MICROZONATION WITH RESPECT TO EARTHQUAKE HAZARDS

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OBJECTIVES

The seismic microzonation maps indicate the distribution of site response with respect to ground shaking intensity, liquefaction and landslide susceptibility at an urban scale.

➔For Urban planning, and urban rehabilitation actions,

➔To improve disaster preparedness,

➔For risk reduction and hazard mitigation decisions.

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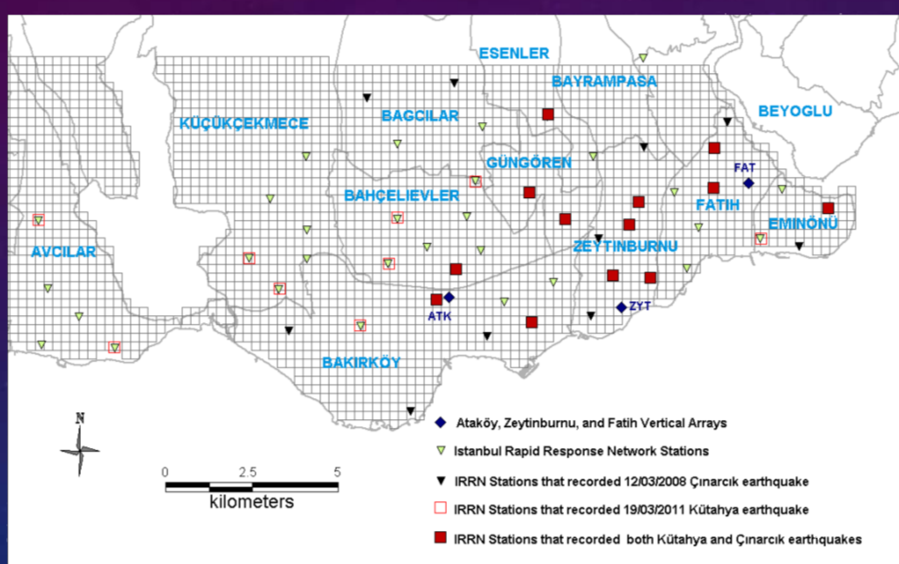
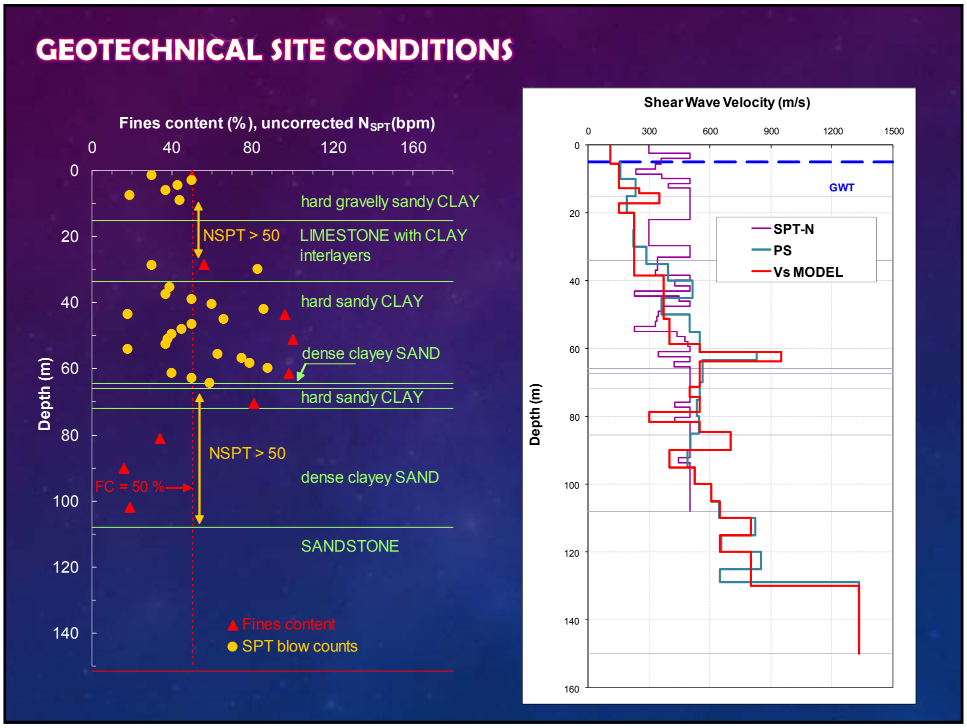
URBAN AND LAND USE PLANNING

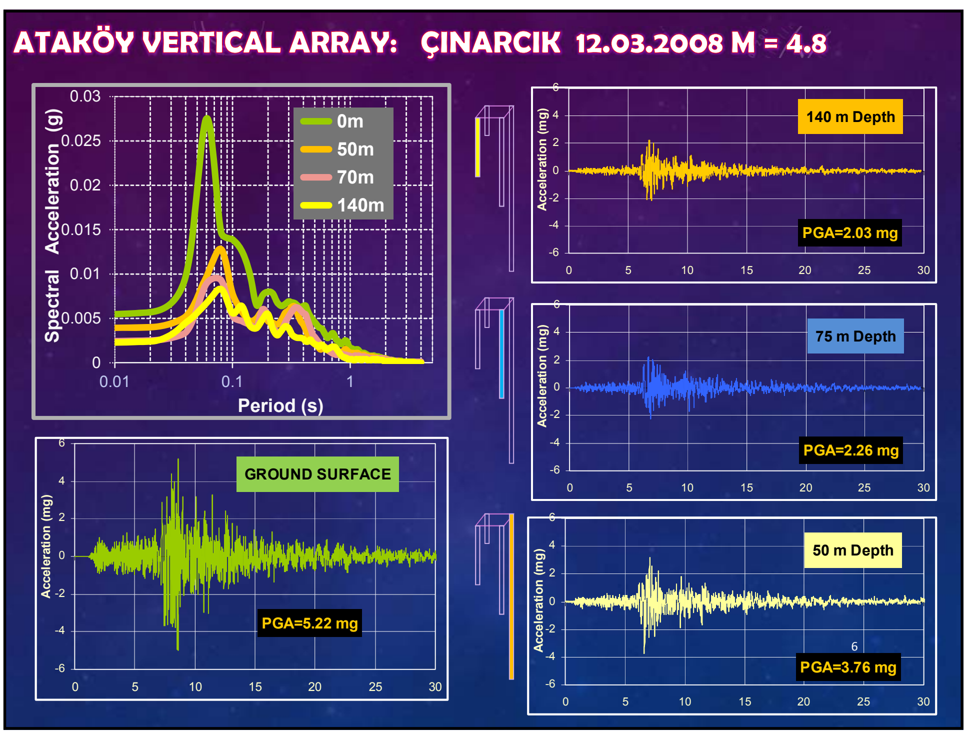
1. To specify building and population densities,
2. To evaluate functional layouts,
3. For selection of locations for important buildings and lifelines.

