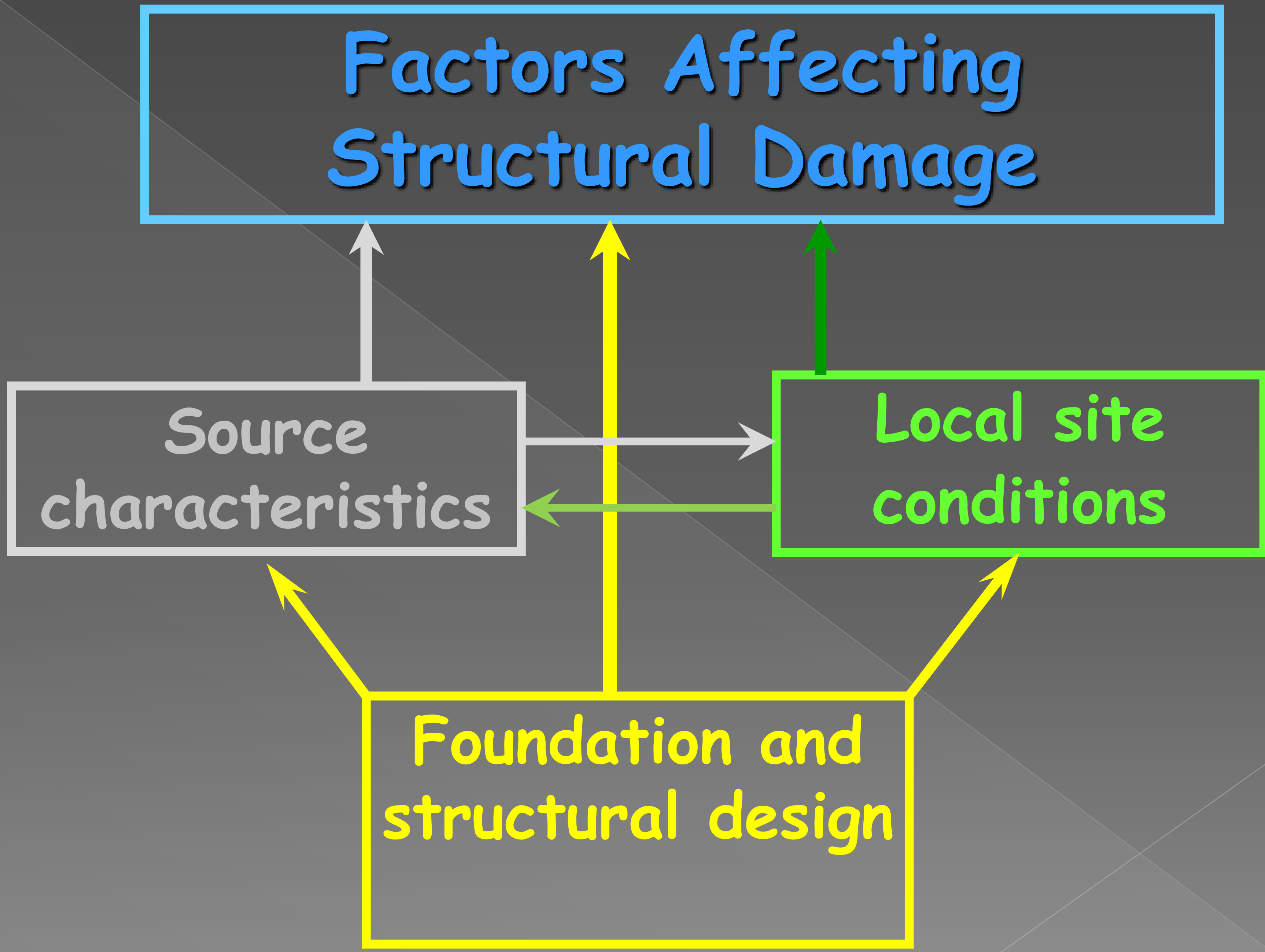
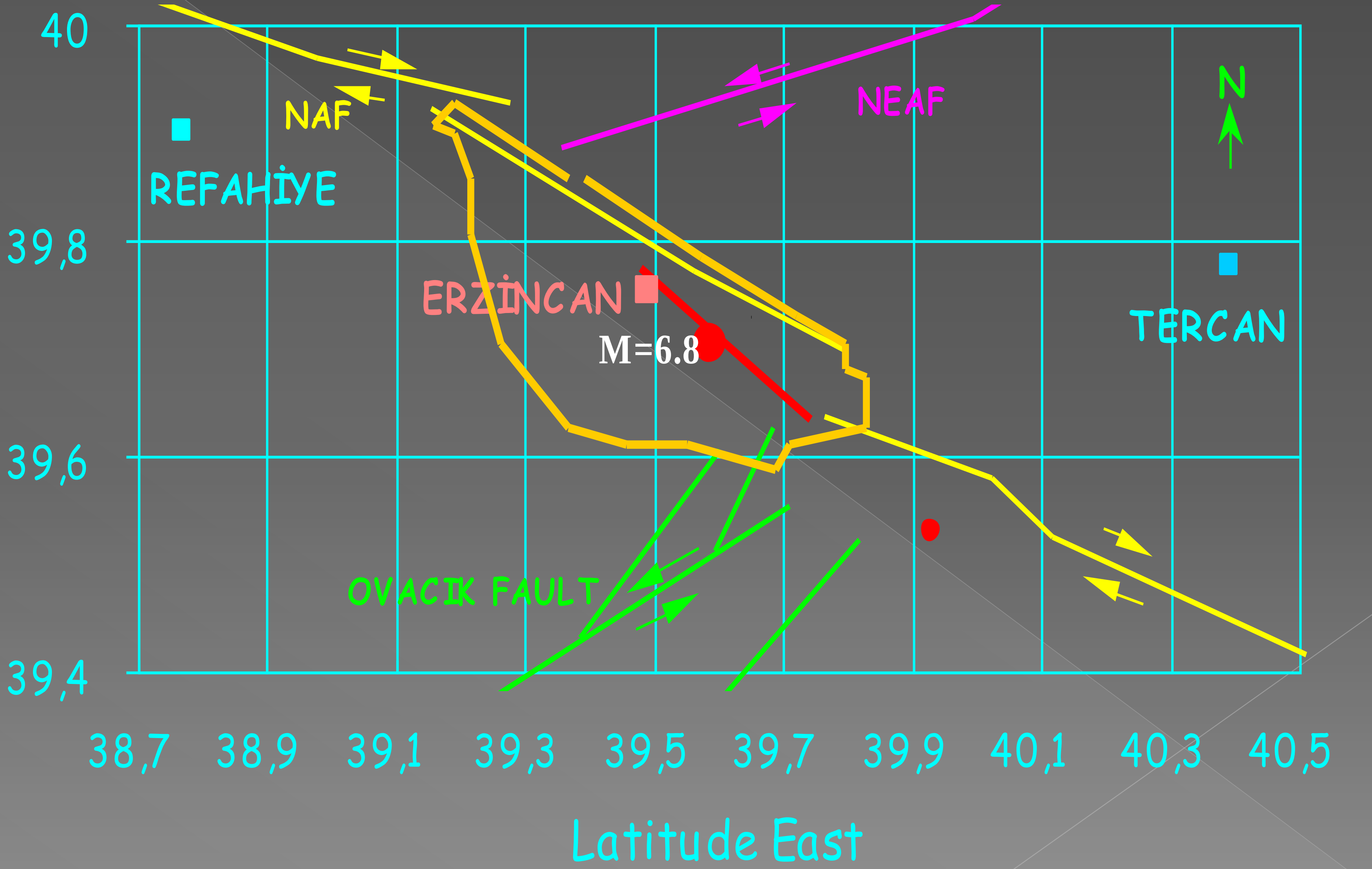
EFFECTS OF SITE CONDITIONS
&
SITE RESPONSE ANALYSES

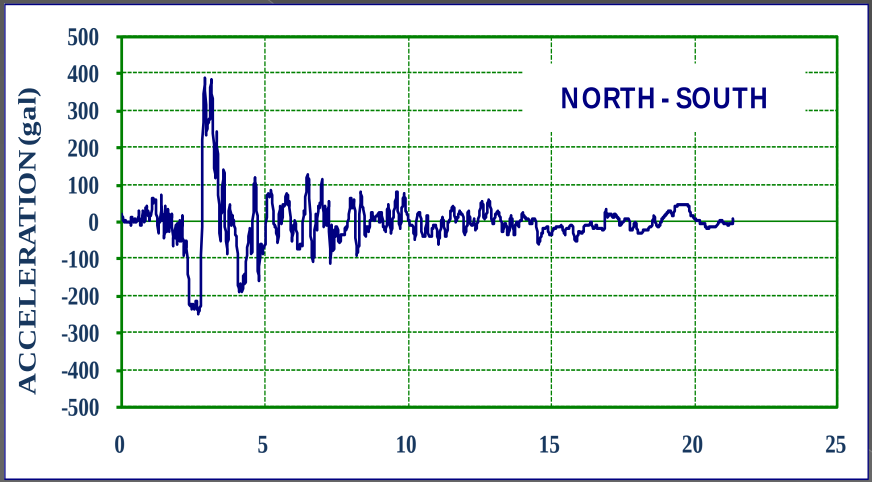
Lecture Notes
by
Atilla Ansal

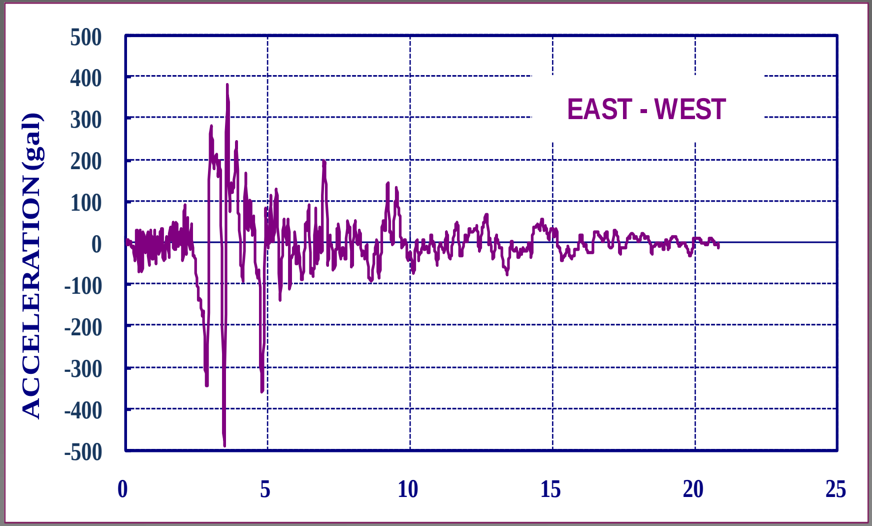

Factors Affecting Structural Damage
Source characteristics
Local site conditions
Foundation and structural design

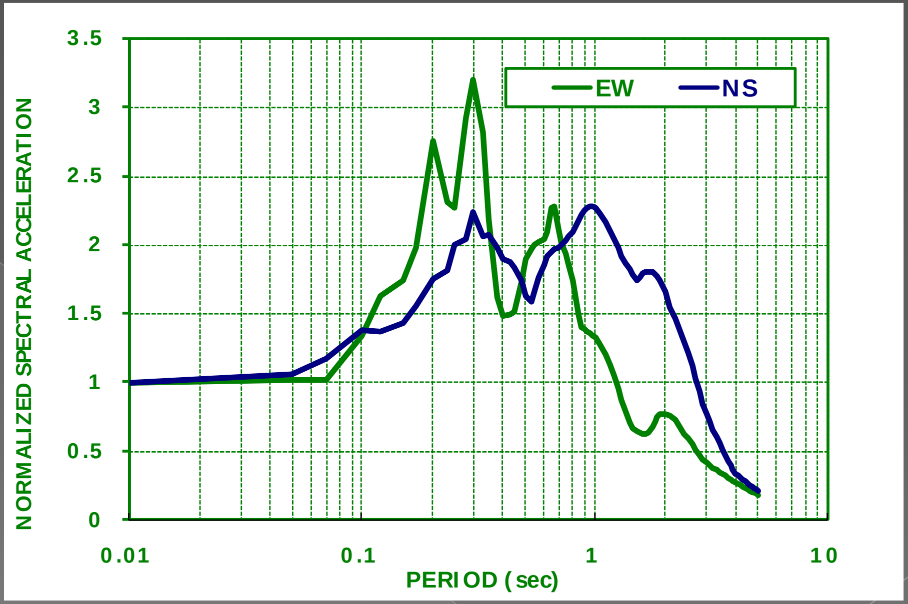
Erzincan Case

- Very thick heterogeneous fluvial and colluvium deposits
- alternating layers of gravelly sandy silts, silty gravelly sands and sandy silty clays
- very dense, partly cemented gravel layers at depths 5-6 m in northern part and 15-20 m in the southern part


40
39,8
39,6
39,4
NAF
NEAF
N
REFAHİYE
ERZİNCAN
M=6.8
TERCAN
OVACIK FAULT
38,7
38,9
39,1
39,3
39,5
39,7
39,9
40,1
40,3
40,5
Latitude East


NORTH - SOUTH
ACCELERATION (gal)
500
400
300
200
100
0
-100
-200
-300
-400
-500
0
5
10
15
20
25

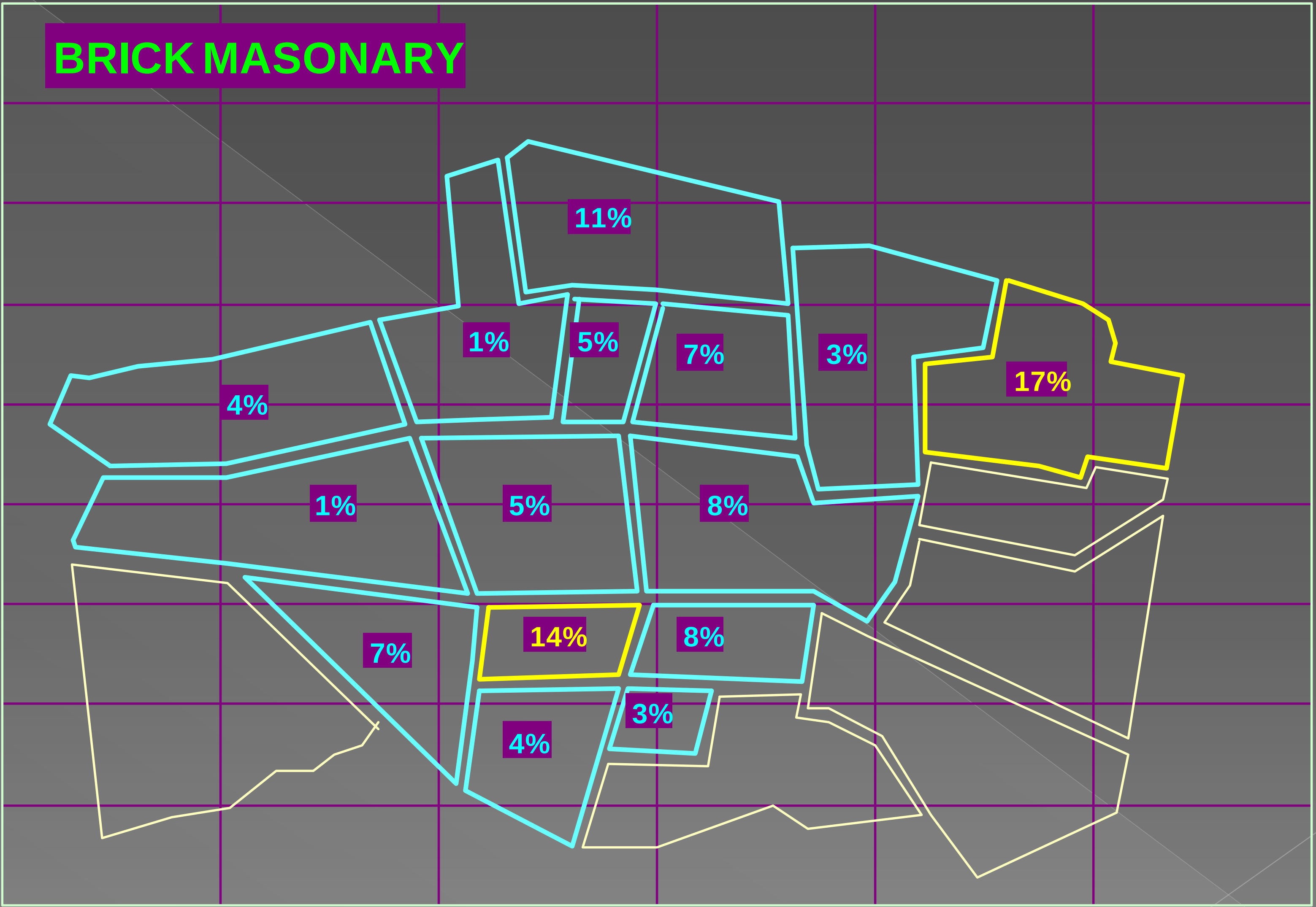

EAST - WEST
ACCELERATION (gal)
500
400
300
200
100
0
-100
-200
-300
-400
-500
0
5
10
15
20
25


EW
NS
NORMALIZED SPECTRAL ACCELERATION
3.5
3
2.5
2
1.5
1
0.5
0
0.01
0.1
1
10
PERIOD (sec)

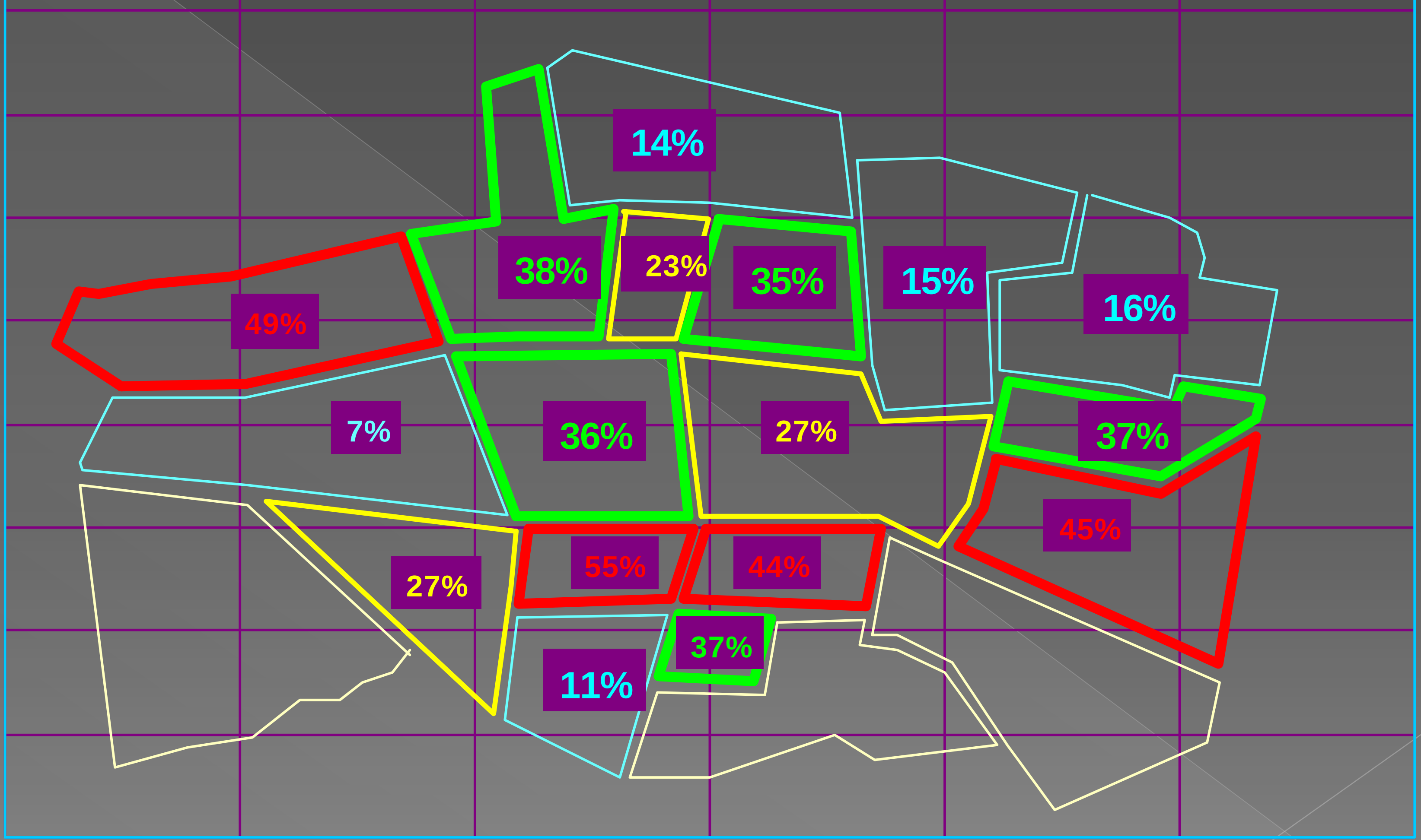
13.3.1992 ERZİNCAN EARTHQUAKE

- M_s = 6.8, R_e = 10 km, D_f = 9 km
- Pure right lateral strike slip, dip 80 °
- Fault direction N125E
- Bilateral rupture, more towards SE
- Rupture length 20-35 km, width 12 km

BRICK MASONARY

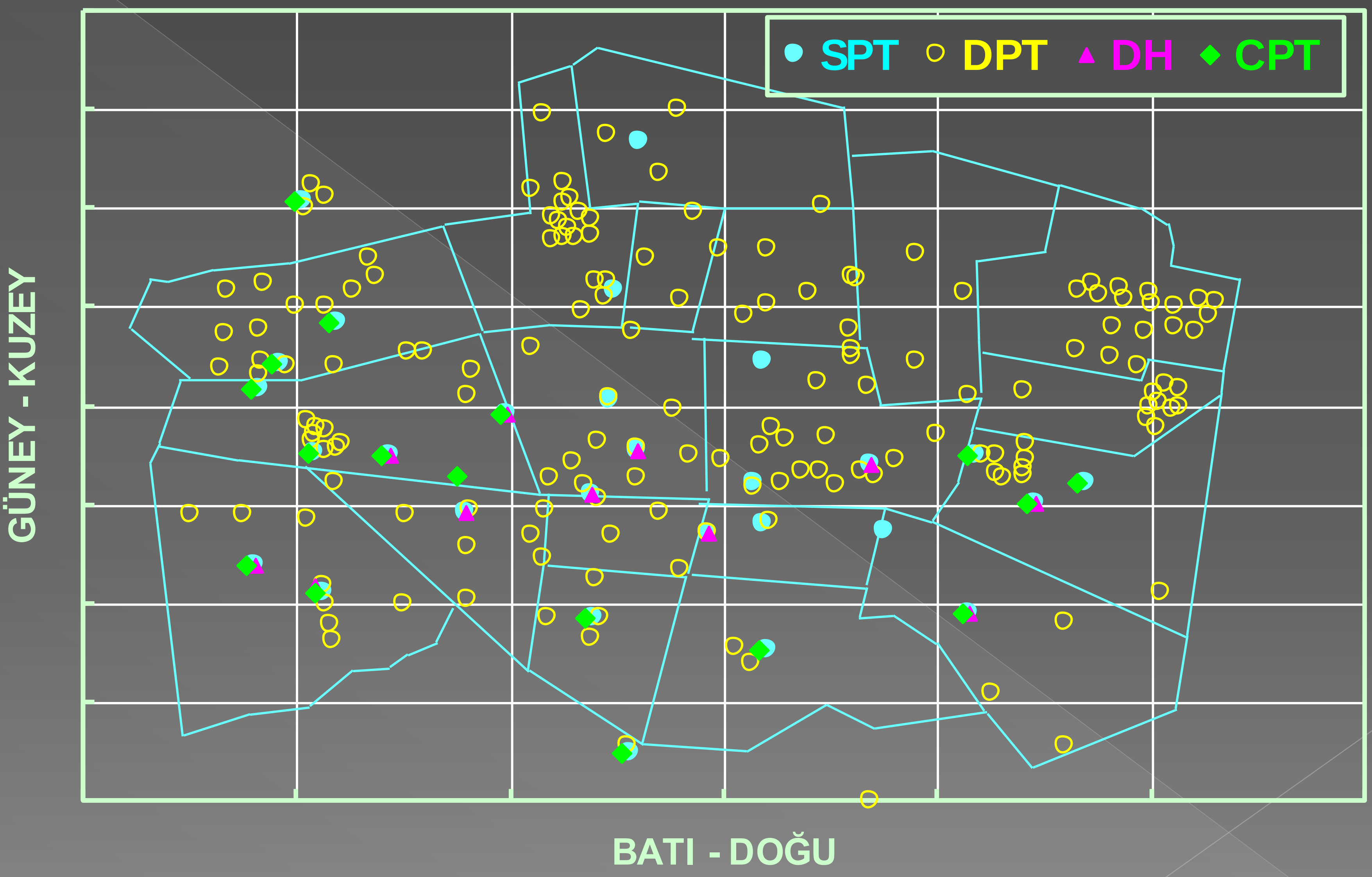


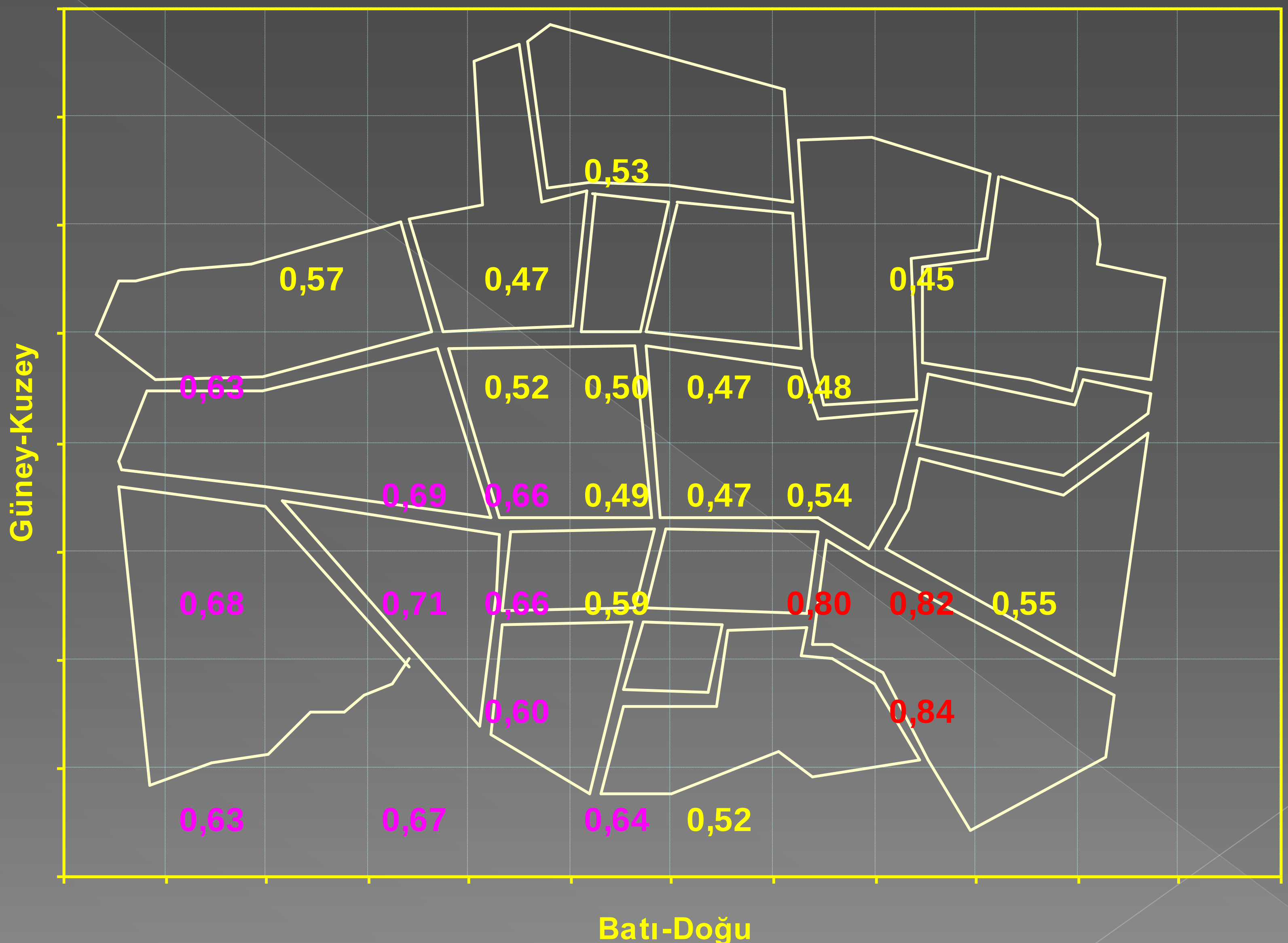
REINFORCED FRAME STRUCTURES



- 180 meshes with 250x250 m.
- average damage ratio for 3-4 story buildings for each mesh
- thickness of the soil layers over the dense gravel layer for each mesh
- equivalent shear wave velocity for each mesh
- data from 74 meshes

90%-71%
68%-50%
48%-30%
28%-10%
8%-0%


SPT
DPT
DH
CPT
GÜNEY - KUZEY
BATI - DOĞU


0,53
0,57
0,47
0,45
0,63
0,52
0,50
0,47
0,48
0,69
0,66
0,49
0,47
0,54
0,68
0,71
0,66
0,59
0,80
0,82
0,55
0,60
0,84
0,63
0,67
0,64
0,52
Güney-Kuzey
Batı-Doğu

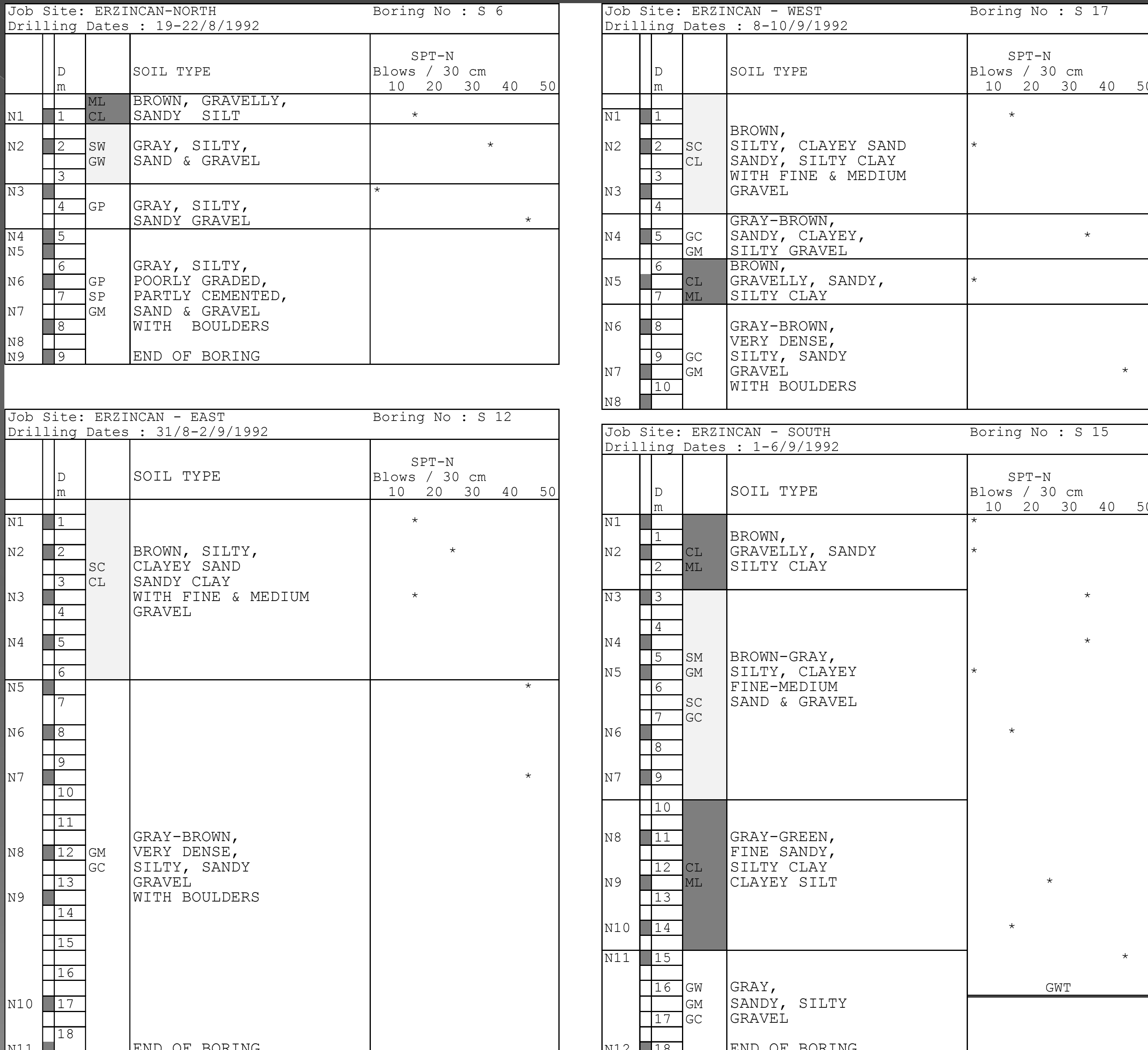
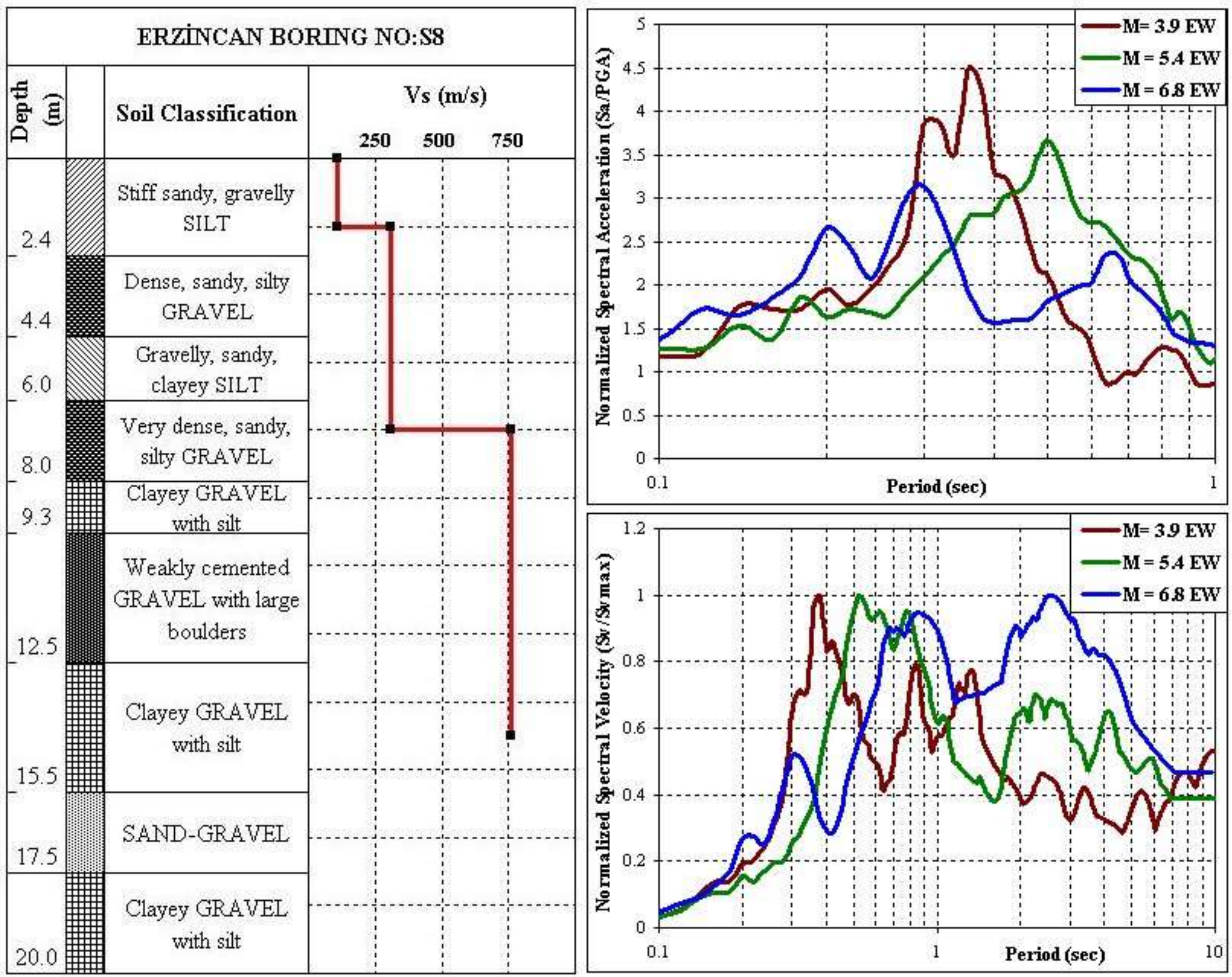
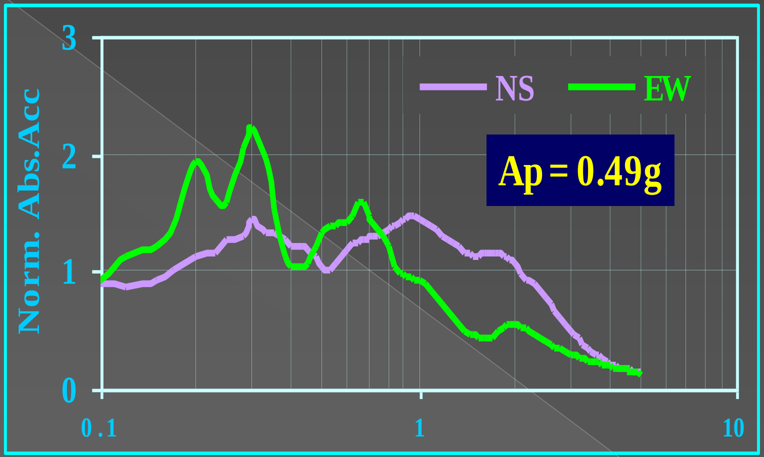
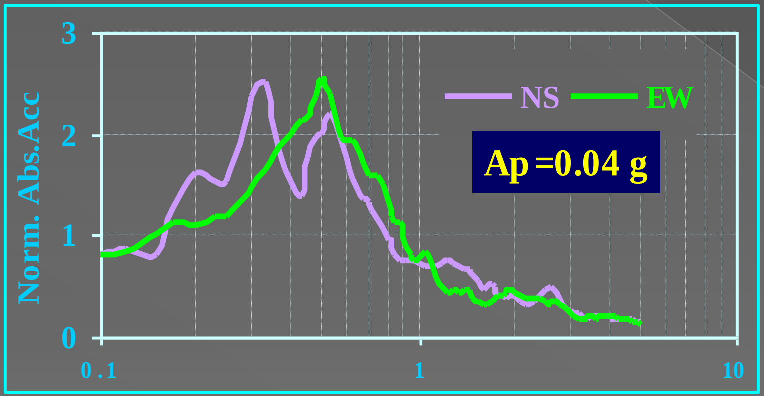
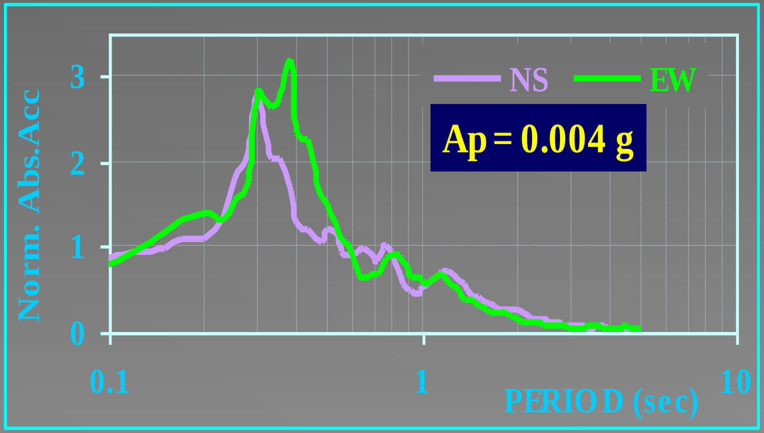


