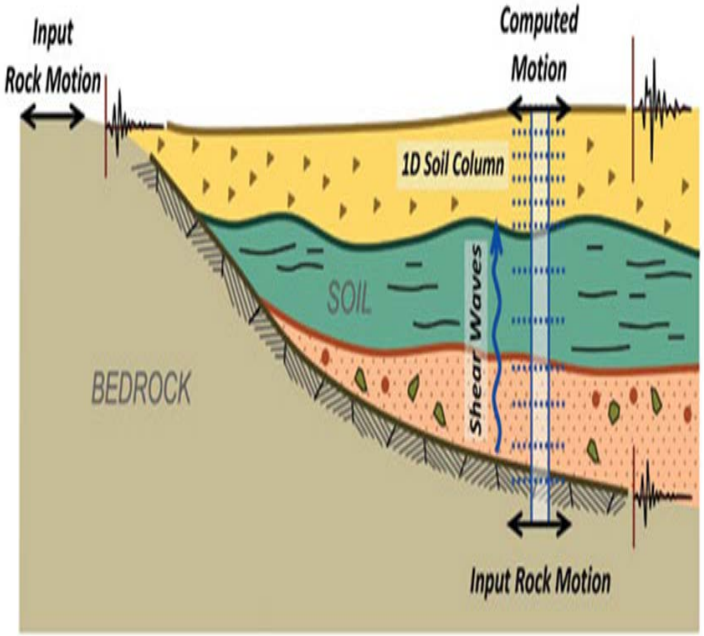
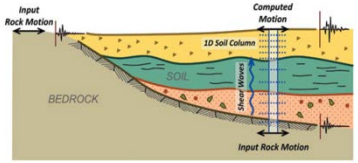


Seismic Ground Motion Response Using SHAKE, EERA and NERA for SRS Soil Profile

1D site response analysis

Jay Amin – Structural Mechanics, Principal Engineer
Shawn Carey, PhD, PE – Structural Mechanics, Structural Lead
Rucker Williams, PE – Geotechnical Engineering Lead

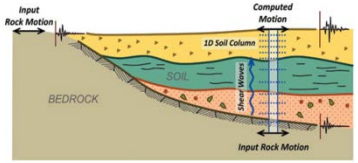
October 22, 2014



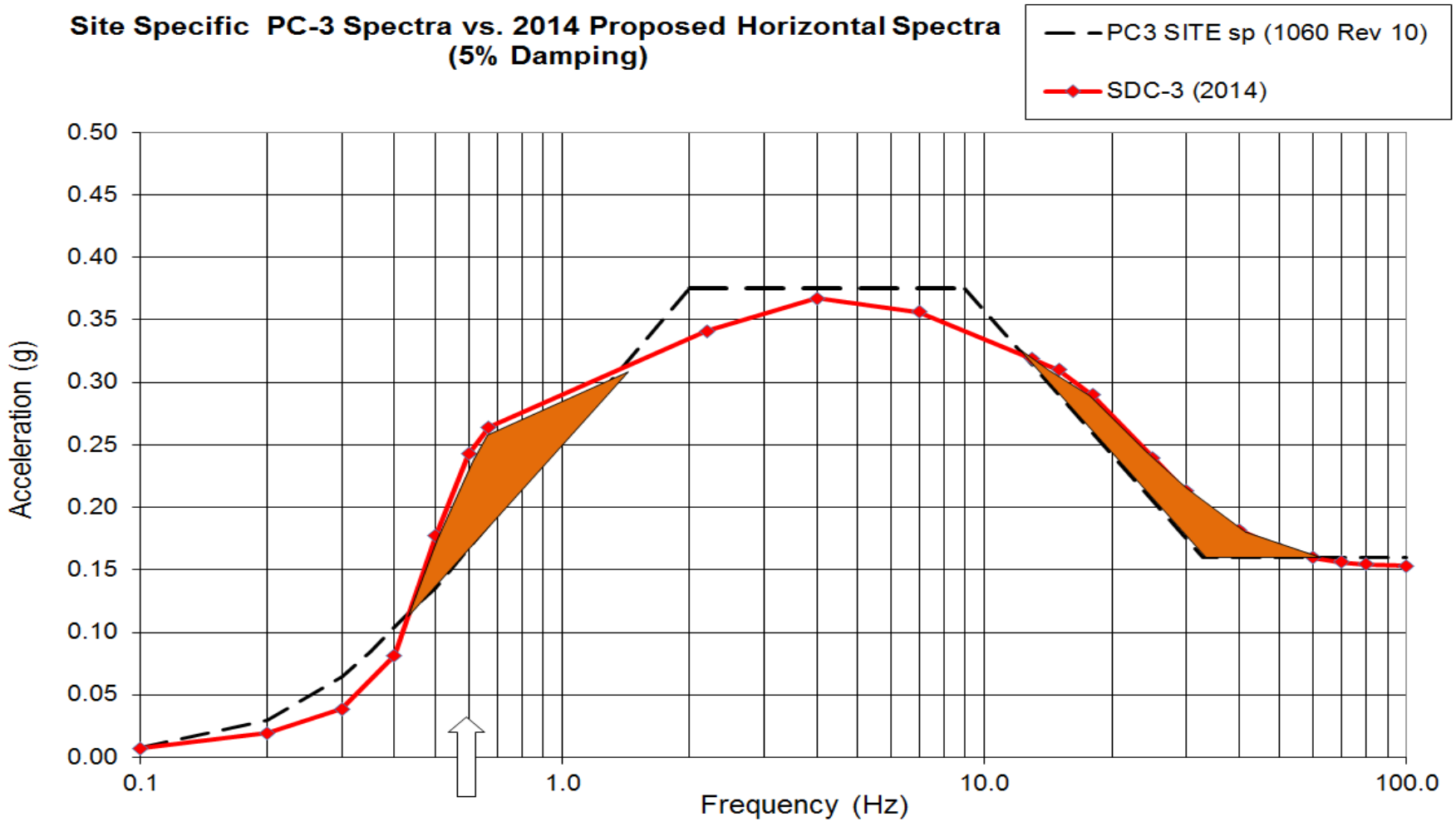
SRS- Effect of 2014 Site Specific Spectra on Building Settlement Analysis

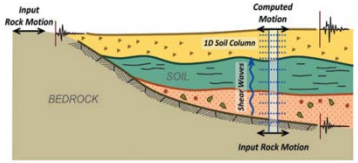
A Probabilistic Seismic Hazard (PSHA) report at SRS was recently completed that computed the rock and surface spectra utilizing the Central and Eastern United States (CEUS) Seismic Source Characterization (SSC) Model and the EPRI 2004/2006 ground motion model.

The results of the PSHA indicated an increase in the surface spectra in the low frequency range (0.5 Hz to 1.2 Hz) as shown in Figure on next slide, which affects the site response and indicates an increase in liquefaction potential for SRS.



2014- Proposed Site Specific Spectra - SRS



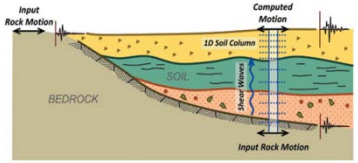


SHAKE - EERA - NERA

An important aspect of the Non-linear 1d site response analysis at SRS is to reduce building settlement as proposed 2014 site-specific spectra is high at 0.6 Hz frequency.

