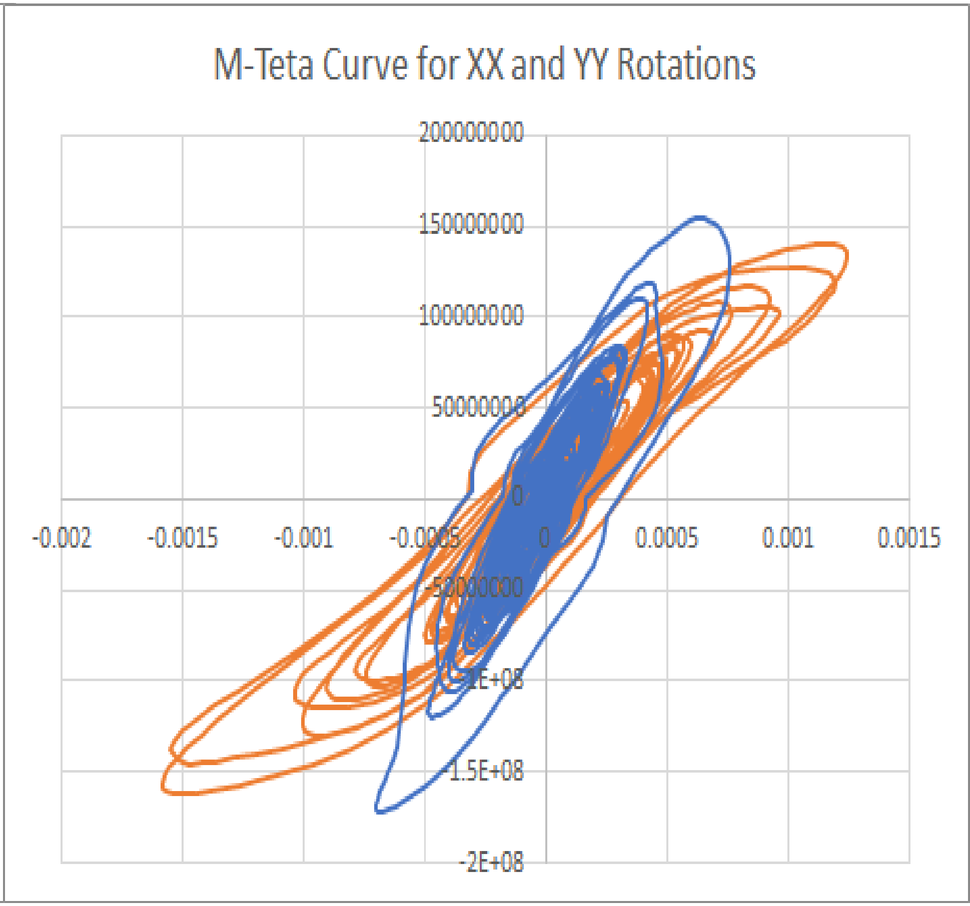
# M-Teta Hysteretic Curves for Nonlinear Rocking XX and YY Responses for 0.7g and 1.4g Input