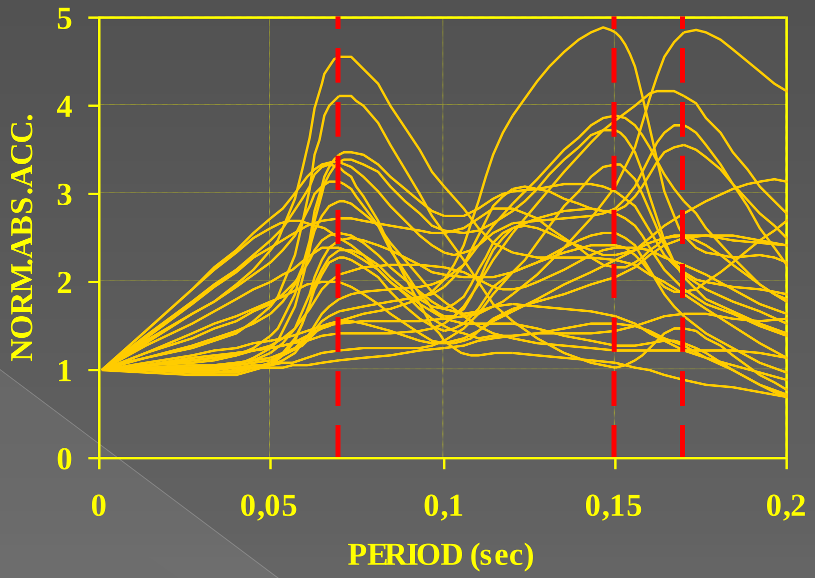
Figure 6.Some Typical Soil Profiles within Erzincan


ERZİNCAN BORING NO:S8
Depth (m)
Soil Classification
Vs (m/s)
250
500
750
Stiff sandy, gravelly SILT
2.4
Dense, sandy, silty GRAVEL
4.4
Gravelly, sandy, clayey SILT
6.0
Very dense, sandy, silty GRAVEL
8.0
Clayey GRAVEL with silt
9.3
Weakly cemented GRAVEL with large boulders
12.5
Clayey GRAVEL with silt
15.5
SAND-GRAVEL
17.5
Clayey GRAVEL with silt
20.0
M= 3.9 EW
M = 5.4 EW
M = 6.8 EW
Normalized Spectral Acceleration (Sa/PGA)
Period (sec)
0.1
1
Normalized Spectral Velocity (Sv/Svmax)
Period (sec)
0.1
1
10









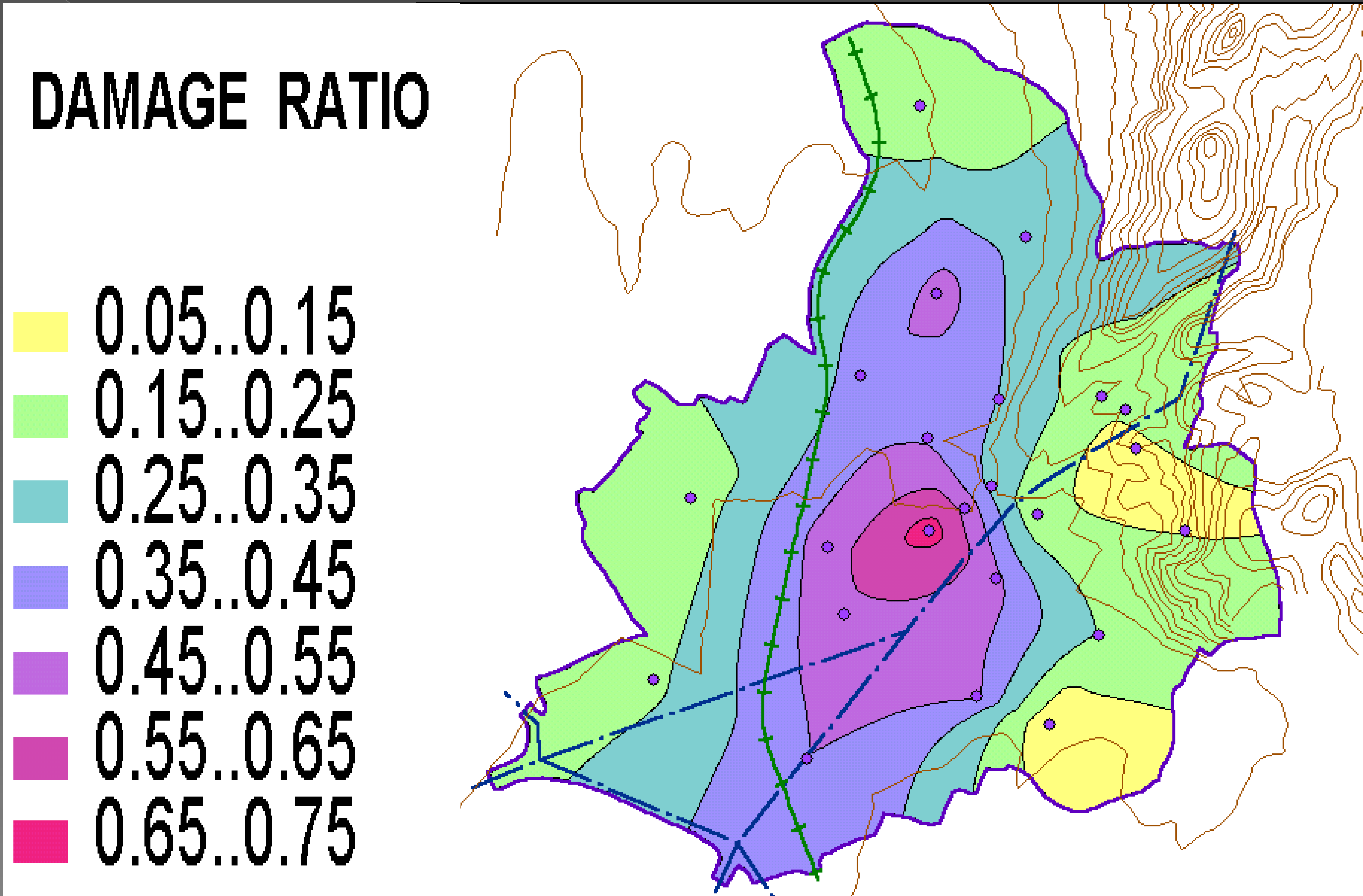
ERZİNCAN SM Station -1

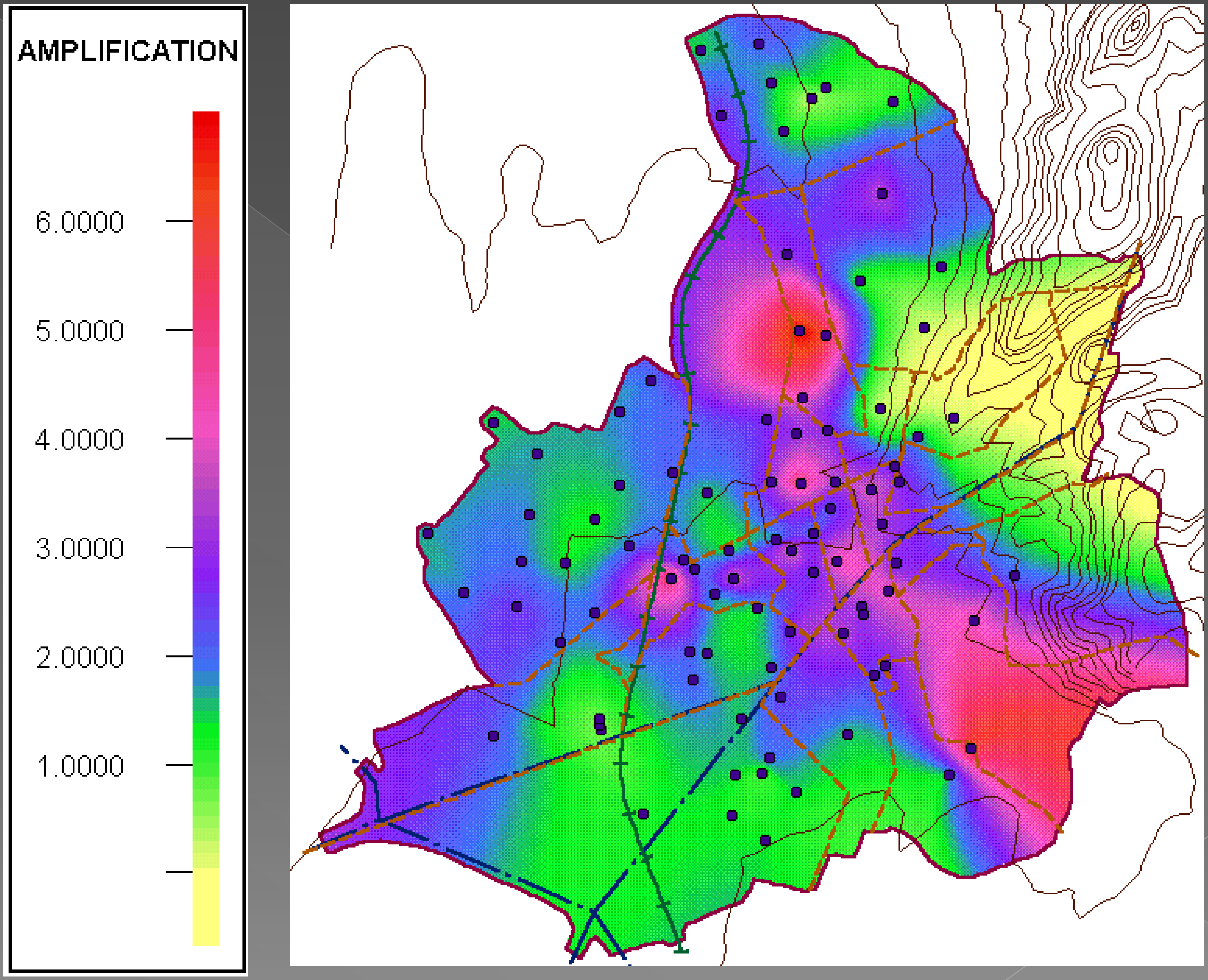
Dinar Case

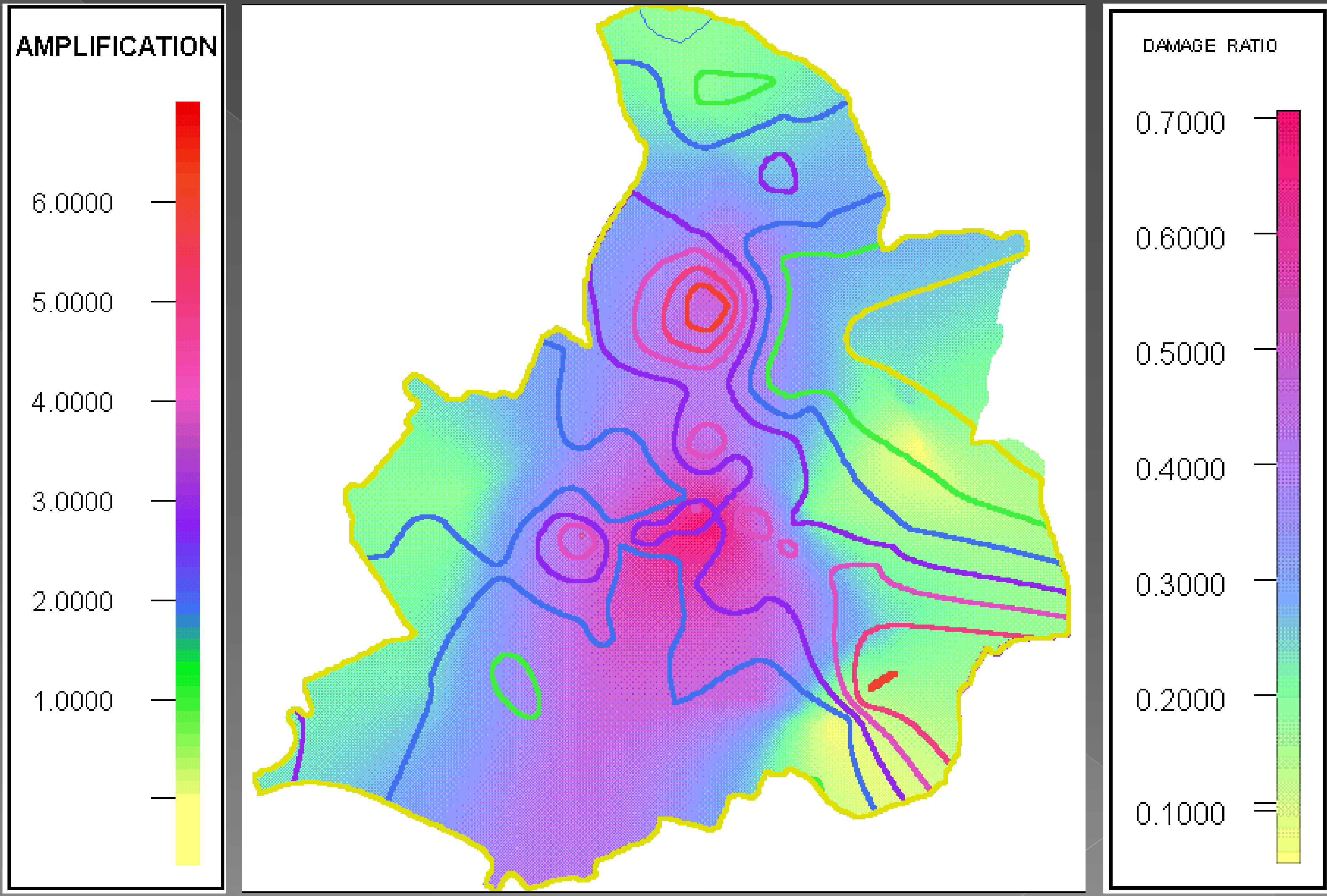
- Located partly on the limestone, marl and schist formations
- **Partly on alluvium deposit with alternating layers of loose to medium silty sands and soft to medium stiff silty clays and organic clays and silts**

1.10.1995 DİNAR EARTHQUAKE

- M_L = 5.9, R_e = 10 km, D_f = 24 km
- Normal faulting with right lateral component
- Fault direction N300E, dip 40 °
- Unidirectional rupture, from hypocentre
- Rupture length 10-15 km

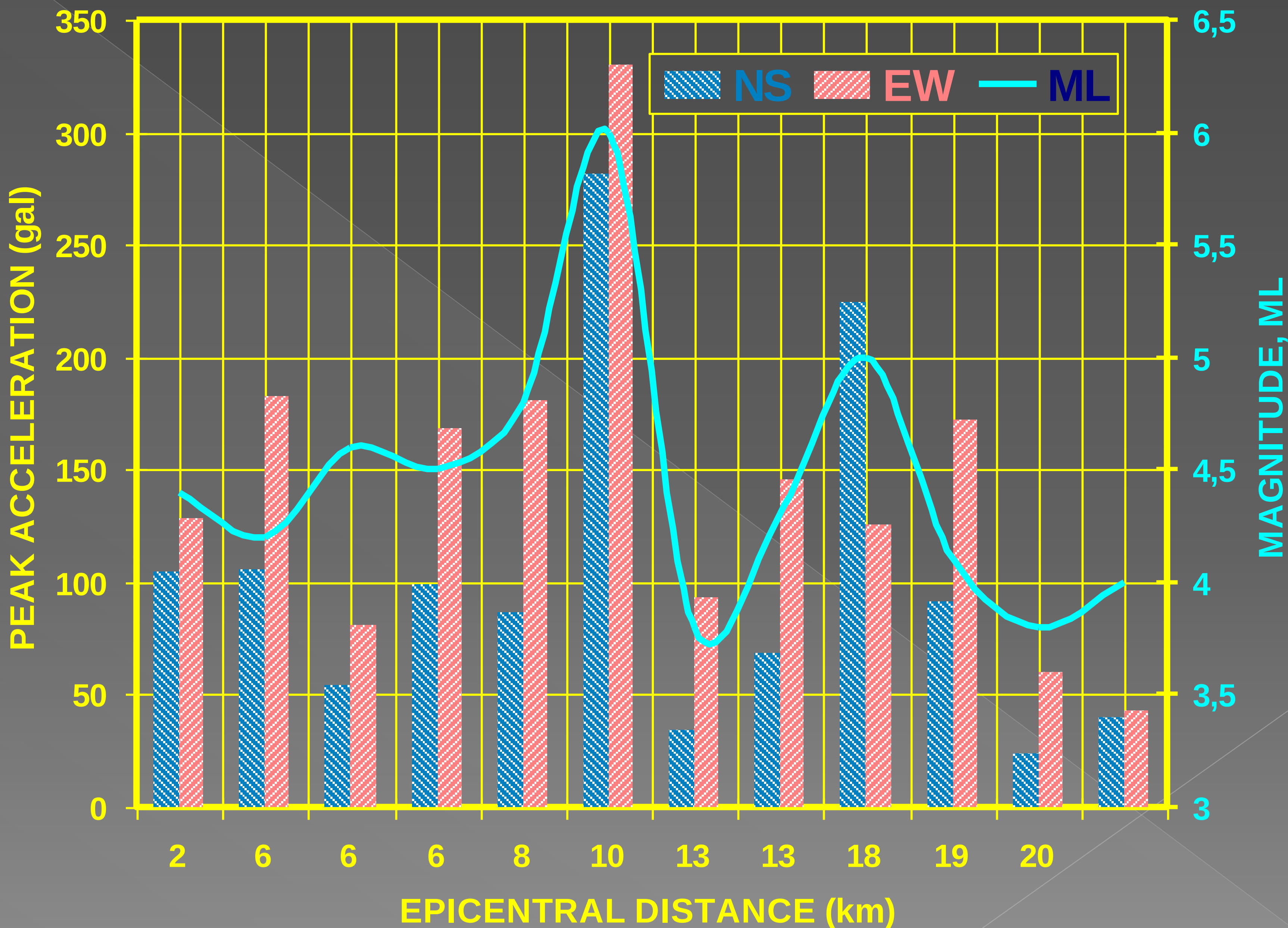

DAMAGE RATIO
0.05..0.15
0.15..0.25
0.25..0.35
0.35..0.45
0.45..0.55
0.55..0.65
0.65..0.75


AMPLIFICATION
6.0000
5.0000
4.0000
3.0000
2.0000
1.0000

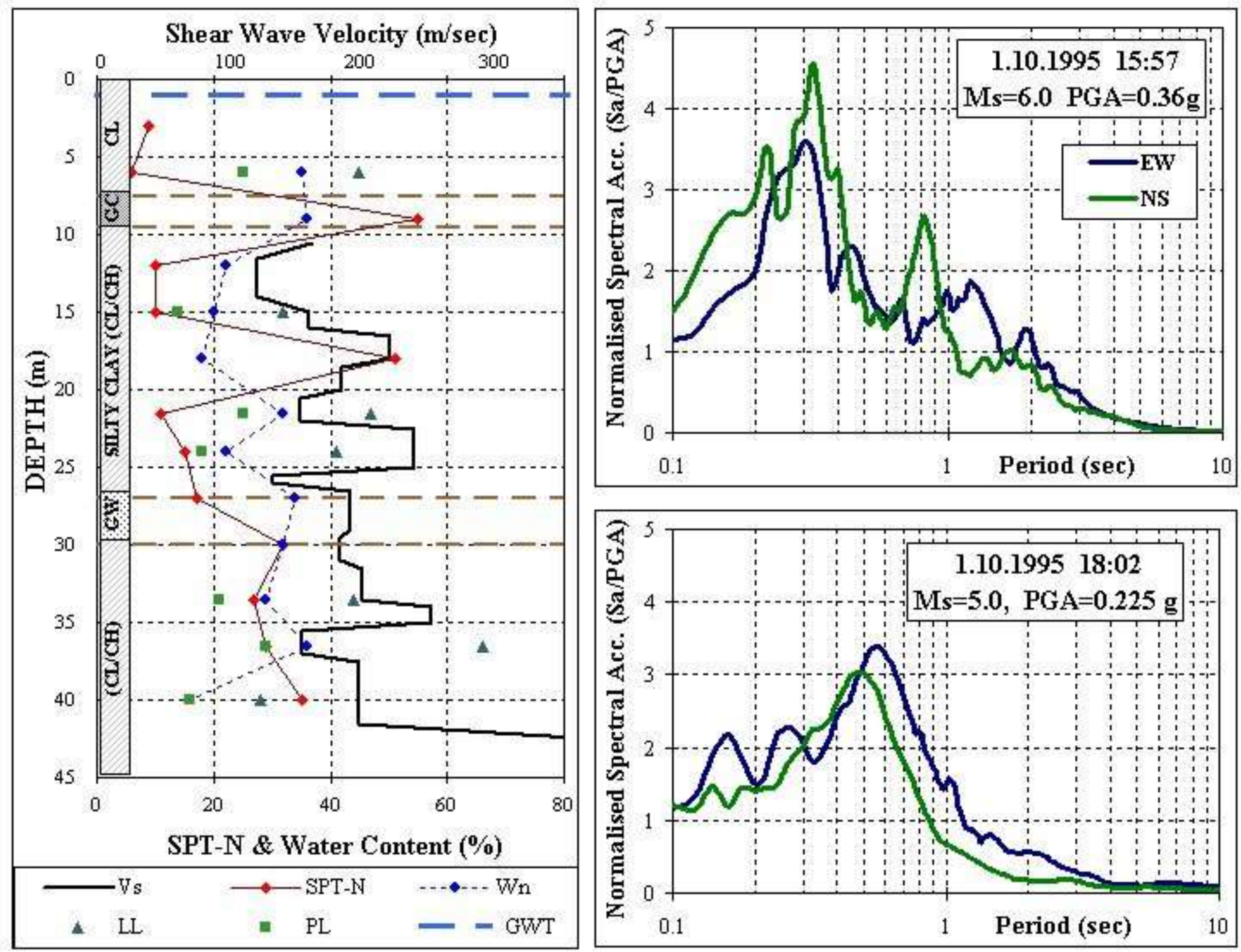

AMPLIFICATION
6.0000
5.0000
4.0000
3.0000
2.0000
1.0000
DAMAGE RATIO
0.7000
0.6000
0.5000
0.4000
0.3000
0.2000
0.1000

M_L=4.1-5.9 & PGA=0.07-0.33g with the increase in PGA

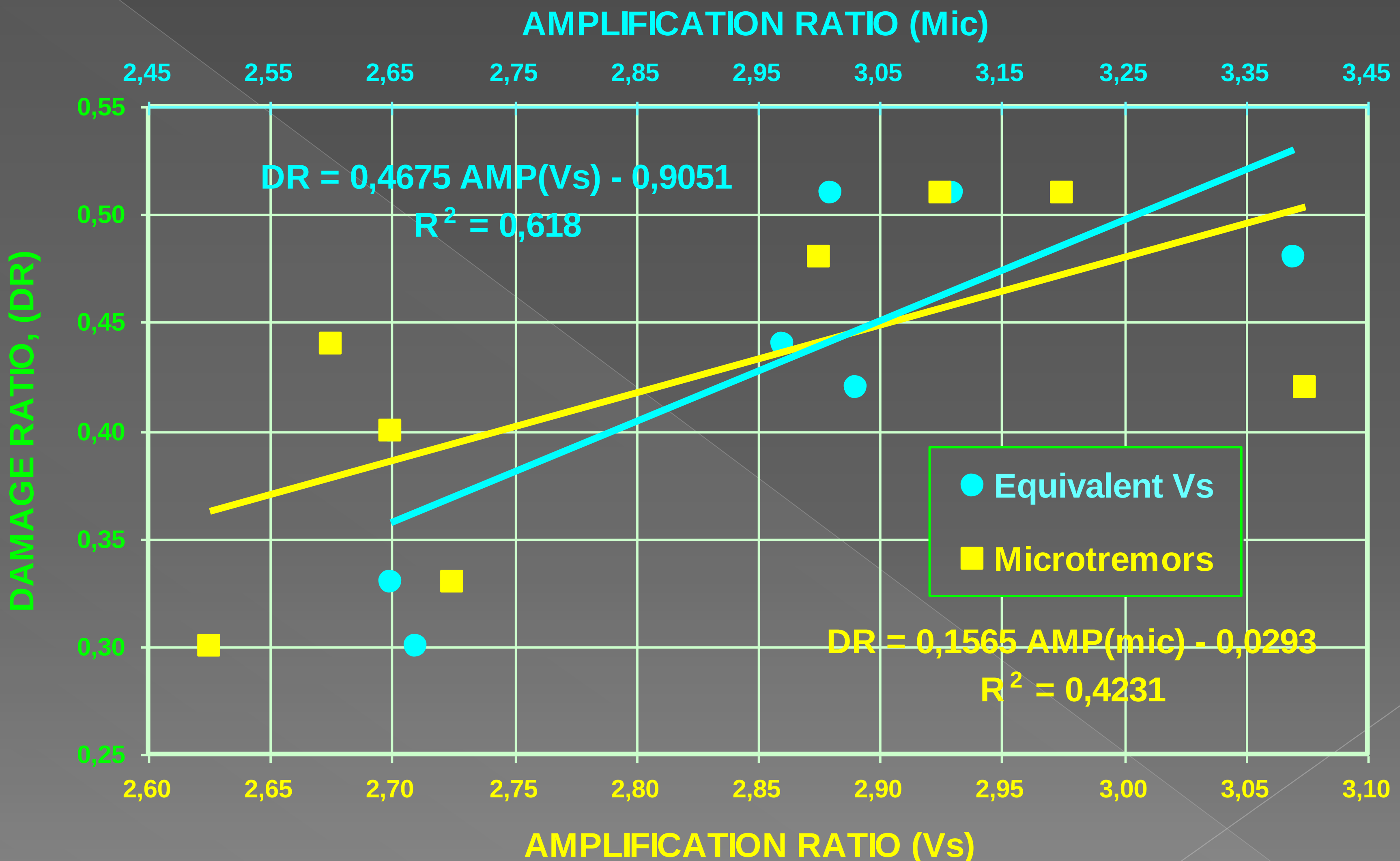
- Shift of acceleration spectra toward longer period
- decrease in spectral amplification
- similar shift in consequent records due to soil degradation and pore pressure buildup



NS
EW
ML
PEAK ACCELERATION (gal)
MAGNITUDE, ML
EPICENTRAL DISTANCE (km)
0
50
100
150
200
250
300
350
3
3,5
4
4,5
5
5,5
6
6,5
2
6
6
6
8
10
13
13
18
19
20



Shear Wave Velocity (m/sec)
0
100
200
300
DEPTH (m)
CL
GC
SILTY CLAY (CL/CH)
GW
(CL/CH)
SPT-N & Water Content (%)
Vs
SPT-N
Wn
LL
PL
GWT
1.10.1995 15:57
Ms=6.0 PGA=0.36g
EW
NS
Normalised Spectral Acc. (Sa/PGA)
Period (sec)
1.10.1995 18:02
Ms=5.0, PGA=0.225 g
Normalised Spectral Acc. (Sa/PGA)
Period (sec)

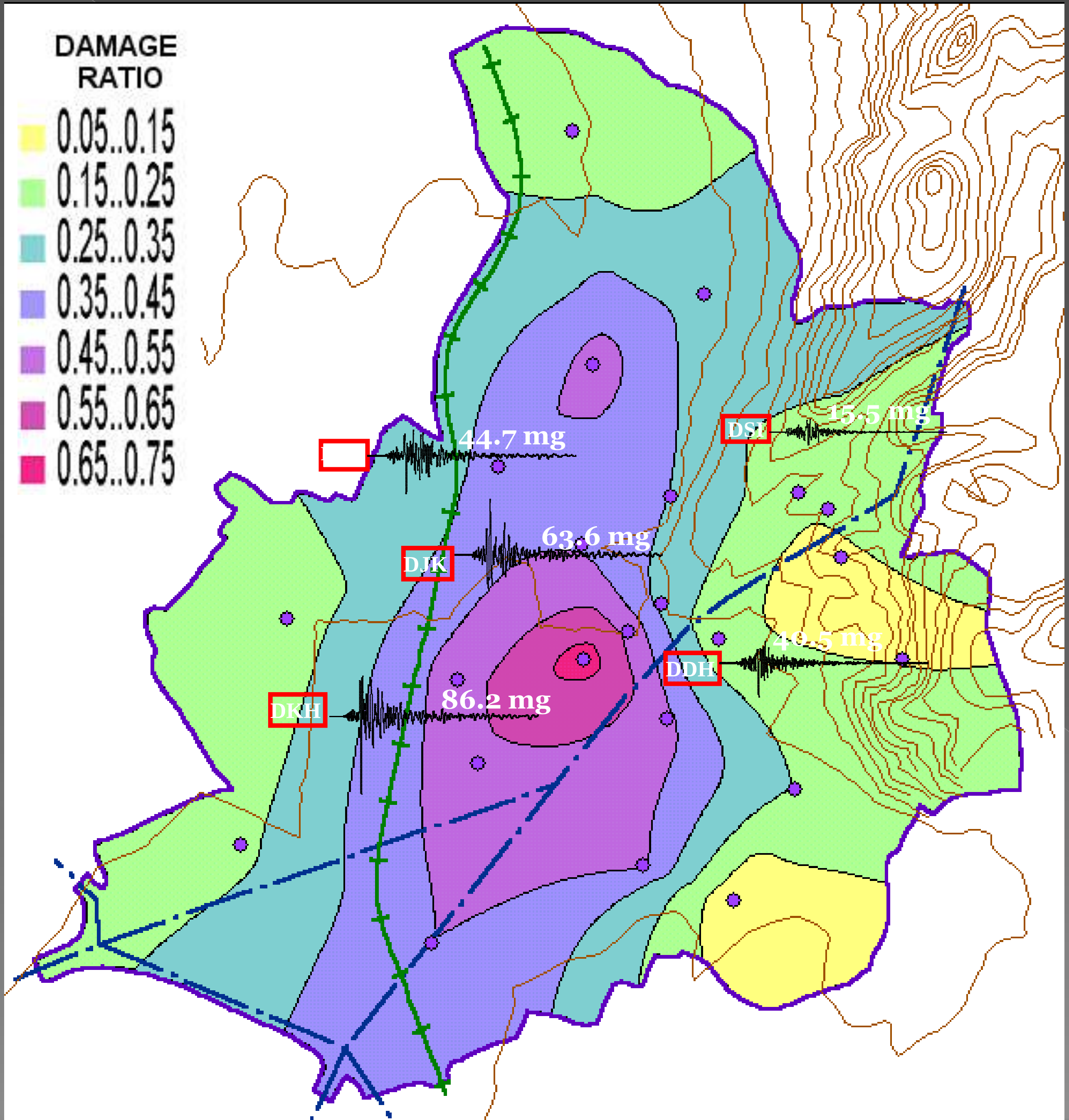


AMPLIFICATION RATIO (Mic)
2,45
2,55
2,65
2,75
2,85
2,95
3,05
3,15
3,25
3,35
3,45
0,55
0,50
0,45
0,40
0,35
0,30
0,25
DAMAGE RATIO, (DR)
DR = 0,4675 AMP(Vs) - 0,9051
R 2 = 0,618
Equivalent Vs
Microtremors
DR = 0,1565 AMP(mic) - 0,0293
R 2 = 0,4231
2,60
2,65
2,70
2,75
2,80
2,85
2,90
2,95
3,00
3,05
3,10
AMPLIFICATION RATIO (Vs)