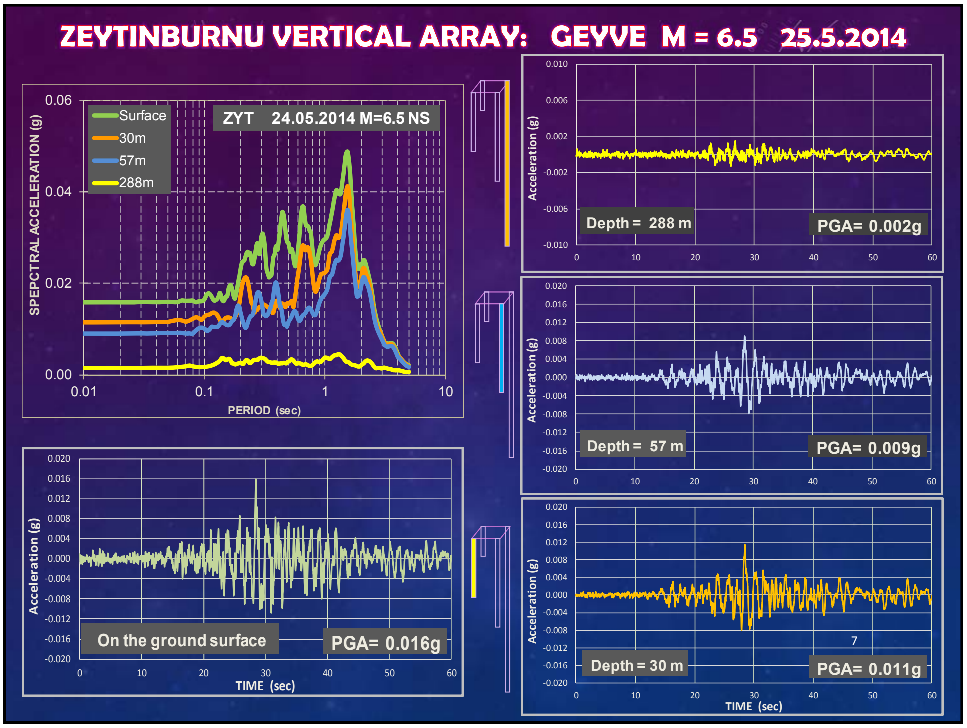
3

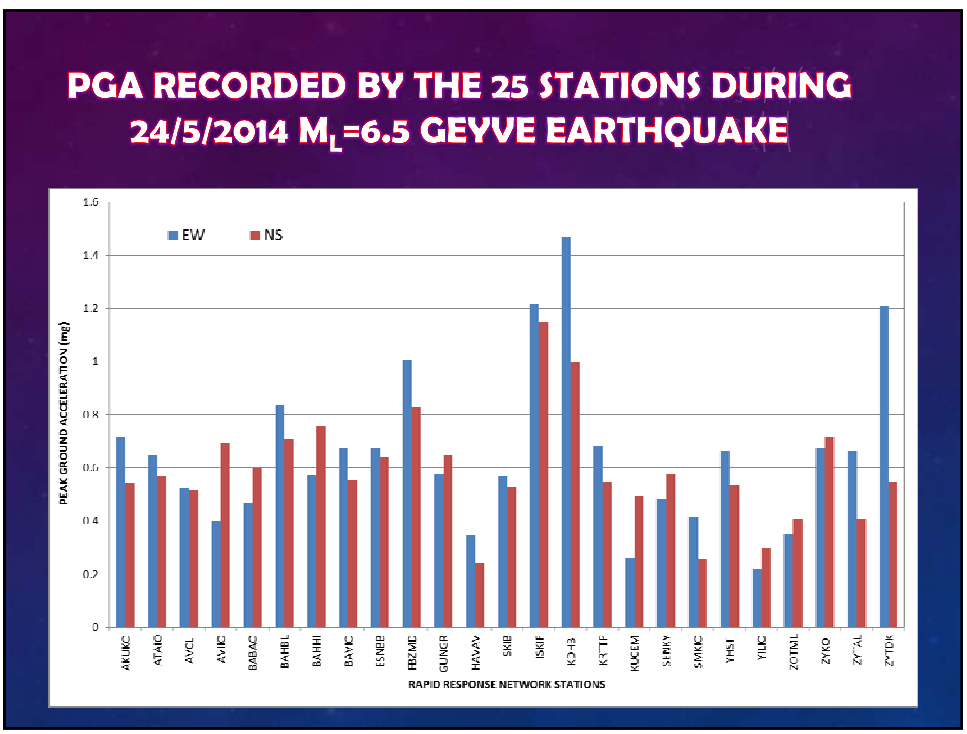
ISTANBUL STRONG MOTION RAPID RESPONSE NETWORK



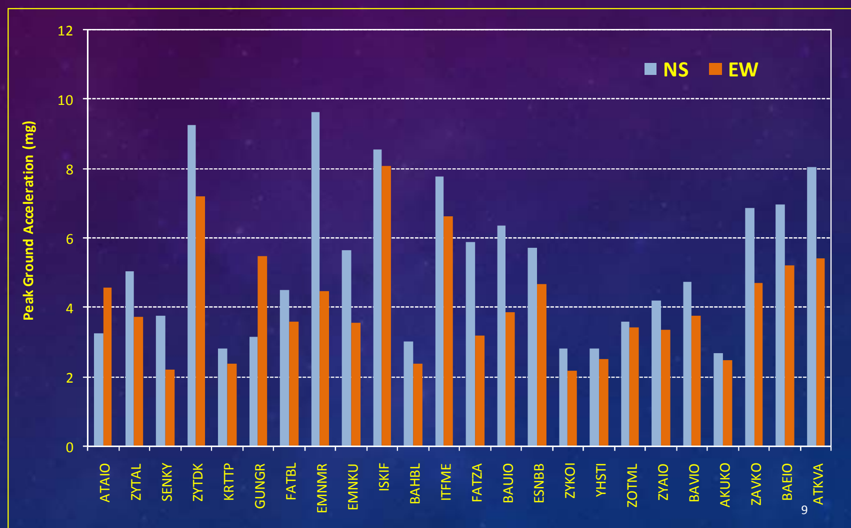

GEOTECHNICAL SITE CONDITIONS
Fines content (%), uncorrected NSPT(bpm)
0 40 80 120 160
Depth (m)
0 20 40 60 80 100 120 140
hard gravelly sandy CLAY
NSPT > 50
LIMESTONE with CLAY interlayers
hard sandy CLAY
dense clayey SAND
hard sandy CLAY
NSPT > 50
FC = 50 %
dense clayey SAND
SANDSTONE
Fines content
SPT blow counts
Shear Wave Velocity (m/s)
0 300 600 900 1200 1500
GWT
SPT-N
PS
Vs MODEL
Depth (m)
0 20 40 60 80 100 120 140 160


ATAKÖY VERTICAL ARRAY: ÇINARCIK 12.03.2008 M = 4.8
Spectral Acceleration (g)
0 0.005 0.01 0.015 0.02 0.025 0.03
0.01 0.1 1
Period (s)
0m
50m
70m
140m
GROUND SURFACE
PGA=5.22 mg
Acceleration (mg)
140 m Depth
PGA=2.03 mg
75 m Depth
PGA=2.26 mg
50 m Depth
PGA=3.76 mg
0 5 10 15 20 25 30

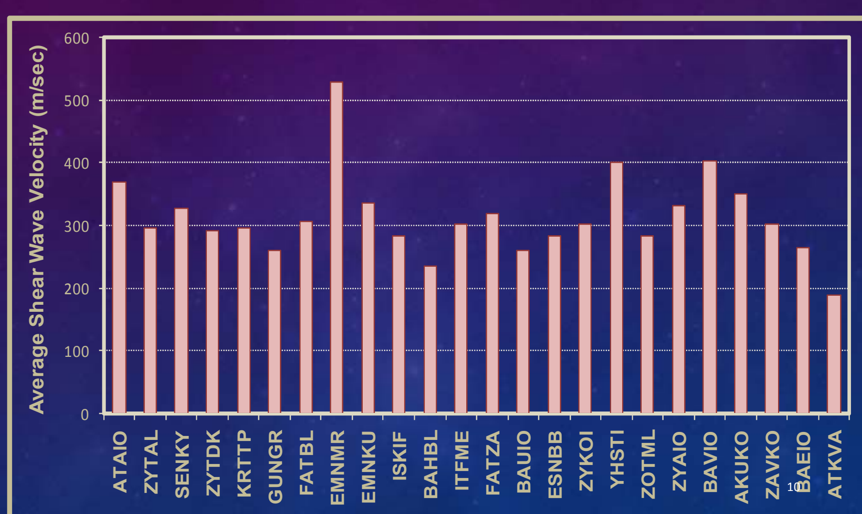

ZEYTINBURNU VERTICAL ARRAY: GEYVE M = 6.5 25.5.2014
ZYT 24.05.2014 M=6.5 NS
Surface
30m
57m
288m
SPEPCTRAL ACCELERATION (g)
PERIOD (sec)
Acceleration (g)
Depth = 288 m
PGA= 0.002g
Depth = 57 m
PGA= 0.009g
Depth = 30 m
PGA= 0.011g
On the ground surface
PGA= 0.016g
TIME (sec)


PGA RECORDED BY THE 25 STATIONS DURING
24/5/2014 M_L=6.5 GEYVE EARTHQUAKE
EW
NS
PEAK GROUND ACCELERATION (mg)
AKUKO ATAIO AVCLI AVIIO BABAO BAHBL BAHHI BAVIO ESNBB FBZMD GUNGR HAVAV ISKIB ISKIF KDHBI KRTTP KUCEM SENKY SMKIO YHSTI YILIO ZOTML ZYKOI ZYTAL ZYTDK
RAPID RESPONSE NETWORK STATIONS

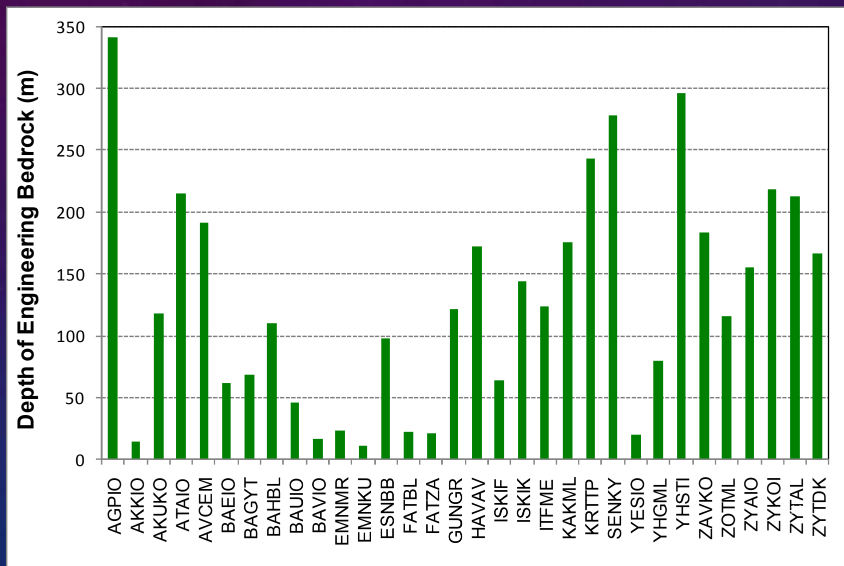
PGAS RECORDED BY THE 24 STATIONS DURING 12/3/2008 M_L=4.8 EARTHQUAKE



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*

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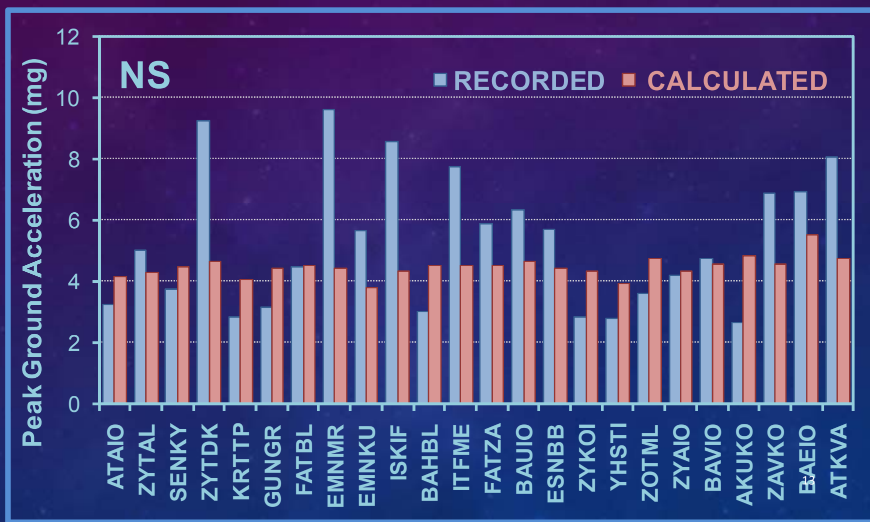
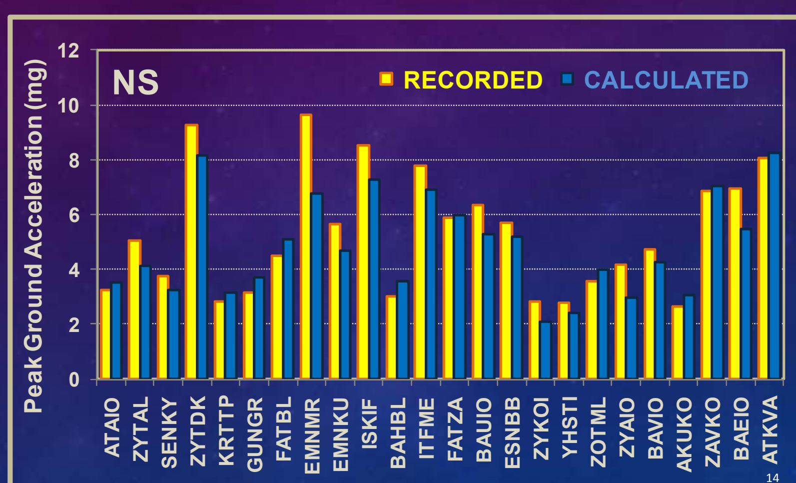
COMPARISON OF RECORDED AND CALCULATED PGA AT 24 STATIONS BASED ON AMPLIFICATION FACTORS