Results of the 1-D SHAKE/ EERA analysis were compared with non-linear (NERA) analysis for SHAKE validation problem # 1 and SRS soil profile , for the following parameters

- Surface response spectra
- Acceleration vs. depth
- Transfer function between surface and bedrock
- Stress vs. depth



METHODOLOGY

SHAKE: 1-D Site Response Analysis (validation problem # 1 from user manual)

EERA: (**E**quivalent –linear **E**arthquake site **R**esponse **A**nalysis Of layered Soil Deposit) by University of Southern California

– SHAKE Validation problem # 1

NERA: (**N**onlinear **E**arthquake site **R**esponse **A**nalysis Of layered Soil Deposit) by University of Southern California –

- SHAKE Validation problem # 1

NERA is a computer code utilizing FORTRAN 90 and Excel Visual Basic programming to implement the NLM. NERA uses a finite difference formulation to solve wave propagation equations in the time domain

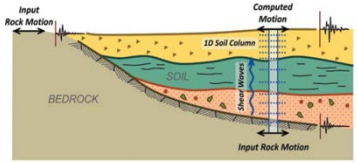
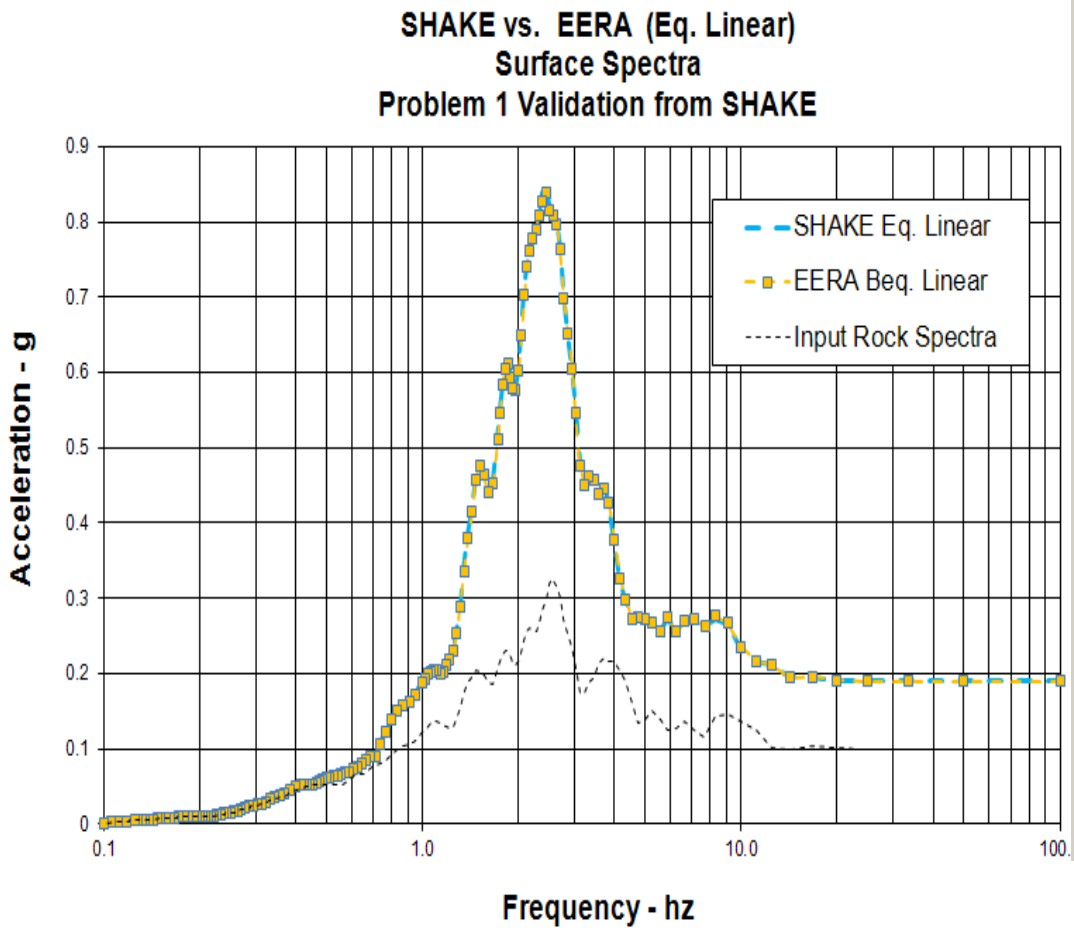
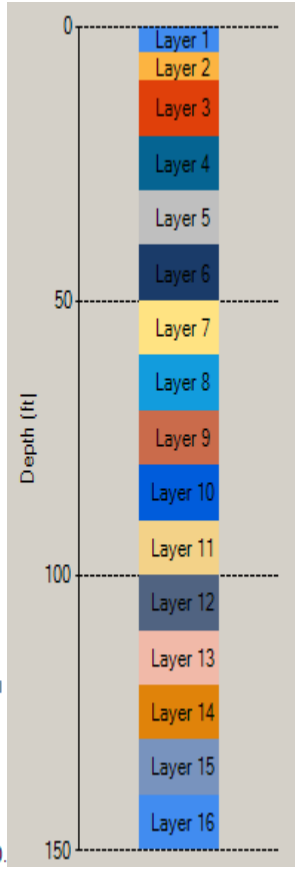


Figure 1 SHAKE vs. EERA

Surface Spectra

SHAKE Val Problem 1





Layer #	Layer Name	Thickness (ft)	Unit Weight (pcf)	Shear Velocity (ft/s)
1		5	125	1000
2		5	125	900
3		10	125	900
4		10	125	950
5		10	125	1000
6		10	125	1000
7		10	125	1100
8		10	125	1100
9		10	130	1300
10		10	130	1300
11		10	130	1400
12		10	130	1400
13		10	130	1500
14		10	130	1500
15		10	130	1600
16		10	130	1700

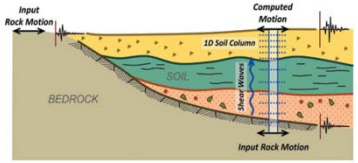
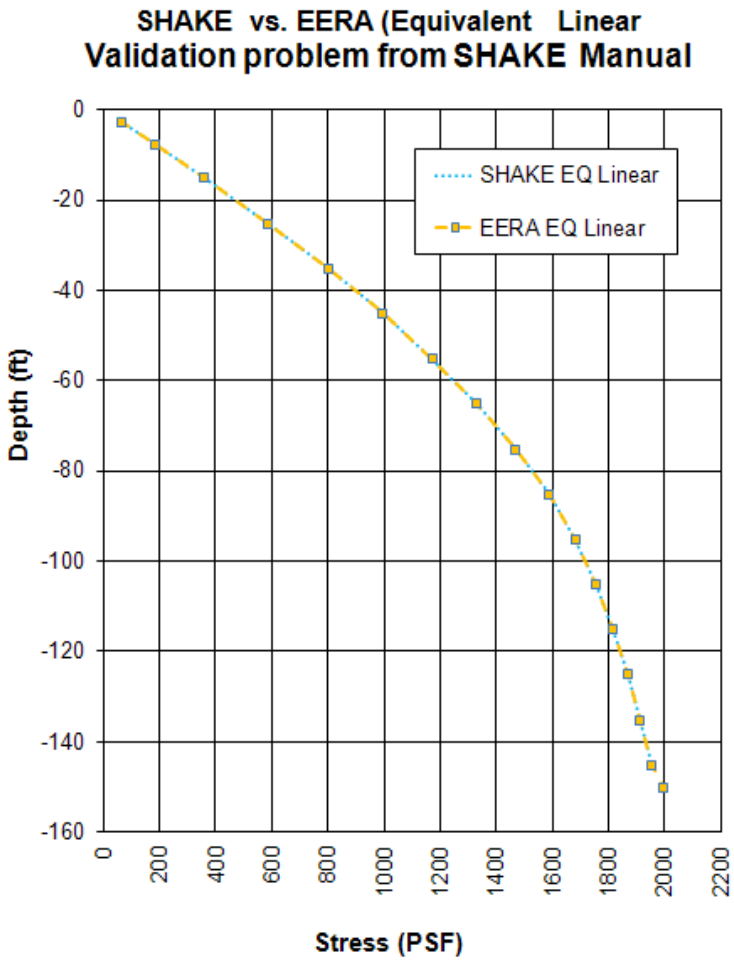
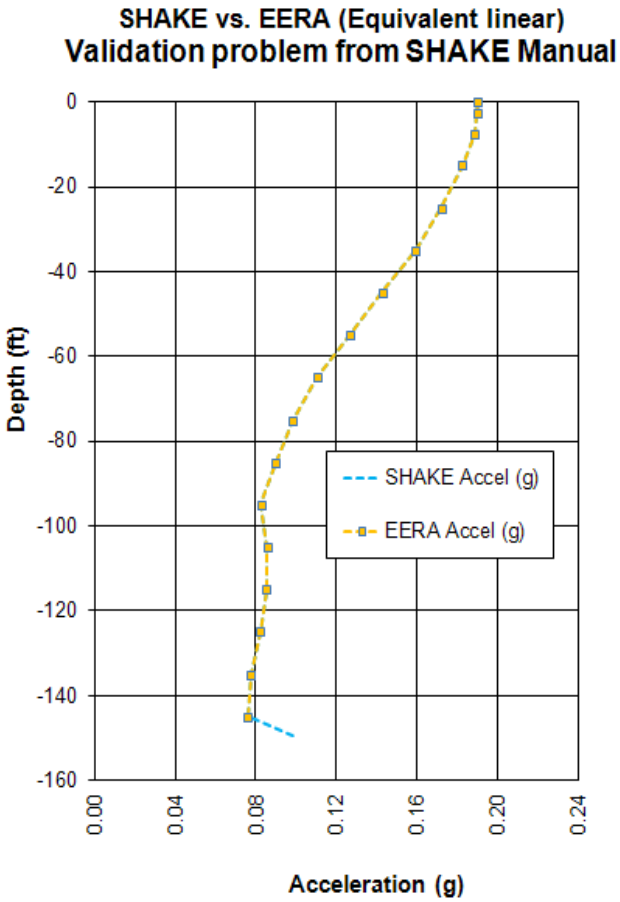