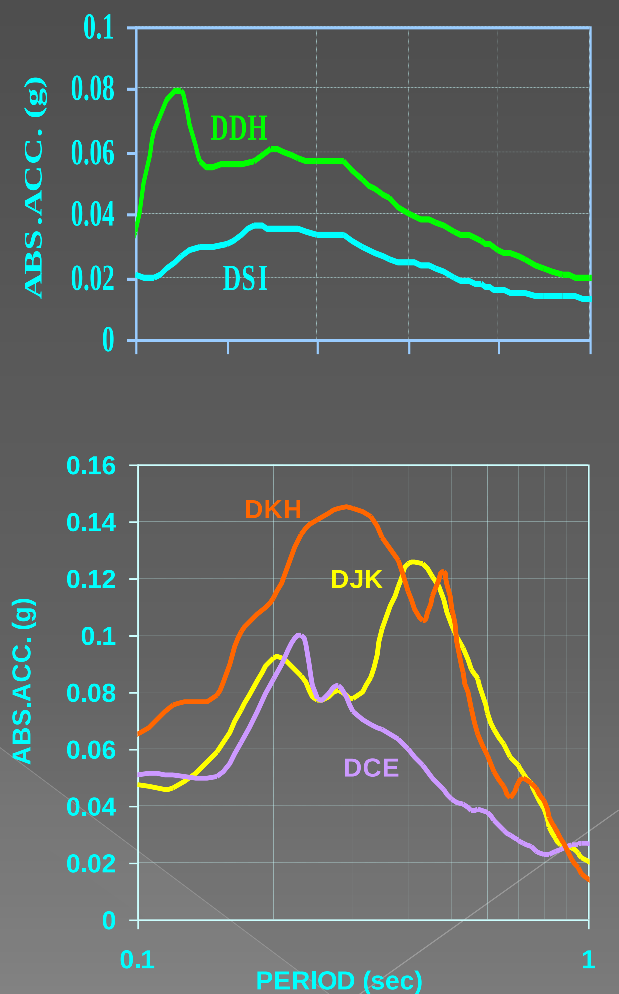
Aftershock (KOERI network) M_L=4.1 & R= 5.2-8.4 km

- ➔ DSI : limestone & schist
- ➔ DDH : weathered limestone & transition zone
- ➔ DJK & DCE : medium stiff-soft soil layers with limited thickness
- ➔ DKH : deep alluvium deposit

1995 DİNAR EARTHQUAKE

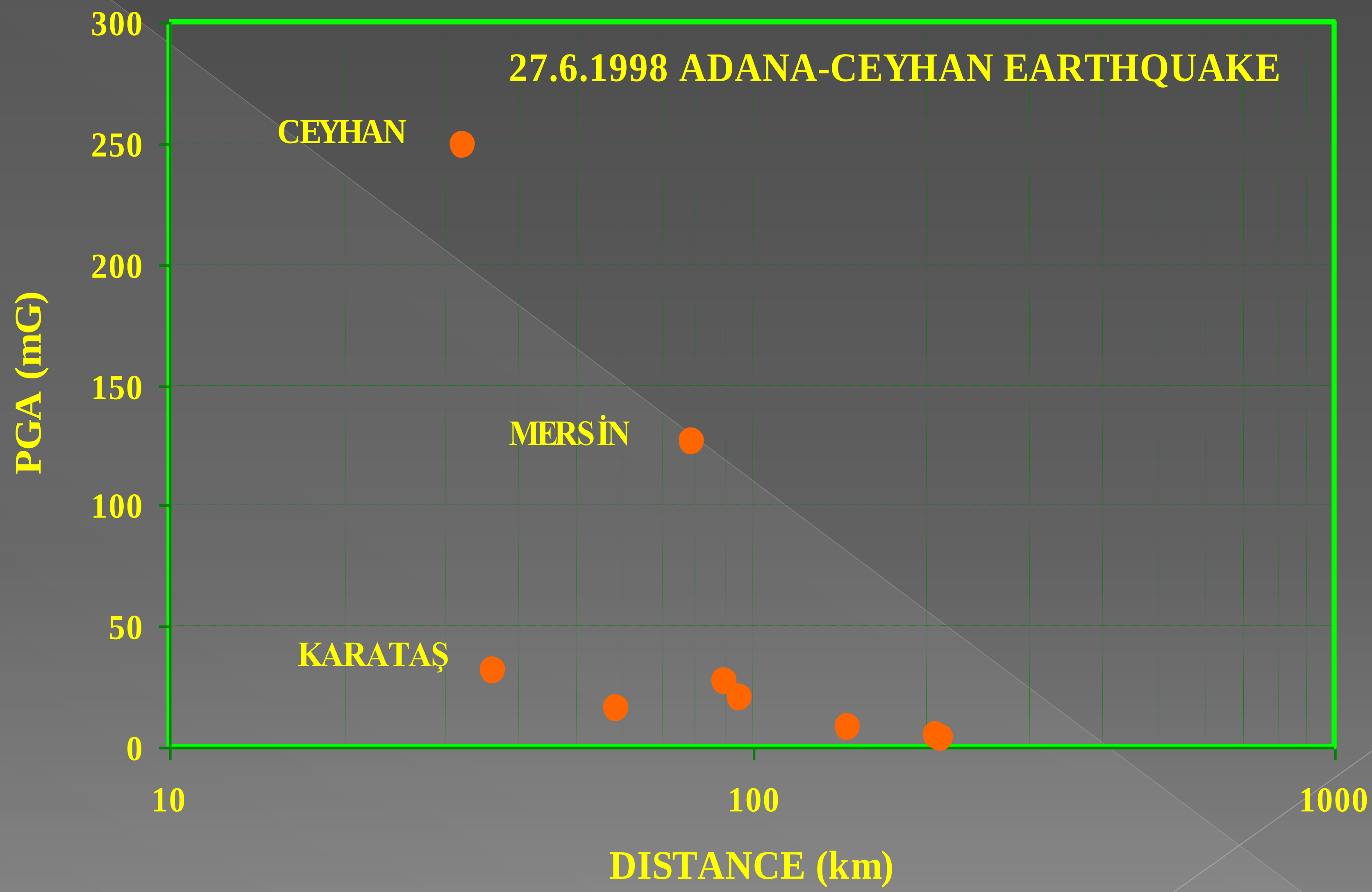


M_L=4.1 & R= 5.2-8.4 km

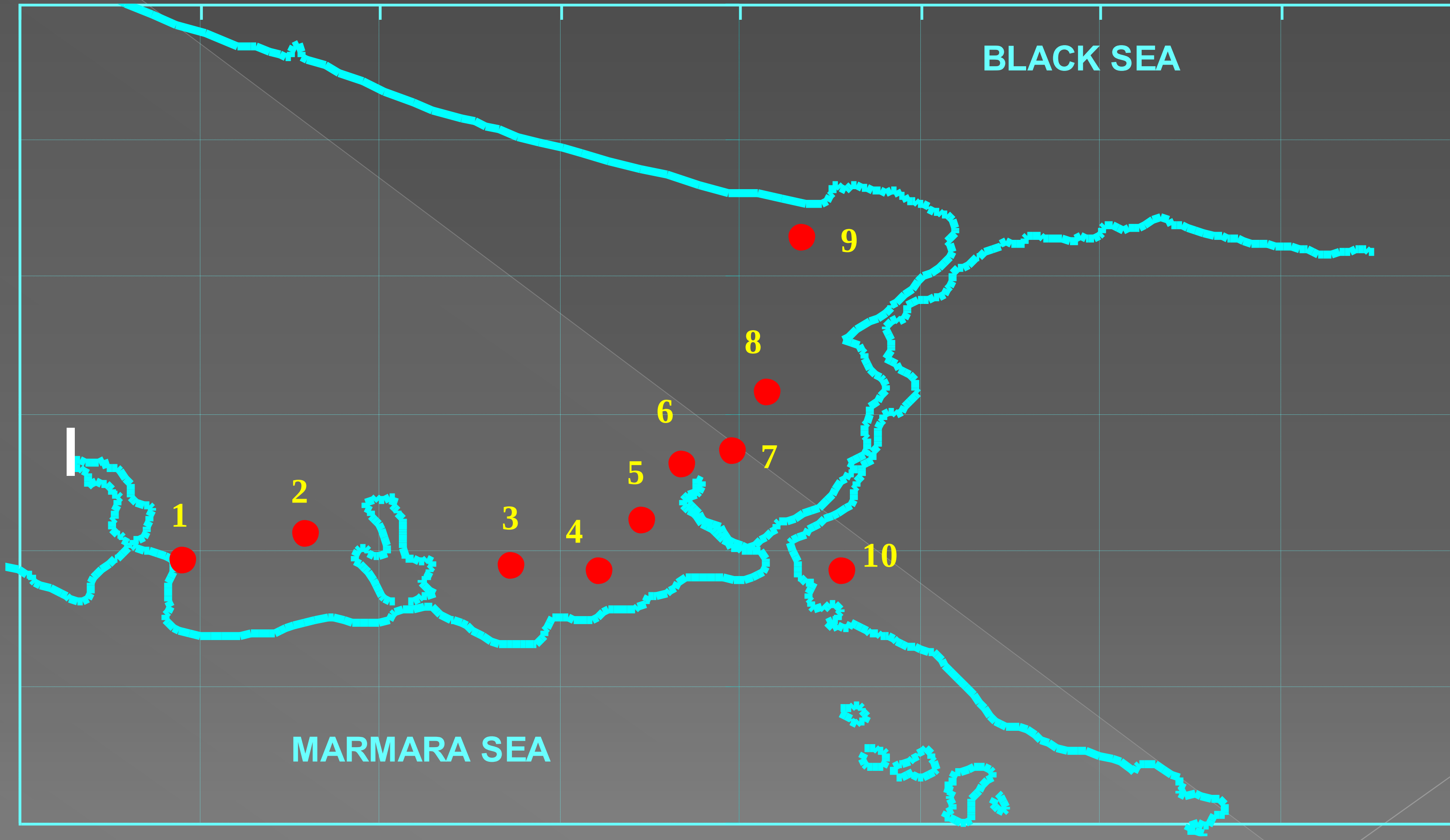


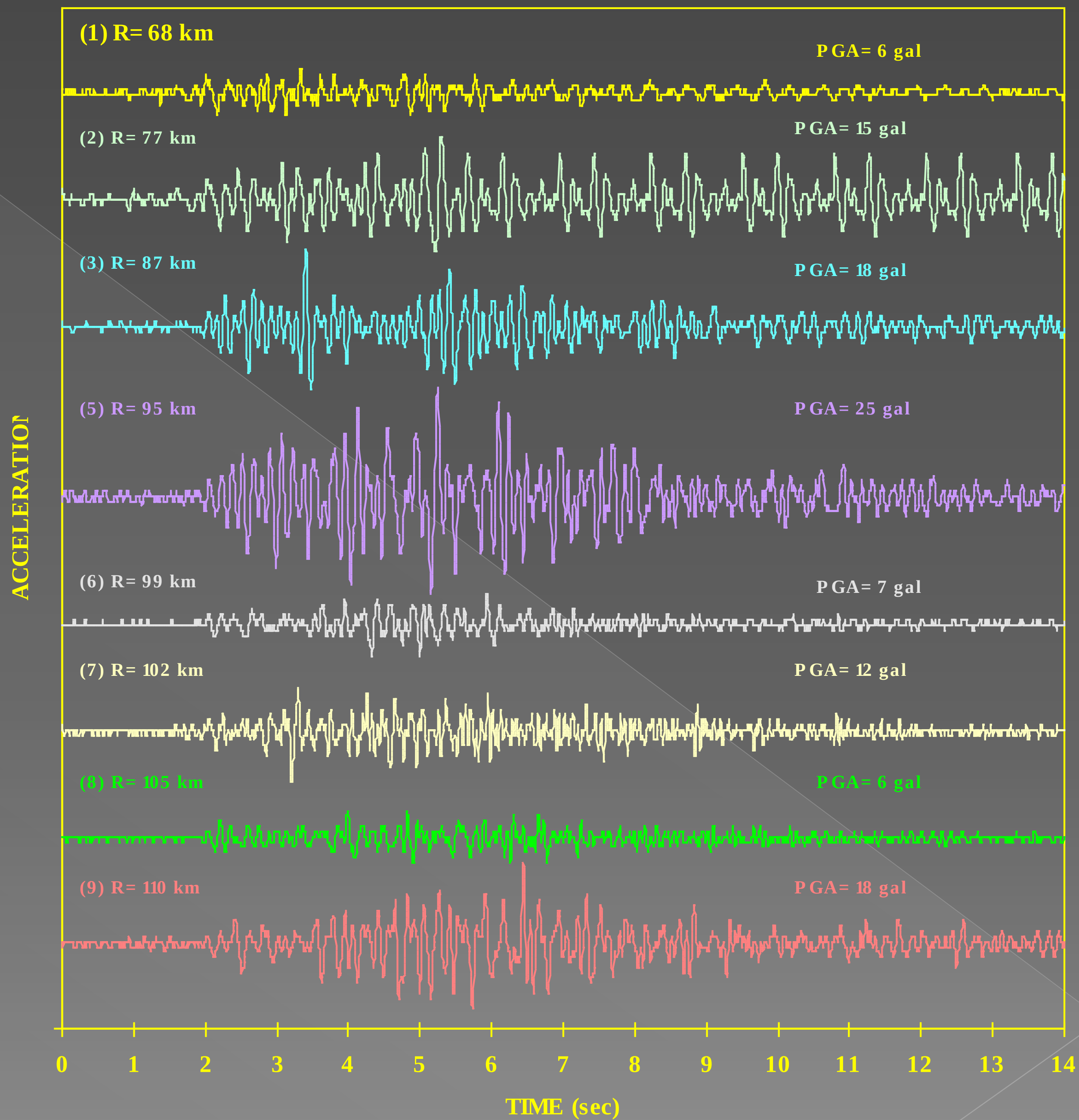
27.6.1998 ADANA-CEYHAN EARTHQUAKE

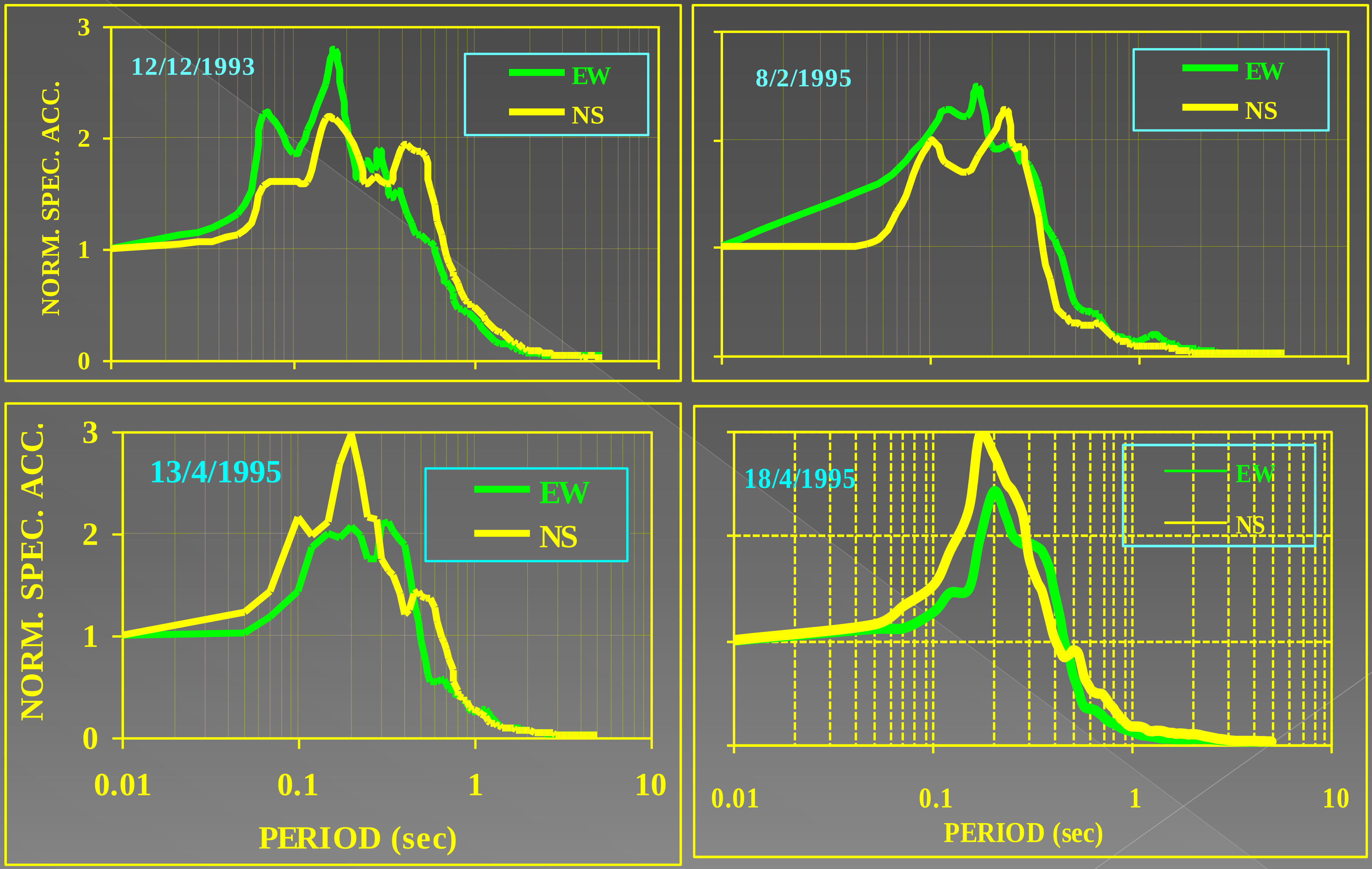
- M_L = 5.9, R_e = 38 km, D_f = 22 km
- Left lateral strike slip with normal faulting
- Fault direction N207E, dip 70 °
- Unidirectional rupture toward north



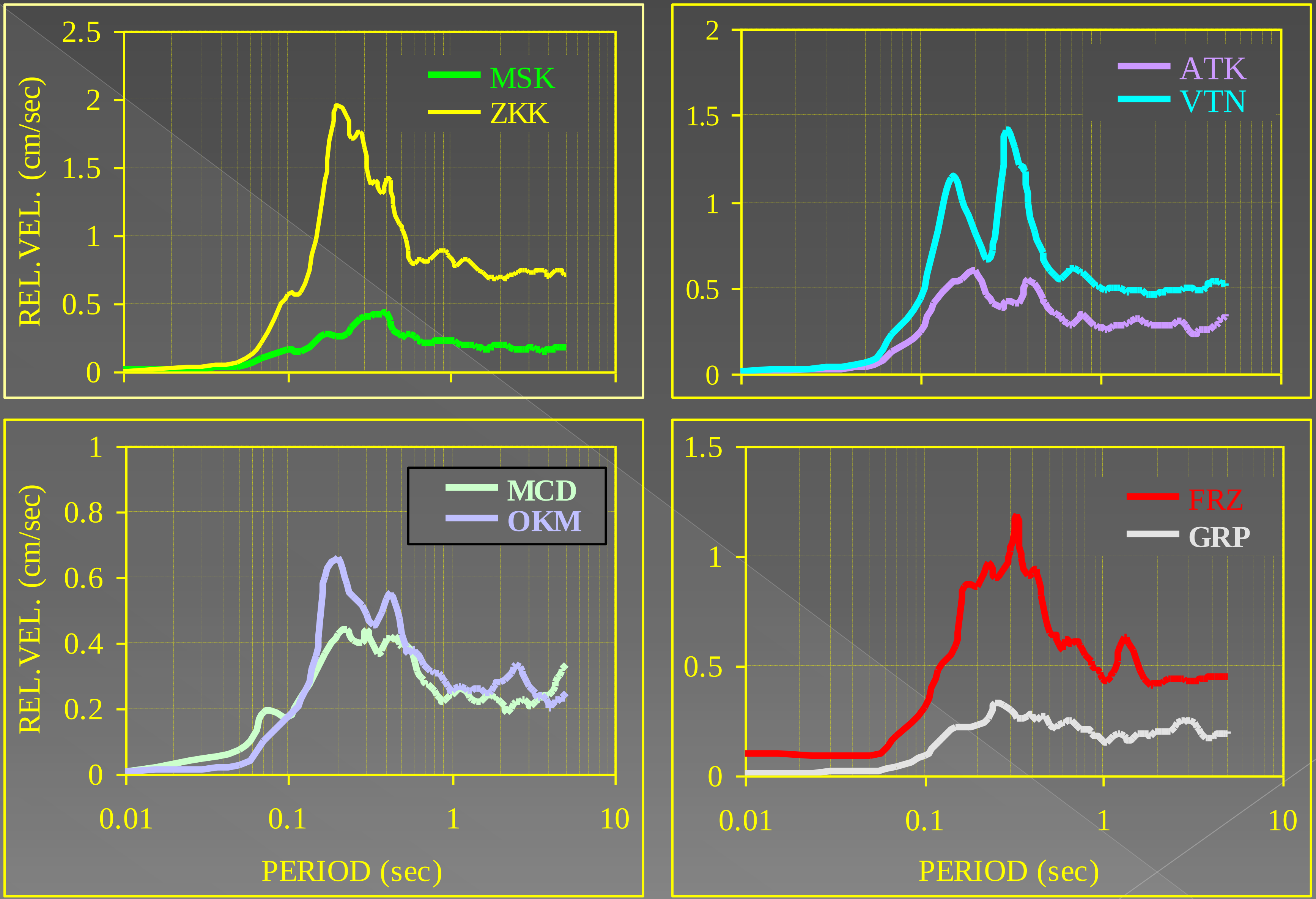
27.6.1998 ADANA-CEYHAN EARTHQUAKE
CEYHAN
MERSİN
KARATAŞ
PGA (mG)
300
250
200
150
100
50
0
10
100
1000
DISTANCE (km)


BLACK SEA
MARMARA SEA
1
2
3
4
5
6
7
8
9
10

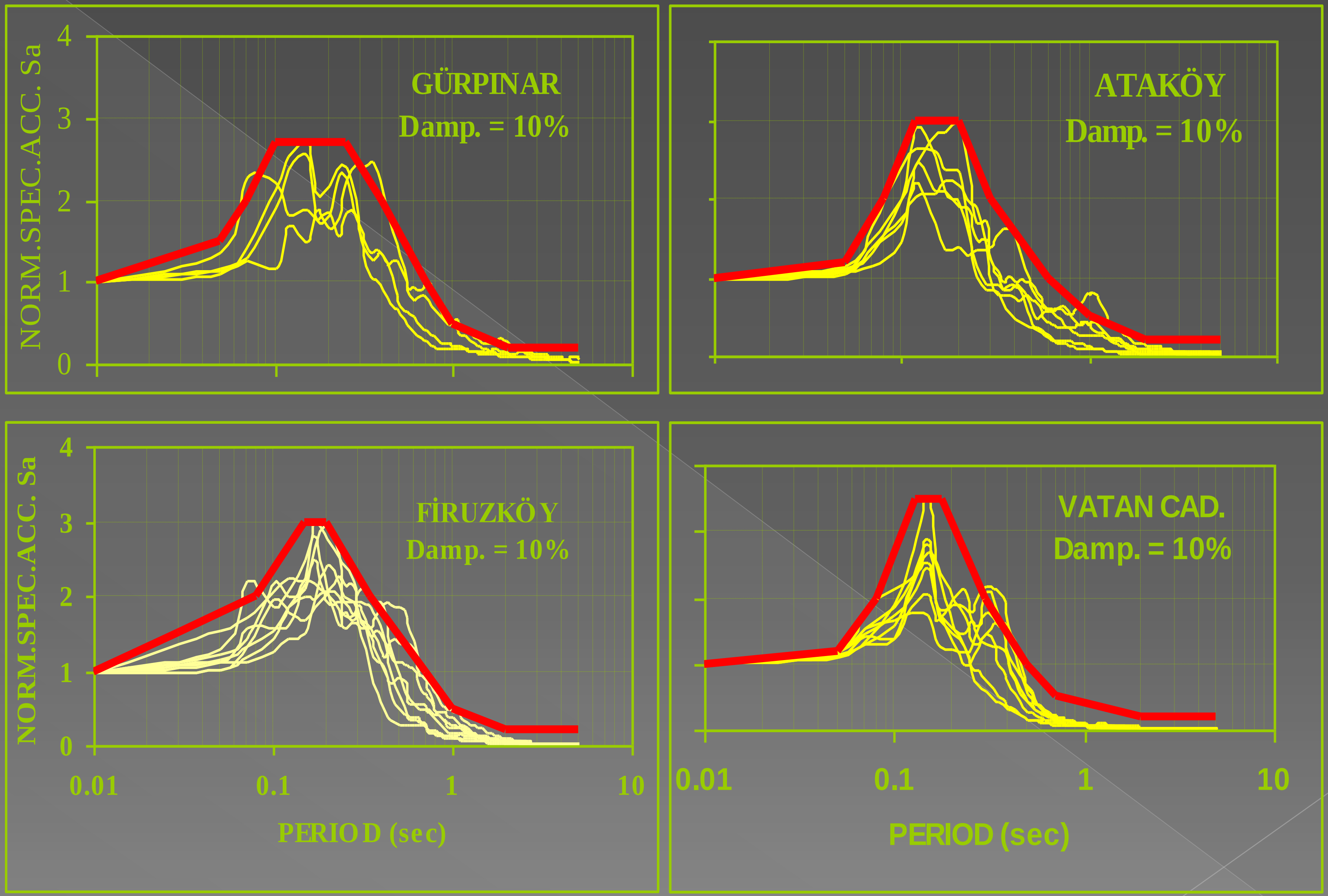

(1) R= 68 km
PGA= 6 gal
(2) R= 77 km
PGA= 15 gal
(3) R= 87 km
PGA= 18 gal
(5) R= 95 km
PGA= 25 gal
(6) R= 99 km
PGA= 7 gal
(7) R= 102 km
PGA= 12 gal
(8) R= 105 km
PGA= 6 gal
(9) R= 110 km
PGA= 18 gal
ACCELERATIO
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
TIME (sec)



NORM. SPEC. ACC.
3
2
1
0
12/12/1993
EW
NS
8/2/1995
EW
NS
NORM. SPEC. ACC.
3
2
1
0
13/4/1995
EW
NS
0.01
0.1
1
10
PERIOD (sec)
18/4/1995
EW
NS
0.01
0.1
1
10
PERIOD (sec)

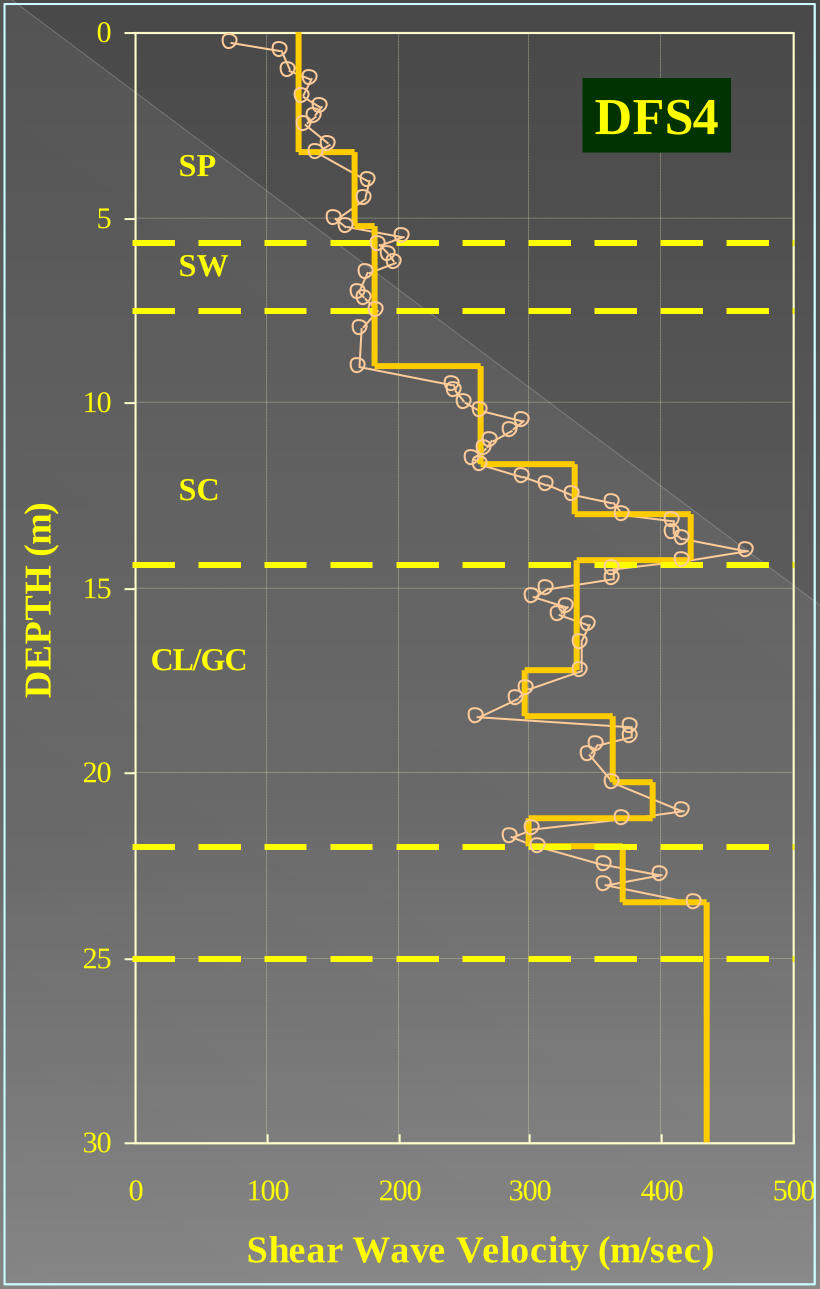


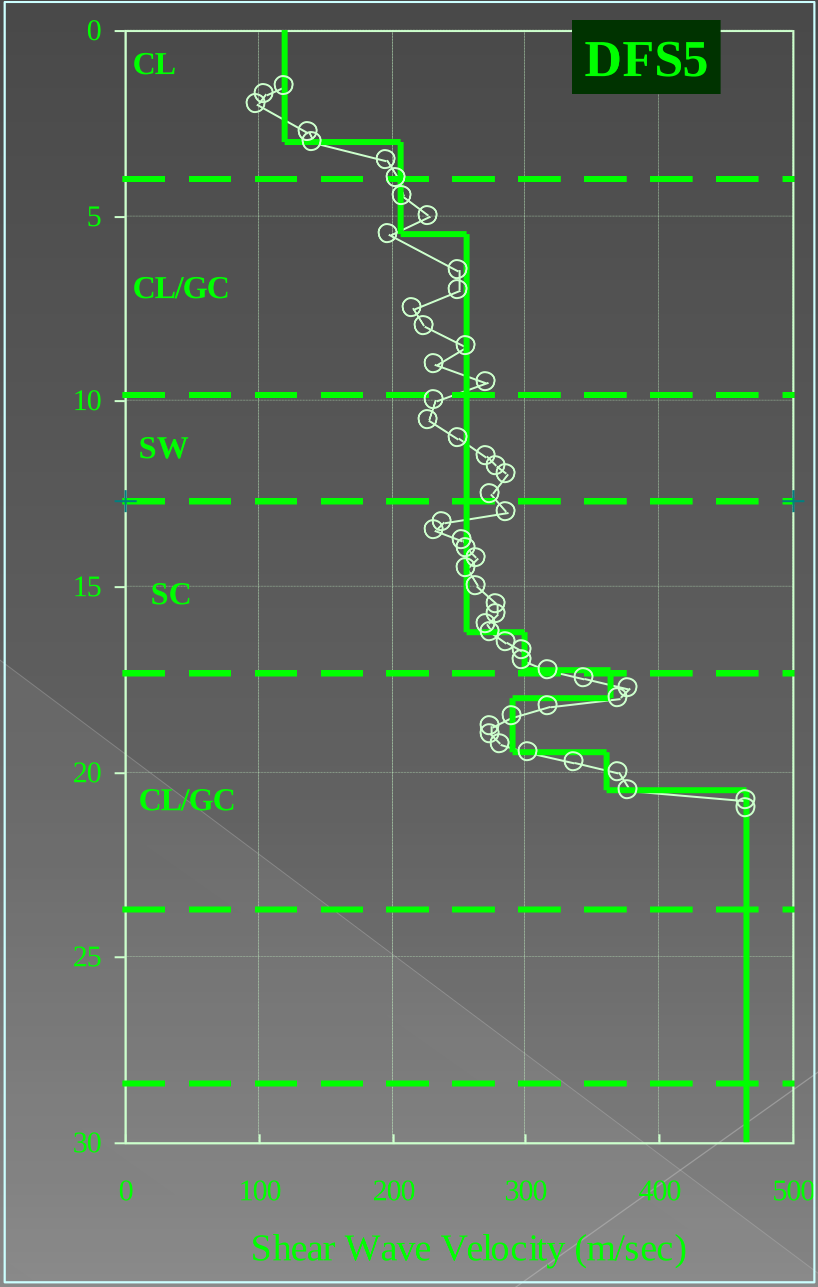
REL.VEL. (cm/sec)
2.5
2
1.5
1
0.5
0
MSK
ZKK
ATK
VTN
0.8
0.6
0.4
0.2
MCD
OKM
FRZ
GRP
0.01
0.1
1
10
PERIOD (sec)



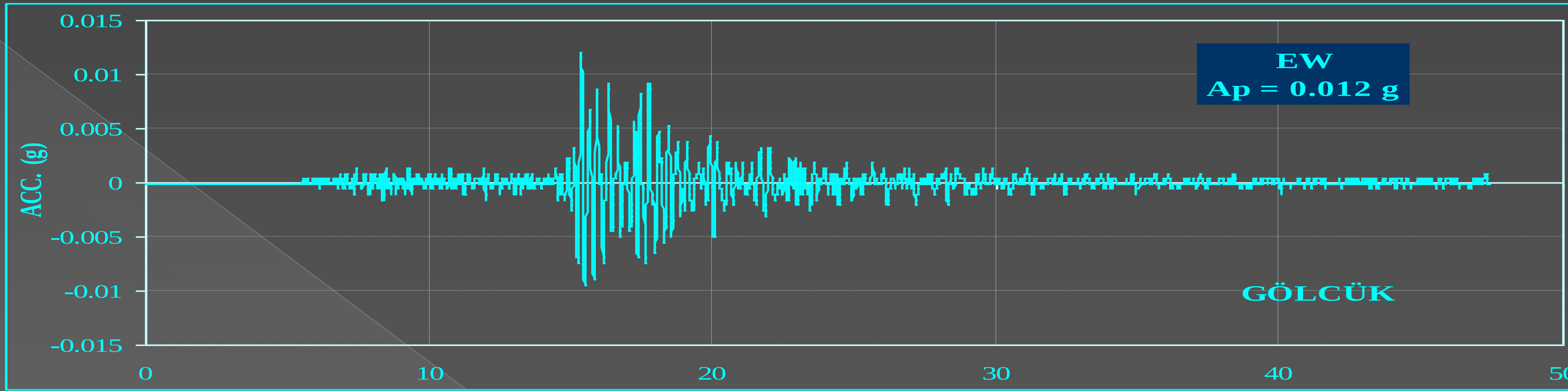
GÜRPINAR
Damp. = 10%
ATAKÖY
Damp. = 10%
FİRUZKÖY
Damp. = 10%
VATAN CAD.
Damp. = 10%
NORM.SPEC.ACC. Sa
NORM.SPEC.ACC. Sa
0
1
2
3
4
0.01
0.1
1
10
PERIOD (sec)
PERIOD (sec)

Izmit Bay
Sapanca Lake
1999
1999
1999
Mw=7.4
KOCAELI
Gölcük
İZMIT
Derbent
Sapanca
Karamürsel
Bahçecik
Körfez
Hereke
PAMUKOVA
GEYVE
Adapazarı
Değirmendere
Yalakdere
Kazımpaşa
Doğançay
Kocaeli Yarımadası
Çene Dağı