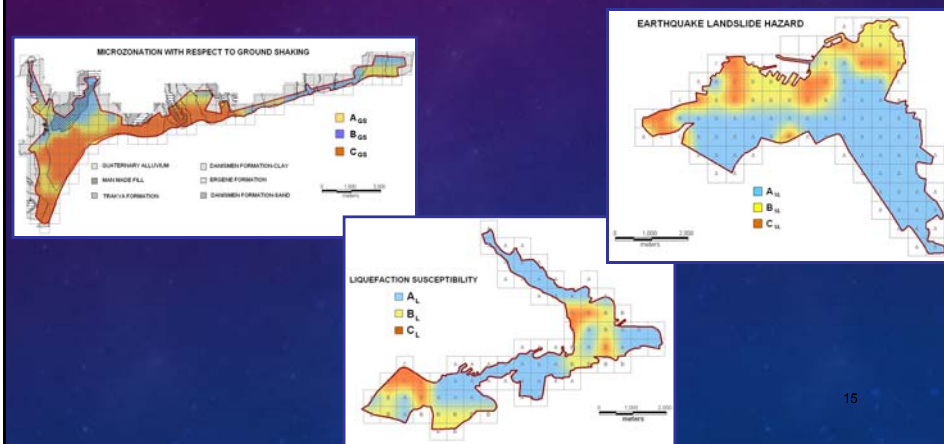


COMPARISON OF RECORDED AND CALCULATED PGA AT 24 STATIONS BASED ON SITE RESPONSE



MAIN PURPOSE:

To estimate *variation of the selected parameters* for land use and urban planning for the mitigation of earthquake risk to man-made environment



Seismic Macrozonation National Seismic Zoning Maps

- **in small scales such as 1:1,000,000 or less and mostly based on seismic source zones defined in similar scales**
- **Independent of site conditions**
- **Used in the earthquake codes for seismic design**

Seismic Microzonation

- zonation with respect to ground motion characteristics taking into account source and site conditions
- major purpose is to estimate the variation of the earthquake ground motion characteristics at a scale of 1:5,000

BASIC STAGES OF EARTHQUAKE MICROZONATION

- Regional earthquake hazard
- Site characterisation
- 1D site response analyses
- Selection of input ground motion
- Microzonation for ground shaking intensity
- Microzonation for liquefaction susceptibility
- Microzonation for landslide hazard

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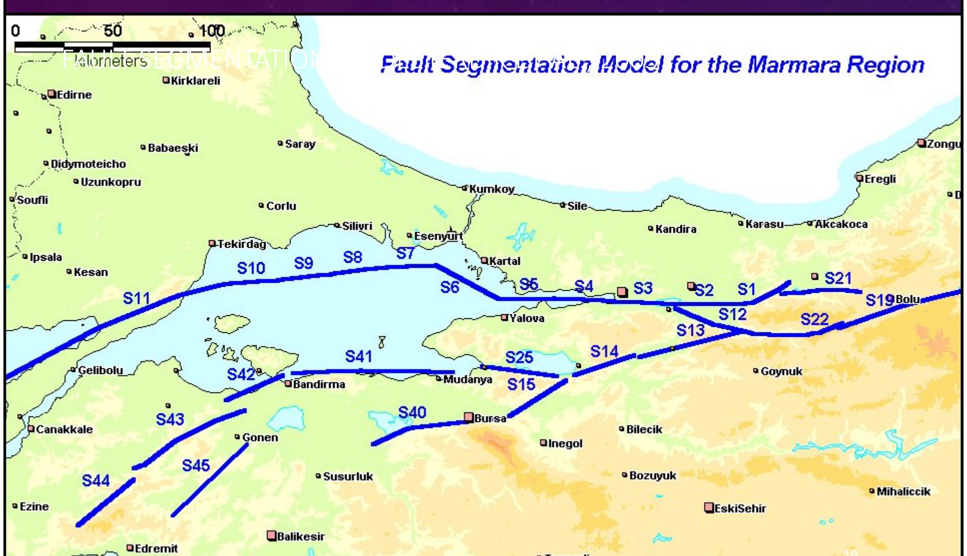
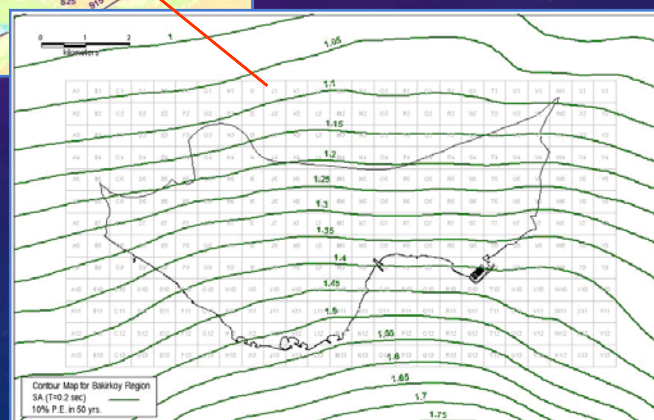
REGIONAL EARTHQUAKE HAZARD



REGIONAL EARTHQUAKE HAZARD

SA (T=0.2sec) Contour Map at NEHRP B/C Boundary for 475 Years Return Period



SITE CHARACTERIZATION

Assigning partly hypothetical boreholes at the centre of each cell

1. **to utilise all available data in each cell to have more comprehensive and reliable data for the soil profile;**
2. **to eliminate the effects of distance among boreholes or site investigation points during the GIS mapping**

	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	
4												SK21	SK23	SK26	SK26			4
5											SK15	SK21	SK23	SK26	S16			5
6					SK4	SK4	SK6			SK15	SK15	SK22	S18	S18	S16			6
7				SK3	SK3	S7	SK5	SK11	SK11	SK13	SK18	SK18	SK24	SK27	SK27			7
8			SK2	SK2	S8	S9	SK10	SK10	SK13	SK17	SK16	SK25	SK25	S14	SK29			8
9	S10	S10	SK2	SK2	SK7	S6	SK9	SK12	SK14	SK17	SK20	SK25	SK28	SK28	SK29	SK29		9
10	SK1	SK1	SK1	SK2	SK7	SK7	SK9	SK12	SK14	S5	SK20	SK20	SK30	SK30	S12	SK29		10
11				SK7	SK7	SK7	SK9					S11	S11	SK30	SK31	SK31	SK31	11
12					SK7	SK7							S11	SK32	SK32	SK32		12
13														SK32	SK32	SK33	SK33	13
14														SK32	SK33	SK33	SK33	14
15															SK34	SK34	SK34	15
16																SK34	SK34	16
	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	

BANDIRMA

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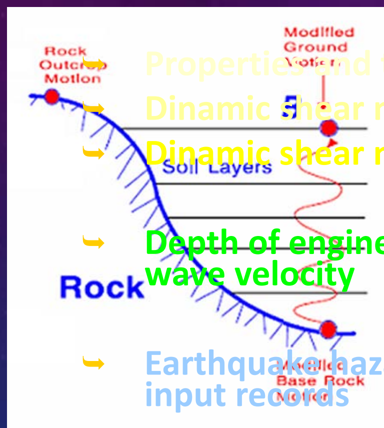
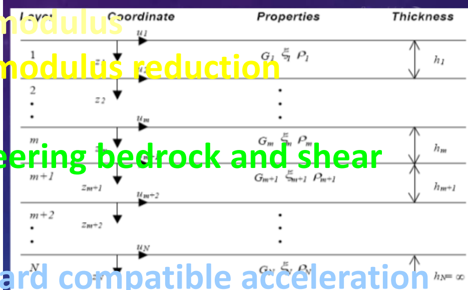
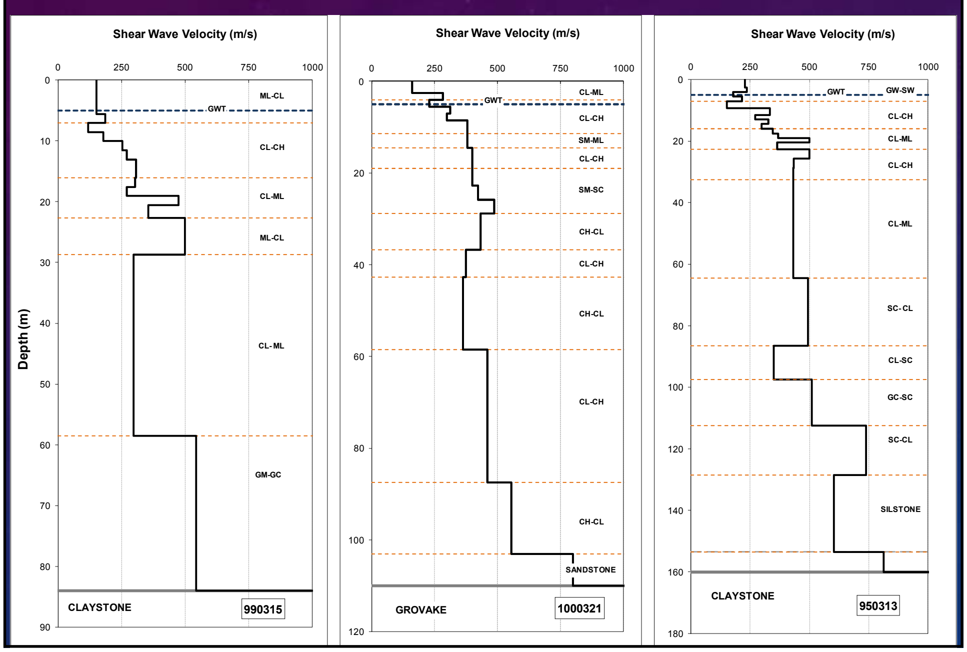
SITE RESPONSE ANALYSIS