Figure 2 SHAKE vs. EERA

Stress and Acceleration vs. depth

SHAKE Val Problem 1





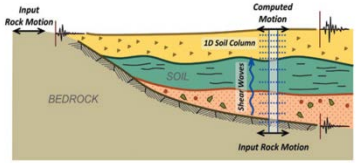
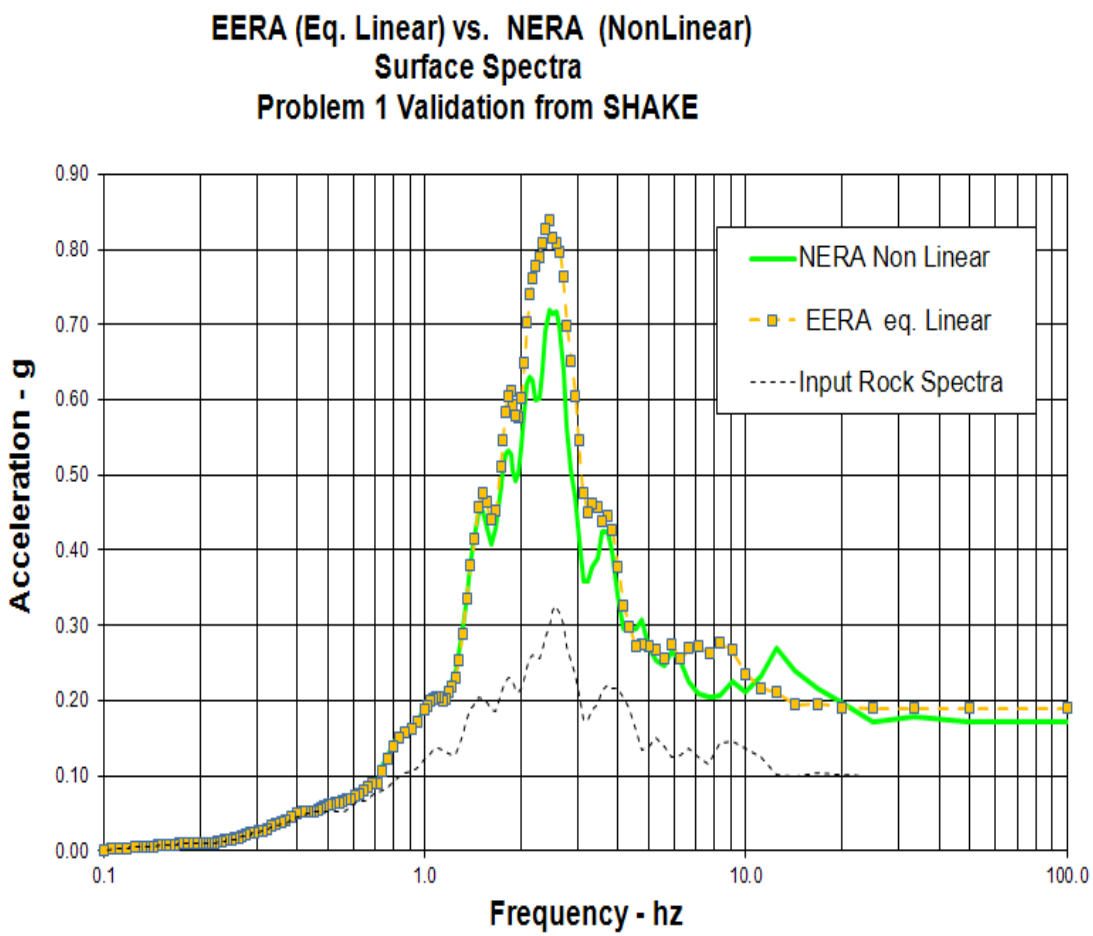
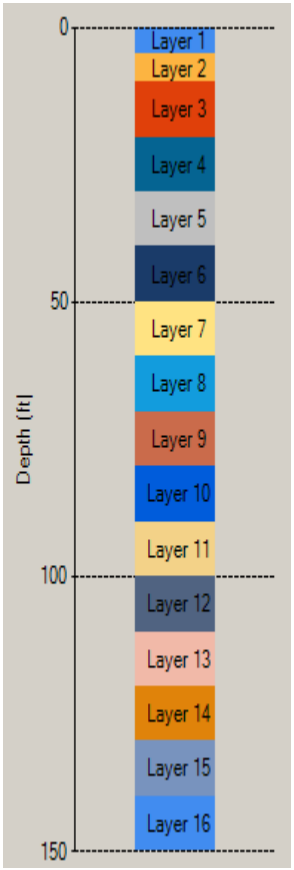


Figure 3 EERA vs. NERA

Surface Spectra

SHAKE Val Problem 1





Layer #	Layer Name	Thickness (ft)	Unit Weight (pcf)	Shear Velocity (ft/s)
1		5	125	1000
2		5	125	900
3		10	125	900
4		10	125	950
5		10	125	1000
6		10	125	1000
7		10	125	1100
8		10	125	1100
9		10	130	1300
10		10	130	1300
11		10	130	1400
12		10	130	1400
13		10	130	1500
14		10	130	1500
15		10	130	1600
16		10	130	1700

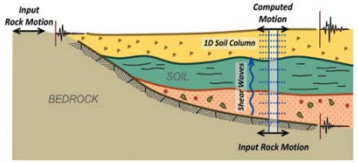
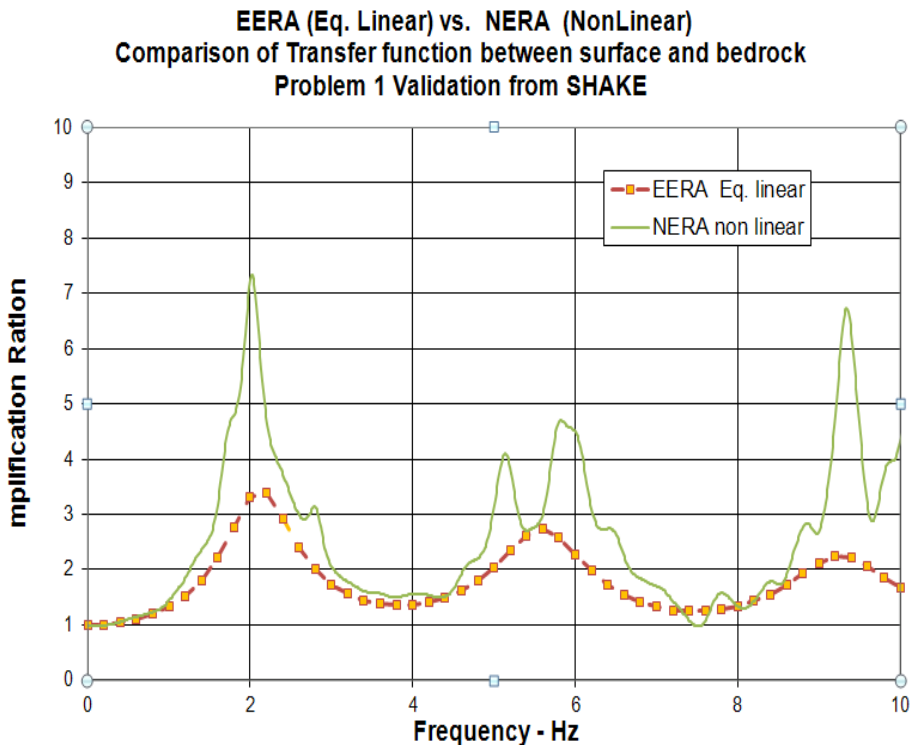
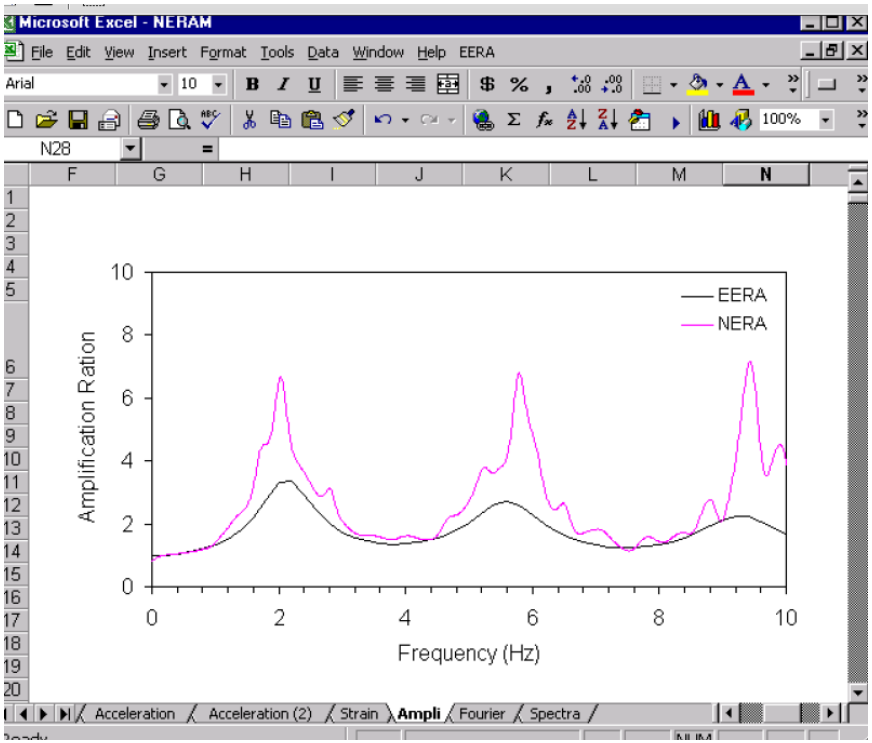