**0.70g**




**1.40g**



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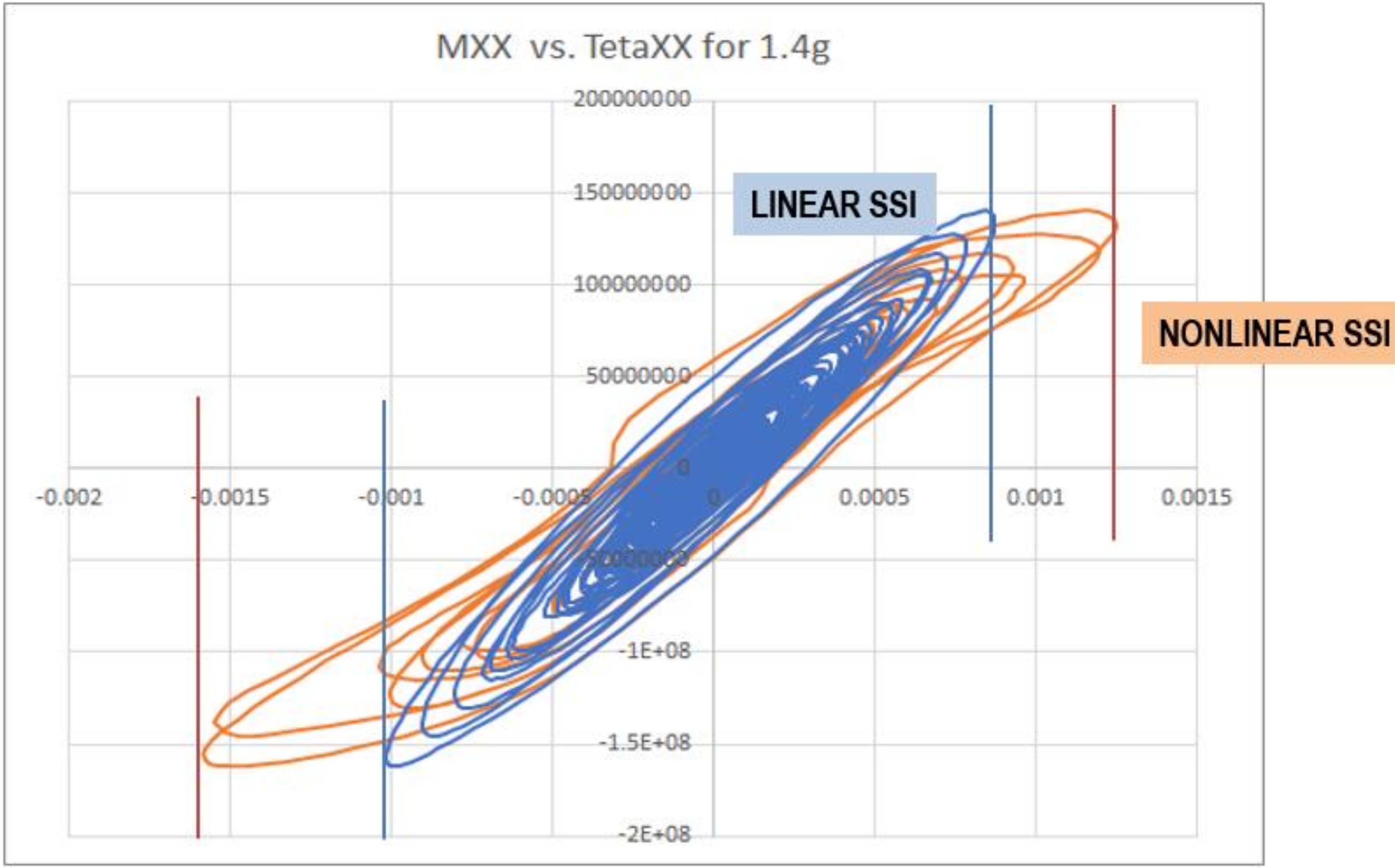
# Base Uplift Moment-Rotation Curve for Linear SSI vs. Nonlinear SSI