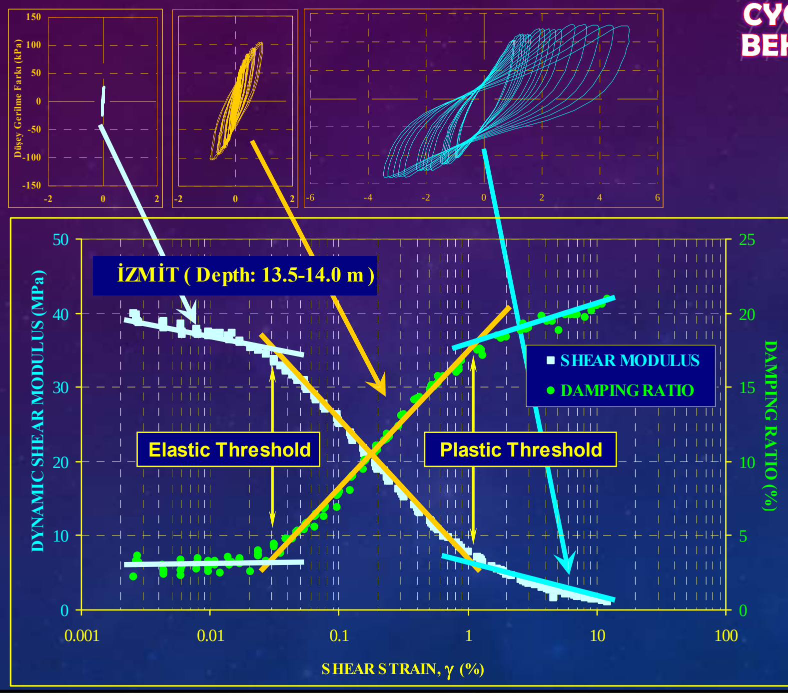


- Properties and thickness of soil layers
- Dinamic shear modulus
- Dinamic shear modulus reduction
- Depth of engineering bedrock and shear wave velocity
- Earthquake hazard compatible acceleration input records
- One dimensional total stress analysis

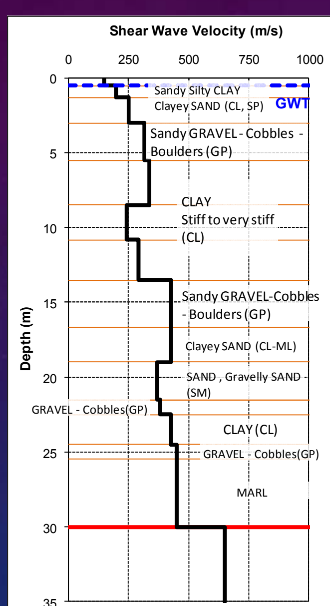
SHEAR WAVE VELOCITY PROFILES

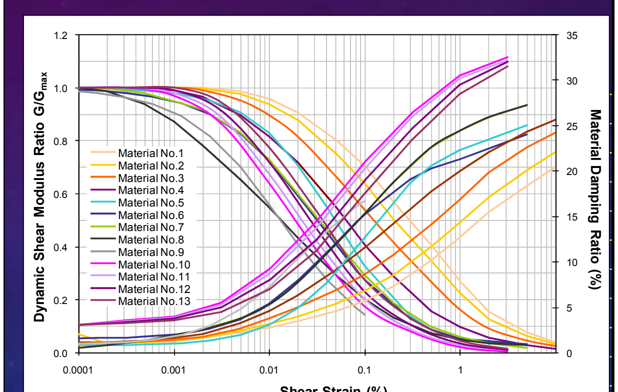


CYCLIC SOIL BEHAVIOUR



MODULUS REDUCTION AND DAMPING RATIO





11	Rock 6-16 m	EPRI
12	Rock 16-37 m	EPRI
13	Rock 37-76 m	EPRI

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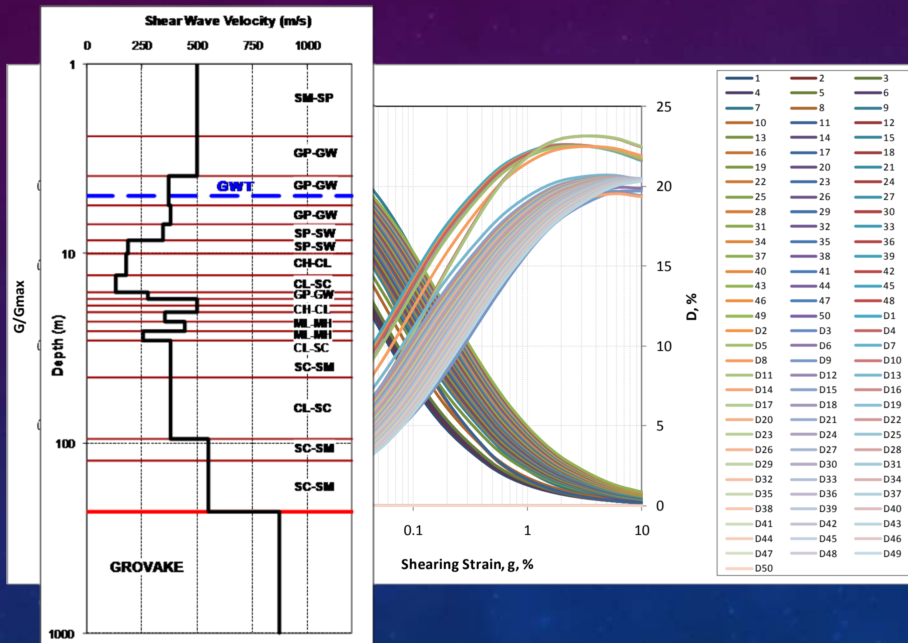
DINAMIK KAYMA MODÜLÜ VE SÖNÜM ORANI



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)

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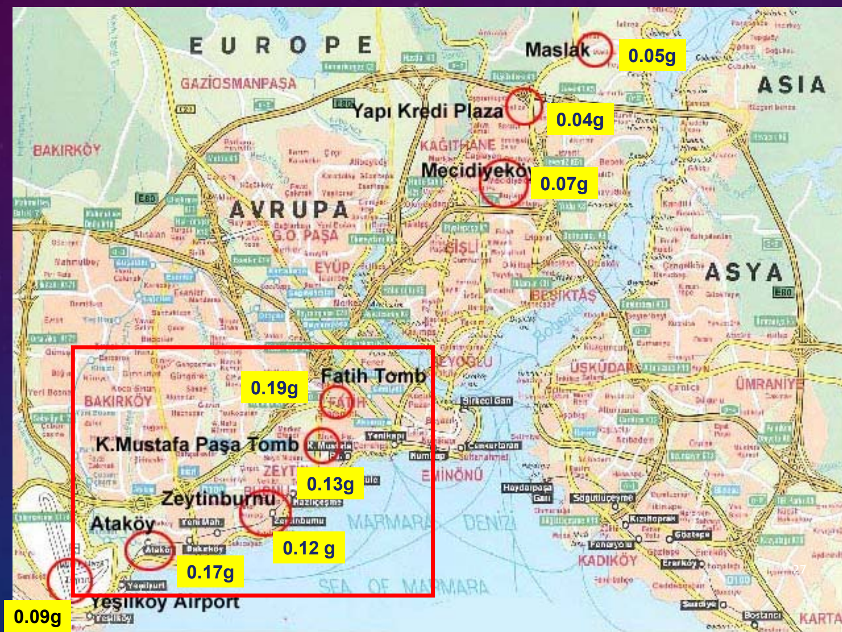
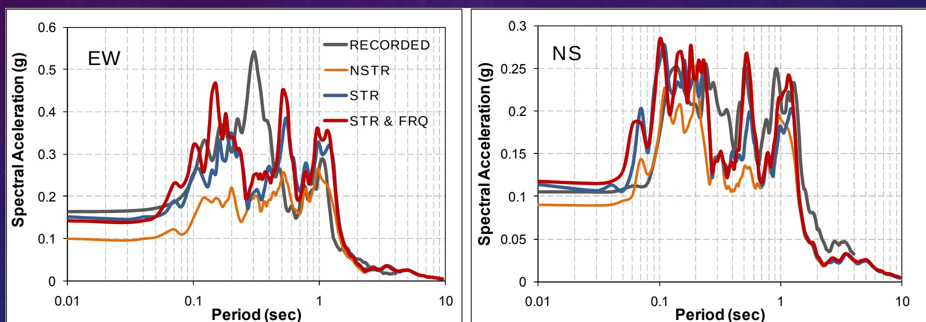
AUGUST 17, 1999 KOCAELI EARTHQUAKE ISTANBUL RECORDS



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



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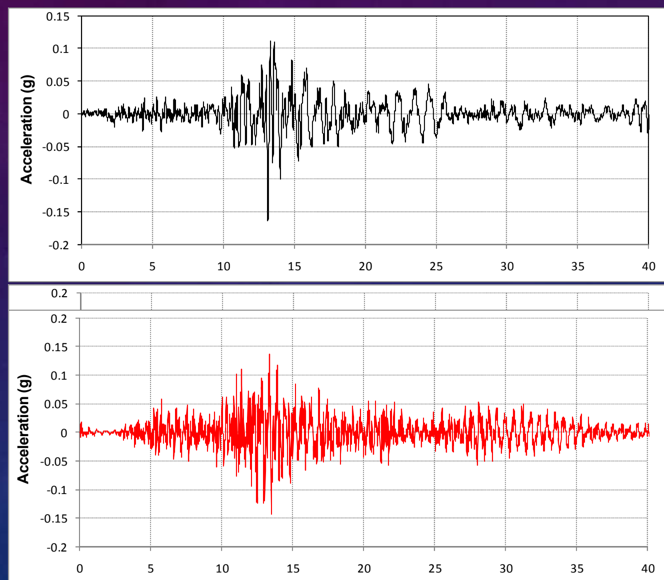
Ataköy