Figure 4 EERA vs. NERA

Transfer Function

SHAKE Val Problem 1





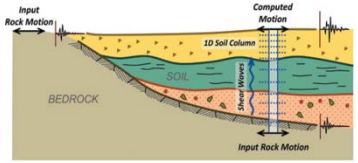
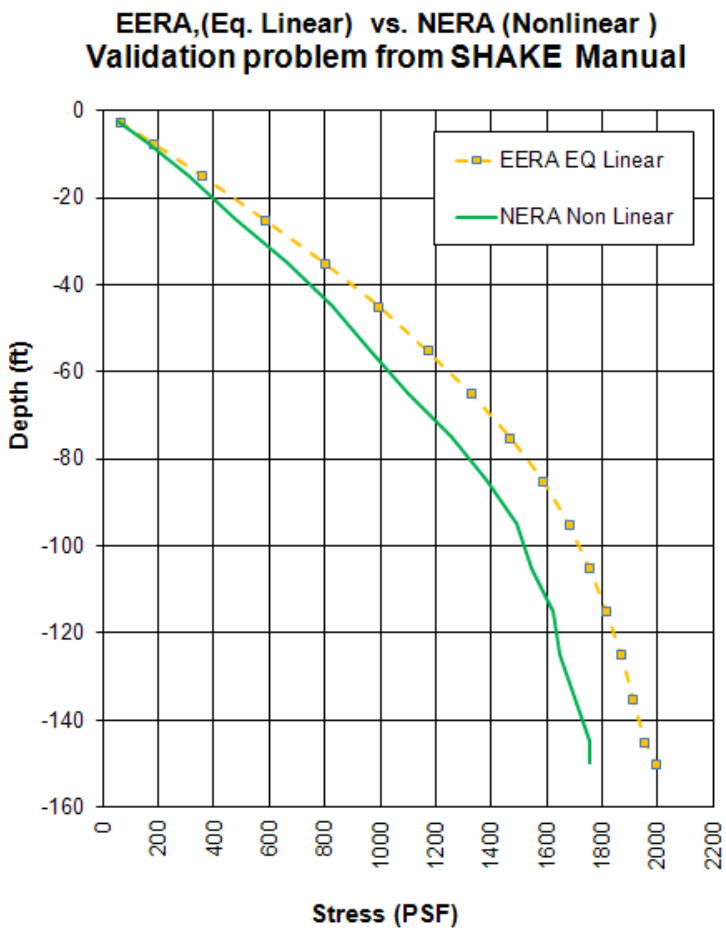
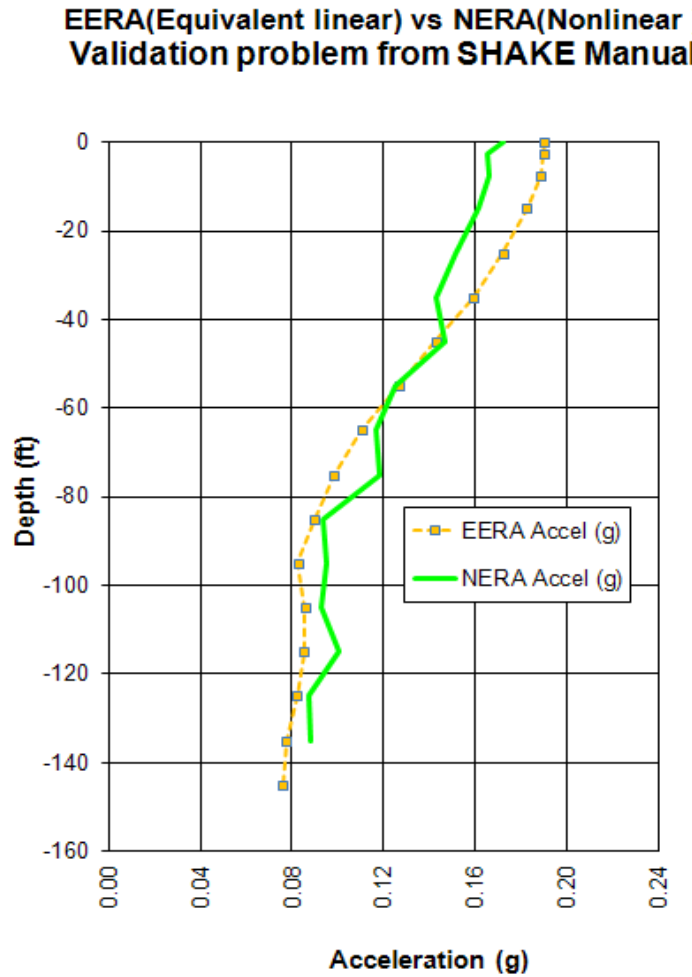


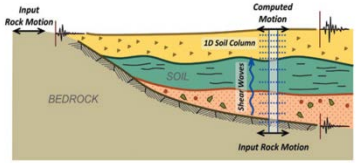
Figure 5 EERA vs. NERA

Stress and Acceleration vs. depth

SHAKE Val Problem 1







EERA - NERA

SRS 2014 SDC-3 is high at 0.6 Hz frequency compared to current site specific spectra, which will affect settlement value for structures at SRS.

For one selected building site, settlement from current site specific spectra is about 3 inches. Preliminary studies indicate the settlement could increase to about 6 inches for the 2014 spectra.

Evaluation of the soil profile is performed with EERA and NERA computer programs.

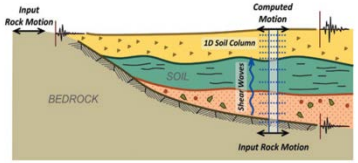
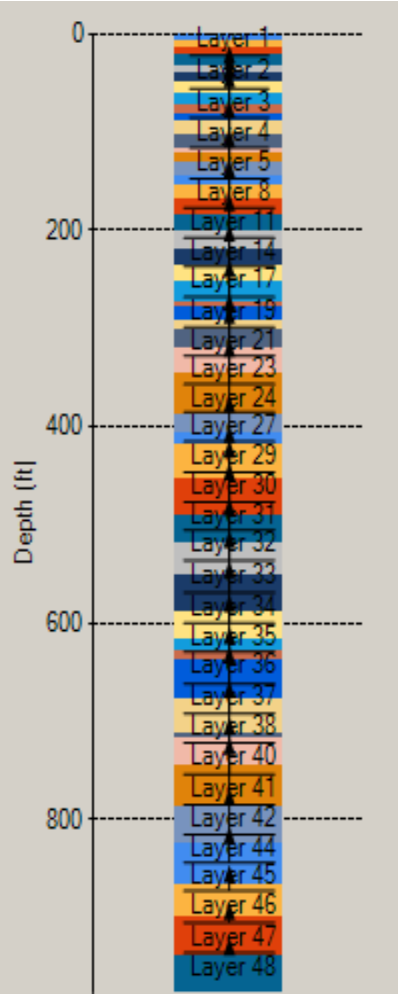