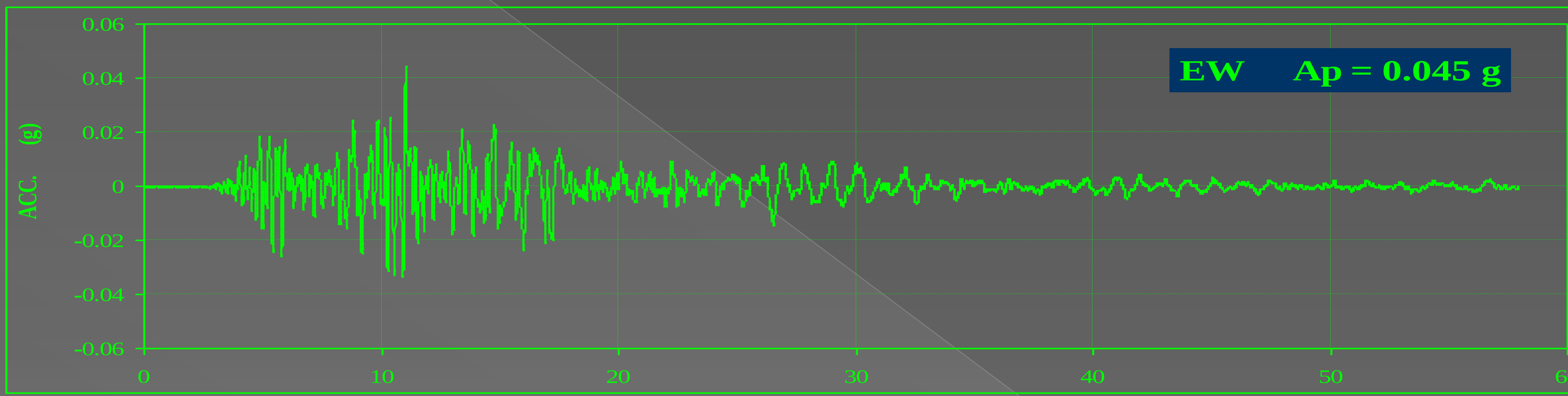

DFS4
DEPTH (m)
Shear Wave Velocity (m/sec)
0
5
10
15
20
25
30
0
100
200
300
400
500
SP
SW
SC
CL/GC


DFS5
Shear Wave Velocity (m/sec)
0
5
10
15
20
25
30
0
100
200
300
400
500
CL
CL/GC
SW
SC
CL/GC

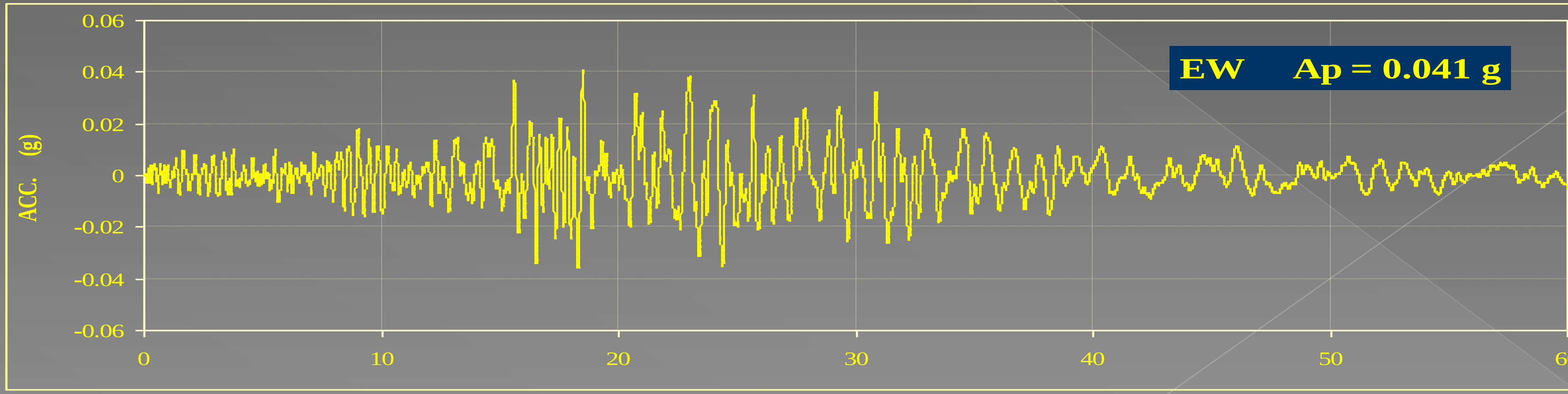
21.10.1999 M=4.4

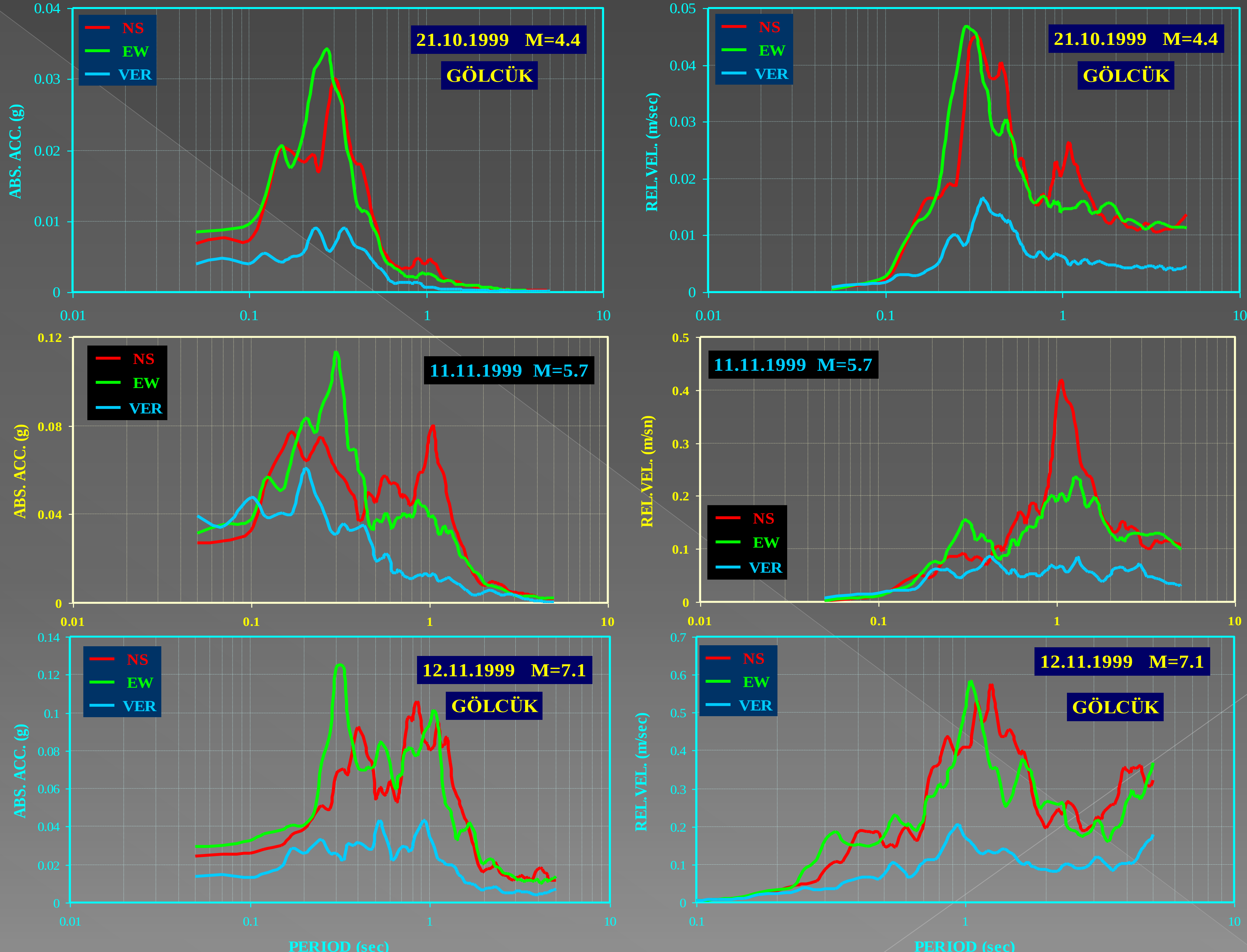


M=5.6 NOV. 11, 1999



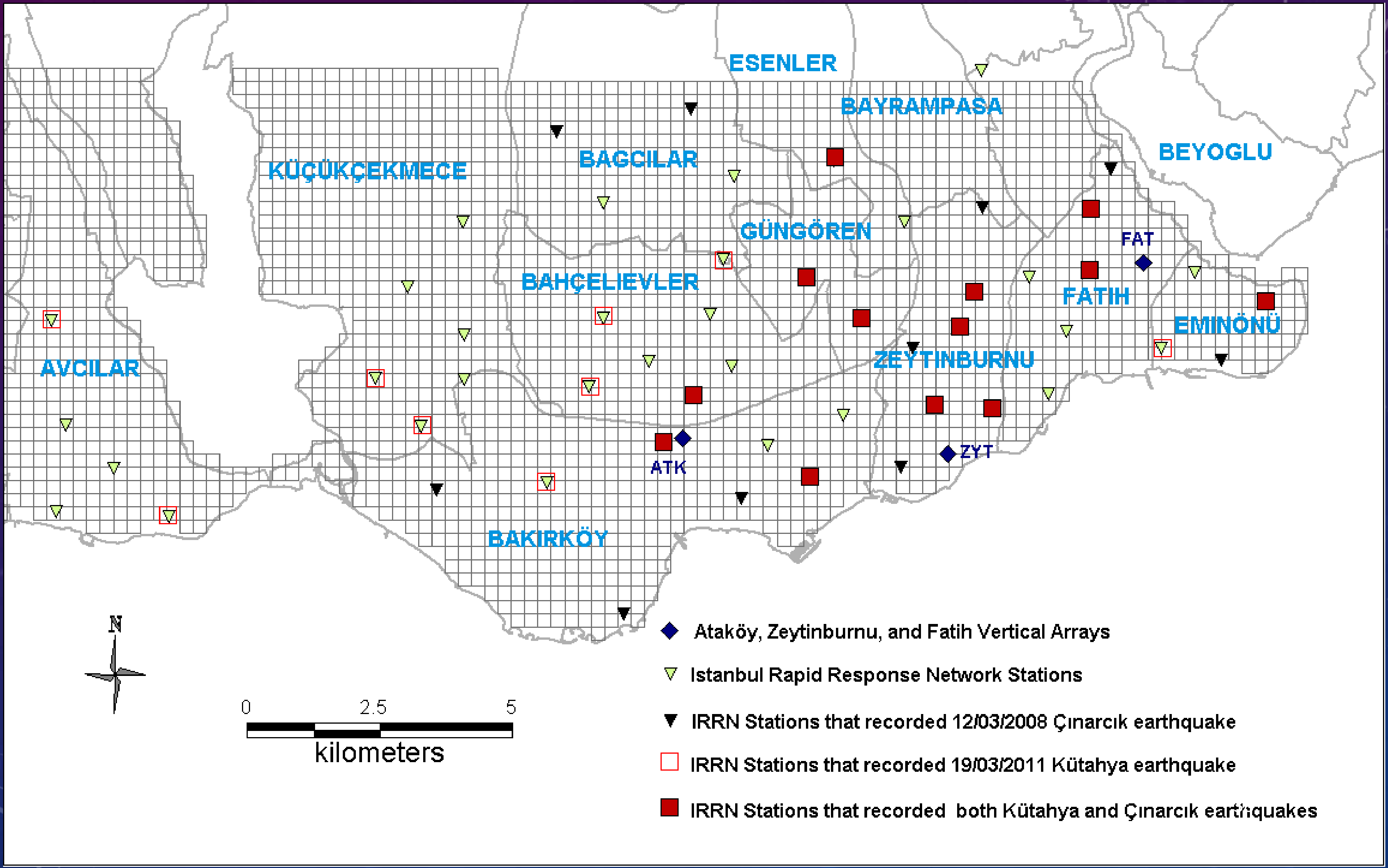
M=7.2 NOV. 12, 1999



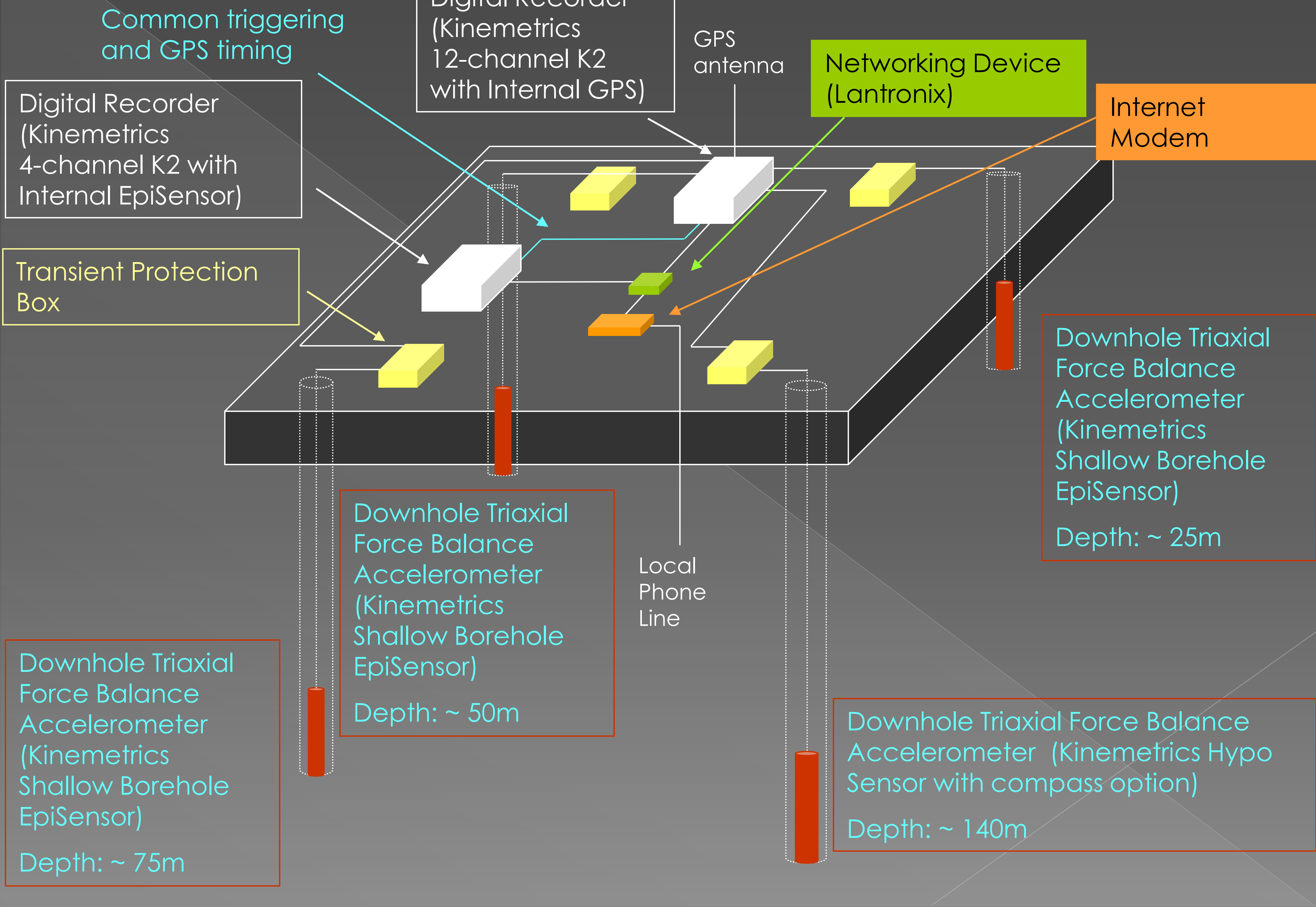


NS
EW
VER
21.10.1999 M=4.4
GÖLCÜK
ABS. ACC. (g)
REL.VEL. (m/sec)
11.11.1999 M=5.7
ABS. ACC. (g)
REL.VEL. (m/sn)
12.11.1999 M=7.1
GÖLCÜK
ABS. ACC. (g)
REL.VEL. (m/sec)
PERIOD (sec)
PERIOD (sec)

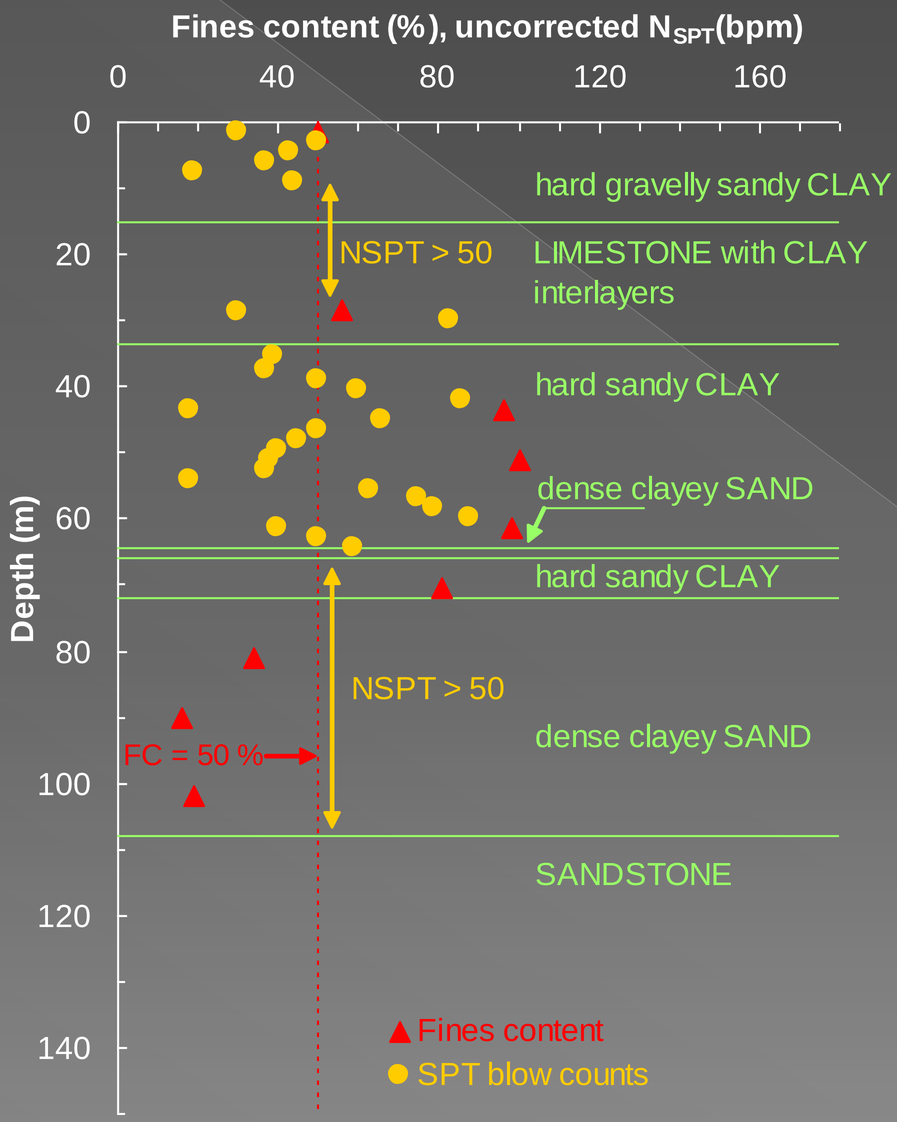
ISTANBUL STRONG MOTION RAPID RESPONSE NETWORK

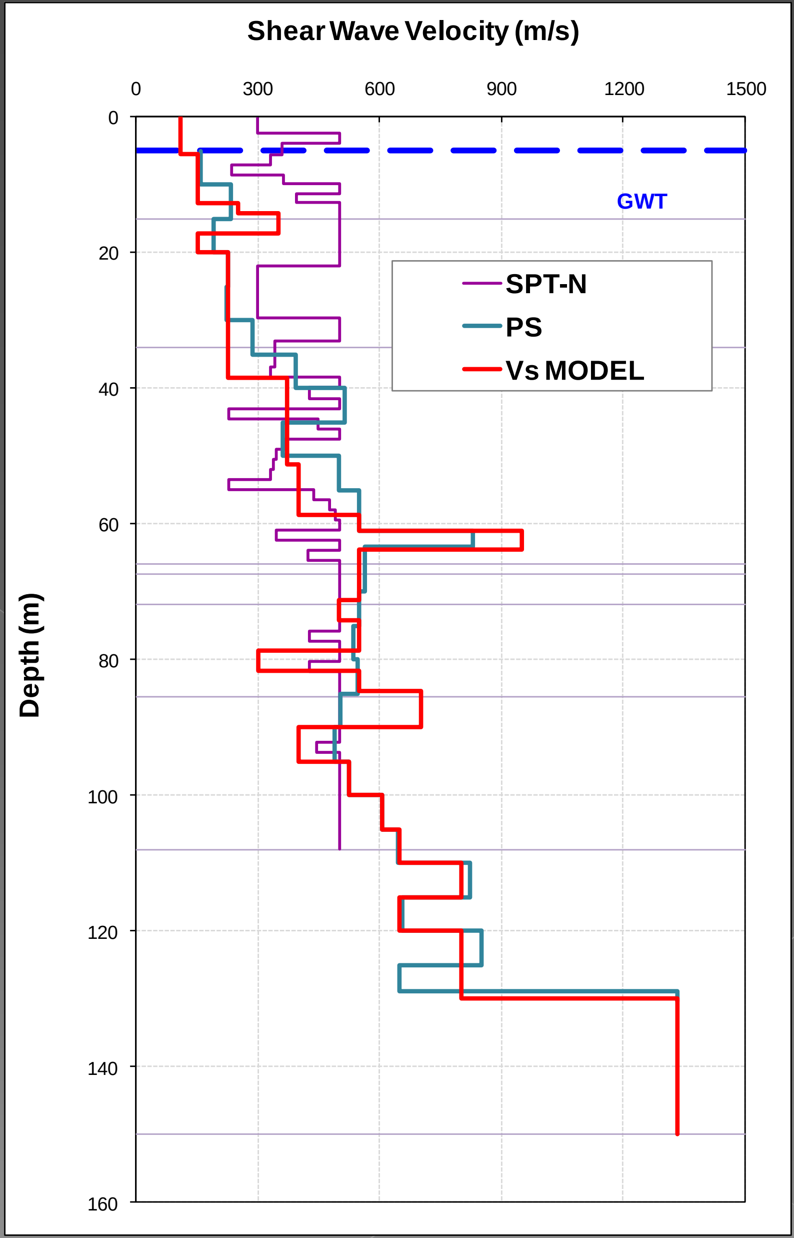


Instrumentation

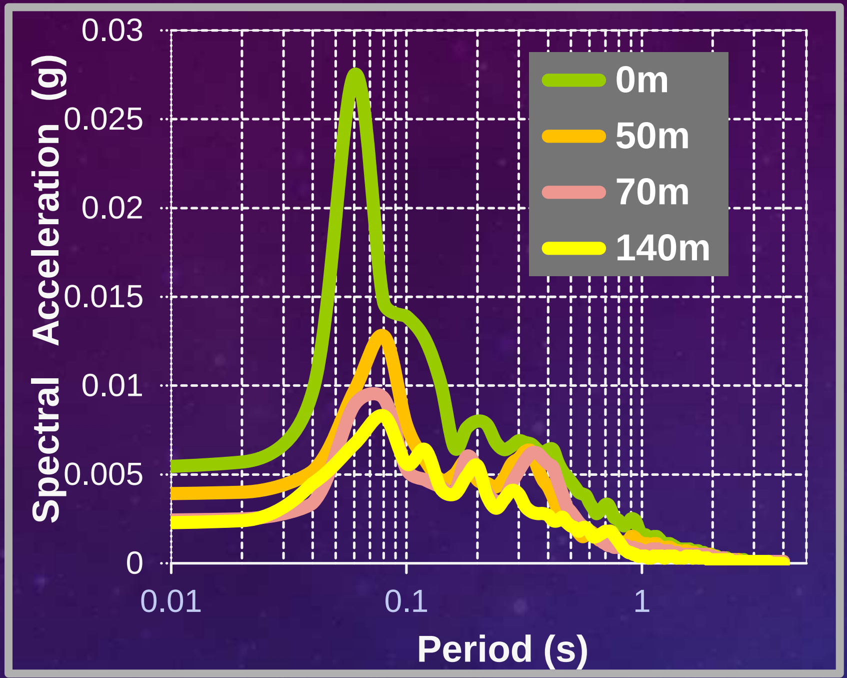


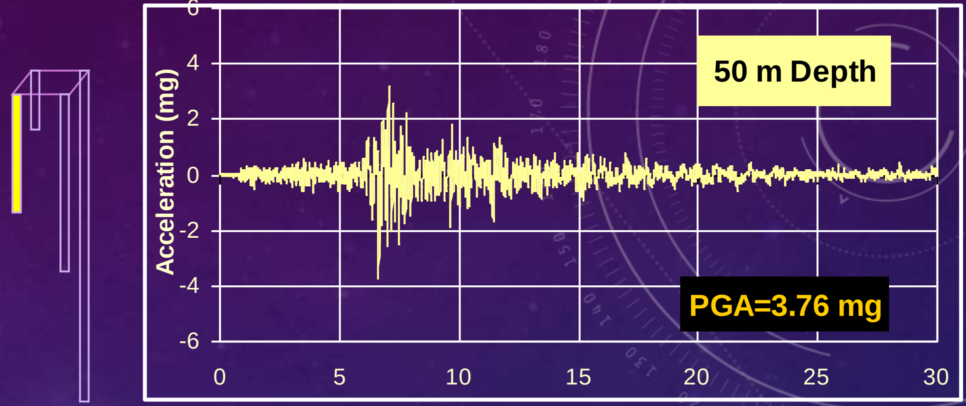
Geotechnical site conditions

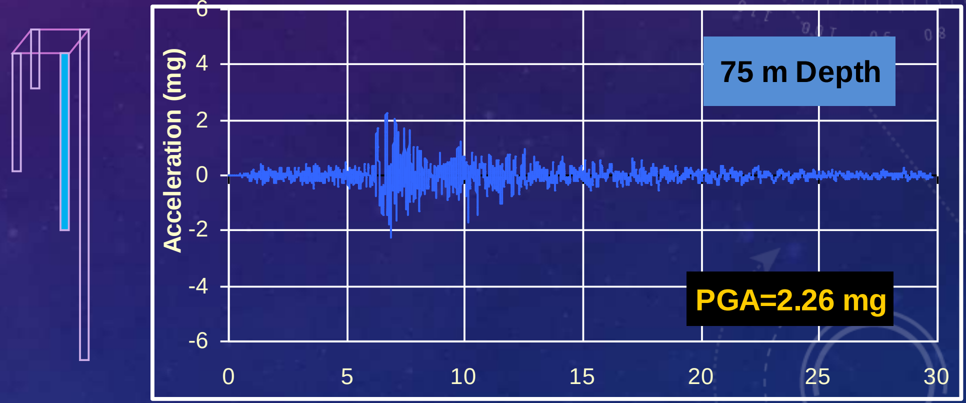


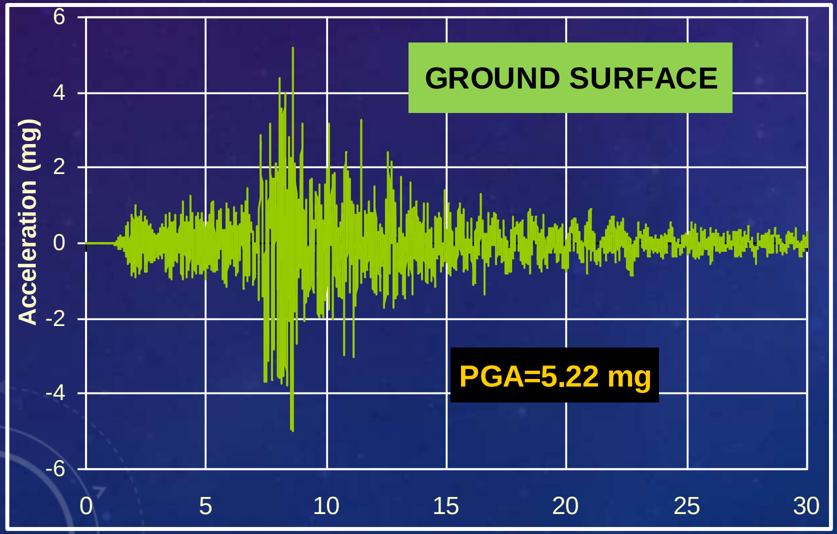


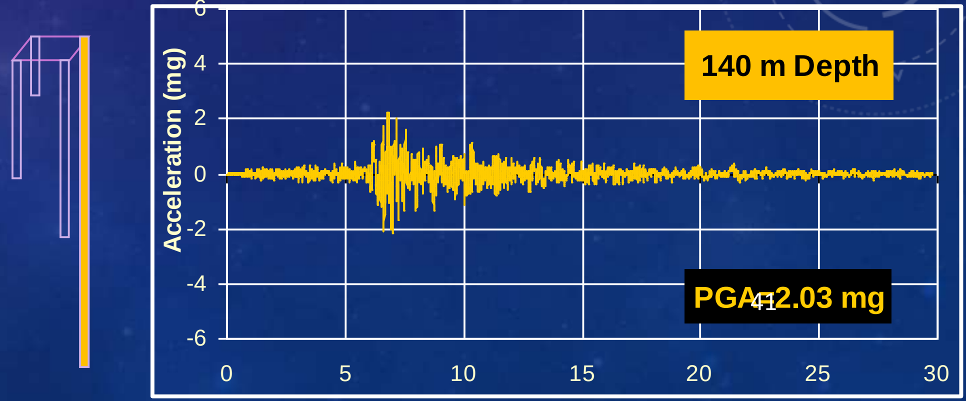
ATAKÖY VERTICAL ARRAY: ÇINARCIK 12.03.2008 M = 4.8



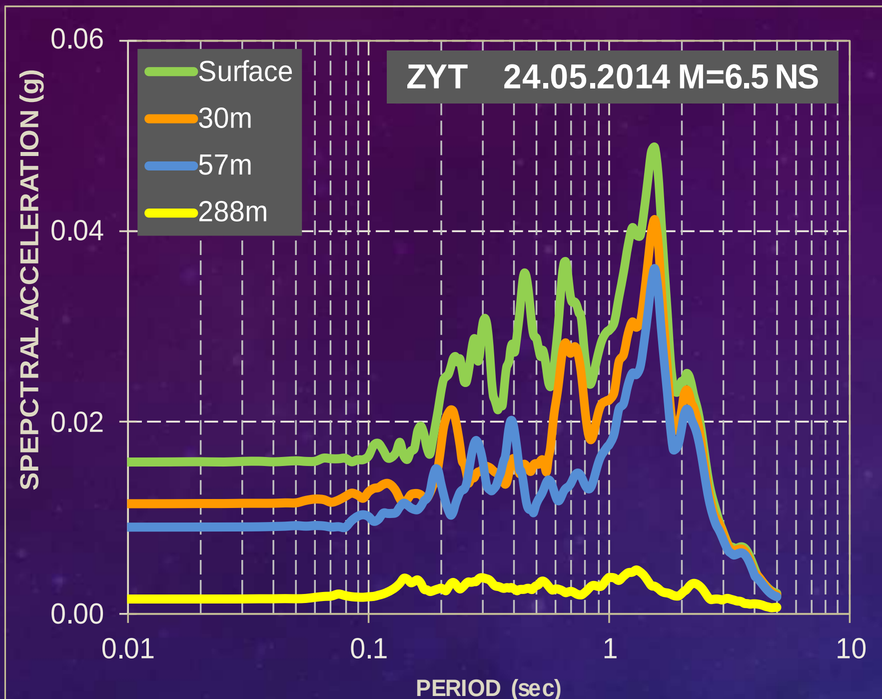


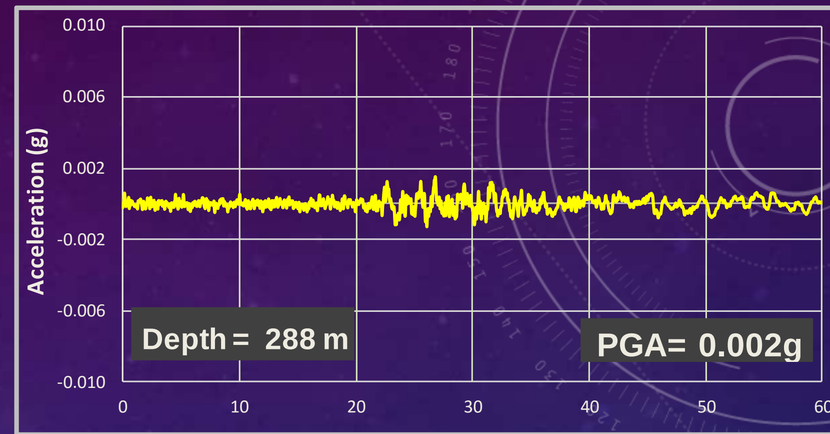


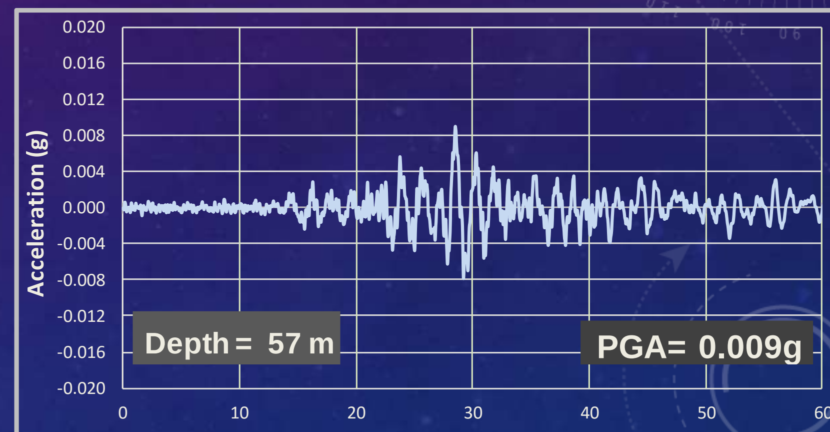


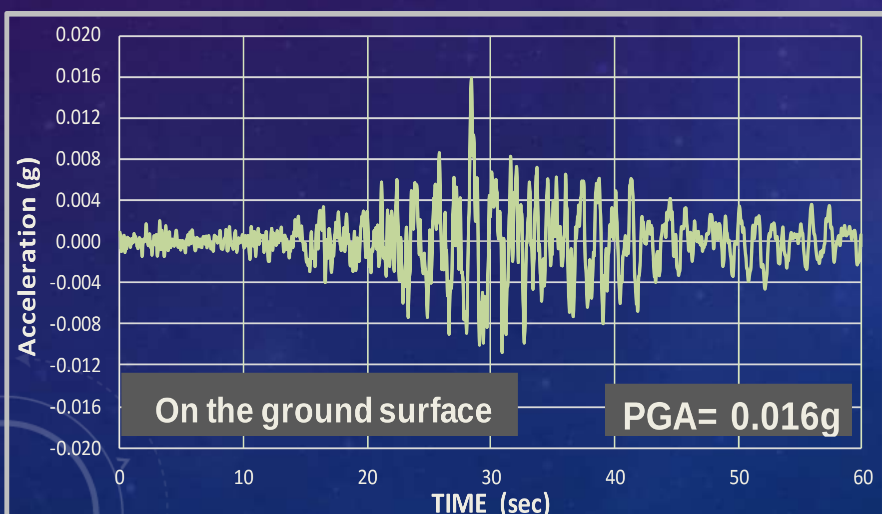


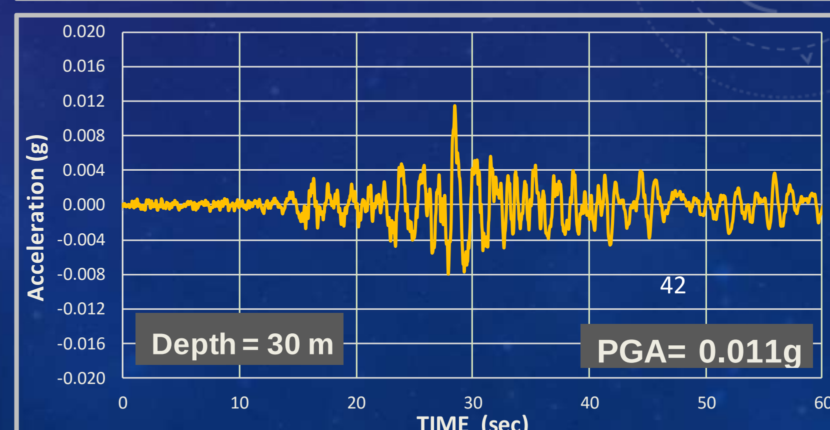
ZEYTINBURNU VERTICAL ARRAY: GEYVE M = 6.5 25.5.2014