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



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SELECTION OF INPUT GROUND MOTION

Simulated

➔ Hazard compatibility with respect to calculated acceleration spectra on rock outcrop

Real Acceleration Records

➔ Compatibility with probable fault type, fault distance, and magnitude

➔ Scaled with respect to calculated peak ground acceleration on rock outcrop

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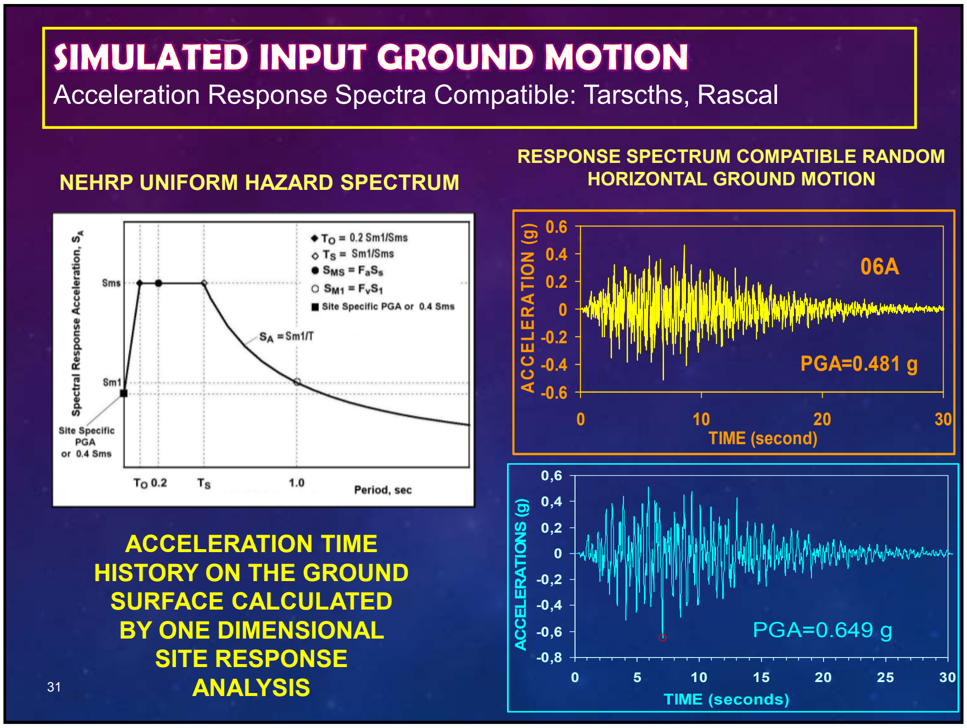
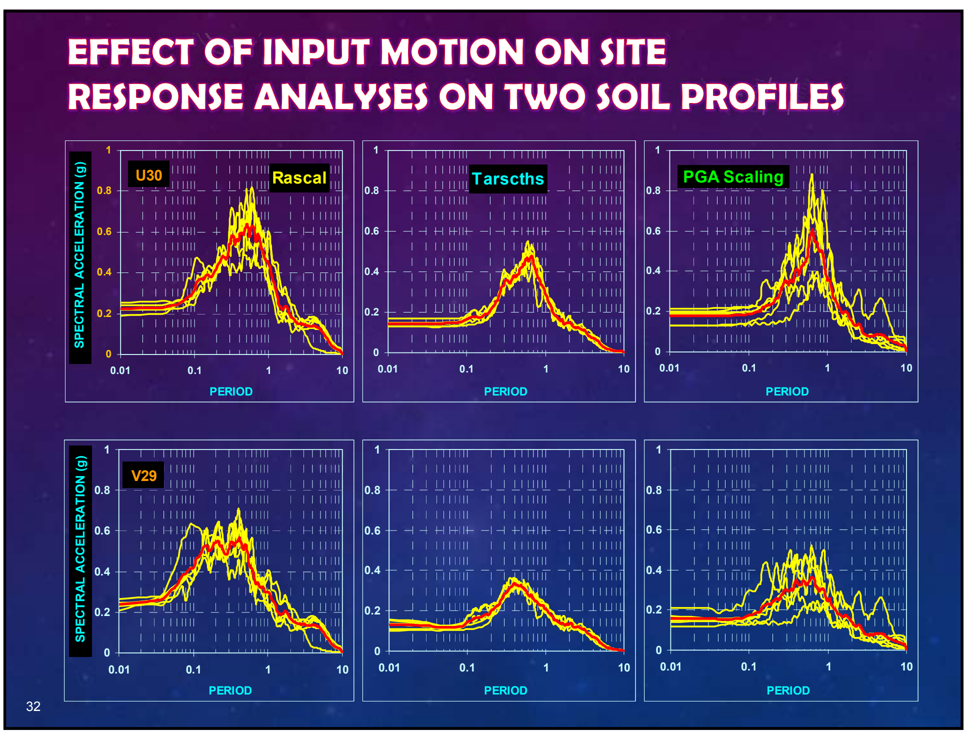
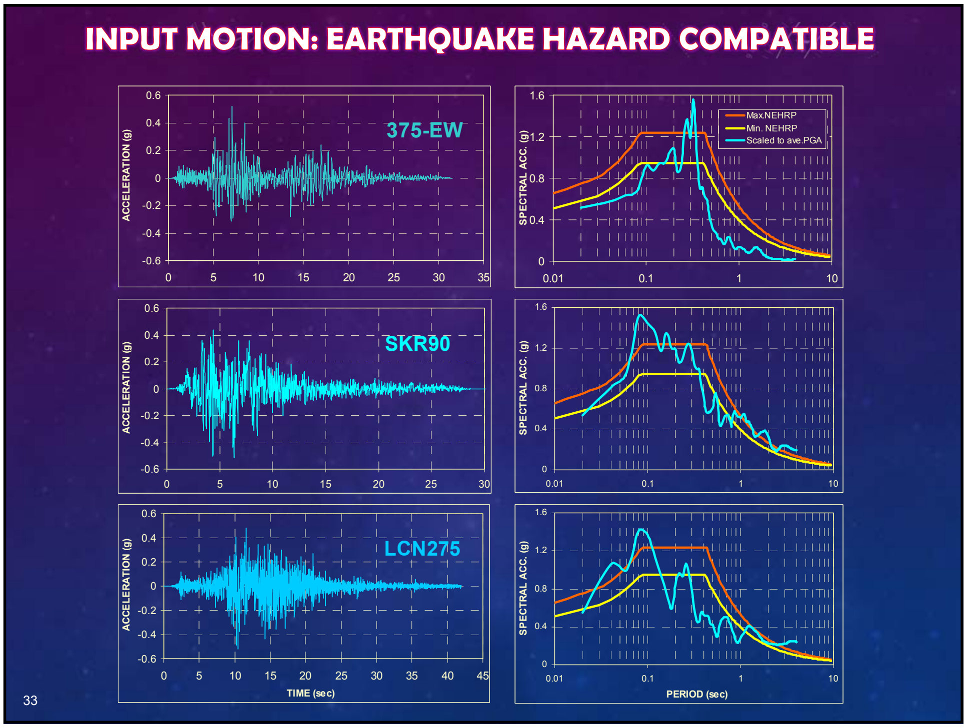
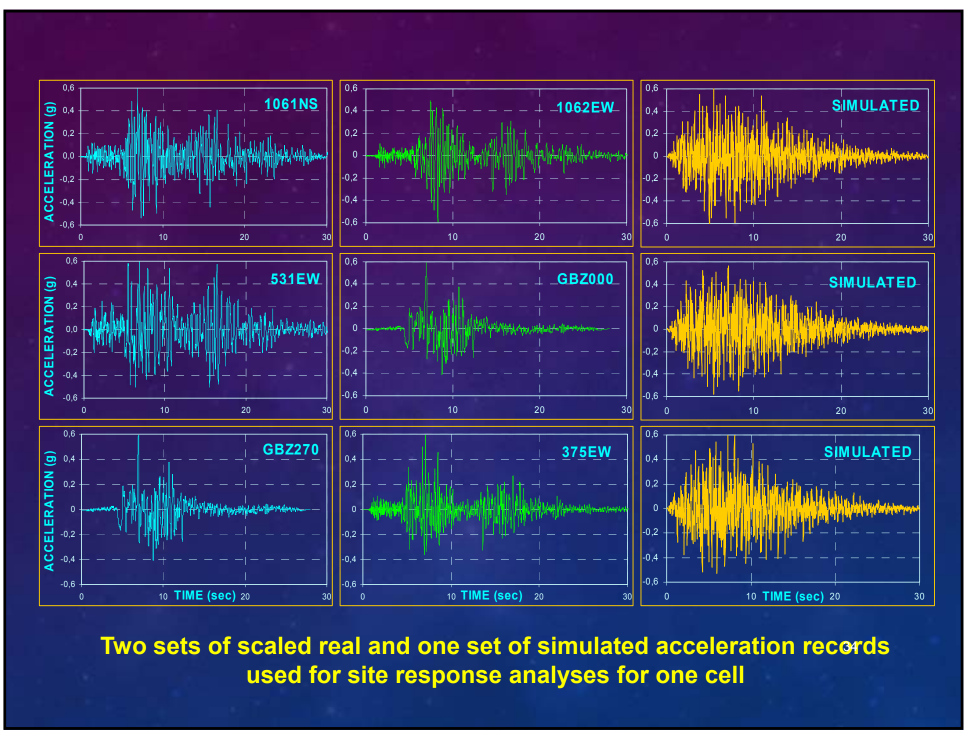
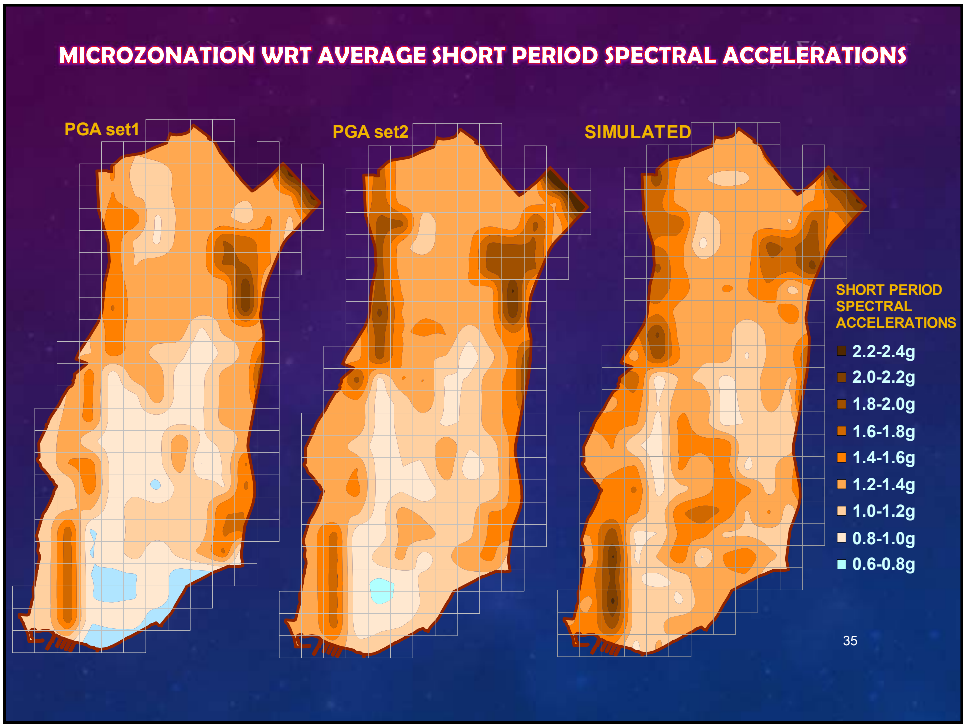
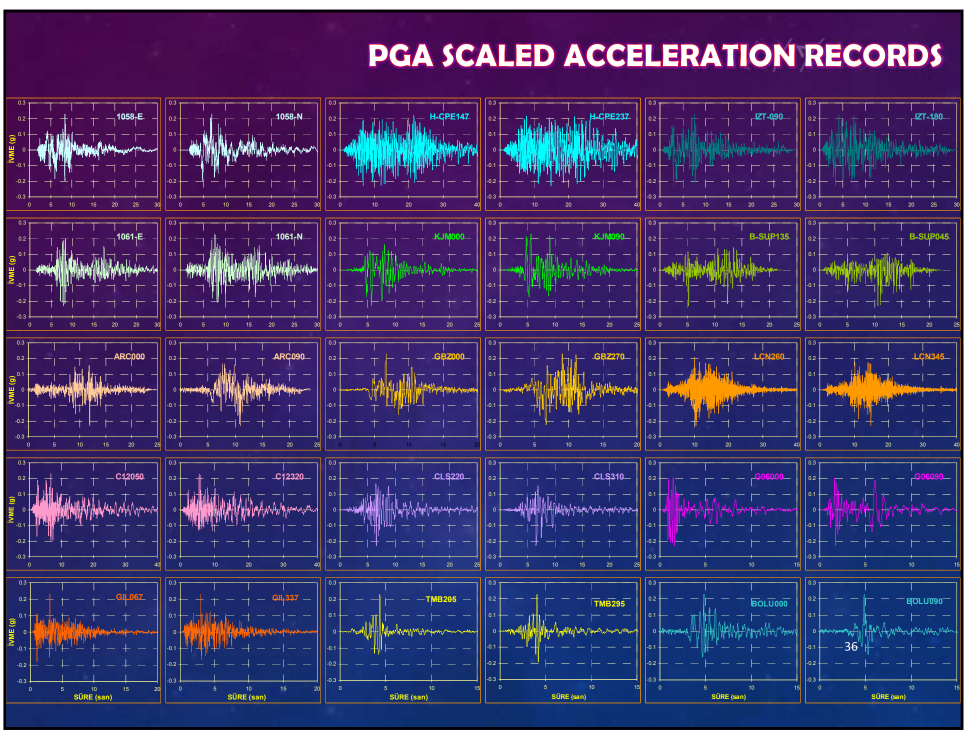