Figure 6 SRS Soil Profile



Layer #	Layer Name	Thickness (ft)	Unit Weight (pcf)	Shear Velocity (ft/s)
1	Nonlin S&I Mean	7.6	120	1510
2	Nonlin S&I Mean	7.6	120	1510
3	Nonlin S&I Mean	6	120	1150
4	Nonlin S&I Mean	11	120	1150
5	Nonlin S&I Mean	7.8	120	1150
6	Nonlin S&I Mean	10.2	120	920
7	Nonlin S&I Mean	12	120	1010
8	Nonlin S&I Mean	10	120	1010
9	Nonlin S&I Mean	10.2	120	1200
10	Nonlin S&I Mean	7	120	1200
11	Nonlin S&I Mean	15	120	1060
12	Nonlin S&I Mean	12	120	1350
13	Nonlin S&I Mean	6.8	120	1350
14	Nonlin S&I Mean	9	120	1000
15	Nonlin S&I Mean	12.2	120	1000
16	Nonlin S&I Mean	11.2	120	1510
17	Nonlin S&I Mean	13	125	1273

Layer #	Layer Name	Thickness (ft)	Unit Weight (pcf)	Shear Velocity (ft/s)
18	Nonlin S&I Mean	16.4	125	1289
19	Nonlin S&I Mean	16.4	125	1196
20	Nonlin S&I Mean	19.7	125	1463
21	Nonlin S&I Mean	16.4	125	1339
22	Nonlin S&I Mean	16.4	125	1266
23	Nonlin S&I Mean	19.7	125	1432
24	Nonlin S&I Mean	6	125	1505
25	Nonlin S&I Mean	13.6	125	1505
26	Nonlin S&I Mean	8	125	1783
27	Nonlin S&I Mean	18.3	125	1783
28	Nonlin S&I Mean	26.2	125	1892
29	Nonlin S&I Mean	42.7	125	2148
30	Nonlin S&I Mean	19.5	130	2282
31	Nonlin S&I Mean	10	130	2283
32	Nonlin S&I Mean	36.1	130	2159
33	Nonlin S&I Mean	36.1	130	2277
34	Nonlin S&I Mean	29.5	130	2199

Layer #	Layer Name	Thickness (ft)	Unit Weight (pcf)	Shear Velocity (ft/s)
33	Nonlin S&I Mean	36.1	130	2277
34	Nonlin S&I Mean	29.5	130	2199
35	Nonlin S&I Mean	32.8	130	2265
36	Nonlin S&I Mean	36.1	130	2329
37	Nonlin S&I Mean	29	130	2679
38	Nonlin S&I Mean	10.4	130	2679
39	Nonlin S&I Mean	11	130	2531
40	Nonlin S&I Mean	38.2	130	2531
41	Nonlin S&I Mean	36.1	135	2362
42	Nonlin S&I Mean	5	135	2516
43	Nonlin S&I Mean	27.8	135	2516
44	Nonlin S&I Mean	42.6	135	2447
45	Nonlin S&I Mean	36.1	135	2644
46	Nonlin S&I Mean	42.7	135	3263
47	Nonlin S&I Mean	32.8	135	2328
48	Nonlin S&I Mean	39.4	135	2878
49	Nonlin S&I Mean	38.2	135	5364

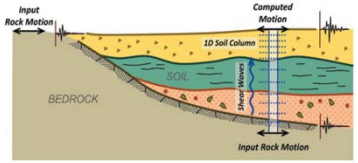
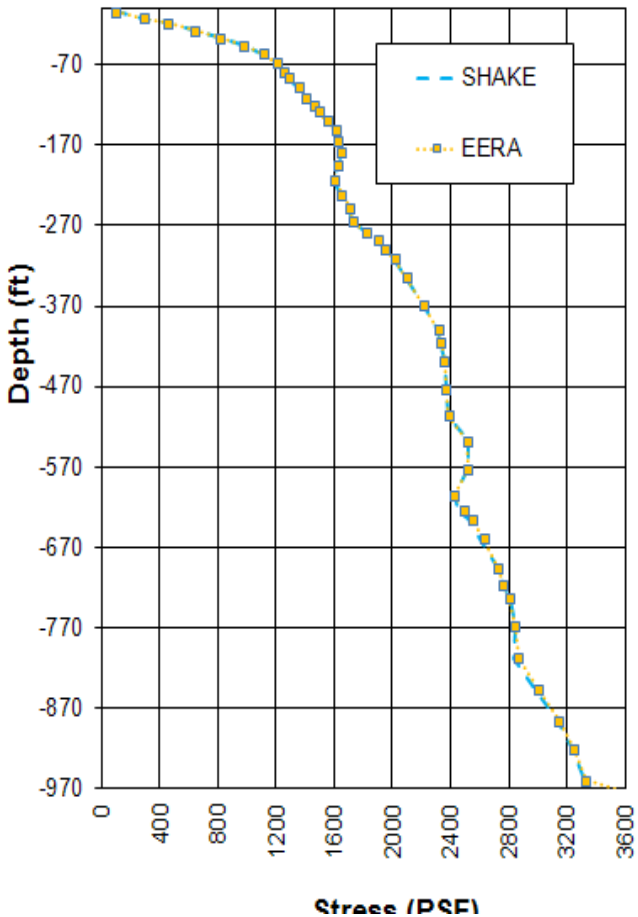
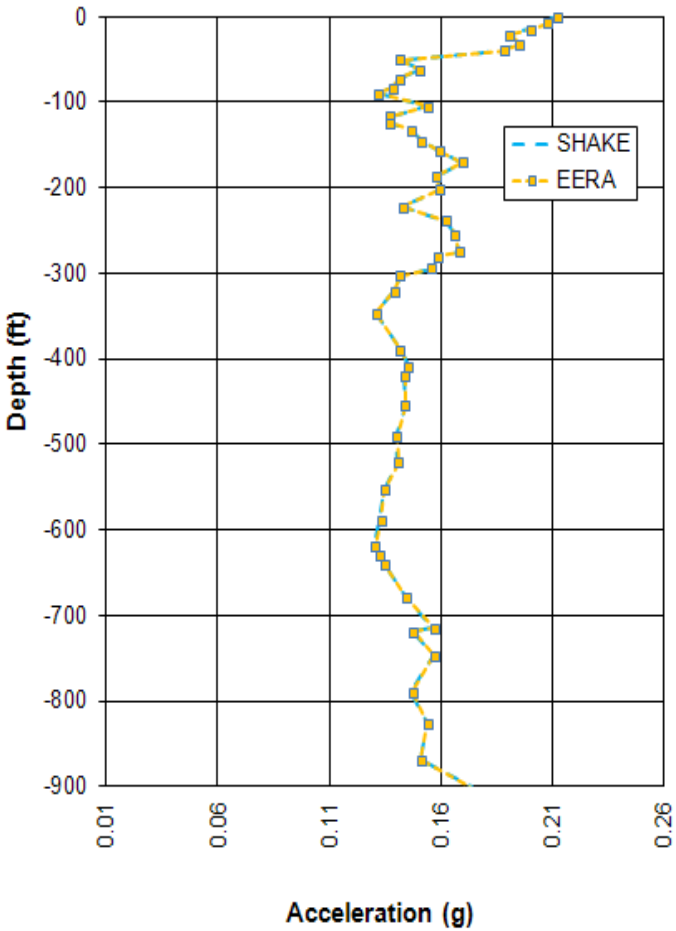