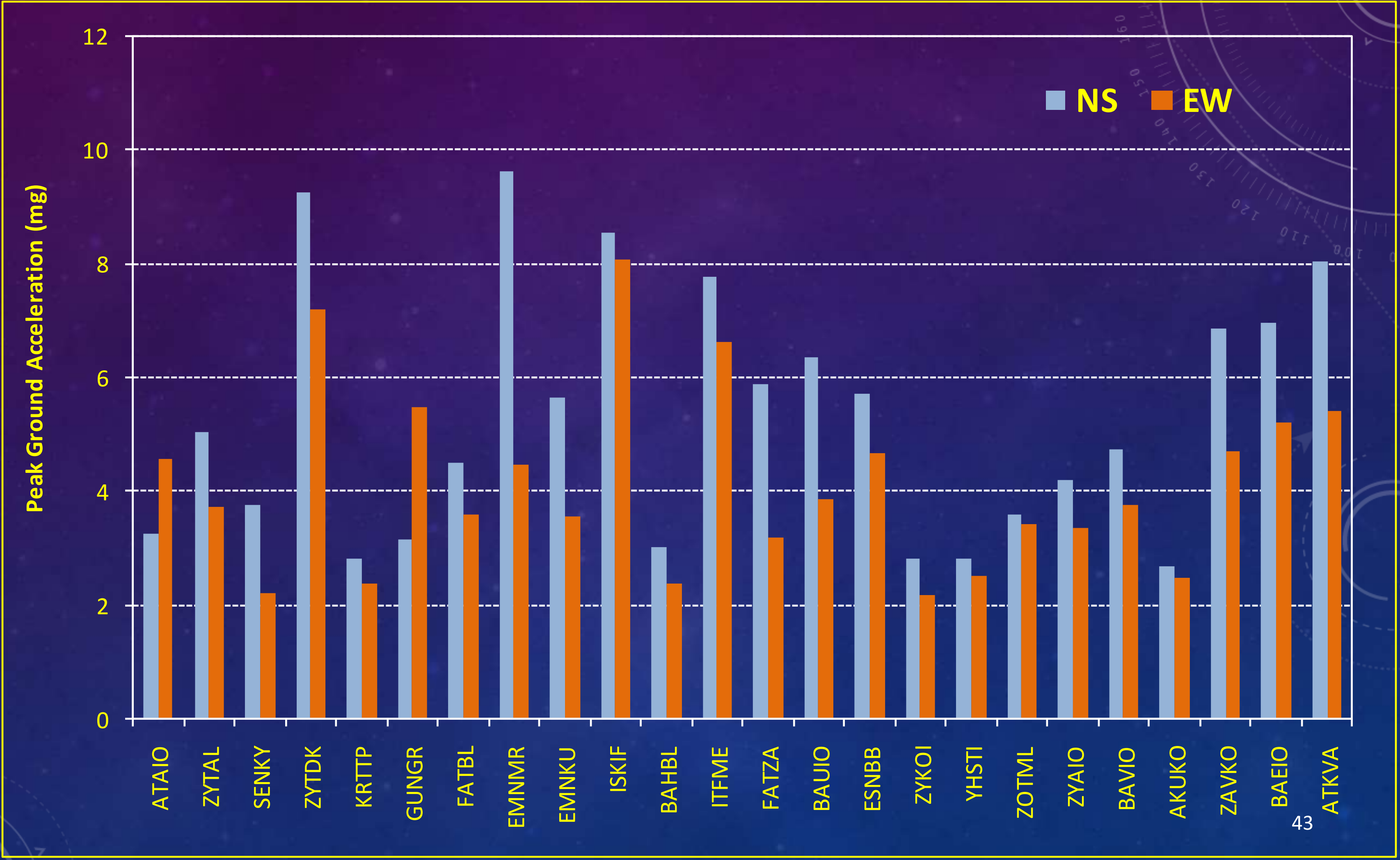






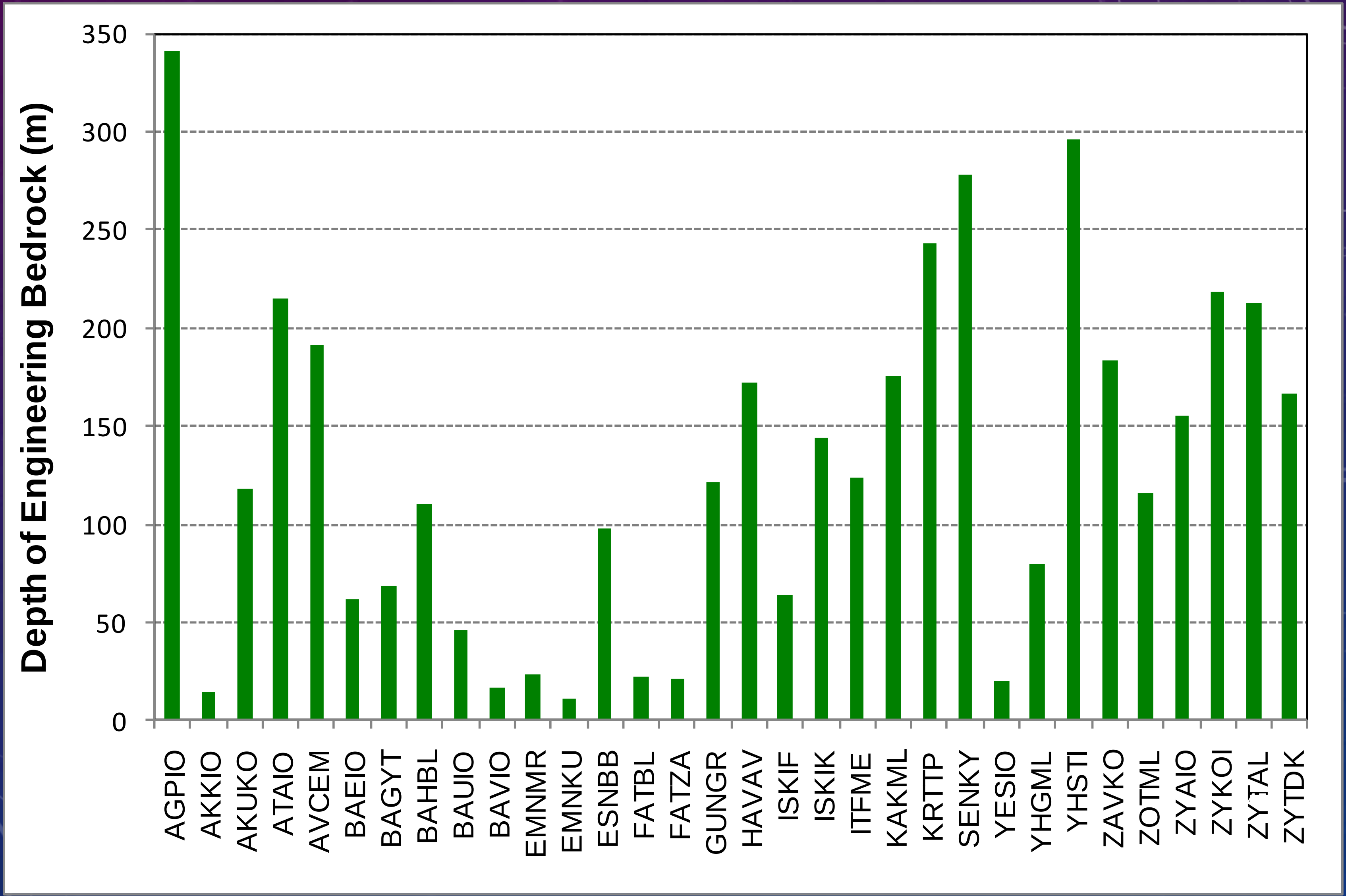


PGAS RECORDED BY THE 24 STATIONS DURING 12/3/2008 M_L=4.8 EARTHQUAKE



AVERAGE SHEAR WAVE VELOCITIES AT 24 STATIONS THAT RECORDED 12/3/2008 EARTHQUAKE

DEPTH TO ENGINEERING BEDROCK

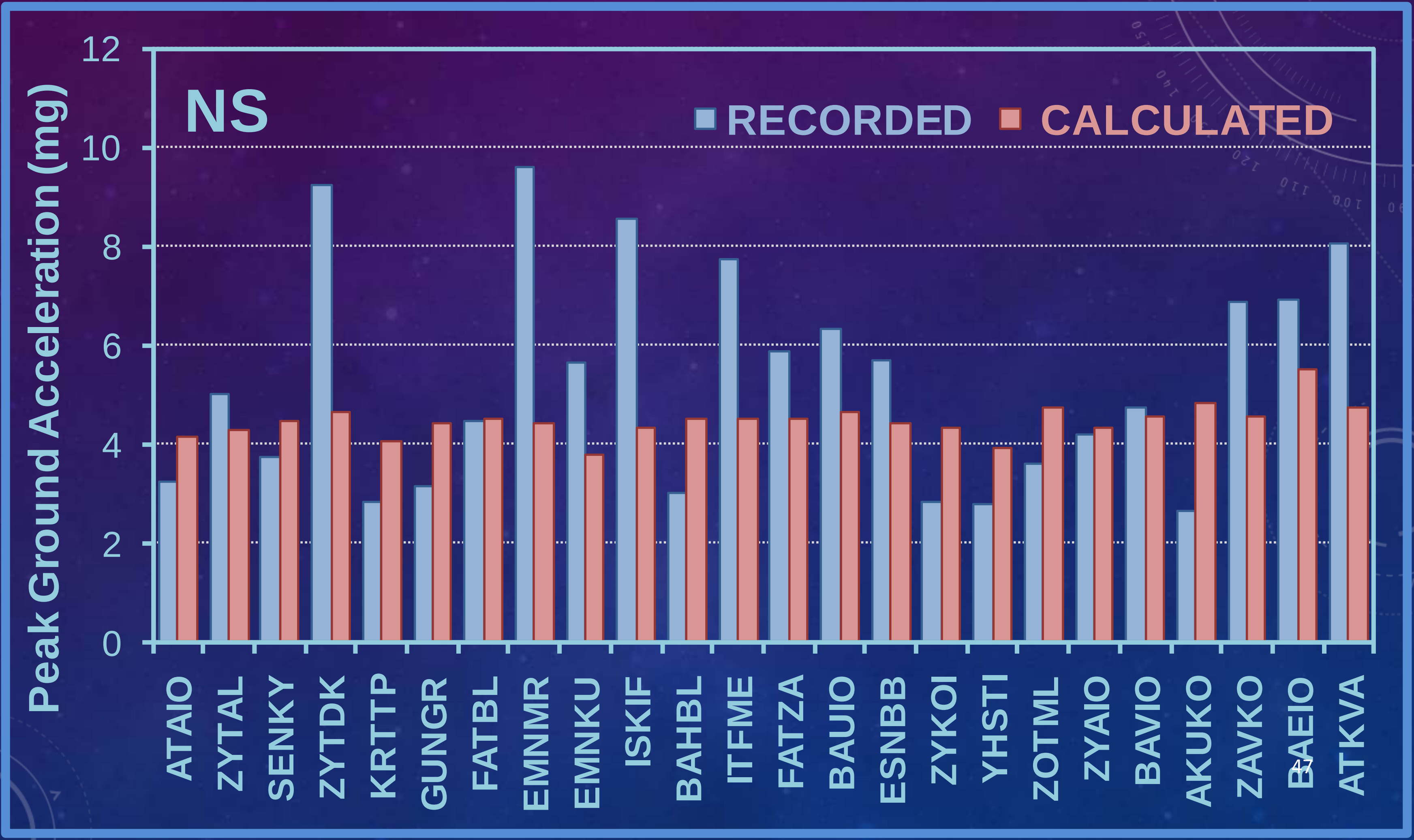


AN ALTERNATIVE SIMPLIFIED APPROACH BASED ON V_{S30}: BORCHERDT FORMULATION

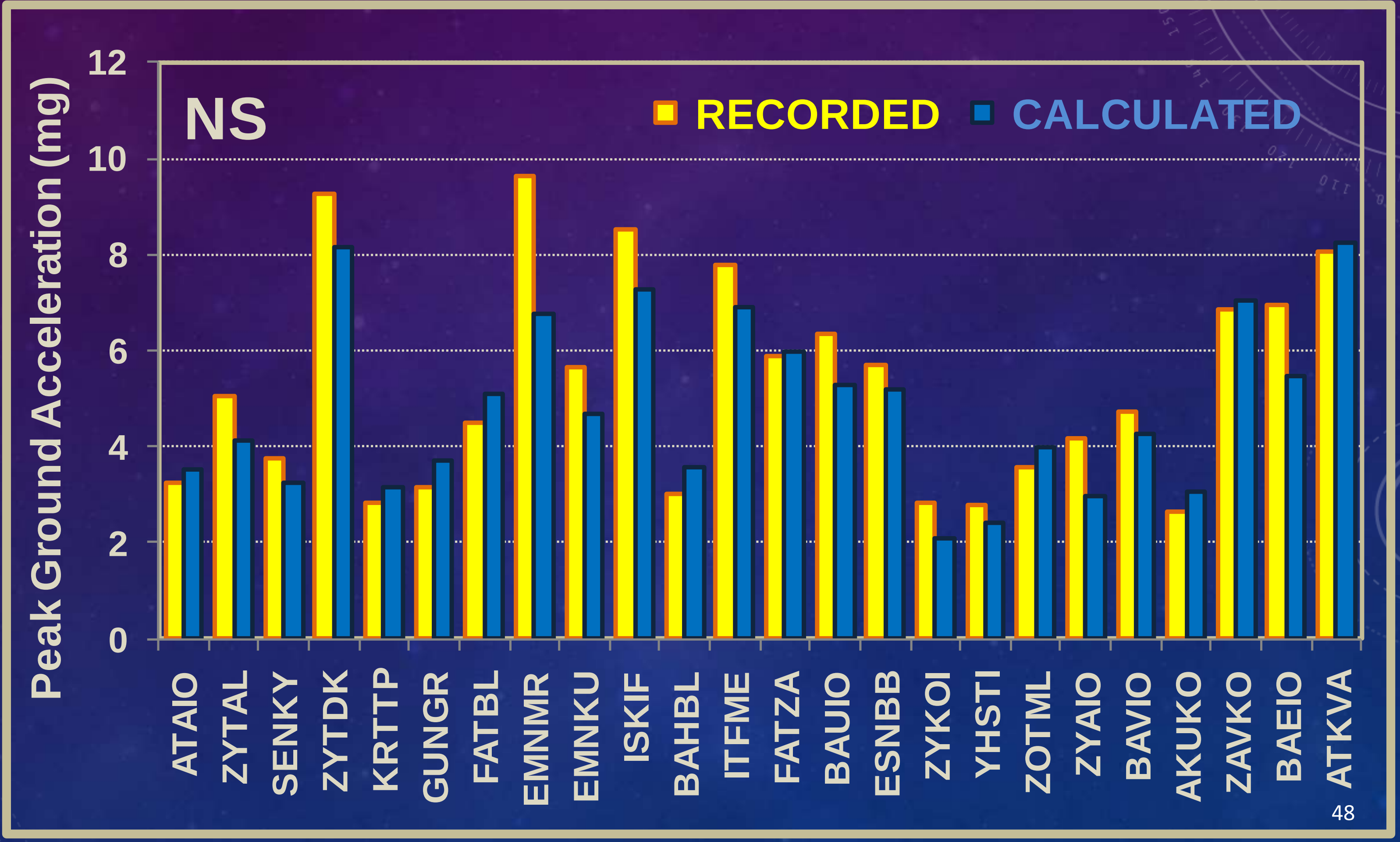
$$S_a = [(760 / V_{s30})^{ma}]*S_S$$

where S_S is the spectral acceleration at T=0.2s on the rock outcrop, V_{s30} is the average shear wave velocity, and the power coefficient $ma = 0.35$ *when using the lower bound*

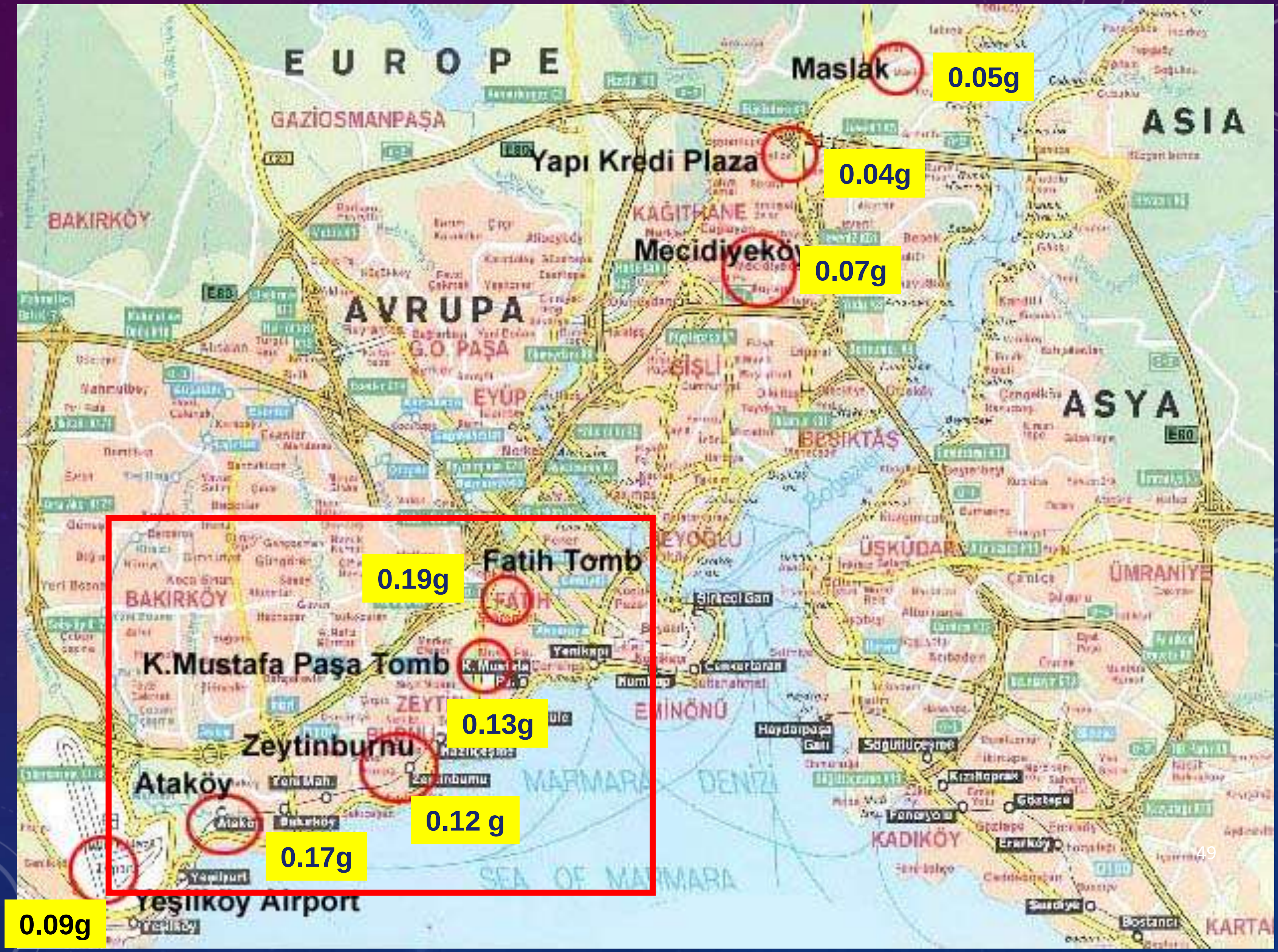
COMPARISON OF RECORDED AND CALCULATED PGA AT 24 STATIONS BASED ON AMPLIFICATION FACTORS



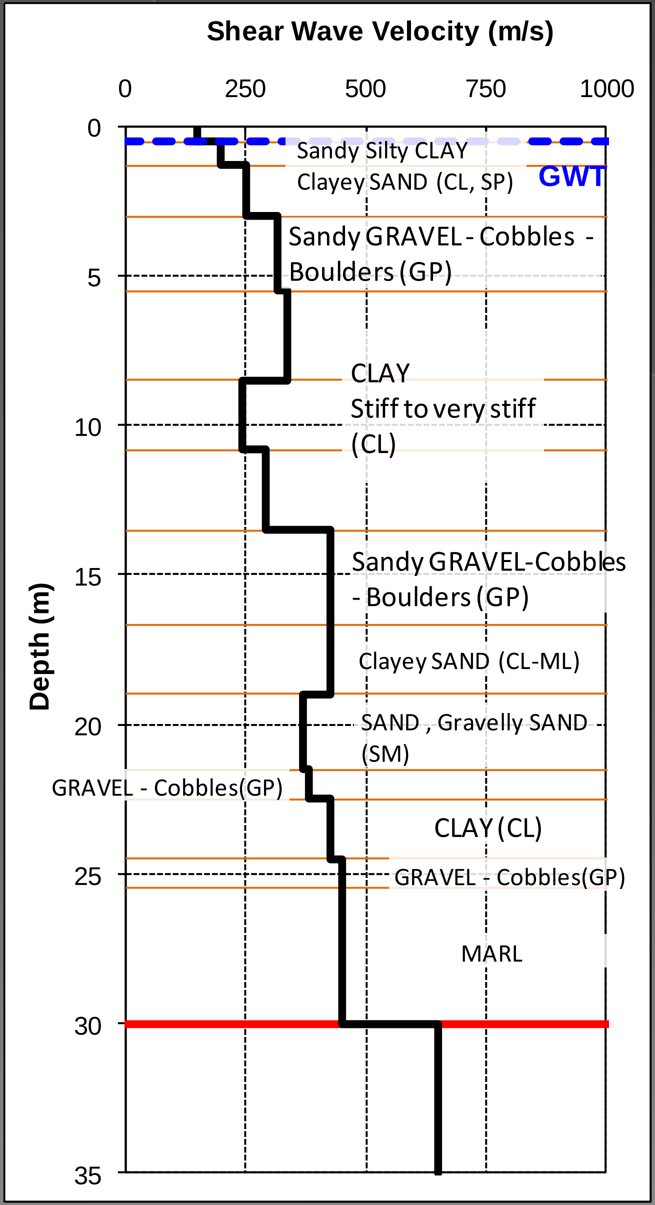
COMPARISON OF RECORDED AND CALCULATED PGA AT 24 STATIONS BASED ON SITE RESPONSE



AUGUST 17, 1999 KOCAELI EARTHQUAKE ISTANBUL RECORDS

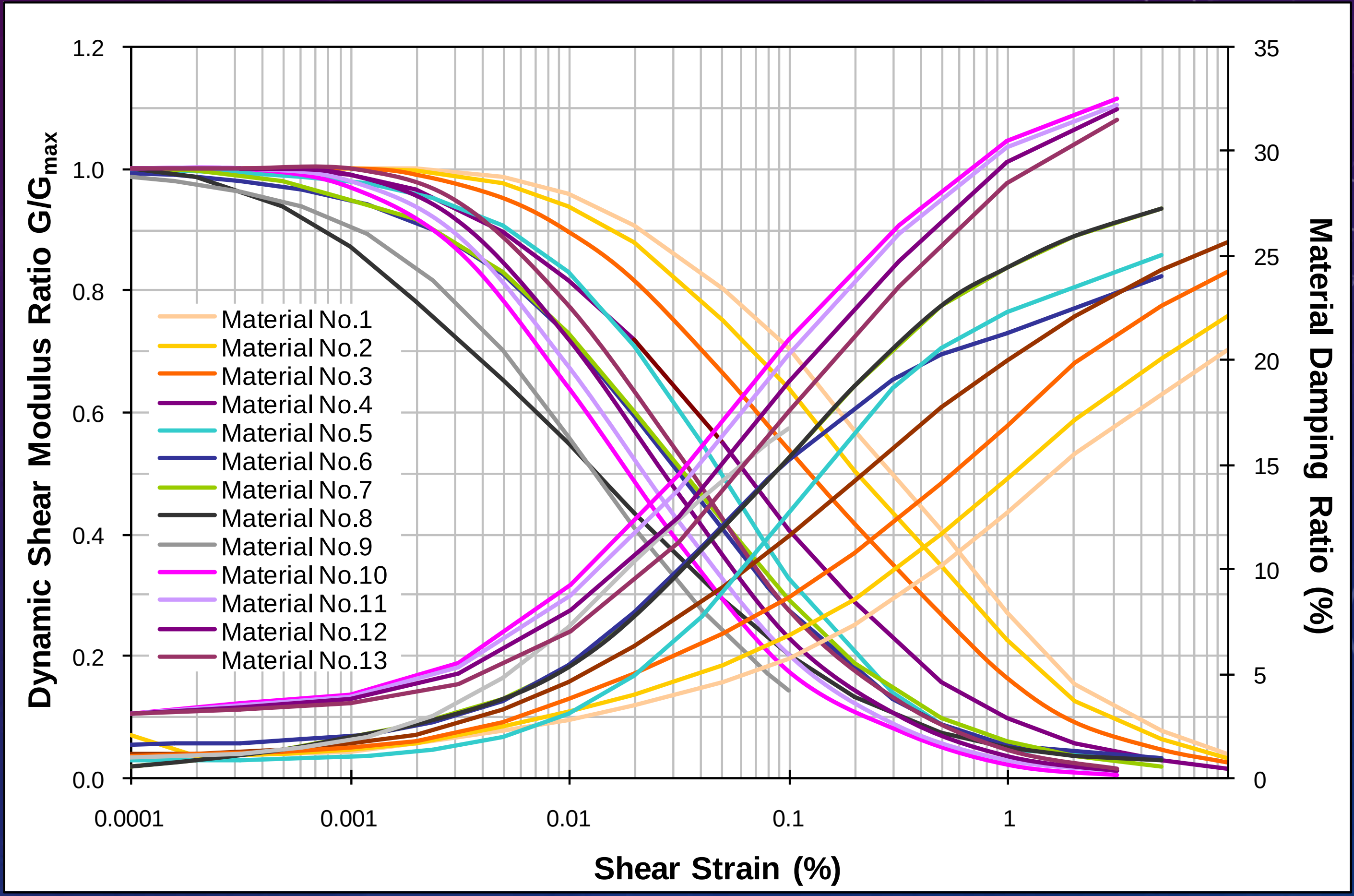


SITE SPECIFIC RESPONSE ANALYSIS
BASIC STEPS
MODULUS REDUCTION AND DAMPING RATIO CURVES FOR DIFFERENT SOIL LAYERS

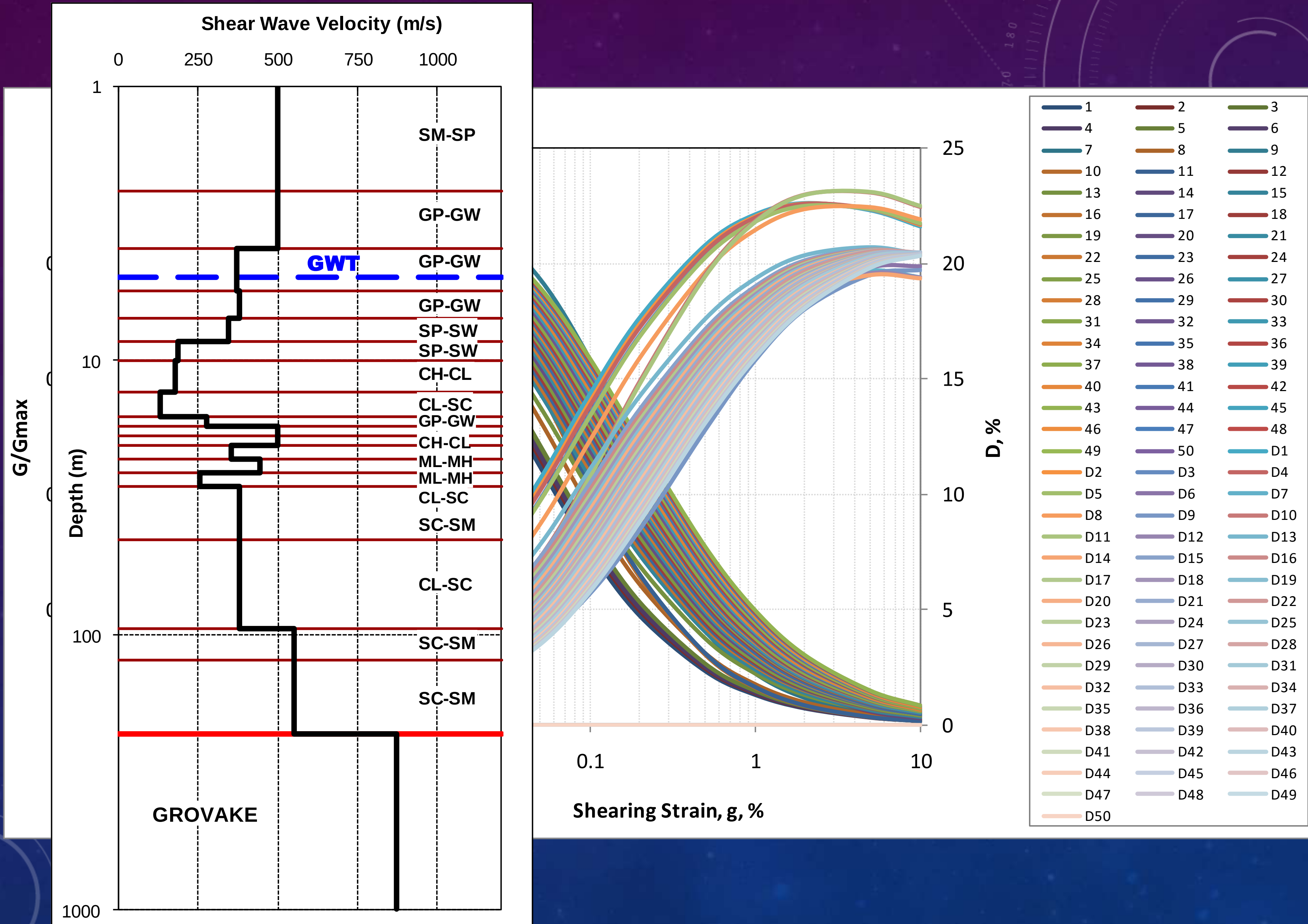


Material No	Soil Type	Reference
1	Clay (CH) PI=60%	Vucetic ve Dobry (1991)
2	Clay (CL) PI=45%	Vucetic ve Dobry (1991)
3	Clay (CH) PI=30%	Vucetic ve Dobry (1991)
4	Clay (CL) PI=15%	Vucetic ve Dobry (1991)
5	Silt	Darendeli (2001)
6	Sand (SC-SM)	Darendeli (2001)
7	Sand	Seed and Idriss
8	Gravel	Seed
9	Gravel	Menq
10	Rock 0-6 m	EPRI
11	Rock 6-16 m	EPRI
12	Rock 16-37 m	EPRI
13	Rock 37-76 m	EPRI

MODULUS REDUCTION AND DAMPING RATIO CURVES FOR DIFFERENT SOIL LAYERS



DYNAMIC SHEAR MODULUS AND DAMPING RATIO



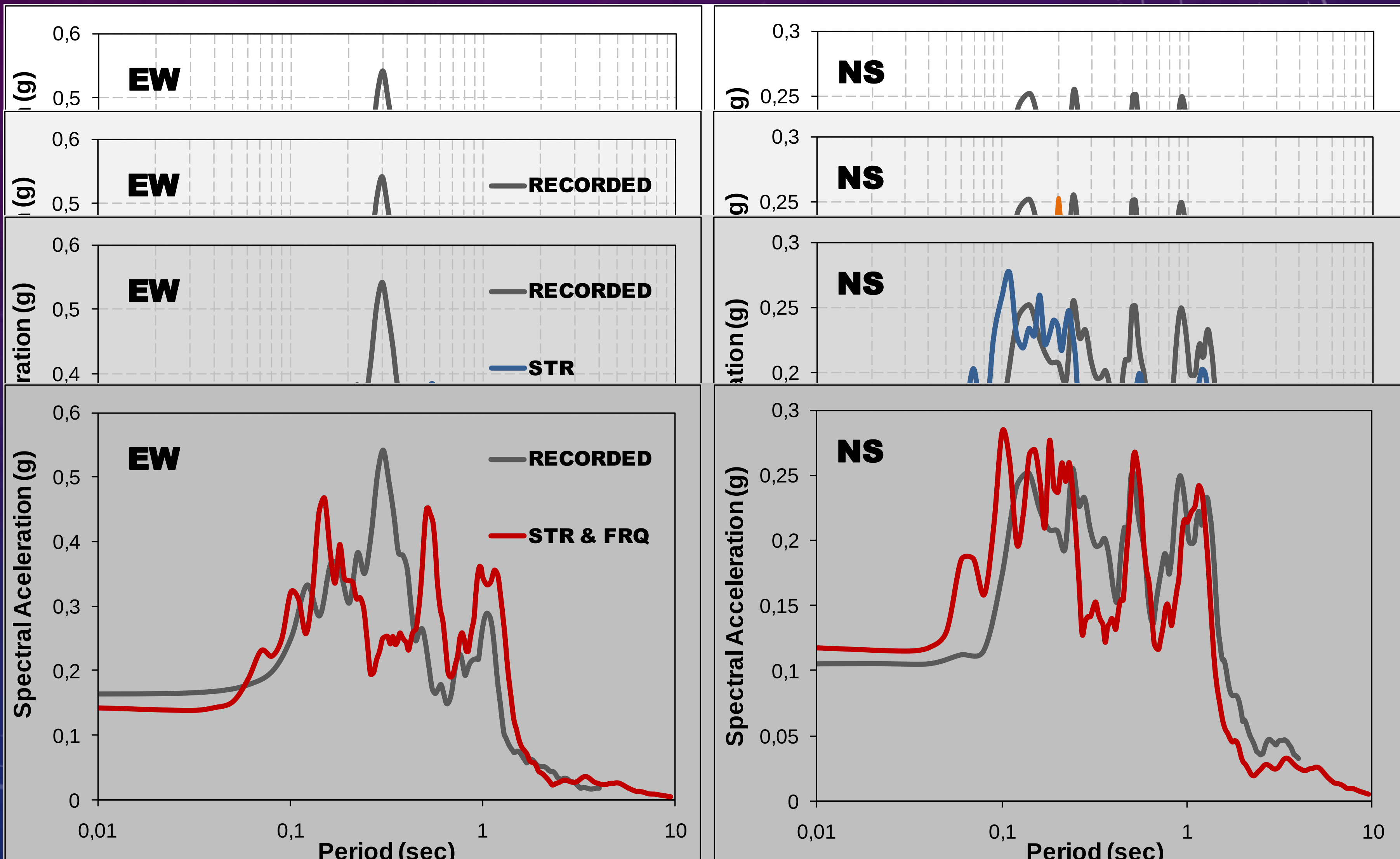
FREQUENCY CORRECTION

Effective strain is expressed as a function with respect to frequency by

$$\gamma_{eff}(\omega) = \alpha\gamma_{max} \cdot \frac{F(\omega)}{F_{max}}$$

where F(ω) is Fourier spectrum of strain, and F_{max} is its peak value as proposed by Sugito, M., Goda, H. and Masuda, T. (1994)