SIMULATED INPUT GROUND MOTION
Acceleration Response Spectra Compatible: Tarscths, Rascal
NEHRP UNIFORM HAZARD SPECTRUM
RESPONSE SPECTRUM COMPATIBLE RANDOM HORIZONTAL GROUND MOTION
Spectral Response Acceleration, S_A
T_O = 0.2 Sm1/Sms
T_S = Sm1/Sms
$S_{MS} = F_aS_s$
$S_{M1} = F_vS_1$
Site Specific PGA or 0.4 Sms
S_A = Sm1/T
Sms
Sm1
Site Specific PGA or 0.4 Sms
T_O 0.2
T_S
1.0
Period, sec
ACCELERATION (g)
06A
PGA=0.481 g
TIME (second)
ACCELERATIONS (g)
PGA=0.649 g
TIME (seconds)
ACCELERATION TIME HISTORY ON THE GROUND SURFACE CALCULATED BY ONE DIMENSIONAL SITE RESPONSE ANALYSIS
31


EFFECT OF INPUT MOTION ON SITE RESPONSE ANALYSES ON TWO SOIL PROFILES
SPECTRAL ACCELERATION (g)
U30
Rascal
Tarscths
PGA Scaling
V29
PERIOD
32


INPUT MOTION: EARTHQUAKE HAZARD COMPATIBLE
375-EW
SKR90
LCN275
ACCELERATION (g)
TIME (sec)
SPECTRAL ACC. (g)
PERIOD (sec)
Max.NEHRP
Min. NEHRP
Scaled to ave.PGA
33


1061NS
1062EW
SIMULATED
531EW
GBZ000
SIMULATED
GBZ270
375EW
SIMULATED
ACCELERATION (g)
TIME (sec)
Two sets of scaled real and one set of simulated acceleration records
used for site response analyses for one cell


MICROZONATION WRT AVERAGE SHORT PERIOD SPECTRAL ACCELERATIONS
PGA set1
PGA set2
SIMULATED
SHORT PERIOD SPECTRAL ACCELERATIONS
2.2-2.4g
2.0-2.2g
1.8-2.0g
1.6-1.8g
1.4-1.6g
1.2-1.4g
1.0-1.2g
0.8-1.0g
0.6-0.8g
35