Figure 7 SHAKE vs. EERA

Stress and Acceleration vs. depth





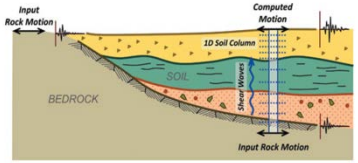
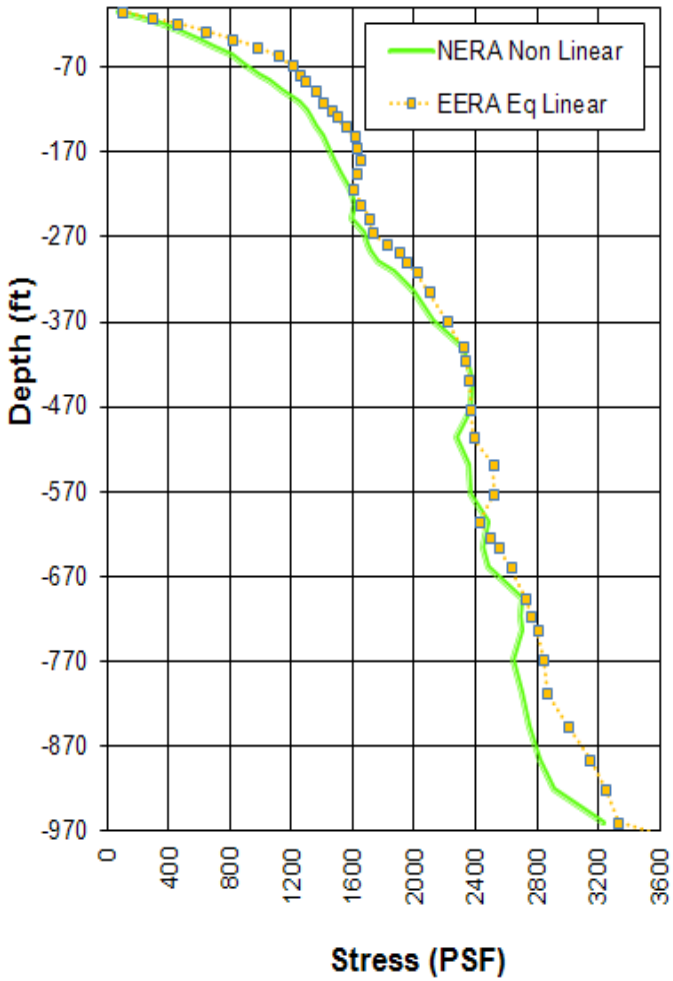
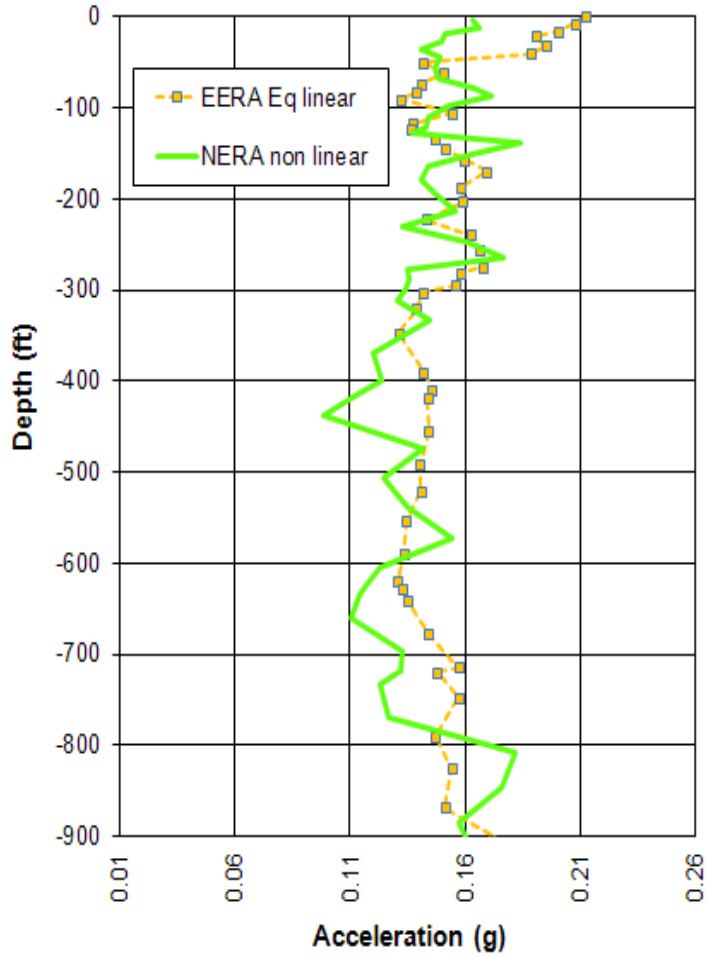


Figure 8 EERA vs. NERA

Stress and Acceleration vs. depth





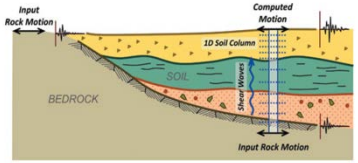
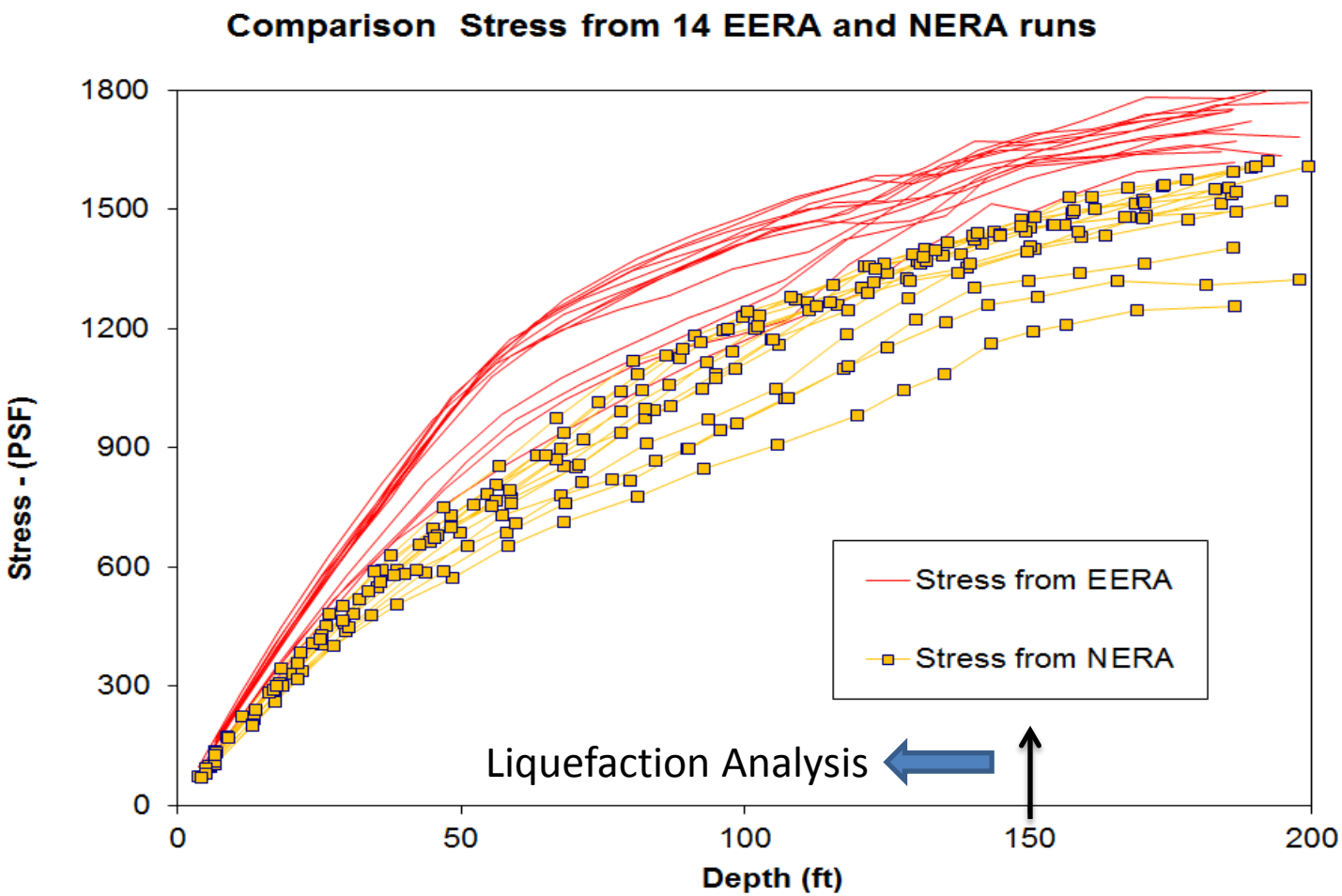
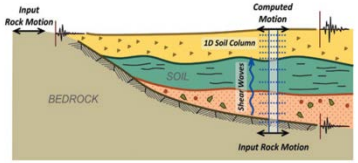


Figure 9 EERA vs. NERA

Stress vs. depth



14 Soil profiles

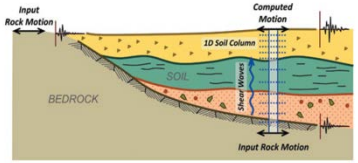


Conclusion

As shown in Figure 9, Soil column stress from 14 NERA runs is less than EERA analysis.

Using NERA results form Figure 9 a settlement of about 3 inches calculated with SDC-3 spectra. .

Non linear analysis may be a method to reduce settlement values under higher seismic loads at SRS.