OBSERVED AND CALCULATED ACCELERATION RESPONSE SPECTRA FOR THE 17/08/1999 MW=7.4 EARTHQUAKE IN THE ATAKÖY STATION ON THE GROUND SURFACE



SITE RESPONSE ANALYSES

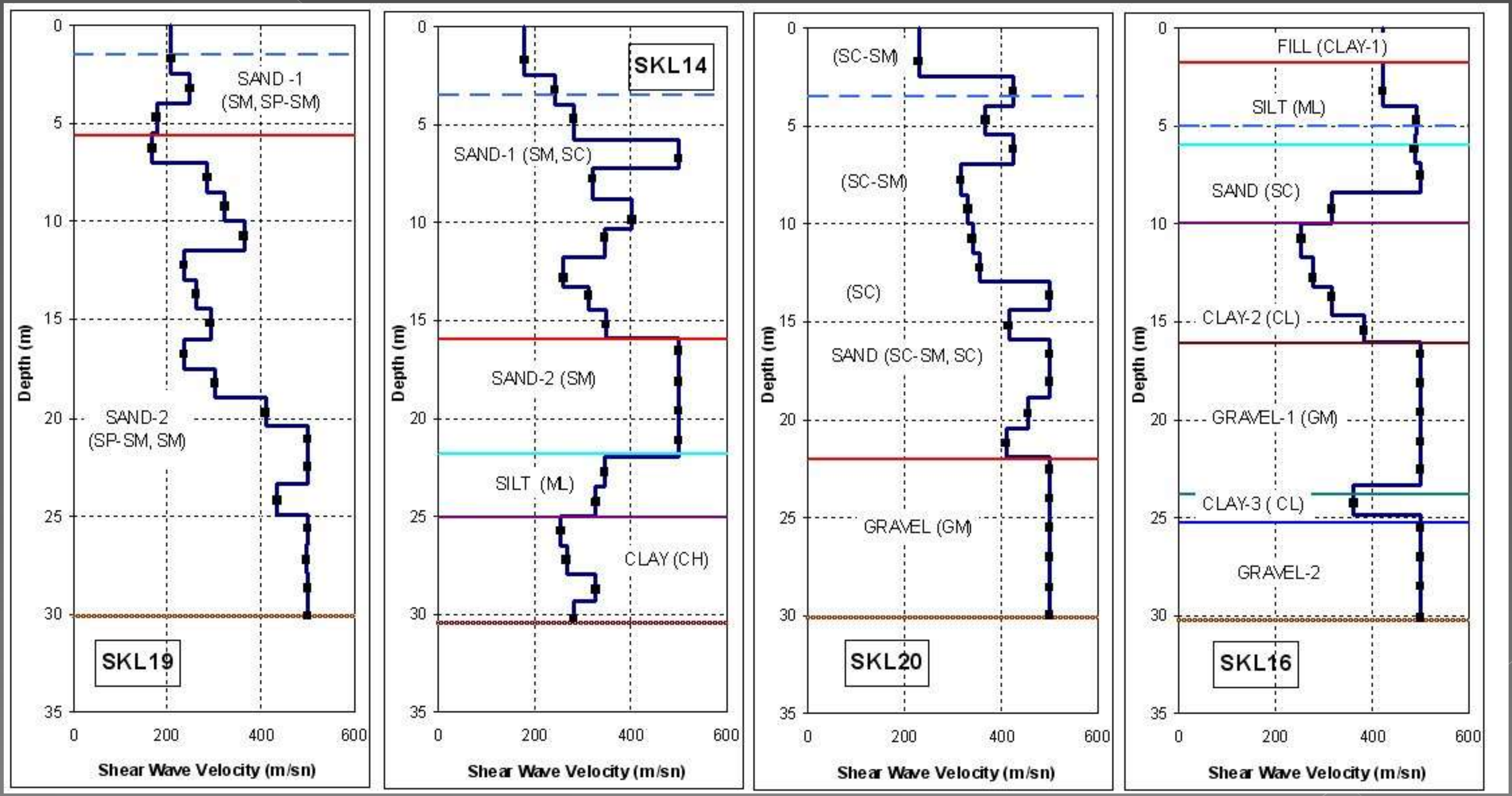
BASIC STAGES OF SITE SPECIFIC DESIGN SPECTRUM

- **Regional earthquake hazard**
- **Site characterisation**
- **Selection of input ground motion**
- **1D site response analyses**

SITE SPECIFIC RESPONSE ANALYSIS
BASIC STEPS

- ***Site Characterization:***
  - **Soil profiles for the site based on geotechnical, geological and geophysical investigations and laboratory test results,**
  - **Ground water table**
  - **Shear wave velocity (Vs) profile to represent dynamic shear modulus at low strains**
  - **Dynamic shear modulus reduction curve and damping ratio curve for different soil layers**
- *Selection of the rock (input) motions*
- *Site response analyses*

SITE CHARACTERISATION



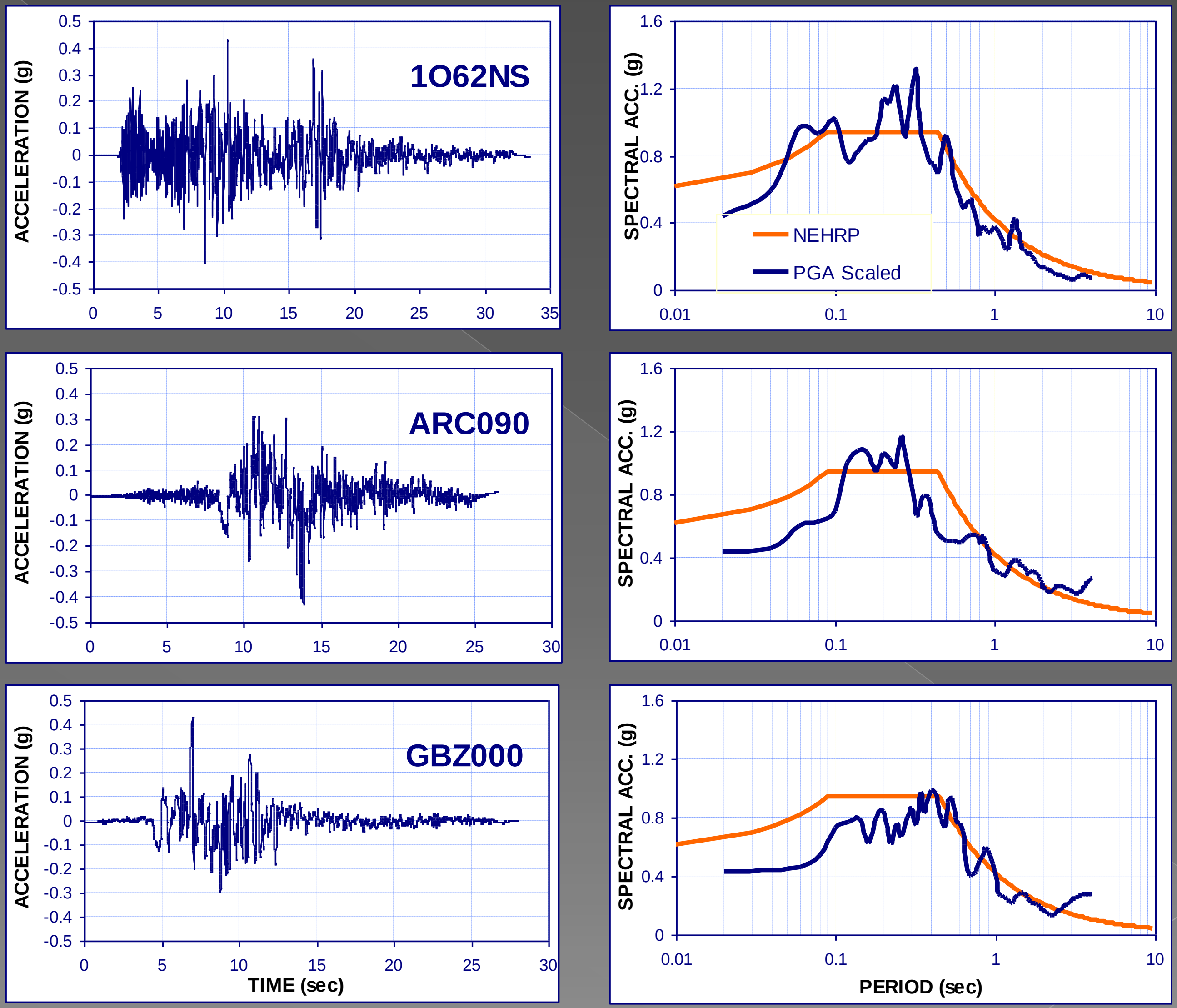
SITE SPECIFIC RESPONSE ANALYSIS
BASIC STEPS

- *Site Characterization*

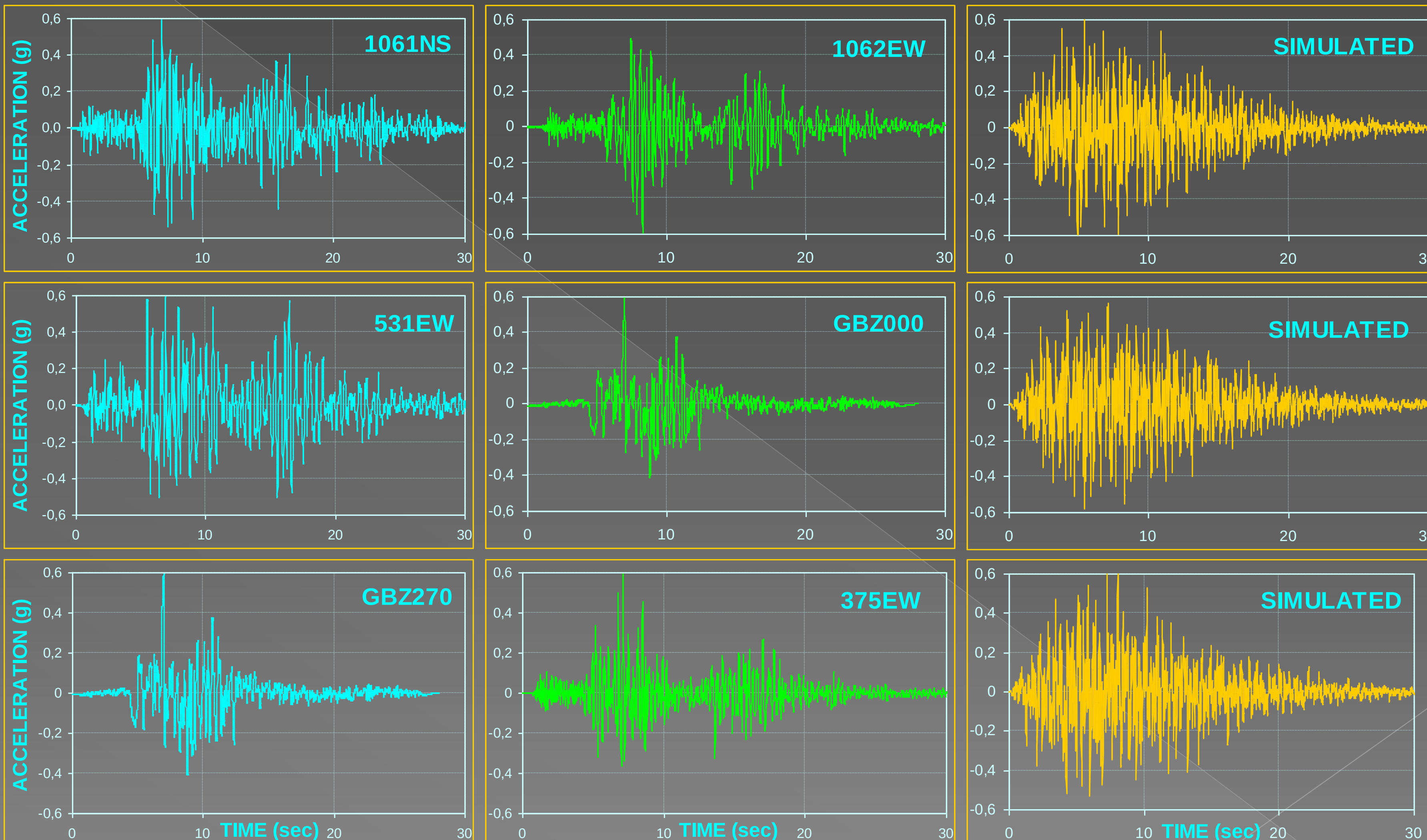
- ***Selection of the rock (input) motions:***
  - **Real or synthetic acceleration time histories as rock outcrop motion for the site compatible with estimated fault distance, fault type, earthquake magnitude**
  - **A set of time histories with similar characteristics (e.g., peak ground motion parameters, response spectral content, and duration of strong shaking) estimated for the site rock outcrop motions are selected,**
  - **Scaling acceleration time histories by a parameter (i.e. PGA, PGV, Arias Intensity, Response spectra) matching the selected design hazard**
  - **Preferably, input motions are assigned as outcrop motion rather than directly at the base of the soil profile because the hazard is generally conducted for soft rock site conditions (Vs>700m/s)**

- *Site response analyses*

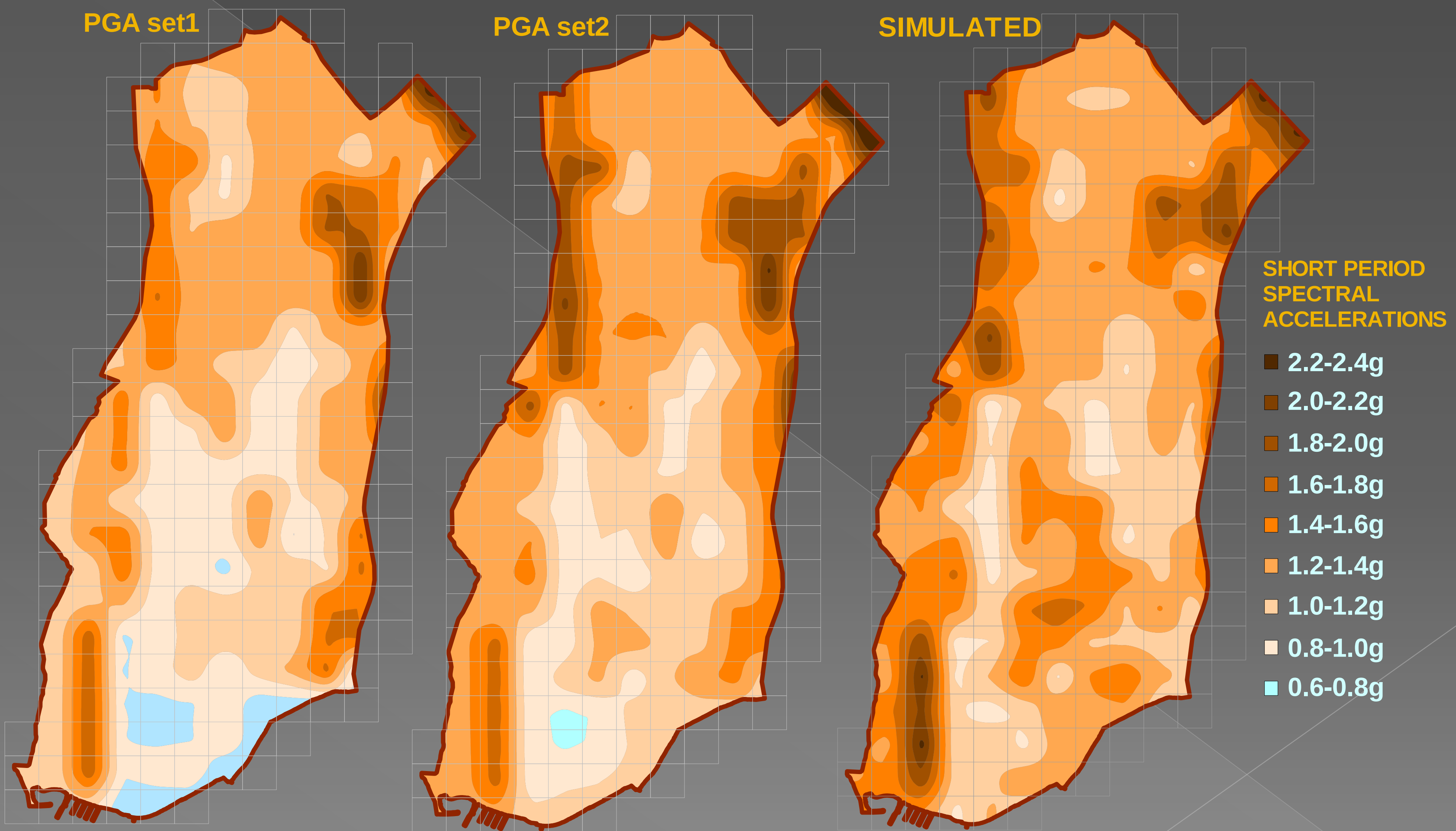
SITE SPECIFIC RESPONSE ANALYSIS
BASIC STEPS
INPUT MOTION: EARTHQUAKE HAZARD COMPATIBLE



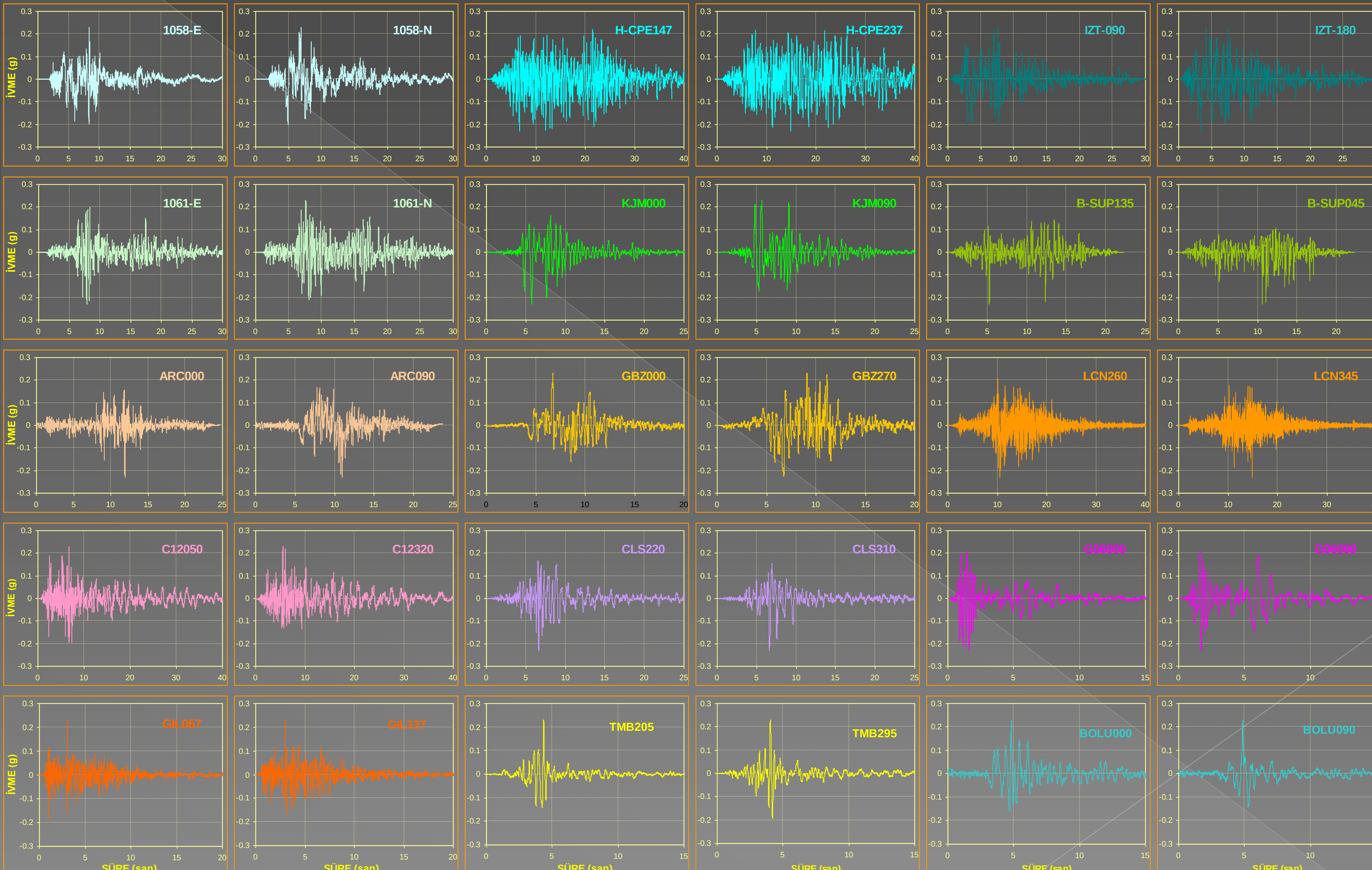
Zeytinburnu Case Study



Microzonation for average spectral accelerations



PGA scaled acceleration records



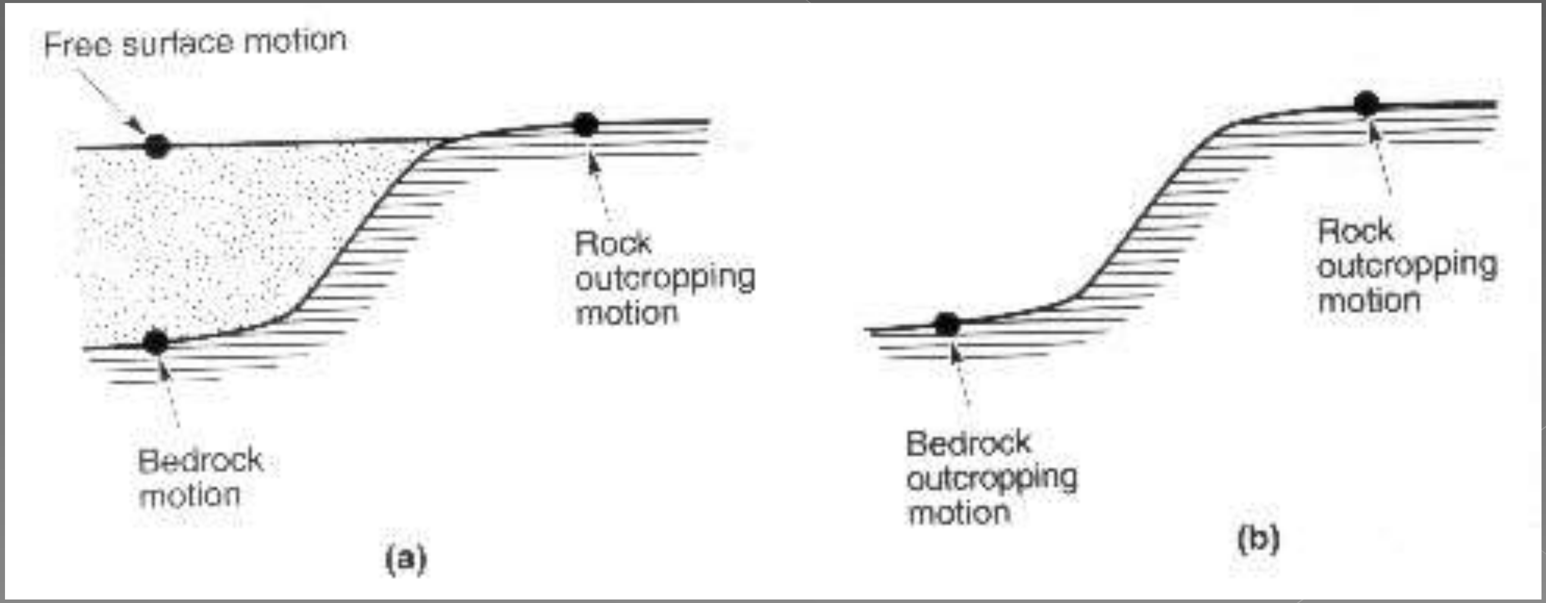
SITE SPECIFIC RESPONSE ANALYSIS
Ground Response Nomenclature

The motion at the surface of a soil deposit is the *free surface motion*.

The motion at the base of the soil deposit is called a *bedrock motion*.

The motion where bedrock is exposed at the ground surface is called a *rock outcropping motion*.

The motion at the top of bedrock would be the *bedrock outcropping motion*.



1D ANALYSIS PROGRAMS
SHAKE91

- Program SHAKE computes the response in a system of homogeneous, visco – elastic layers of infinite horizontal extent subjected to vertically travelling shear waves.
- The program is based on the continuous solution to the wave equation (Kanai, 1951) adapted for use with transient motions through the Fast Fourier Transform algorithm (Cooley and Tukey, 1965).
- The nonlinearity of the shear modulus and damping is accounted for by the use of equivalent linear soil properties (Idriss and Seed, 1968; Seed and Idriss, 1970) using an iterative procedure to obtain values for modulus and damping compatible with the effective strains in each layer.
- The program is able to handle systems with variation in both moduli and damping and takes into account the effect of the elastic base.
- The object motion can be given in any one layer in the system and new motions can be computed in any other layer.

CASE STUDY FOR A SITE SPECIFIC DESIGN SPECTRA

EARTHQUAKE HAZARD LEVELS:

1. EXCEEDANCE PROBABİLİTY OF 2% İN 50 YEARS 2475 YEARS RETURN PERİOD

2. EXCEEDANCE PROBABİLİTY OF 10% İN 50 YEARS 475 YEARS RETURN PERİOD

3. EXCEEDANCE PROBABİLİTY OF 50% İN 50 YEARS 72 YEARS RETURN PERİOD

ANALYSIS STEPS:

- **Twenty four real acceleration time histories compatible with the earthquake hazard in terms of probable magnitude, epicentre distance and fault mechanism recorded on stiff (soft rock-rock) site conditions with average shear wave velocities larger than V_{s30} > 500 m/s as input**
- **The selected acceleration time histories were scaled with respect to PGA calculated from the earthquake hazard assessment corresponding to 2%, 10% and 50% exceedance probabilities in 50 years.**
- **Site response analysis were conducted for 18 soil profiles where the variation of shear wave velocities with depth are estimated based on down hole seismic wave velocity measurements and SPT blow counts.**
- **The design acceleration spectrum is recommended based on the mean + 1 standard deviation spectrum obtained from 264 elastic acceleration response spectra calculated for 18 borings for 24 PGA scaled real input acceleration records for performance levels.**

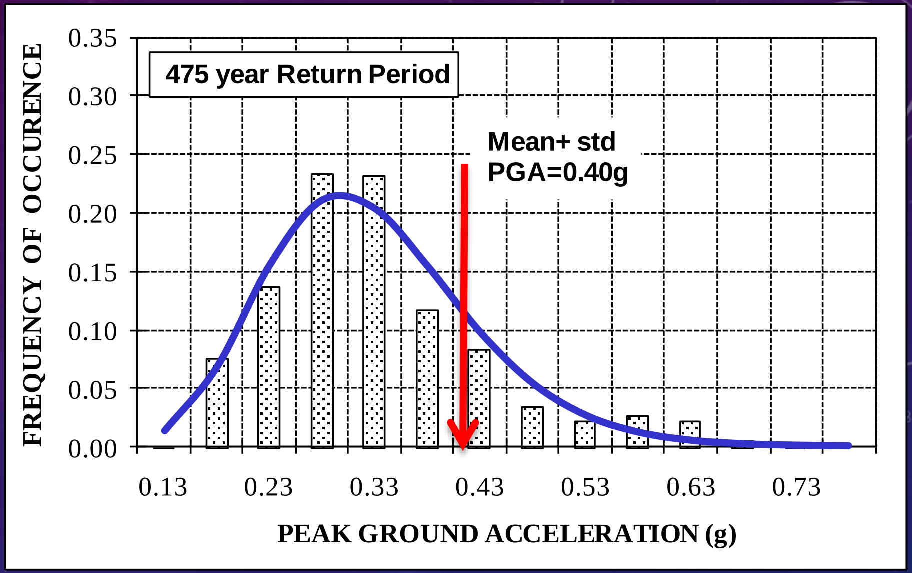
INPUT ACCELERATİON TİME HİSTORİES

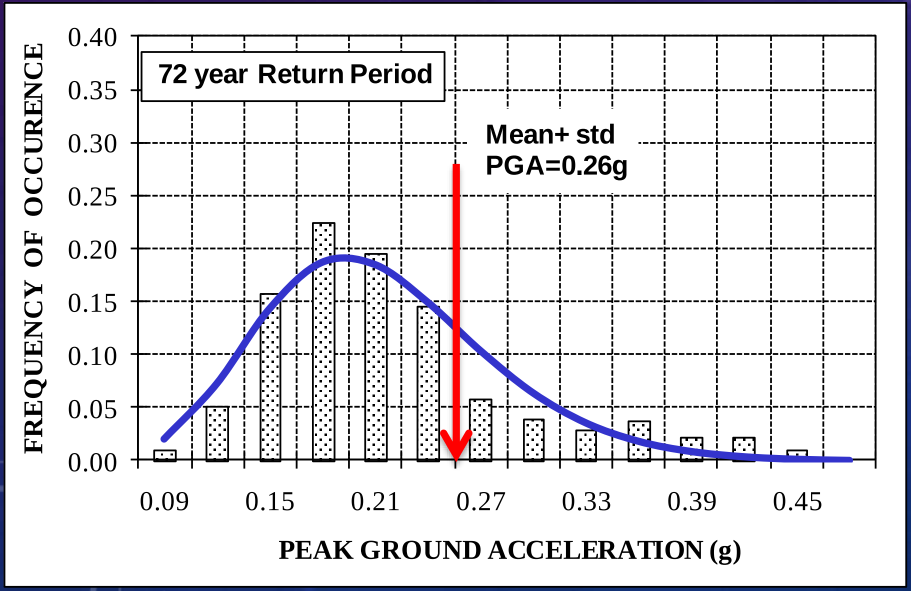
Earthquake hazard compatible in terms of probable magnitude (M=7.0-7.7), Joyner and Boore distance (30km ≤ R ≤ 90km) and fault mechanism (strike-slip) recorded on stiff site conditions with average shear wave velocities larger than $V_{s30} \geq 500$ m/s

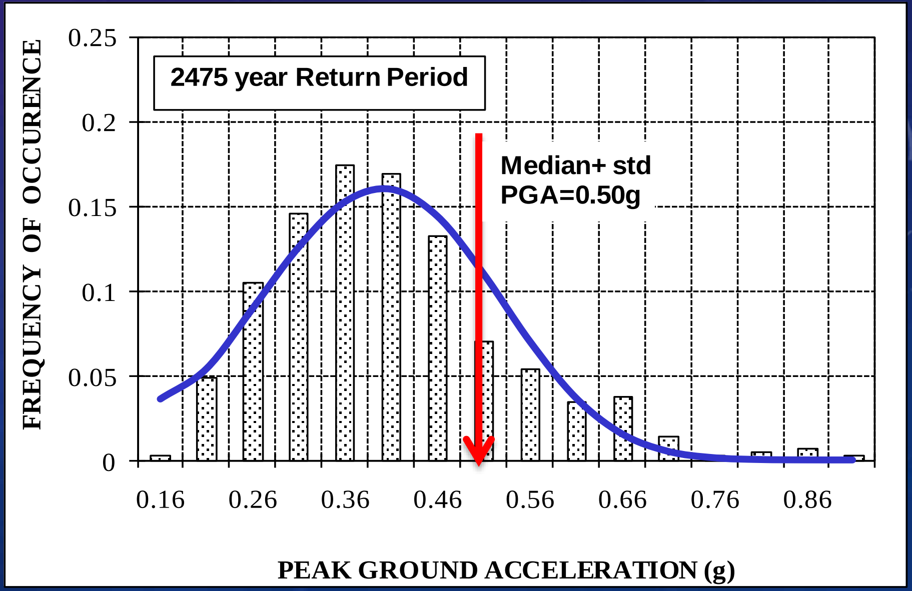
Earthquake Name	Date	Magnitude	Station Name	V_{s30} (m/s)	$R_{J\&B}$ (km)	PGA (g) (Mean)
Hector Mine	16.10.1999	7.13	Twentynine Palms	684.9	42.06	0.0629
			Seven Oaks Dam Project Office	659.6	87.20	0.0529
			Joshua Tree N.M. - Keys View	684.9	50.42	0.0826
			Heart Bar State Park	684.9	61.21	0.0831
			Banning - Twin Pines Road	684.9	83.43	0.0205
			Anza - Pinyon Flat	724.9	89.98	0.0315
Sitka, Alaska	30.07.1972	7.68	Sitka Observatory	659.6	34.61	0.0941
Duzce, Turkey	12.11.1999	7.14	Mudurnu	659.6	34.30	0.0896
Kocaeli, Turkey	17.08.1999	7.51	Maslak	659.6	52.96	0.0423
			Bursa Sivil	659.6	65.53	0.0559
Landers	28.06.1992	7.28	Twentynine Palms	684.9	41.43	0.0701
			Silent Valley - Poppet Flat	684.9	50.85	0.0463

SİTE DEPENDENT PEAK GROUND ACCELERATİON

Three earthquake design levels
72 years return period 50% exceedance in 50 years
475 years return period 10% exceedance in 50 years
2475 years return period 2% exceedance in 50 years

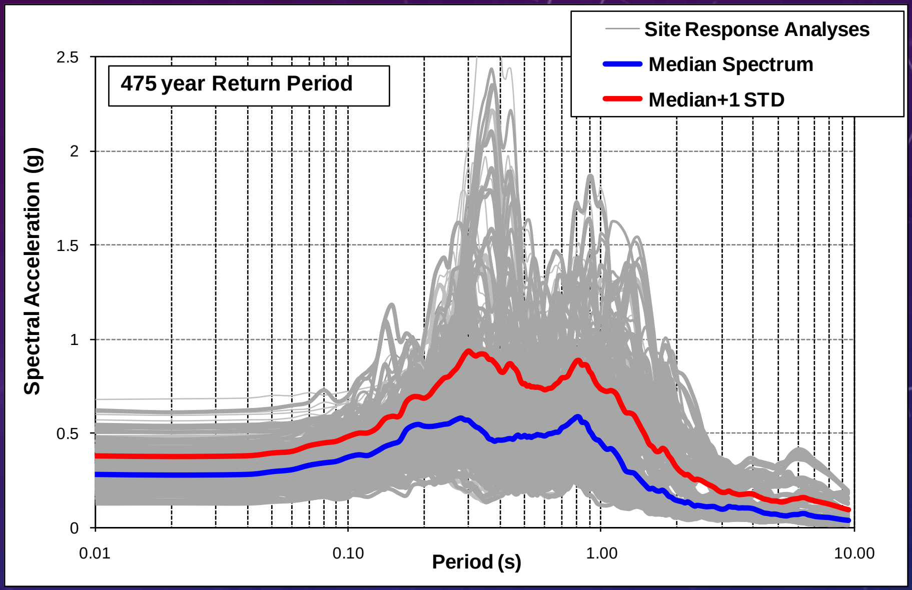


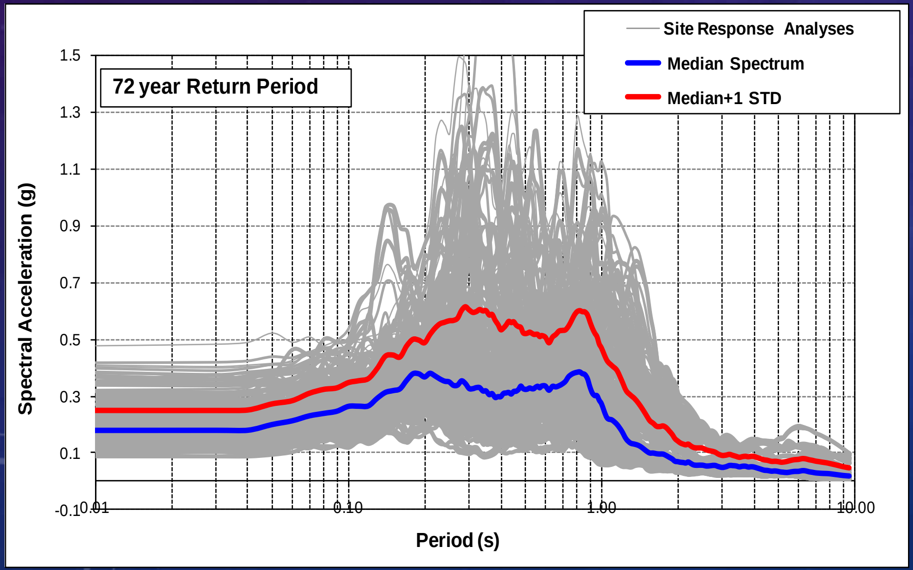


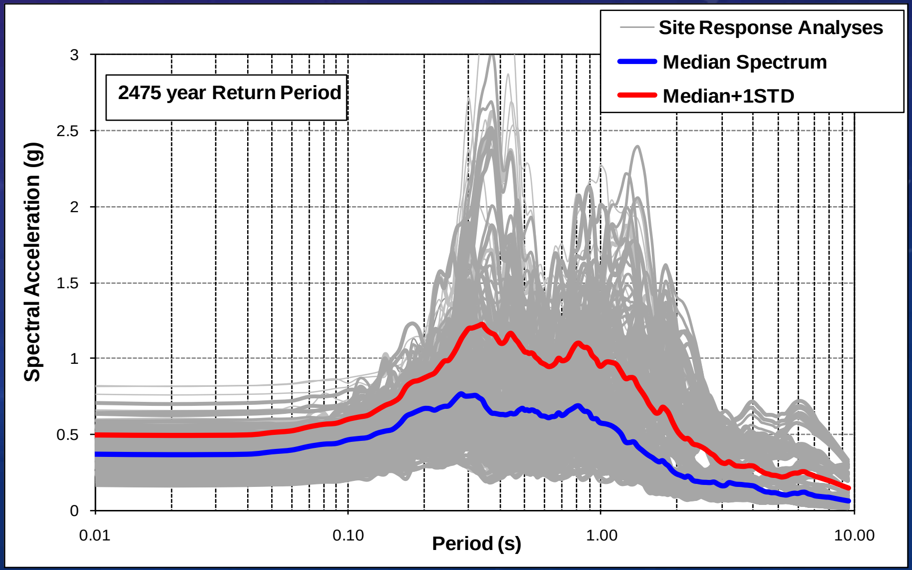


SİTE DEPENDENT ACCELERATİON REPONSE SPECTRA

Three earthquake design levels
72 years return period 50% exceedance in 50 years
475 years return period 10% exceedance in 50 years
2475 years return period 2% exceedance in 50 years