PGA SCALED ACCELERATION RECORDS
1058-E
1058-N
H-CPE147
H-CPE237
IZT-090
IZT-180
1061-E
1061-N
KJM000
KJM090
B-SUP135
B-SUP045
ARC000
ARC090
GBZ000
GBZ270
LCN260
LCN345
C12050
C12320
CLS220
CLS310
G06000
G06090
GIL067
GIL337
TMB205
TMB295
BOLU000
BOLU090
İVME (g)
SÜRE (san)
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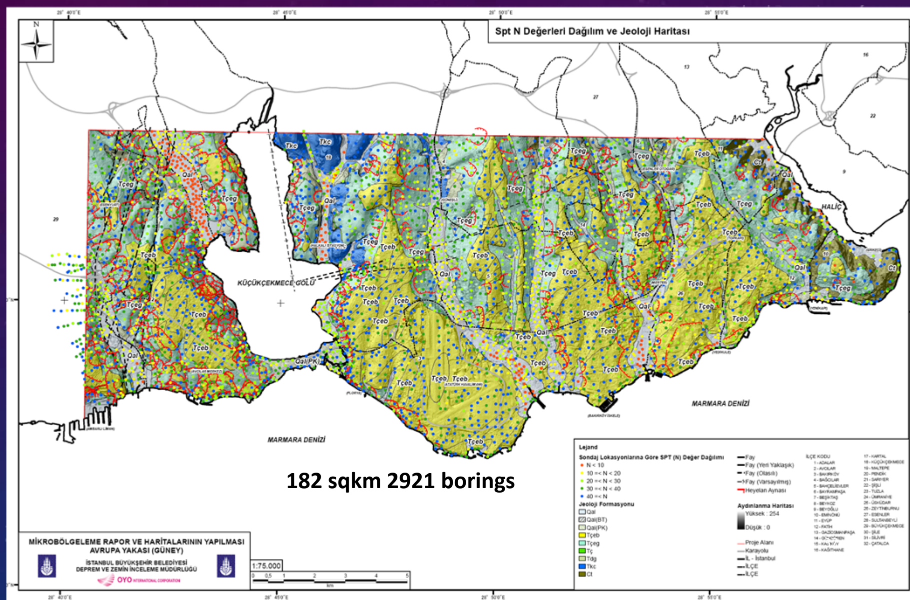
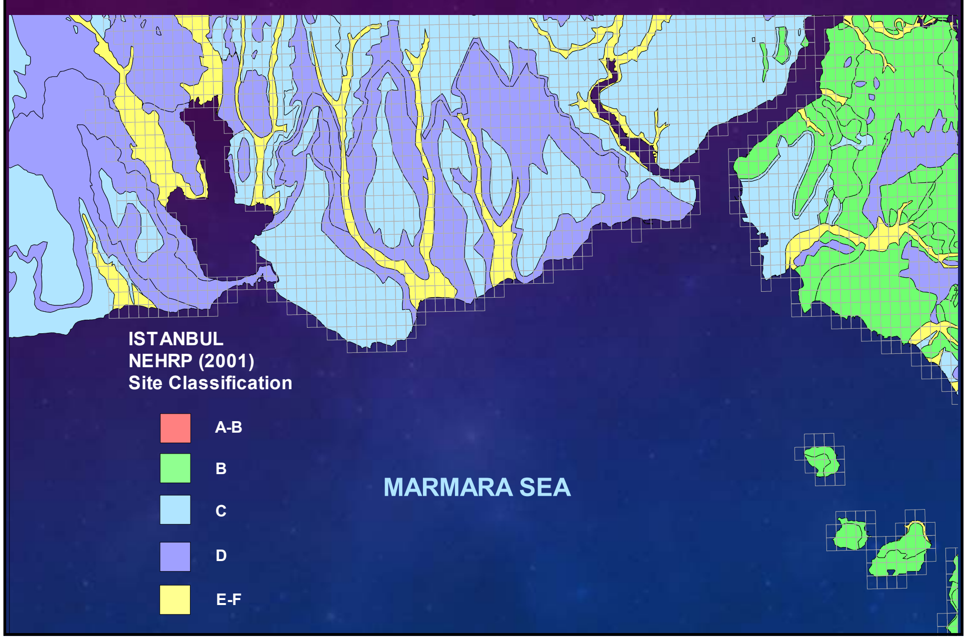
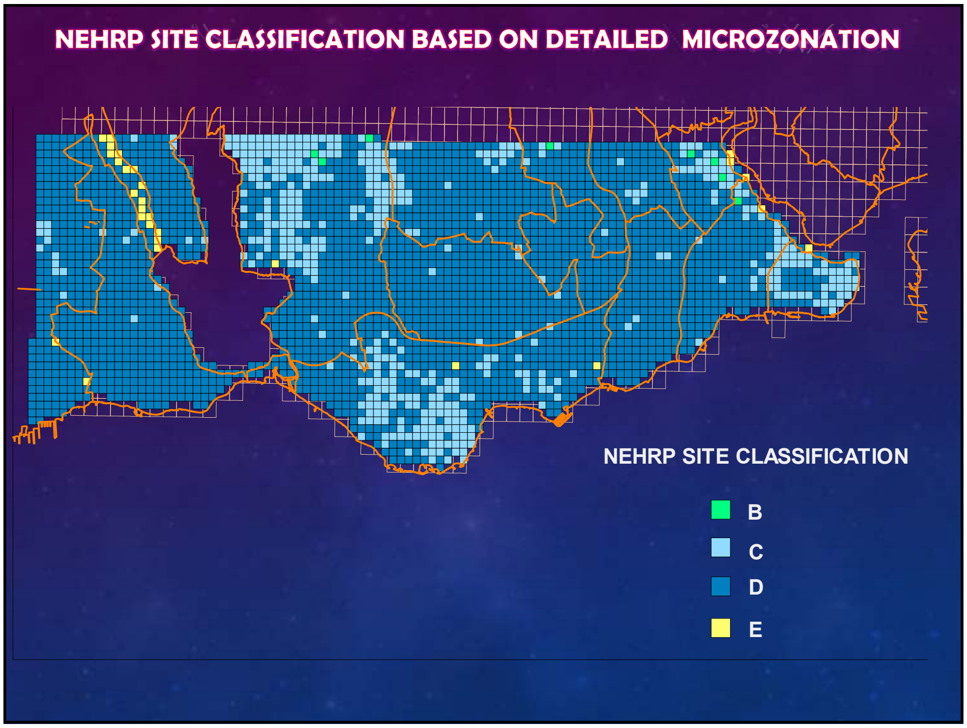
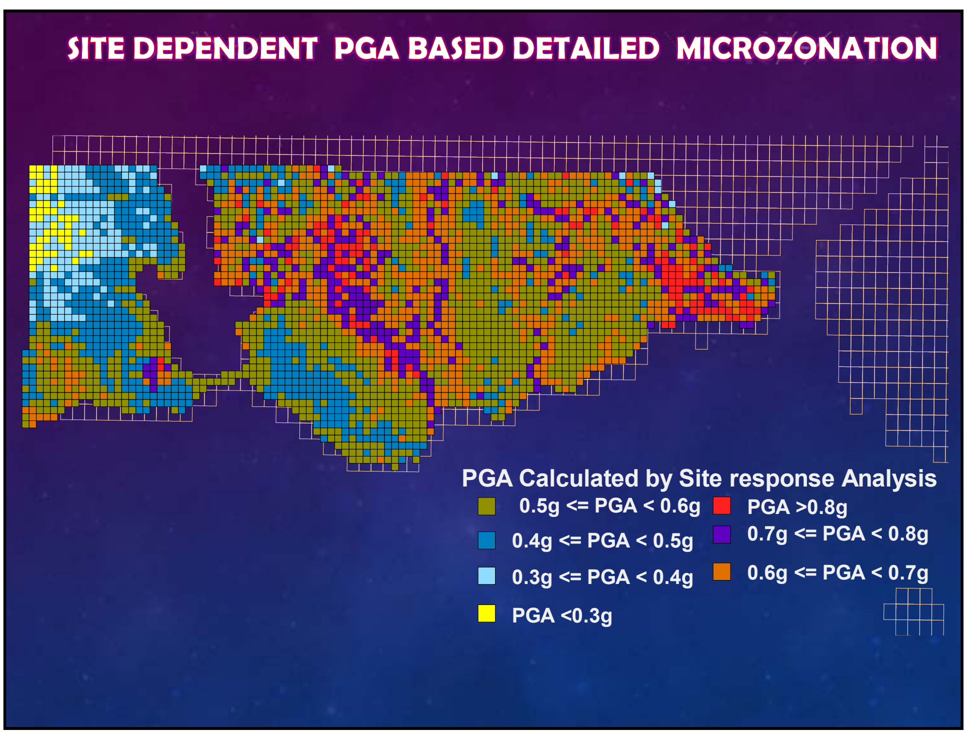
2006 ISTANBUL MICROZONATION PROJECT- VARIATION OF SPT TESTS



ISTANBUL NEHRP SITE CLASSIFICATION BASED ON GEOLOGY




NEHRP SITE CLASSIFICATION BASED ON DETAILED MICROZONATION
NEHRP SITE CLASSIFICATION
B
C
D
E


SITE DEPENDENT PGA BASED DETAILED MICROZONATION
PGA Calculated by Site response Analysis
0.5g <= PGA < 0.6g
PGA >0.8g
0.4g <= PGA < 0.5g
0.7g <= PGA < 0.8g
0.3g <= PGA < 0.4g
0.6g <= PGA < 0.7g
PGA <0.3g

MICROZONATION CRITERIA

- Peak ground acceleration (Grosso and Maugeri, 2009),
- Peak ground velocity (Singh et al., 2007),
- Peak ground displacement (Parvez et al., 2003),
- Spectral accelerations and amplification ratios (Papadimitriou et al., 2008),
- Arias Intensity (Alvarez et al., 2005),
- Normalized peak strain (Todorovska and Trifunac, 1996),
- Response spectra ratio (Alvarez et al., 2004),
- Spectral intensity (Pergalania et al., 1999).

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GROUND SHAKING INTENSITY

SPECTRAL ACCELERATIONS ON THE GROUND SURFACE

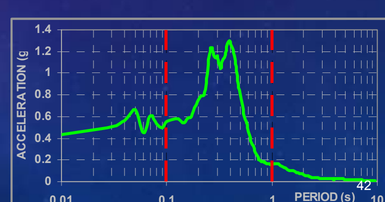
BY SUPERPOSITION OF

Spectral accelerations (short period) based on average shear wave velocity (Borcherdt, 1994)

$$F_a = (760/v)^{m_a}$$

$$S_a = F_a S_s$$

Average spectral accelerations (0.1-1s) calculated by site response analysis



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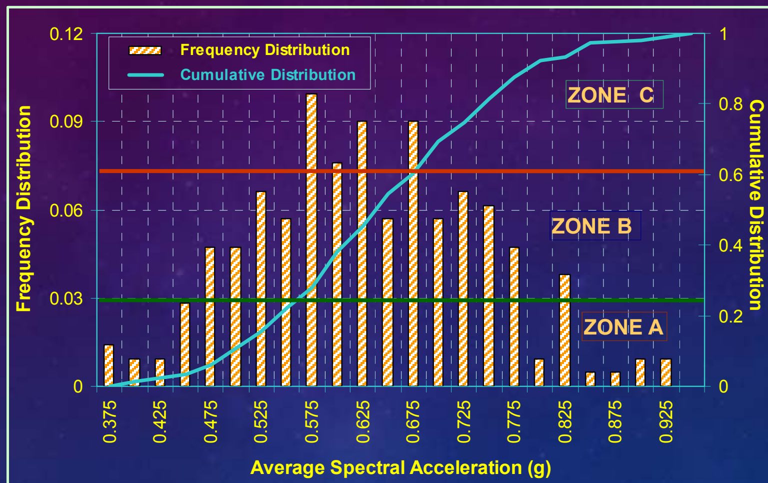
RELATIVE MICROZONATION PROCEDURE



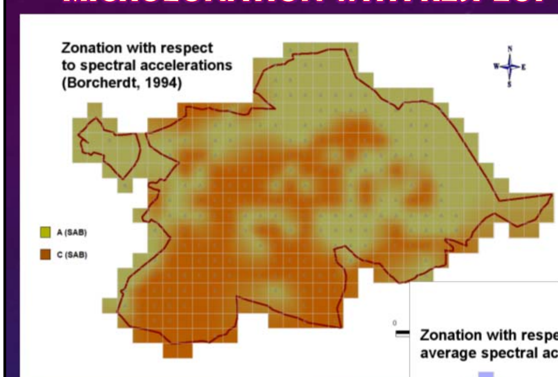
C Upper 33% percentile

B Intermediate 34 % percentile

A Lower 33% percentile

NOTE: ***If the difference between 33% and 67% percentiles is smaller than 20%, the area is divided into two zones using 50% percentile (median).***

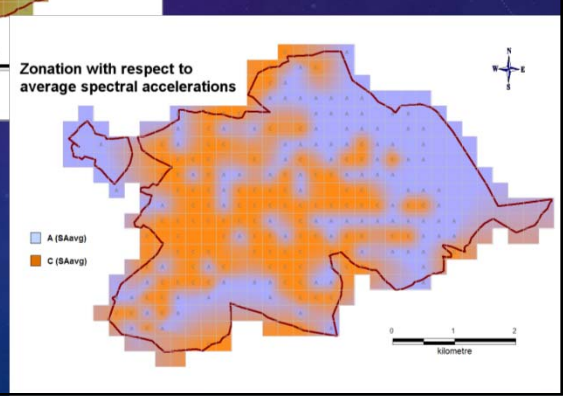
MICROZONATION WITH RESPECT TO GROUND SHAKING