Comments:

(ref. paper Nonlinear Site Response and Its Evaluation and Prediction)

- Comparisons between the equivalent linear and nonlinear analyses were also made by several researchers. When compared with earthquake observation, the nonlinear analysis is shown to agree with the observed record better than the equivalent linear analysis as shown later. Generally, equivalent linear analysis has a tendency to give larger peak acceleration and shear stress under large earthquakes, and lower amplification in high frequency range.

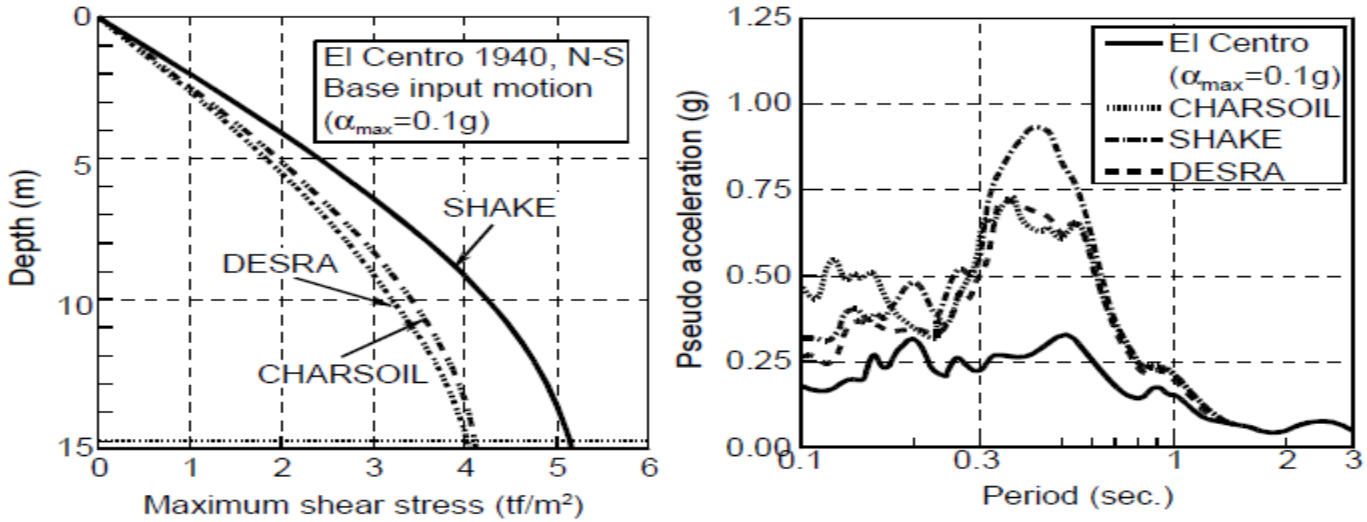
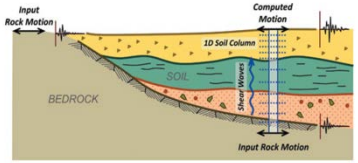


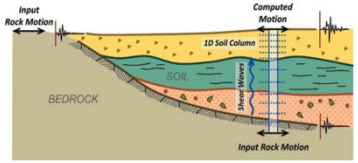
Figure 10 Comparison of three computer codes



NERA validation problems ??

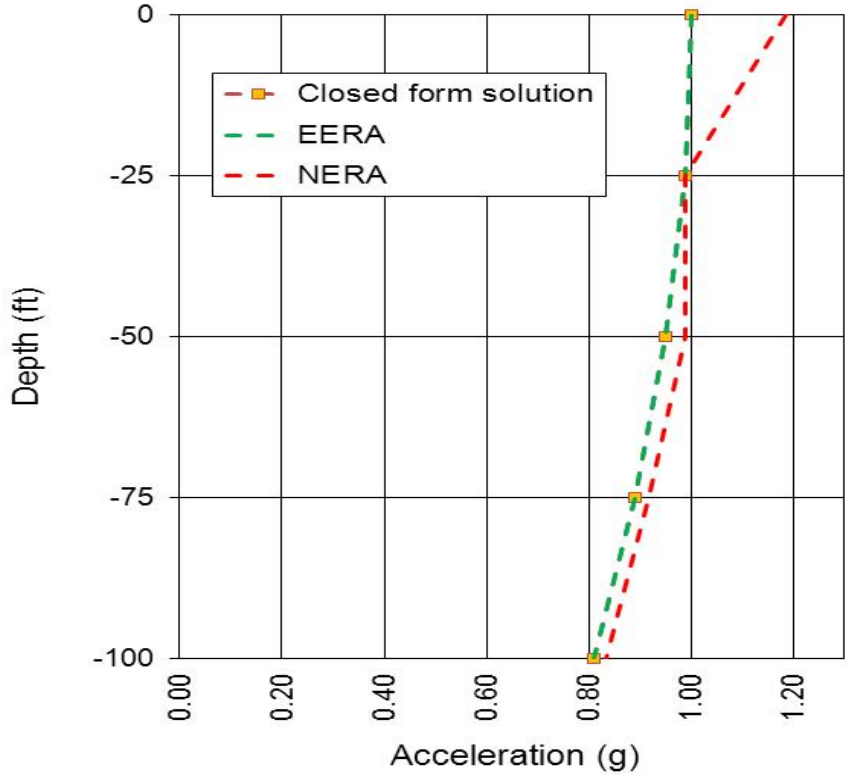
* NERA must be validated in order to be used at SRS.

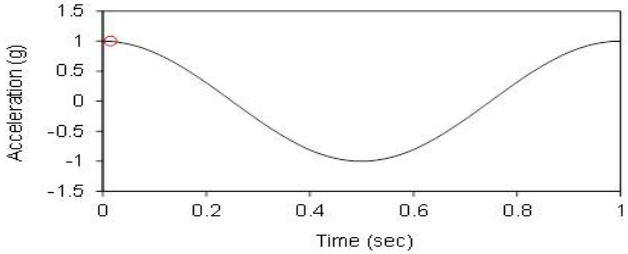
- We try to use close form solution problem from SHAKE validation (four problems) with NERA but don't know if this approach is valid.



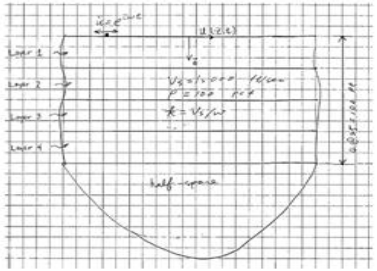
Closed form solution SQAEX1 from SHAKE vs. EERA and. NERA

SQAEX1 - Response of undamped free field subjected to an acceleration time-history at ground surface defined by a unit cosine function of 1 Hz frequency