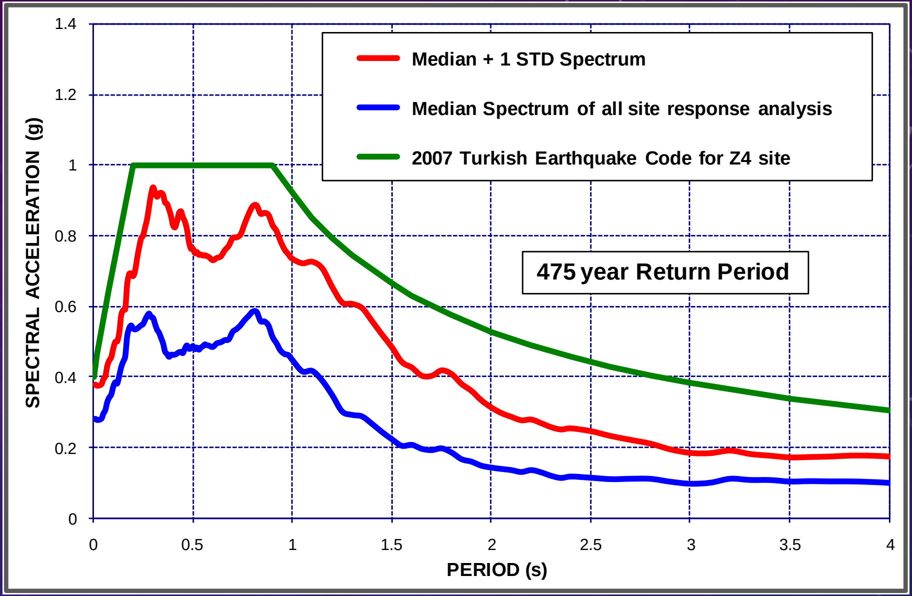


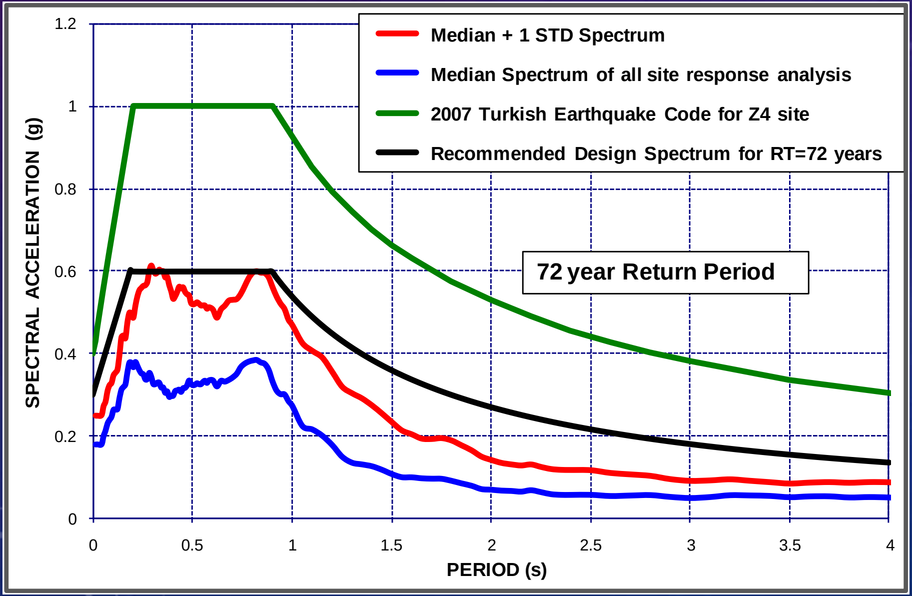


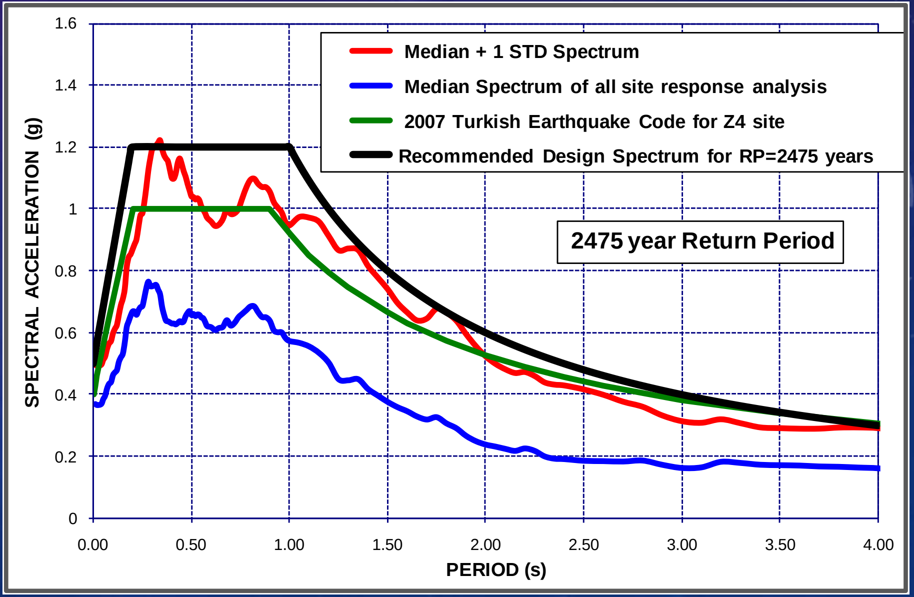


RECOMMENDED DESİGN SPECTRA BASED ON THE MEAN + 1 STANDARD DEVİATİON

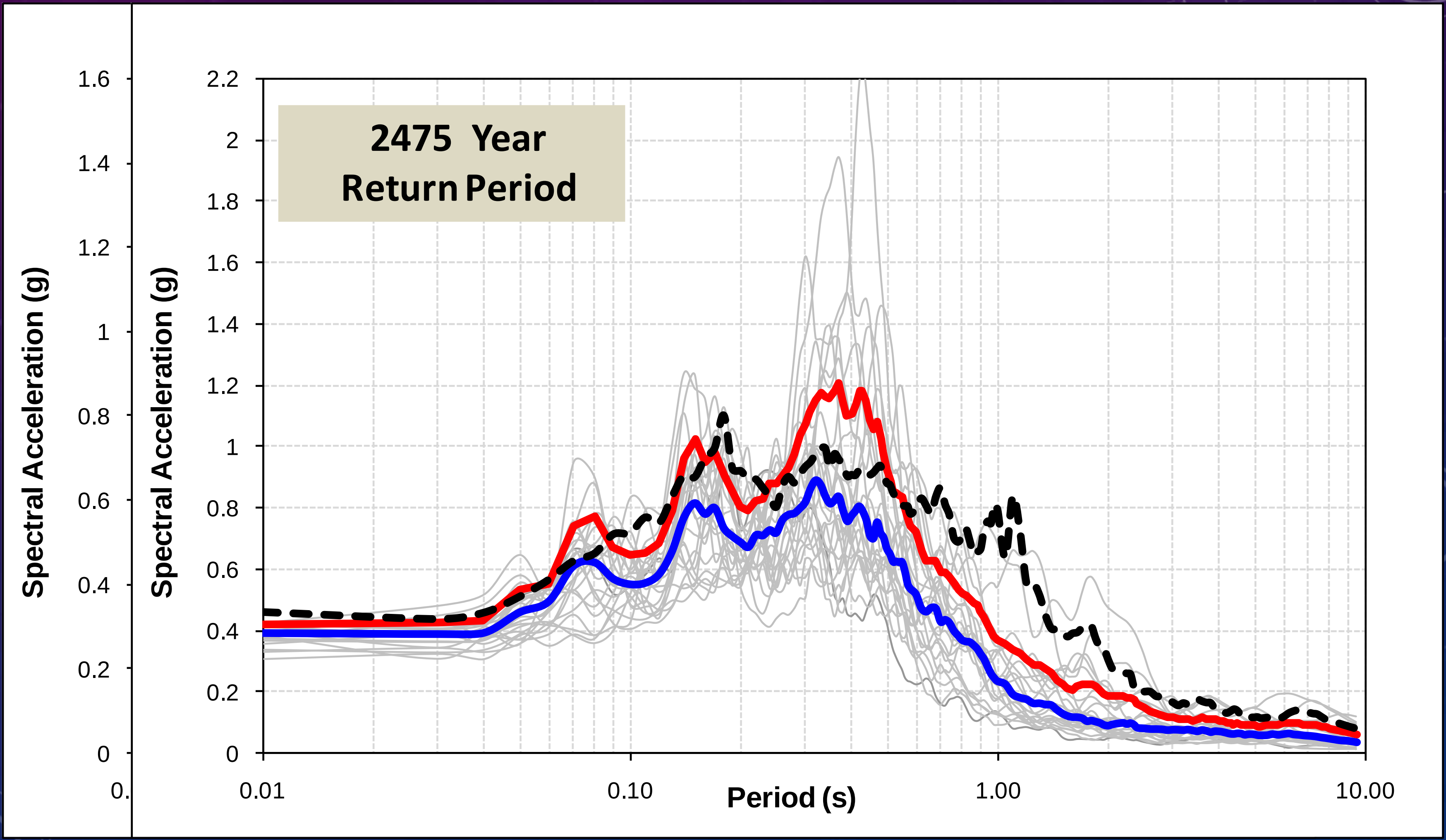
Three earthquake design levels
72 years return period 50% exceedance in 50 years
475 years return period 10% exceedance in 50 years
2475 years return period 2% exceedance in 50 years







RESULTS OF TOTAL PROBABILITY ANALYSIS



PARAMETRIC STUDY

The first site is located in medium to high seismicity zone with possible PGA range of 0.15-0.25g. The thickness of the soil deposit is between 60-110 m mostly composed of medium stiff to stiff clay layers.

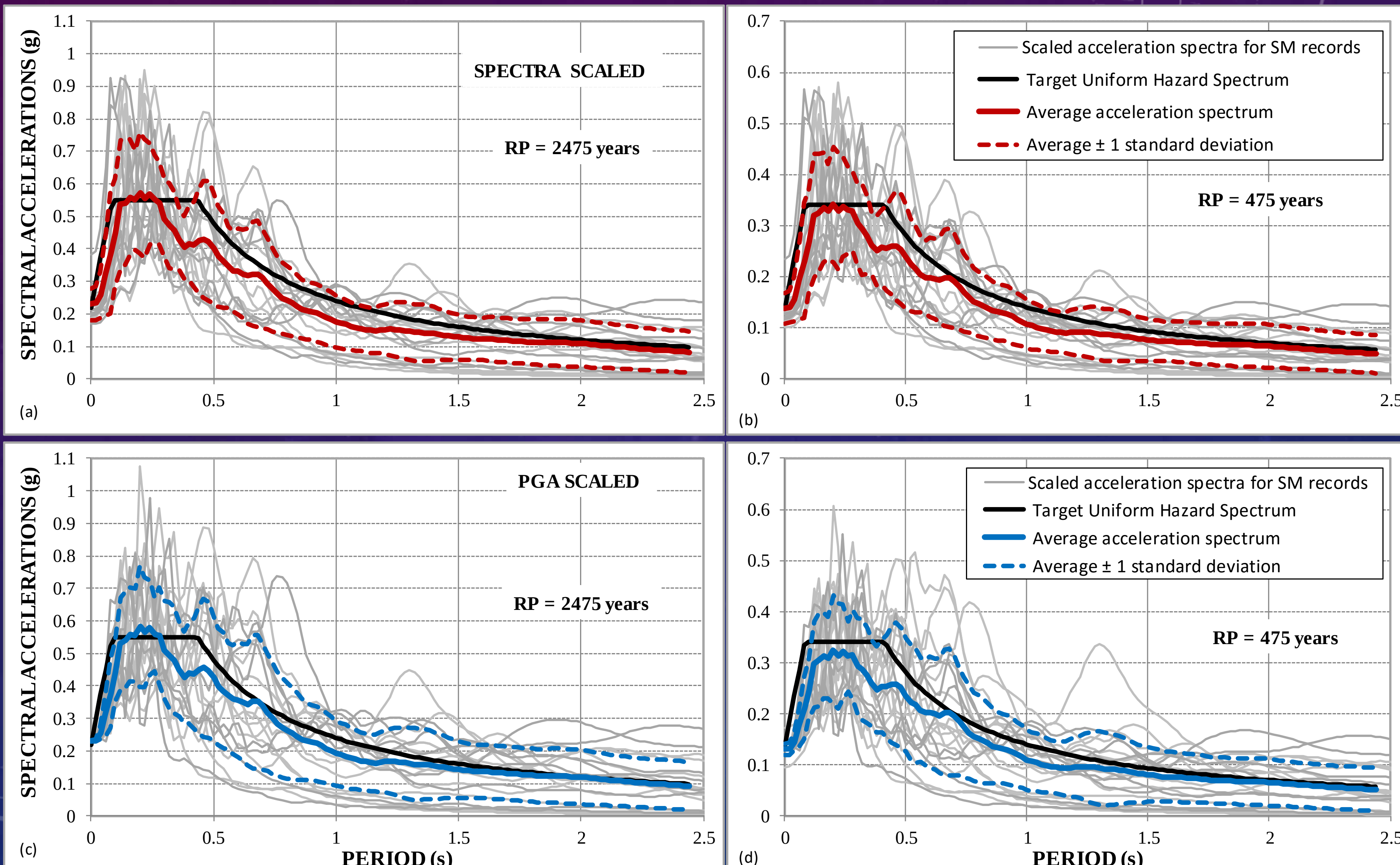
The second site is located in high seismicity zone with possible PGA range of 0.5-0.8g. The thickness of the soil deposit is around 50m with alternating layers of medium stiff sandy clays and clayey sands.

SELECTION OF INPUT GROUND MOTION

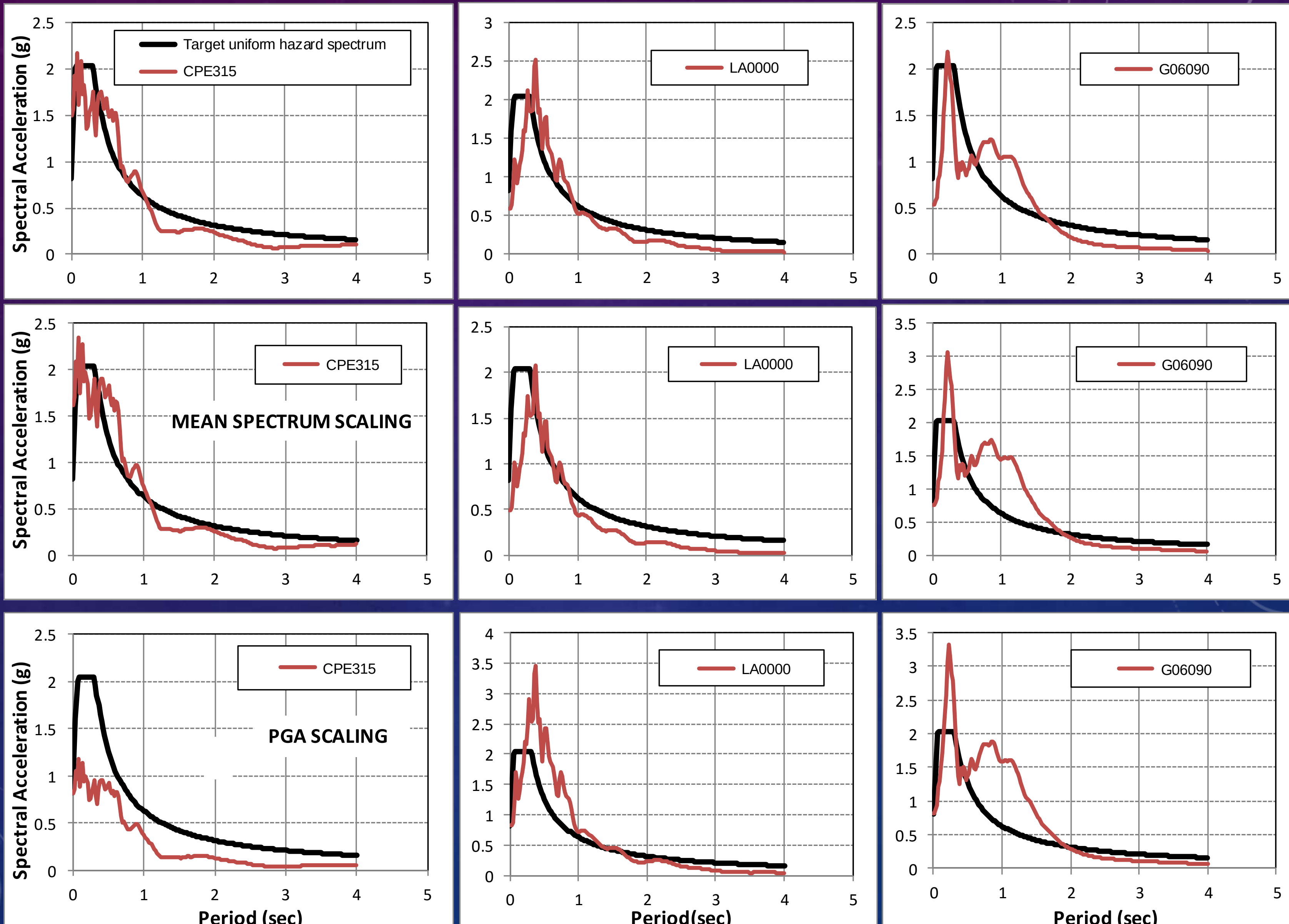
Real Acceleration Records based on local hazard study:

1. Compatibility with magnitude, fault type, fault distance, and rock outcrop with $V_{s30} \geq 760$ m/s
2. Compatibility with PGA and spectral acceleration levels with the target uniform hazard spectra

PGA AND SPECTRA SCALED INPUT ACCELERATION RECORDS



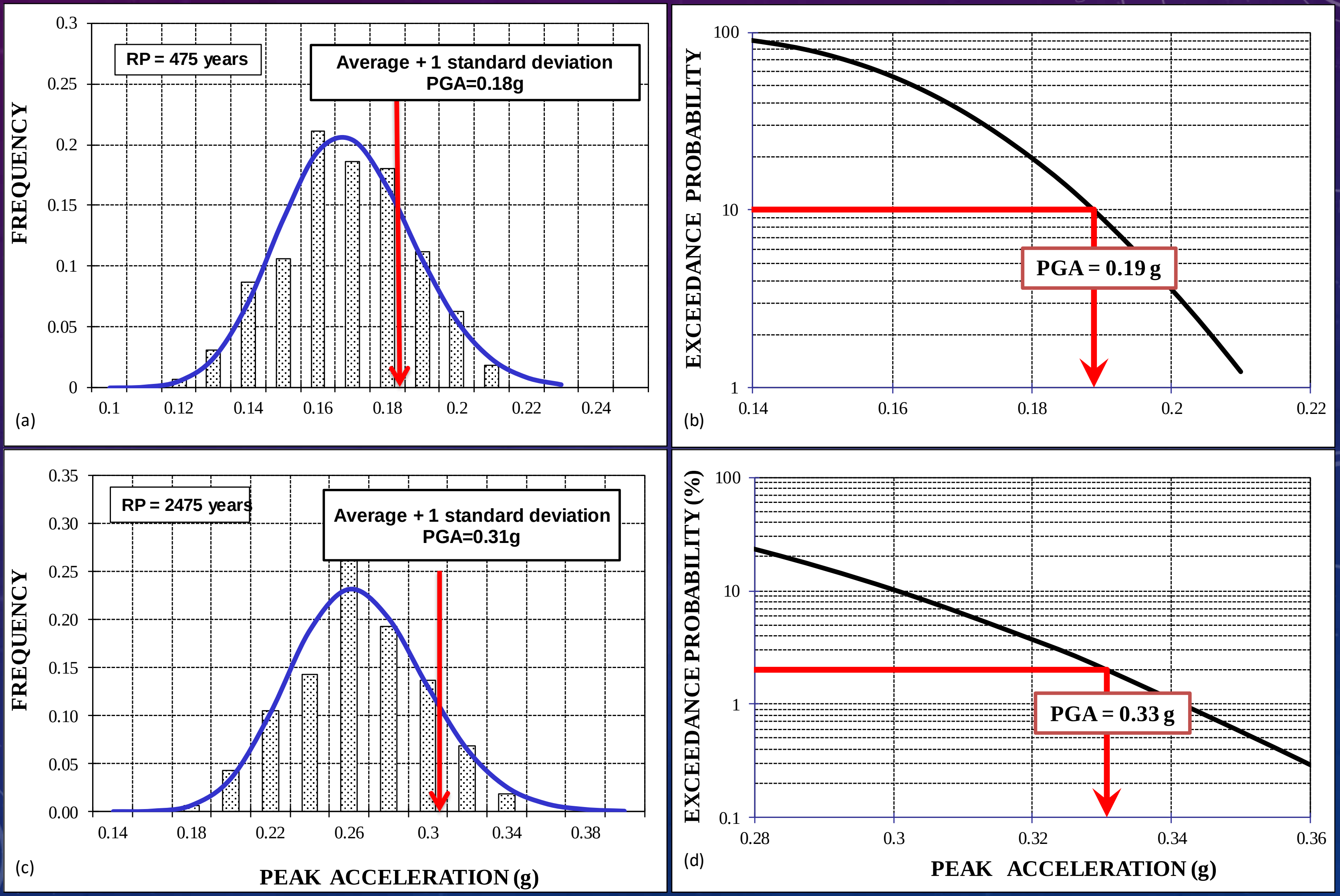
COMPARISON OF PGA, MEAN SPECTRUM, AND SPECTRA SCALED INPUT ACCELERATION RECORDS



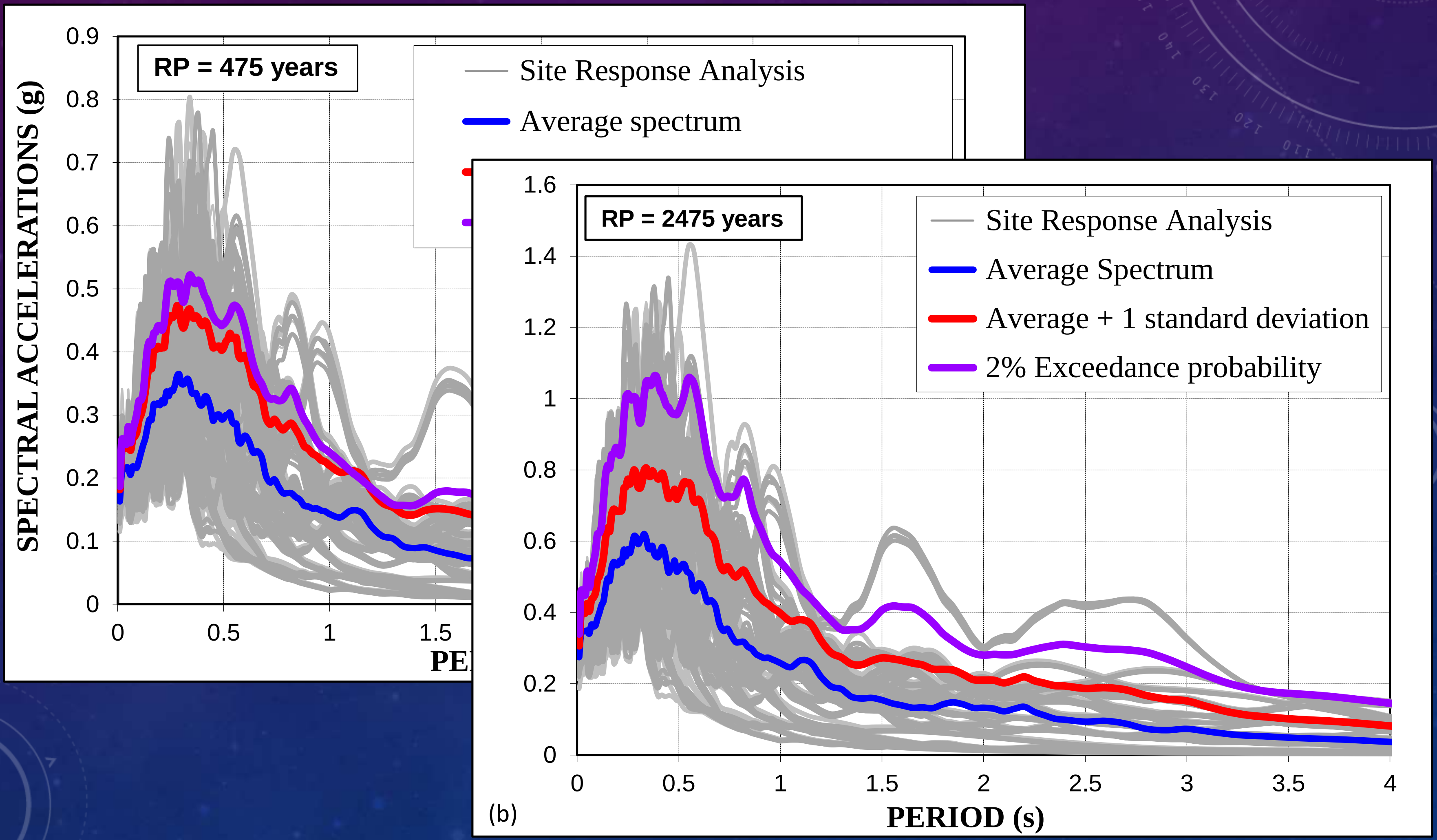
DESIGN PEAK GROUND ACCELERATION FOR SPECTRA SCALED RECORDS

Mean + 1 Standart Deviation

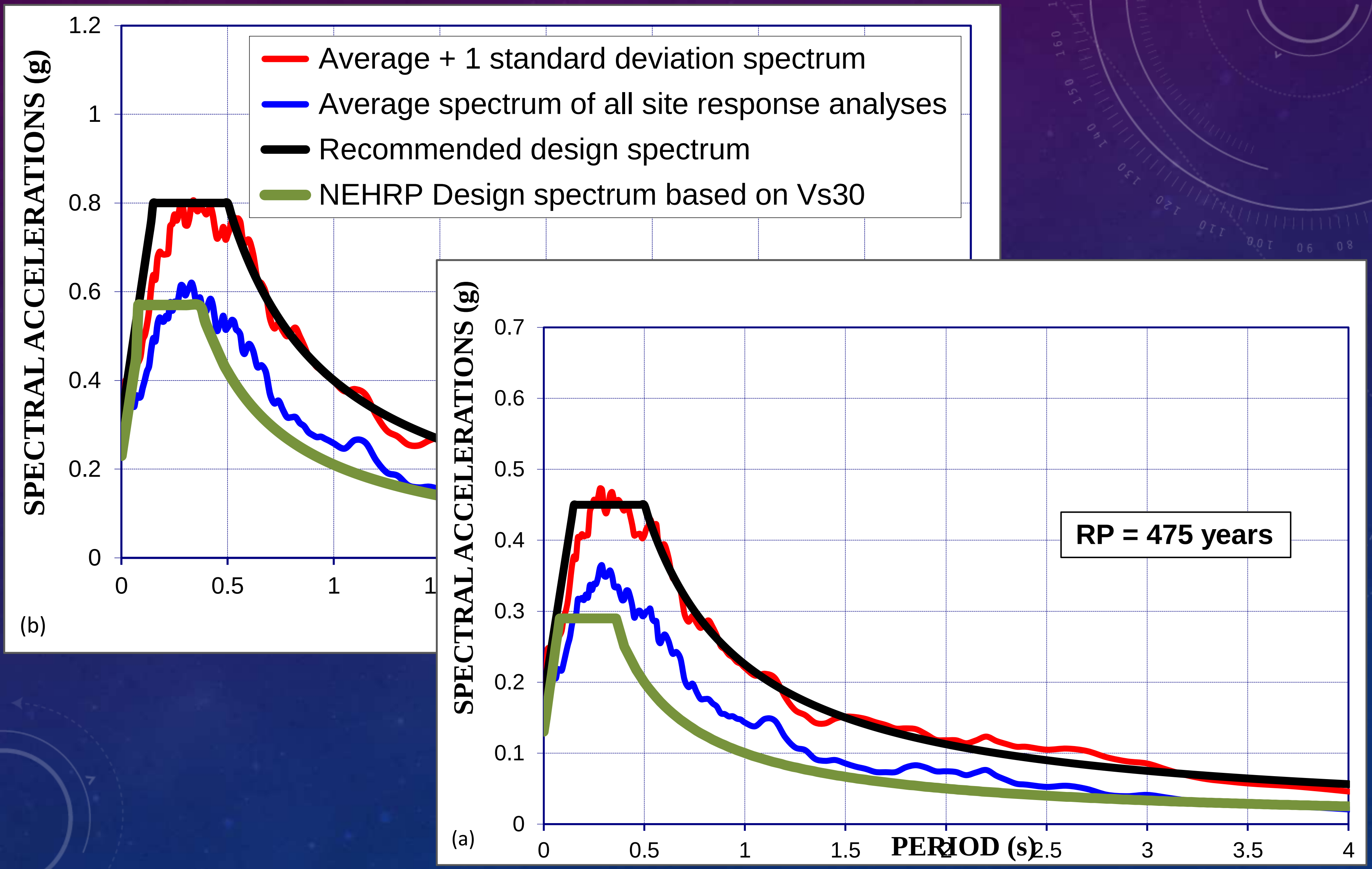
Probabilistic based on distribution



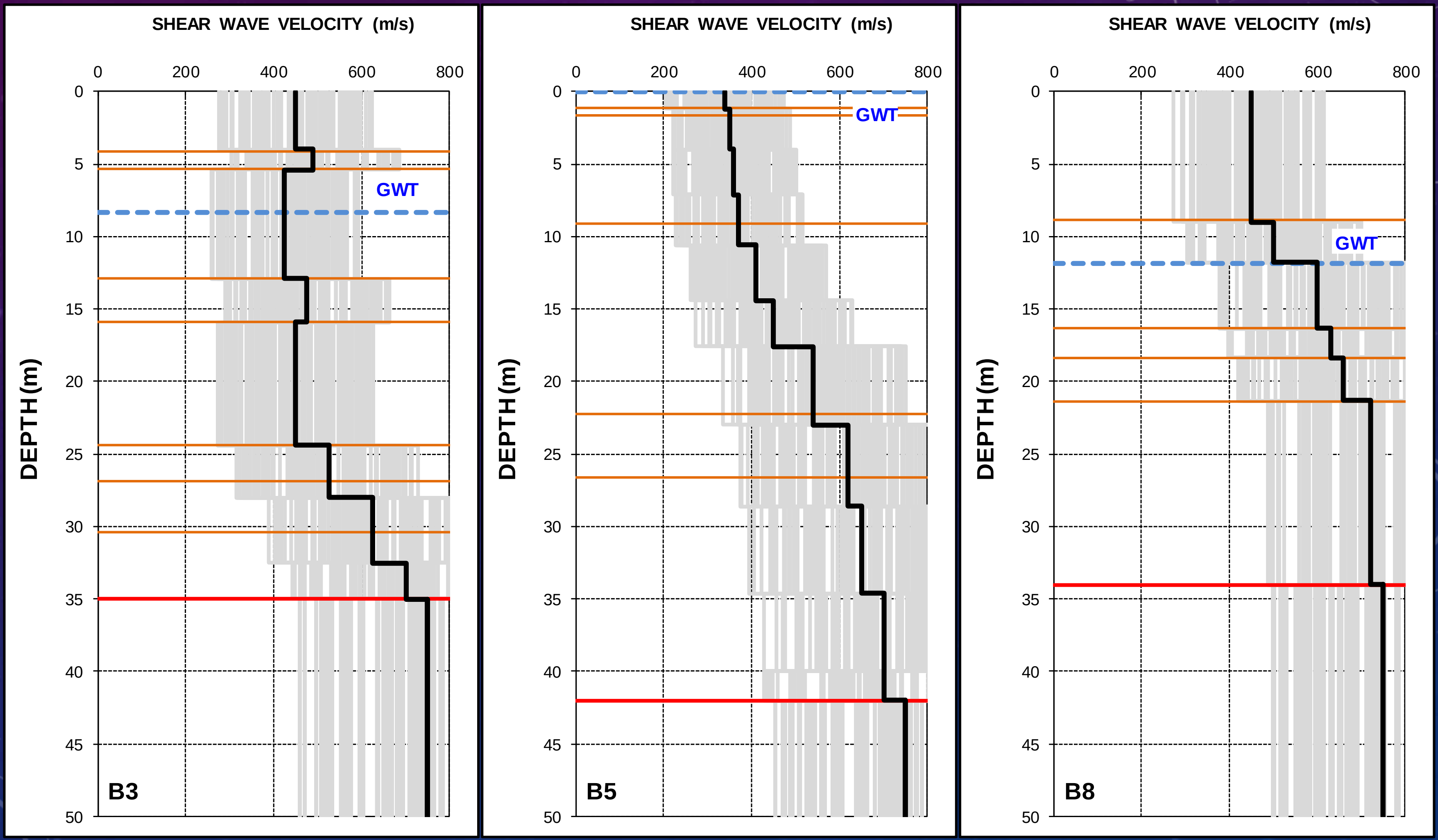
ACCELERATION SPECTRA ON THE GROUND SURFACE BASED ON SITE RESPONSE ANALYSIS FOR (A) 475 AND (B) 2475 YEAR RETURN PERIODS