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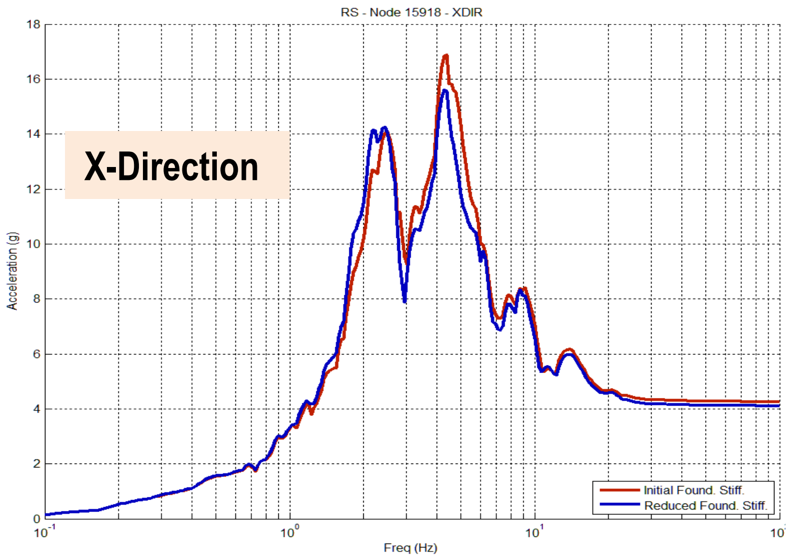
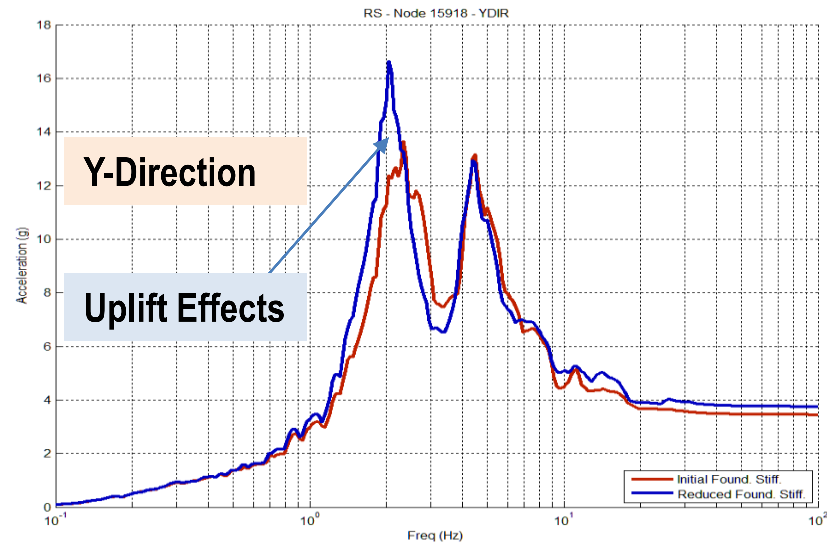
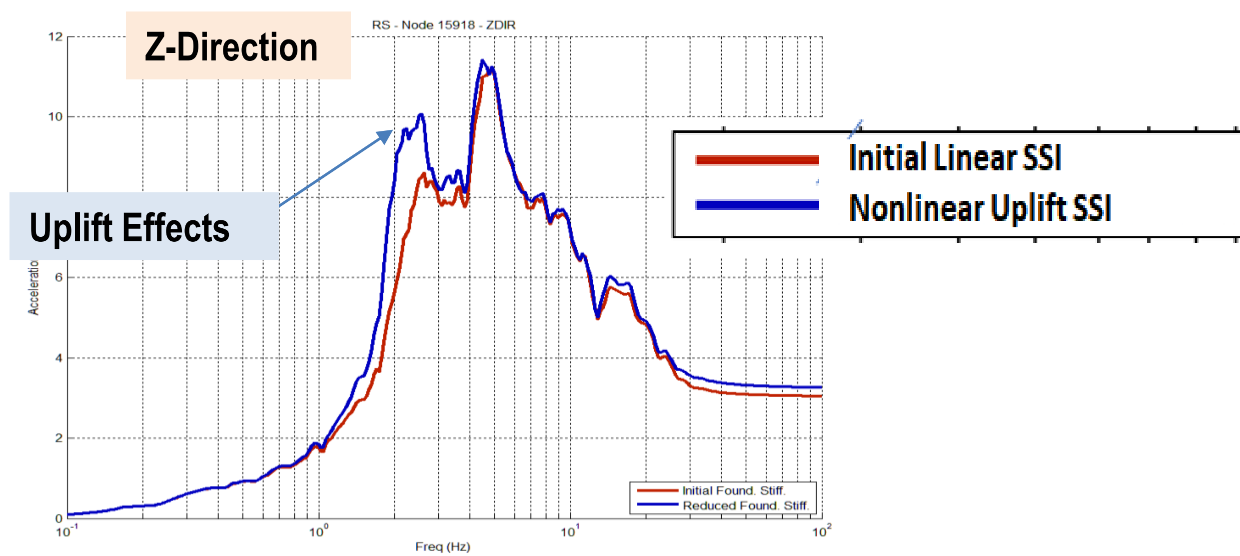
# ISRS Computed for Linear SSI vs. Nonlinear Uplift SSI Analysis for Surface RB Complex

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# End of Part 5 Presentation
# Thank You!



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