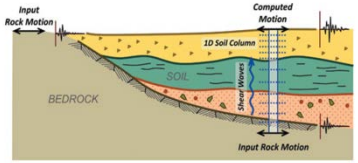




Cosine function of 1 Hz frequency

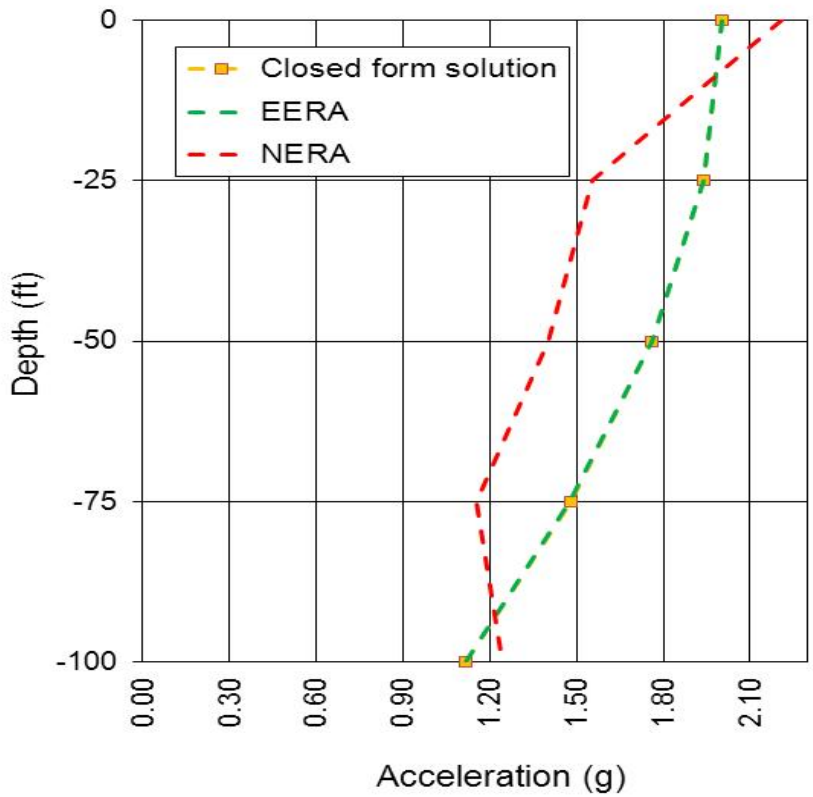


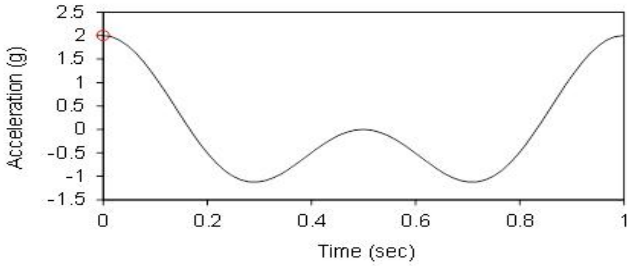
EERA / NERA /SHAKE Model



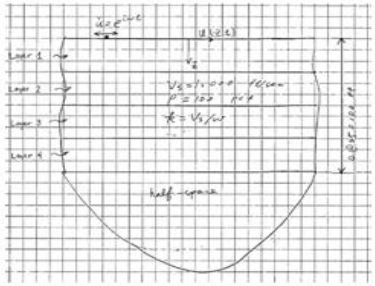
Closed form solution SQAEX2 vs. EERA vs. NERA

SQAEX2 - Response of undamped free field subjected to an acceleration time-history at the ground surafce defined by a combination of two unit cosine wave functions of 1 Hz and 2 Hz frequency.

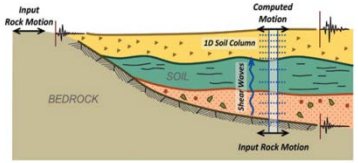




Cosine function of 1 Hz and 2 Hz frequency

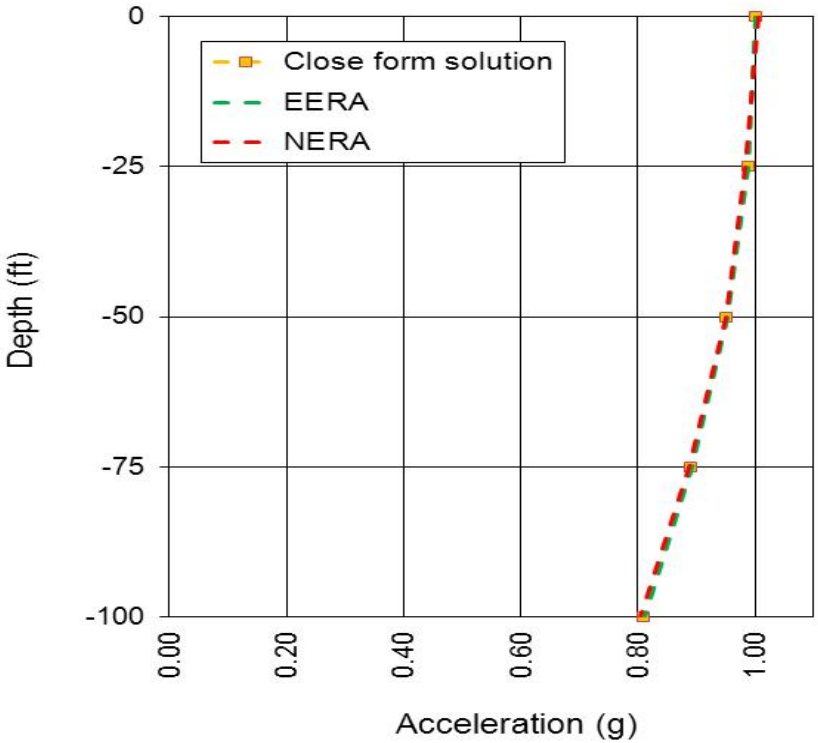


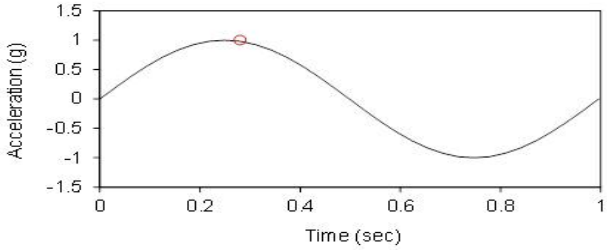
EERA / NERA /SHAKE Model



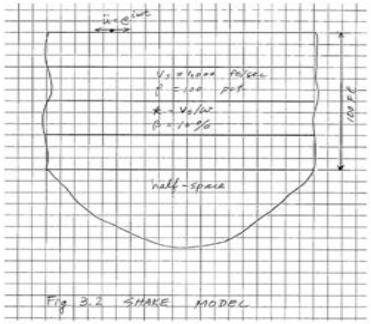
Closed form solution SQAEX3 vs. EERA /NERA

SQAEX3 - Response of 10% damped free field subjected to a horizontal excitation containing a 1 Hz unit amplitude cosine function at ground surface.

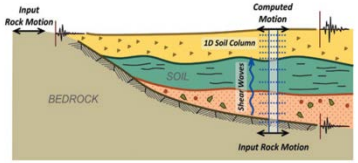




Cosine function of a 1 Hz frequency

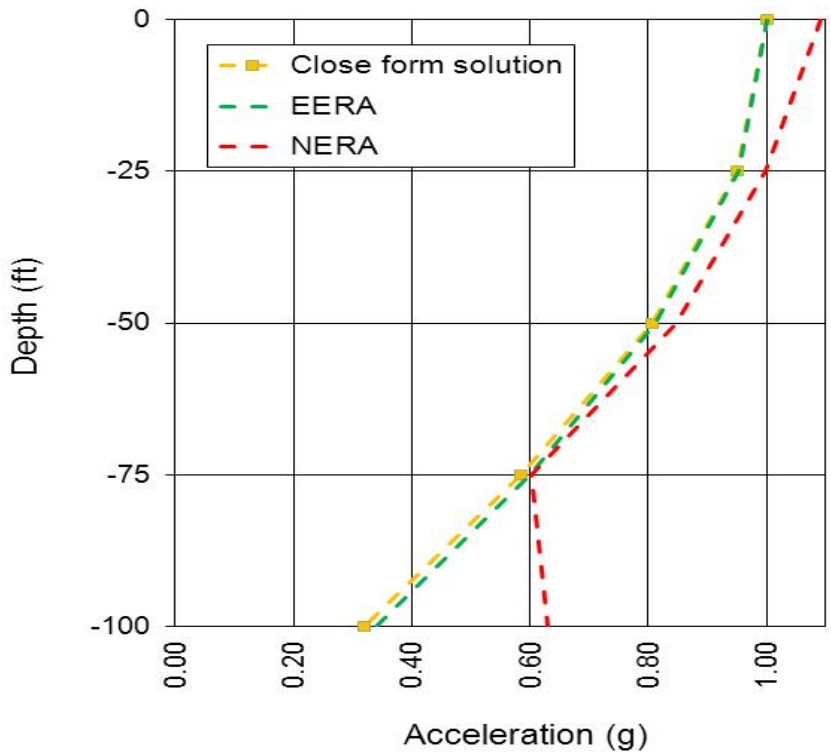


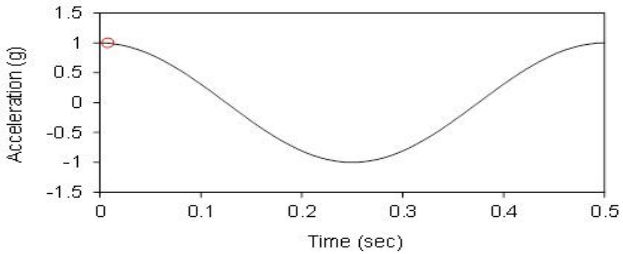
EERA / NERA /SHAKE Model



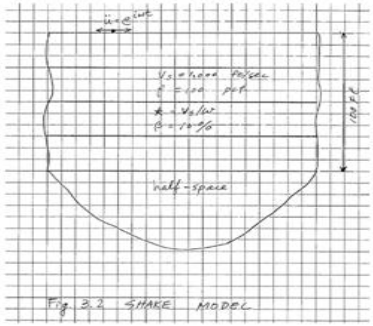
Closed form solution SQAEX4 vs. EERA /NERA

SQAEX4 - Response of 10% dampe free field subjected to a horizontal excitation containing a 2 Hz unit amplitude cosine function at ground surface.





Cosine function of a 2 Hz frequency



EERA / NERA /SHAKE Model