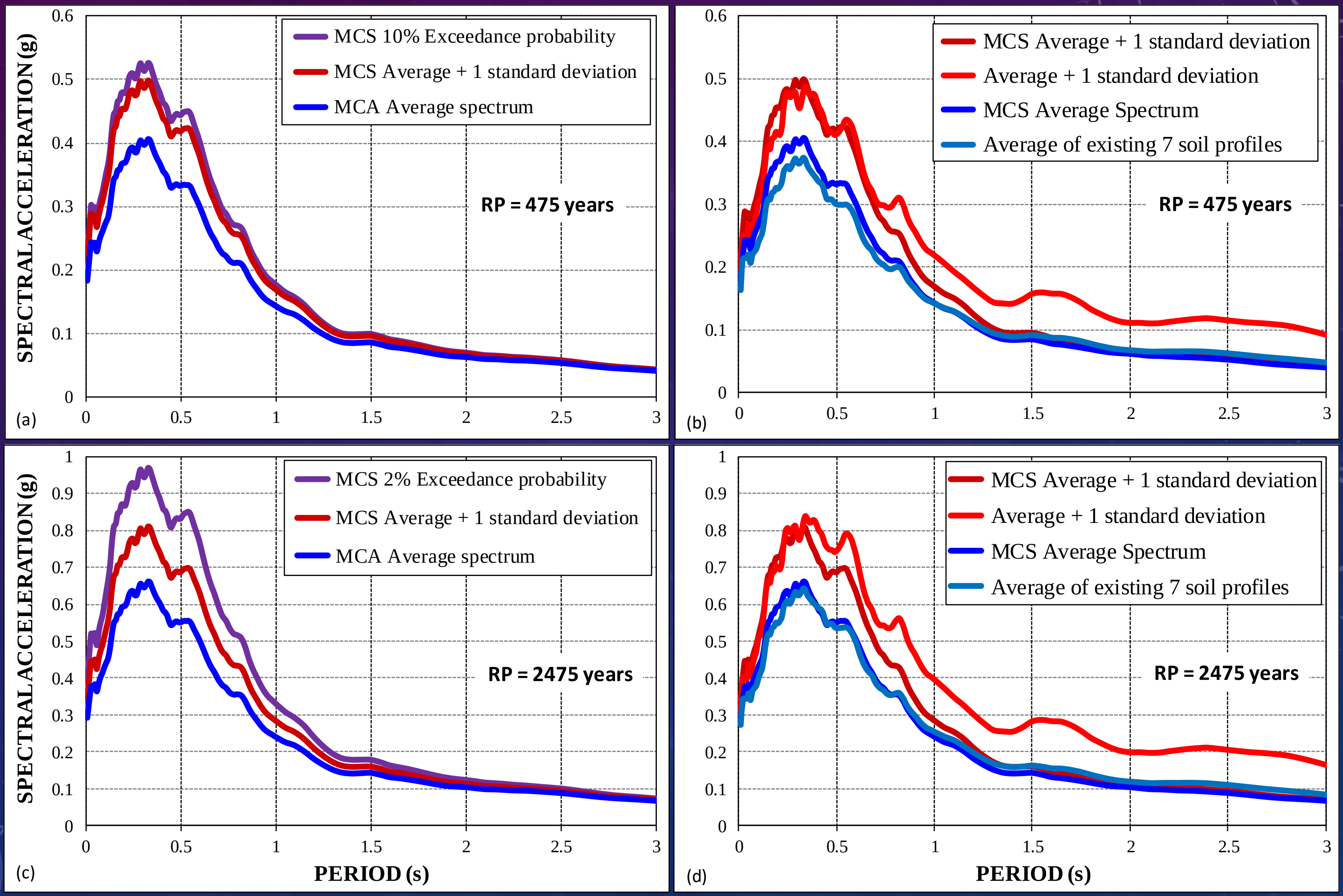
DESIGN ACCELERATION SPECTRA BASED ON SITE RESPONSE ANALYSIS AND NEHRP VS30



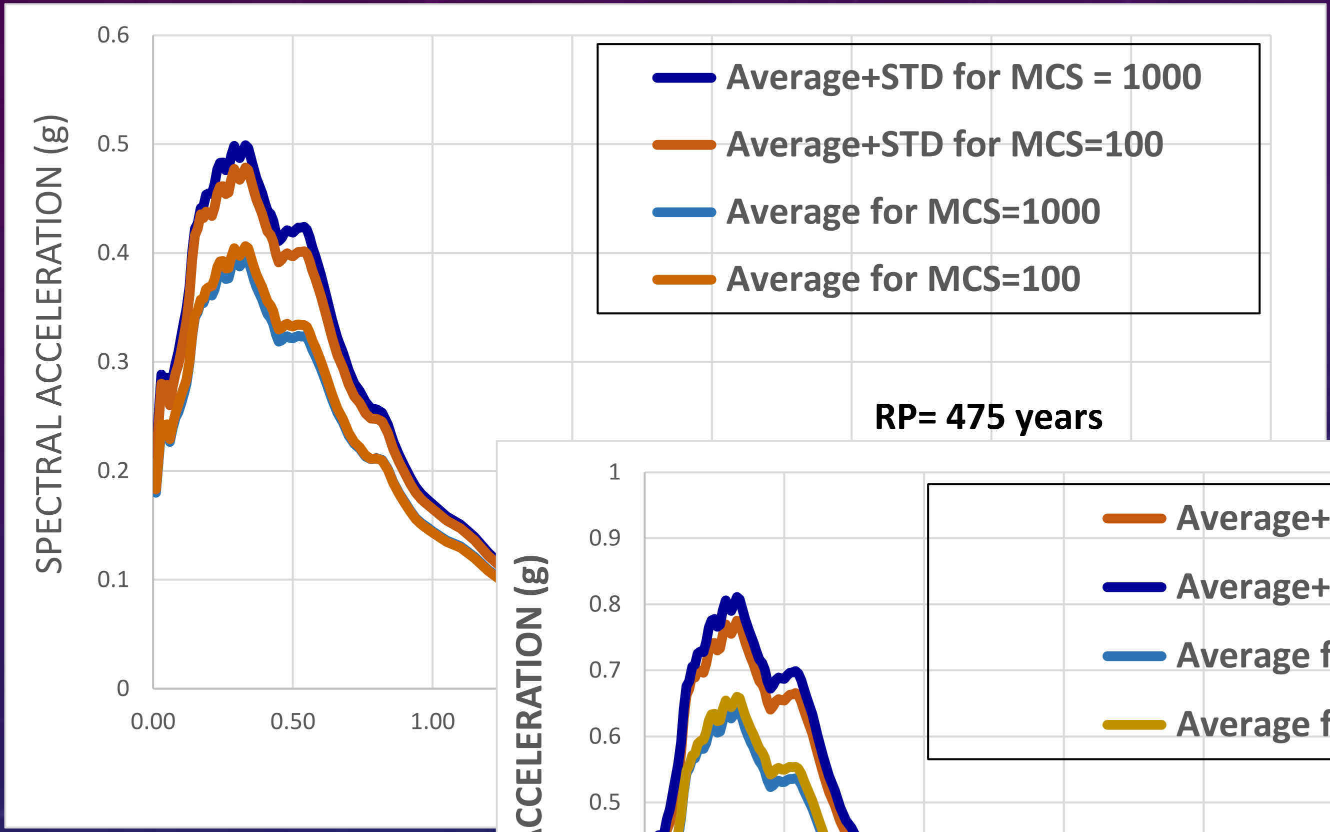
VARIABILITY WRT TO SHEAR WAVE VELOCITIES

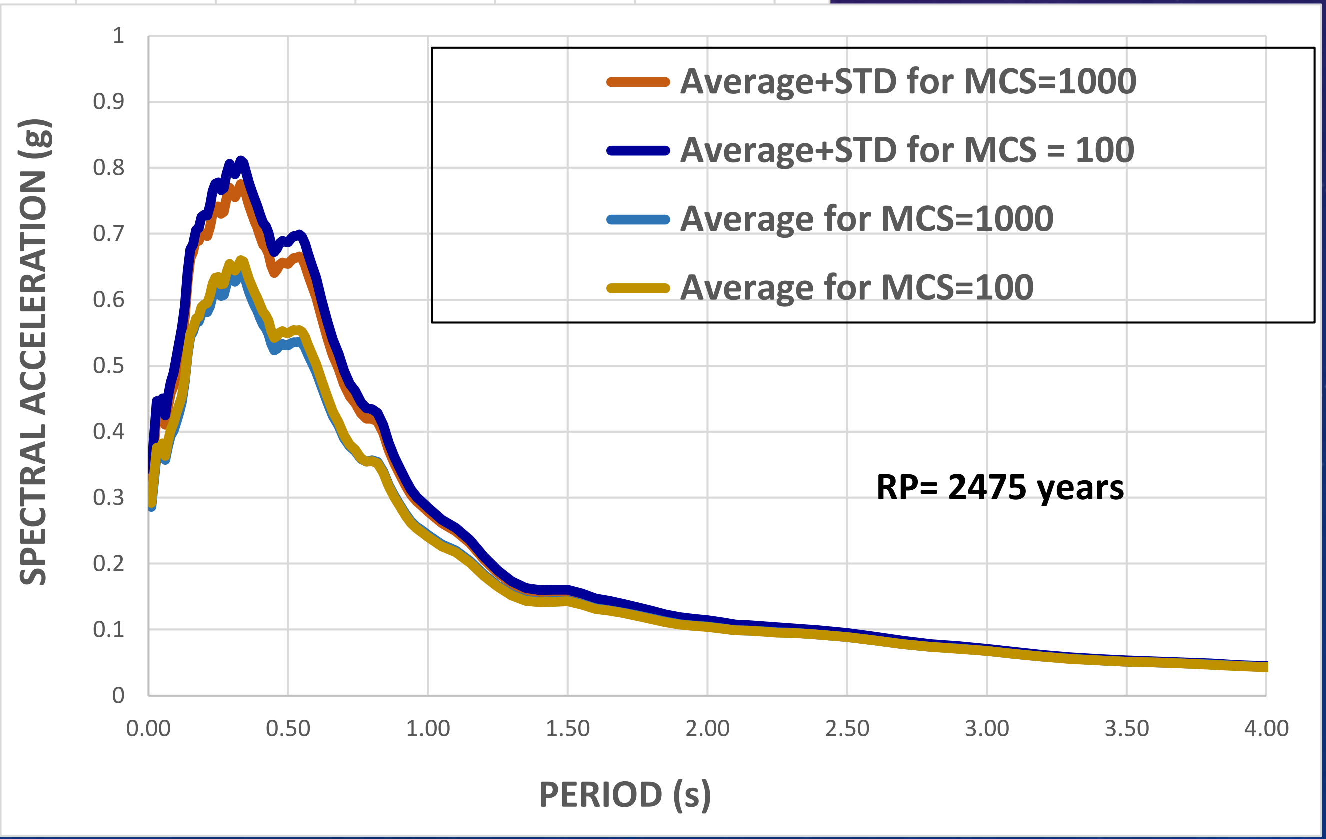


ACCELERATION SPECTRA WITH AND WITHOUT MONTE CARLO SIMULATIONS WRT VS FOR CASE 1

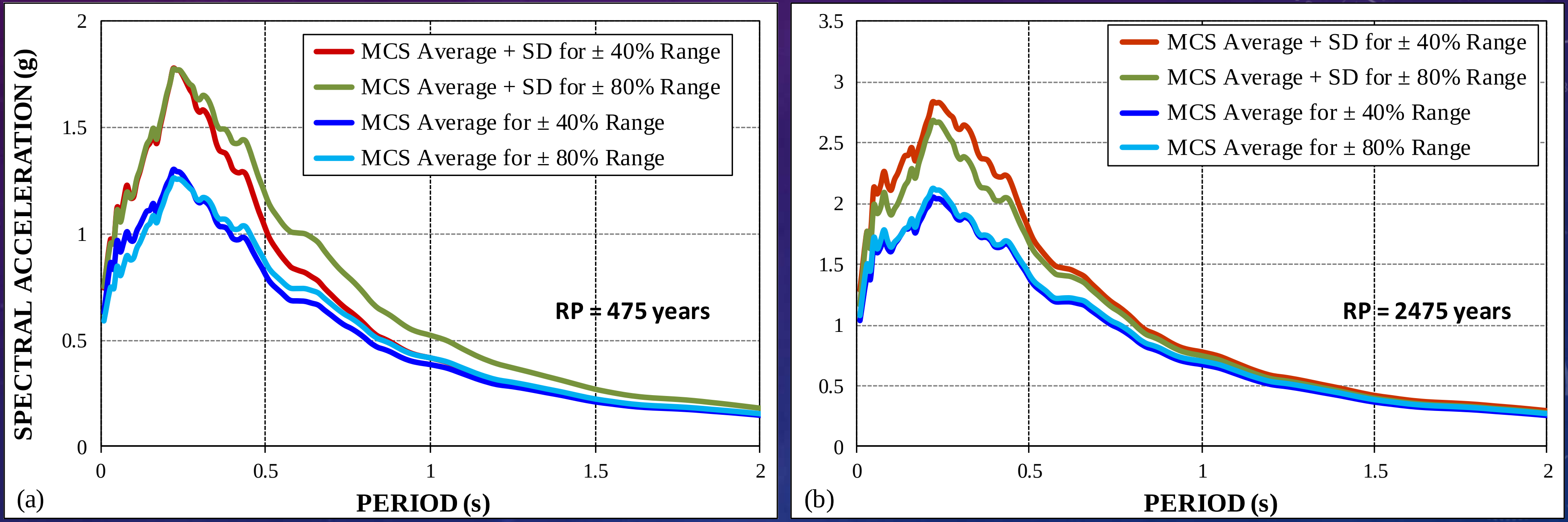


ACCELERATION SPECTRA FOR MCS = 100 AND 1000 WRT VS

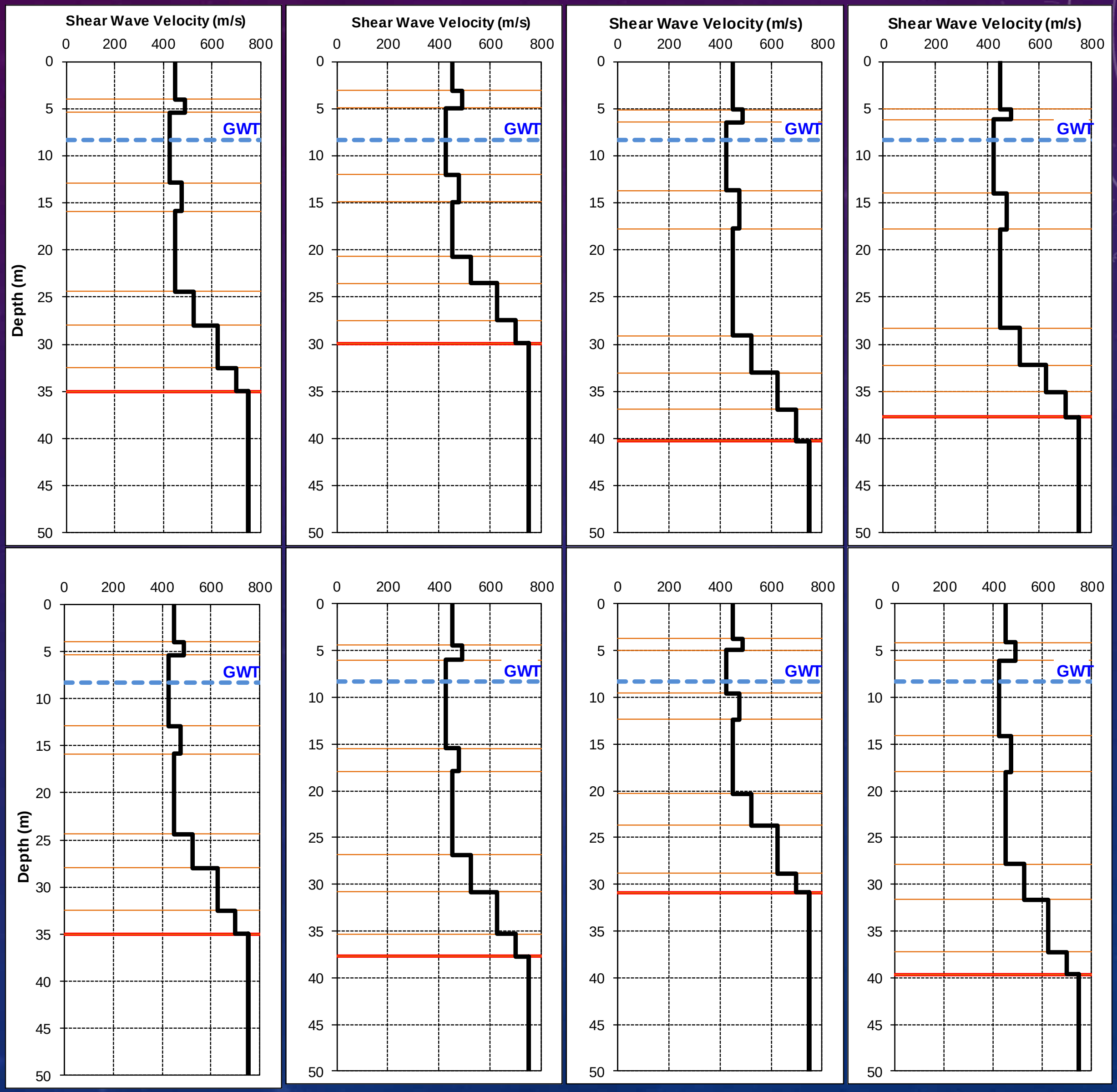




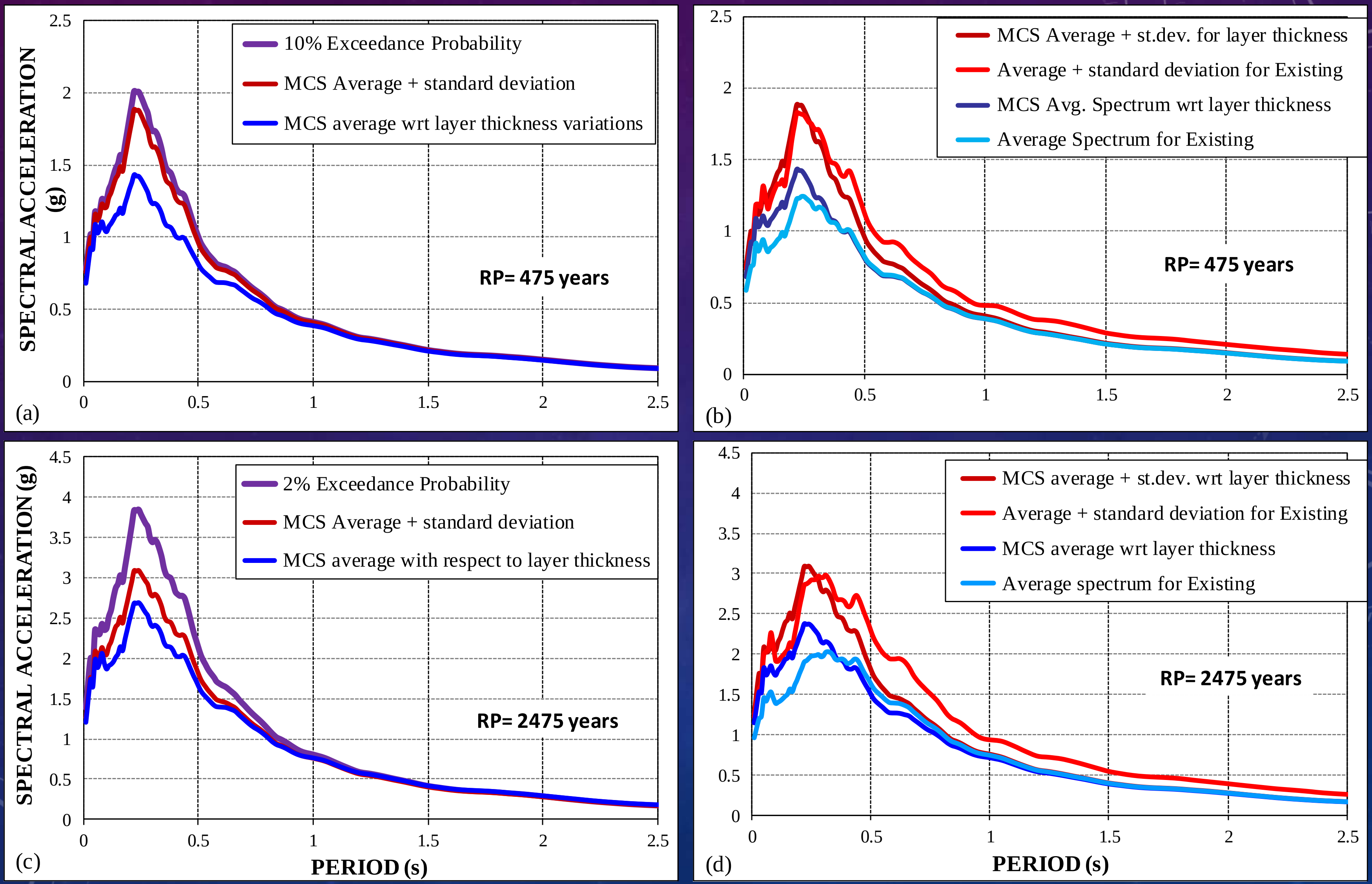
ACCELERATION SPECTRA FOR MCS VARIATION OF ±40 AND ±80 % OF THE ASSIGNED VALUES



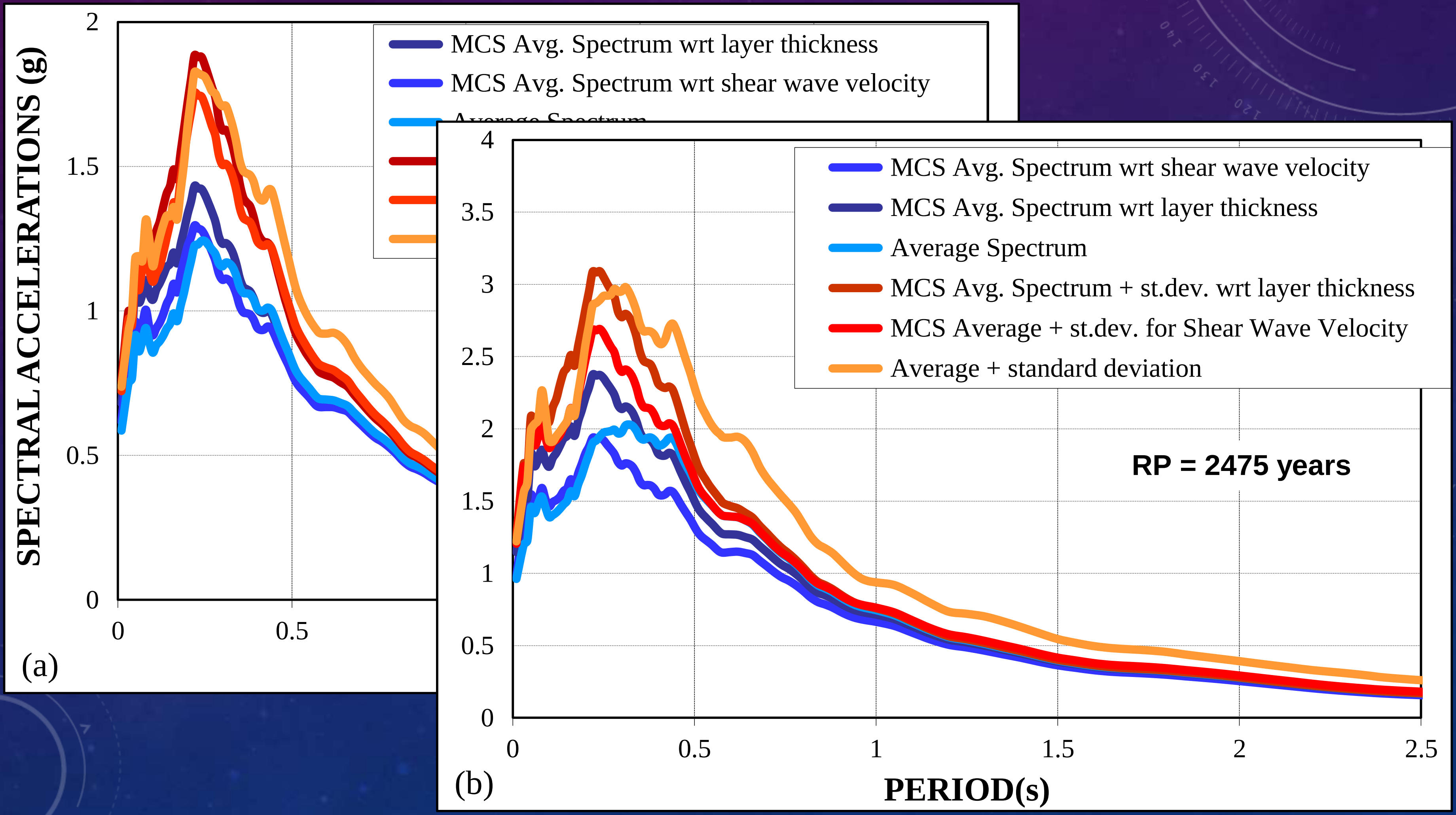
VARIABILITY WRT LAYER THICKNESSES



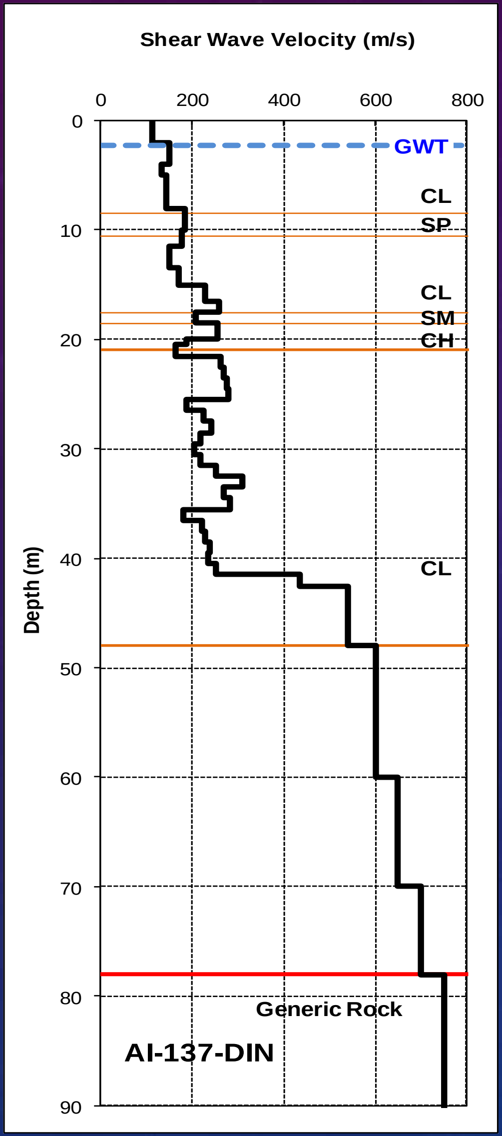
ACCELERATION SPECTRA WITH AND WITHOUT MONTE CARLO SIMULATIONS

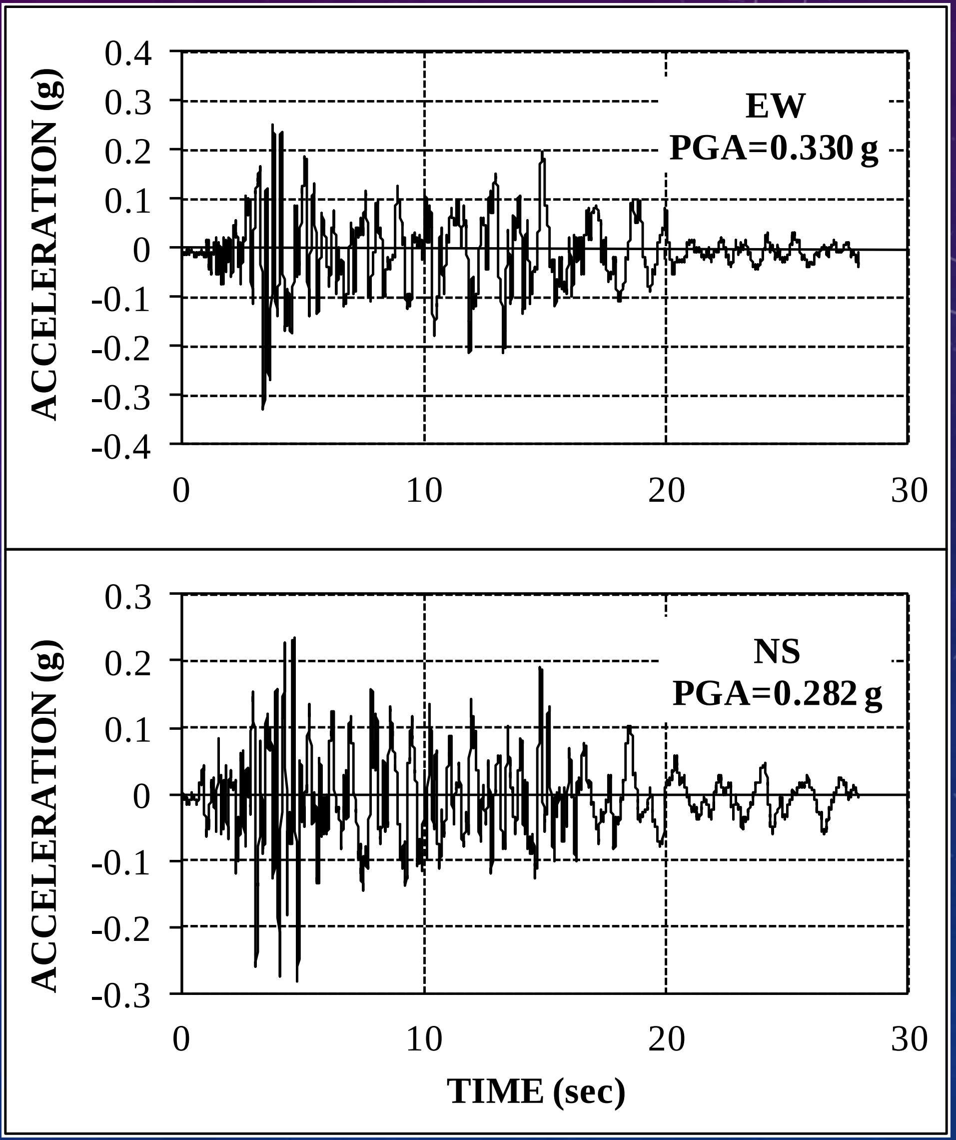


AVERAGE, AVERAGE + 1 STANDARD DEVIATION SPECTRA FOR MCS ±40% WITH RESPECT TO SHEAR WAVE VELOCITY AND LAYER THICKNESS

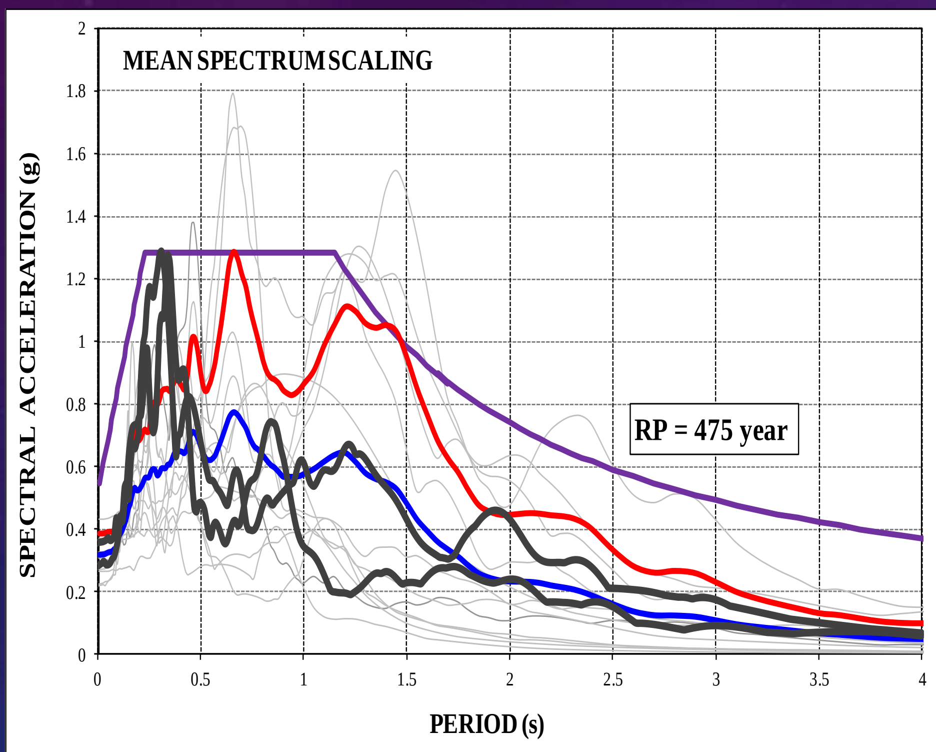


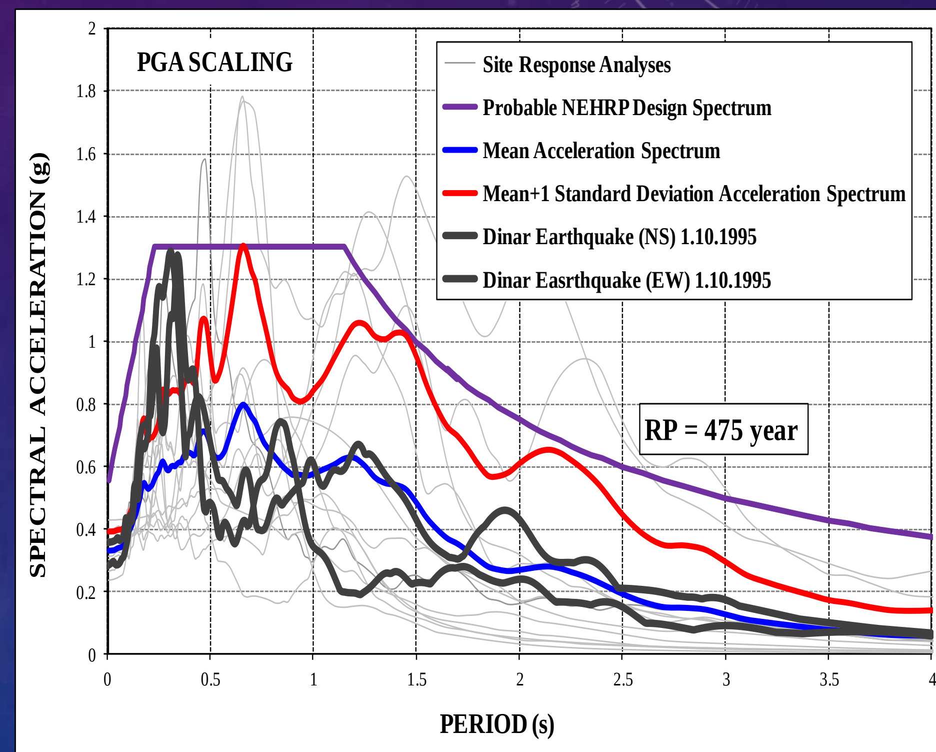
CASE STUDY: DINAR STRONG MOTION SITE





SITE SPECIFIC DESIGN EARTHQUAKE CHARACTERISTICS AND DINAR EARTHQUAKE OF 1.10.1995





SUGGESTED PROCEDURE

1. Regional Hazard on the rock outcrop (scale 1:10 000),
2. Selection of hazard compatible earthquake records (20-25),
3. Scaling these records based on Spectrum Scaling,
4. Detailed site investigation, soil borings with soil classification down to engineering bedrock,
5. Shear wave velocity profile down to engineering bedrock,
6. Site response analysis with Shake 91,
7. Calculation of mean and mean+1STD,
8. Fitting the best NEHRP spectra as design spectra.

CONCLUSIONS

- The proposed approach is based on performing multiple number of site response analysis using 22 hazard compatible acceleration records where each record is scaled separately to give best fit for the target hazard spectrum.
- The results obtained based on limited number of existing soil profiles using 22 acceleration records yielded design acceleration spectrum similar to design spectrum calculated based on large number of site response analyses conducted on large number of simulated soil profiles generated by Monte Carlo simulation.

THE END