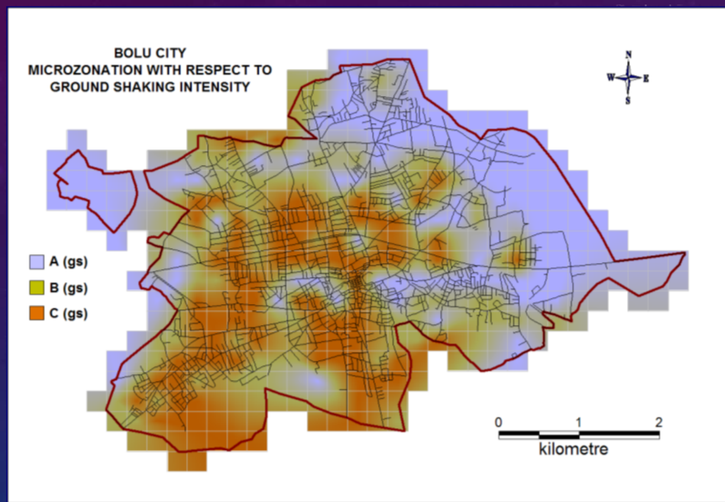
A_{GS} =
A_B & A_S + A_B & B_S + B_B & A_S

B_{GS} =
B_B & B_S + C_B & A_S + A_B & C_S

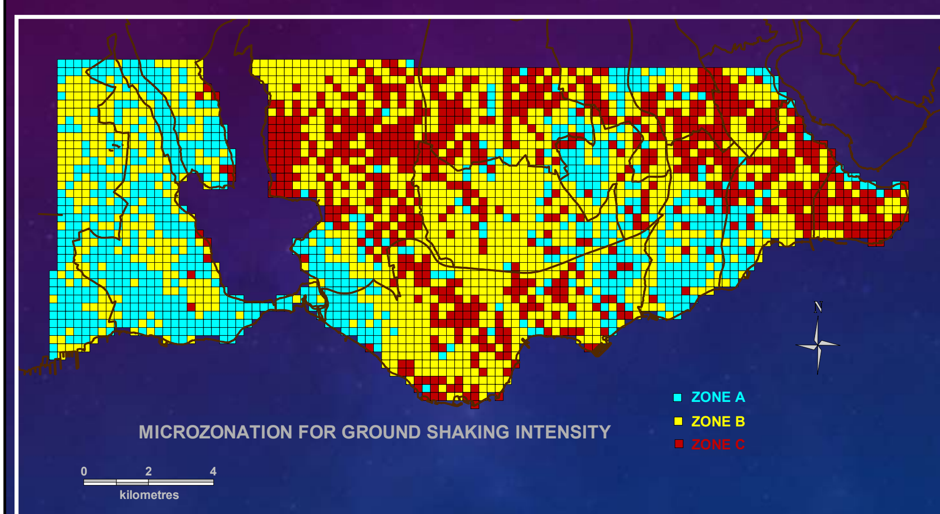
C_{GS} =
C_B & C_S + C_B & B_S + B_B & C_S



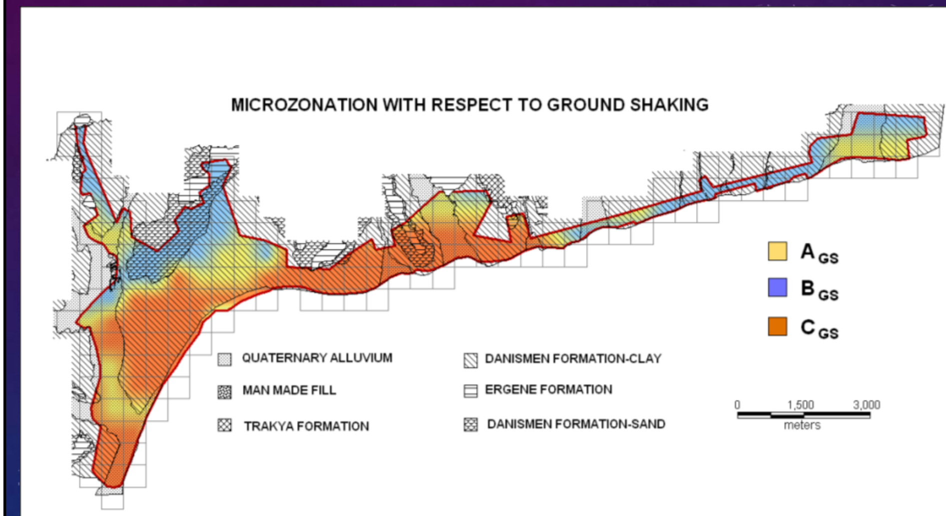
MICROZONATION WITH RESPECT TO GROUND SHAKING



MICROZONATION WRT GROUND SHAKING INTENSITY



ZONATION MAP WRT GROUND SHAKING IN COMPARISON WITH SURFACE GEOLOGY

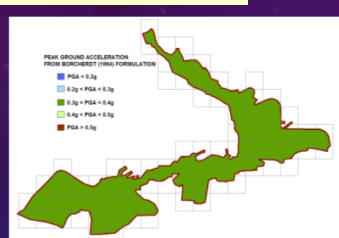


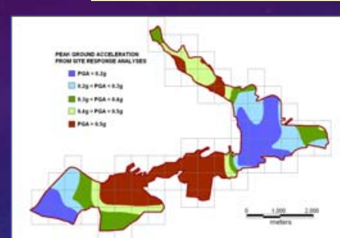
TEKİRDAĞ MUNICIPALITY

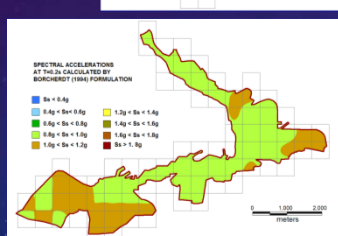
NEHRP VERSUS SITE RESPONSE ANALYSIS

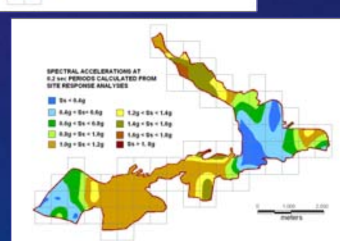
Variation of PGA and spectral acceleration at 0.2s based on NEHRP

Variation of PGA and spectral acceleration at 0.2s by site response analysis



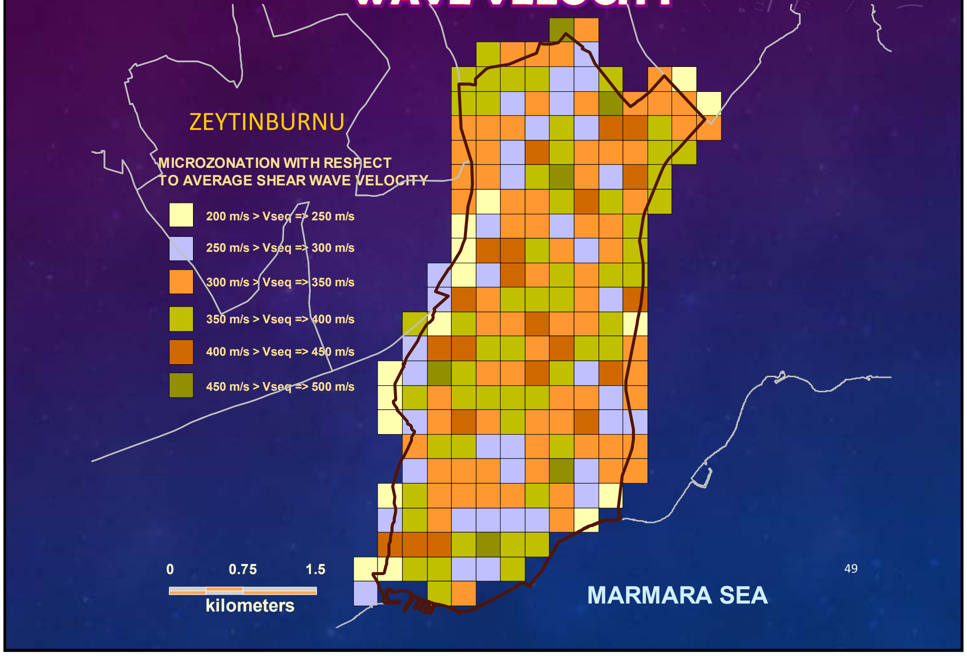




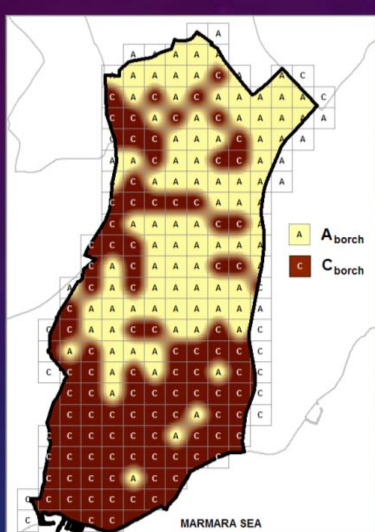


GEMLIK MUNICIPALITY

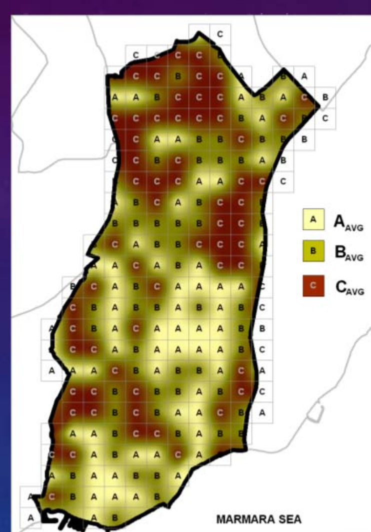
MICROZONATION WRT AVERAGE SHEAR WAVE VELOCITY



MICROZONATION WRT GROUND SHAKING INTENSITY BY SUPERPOSITION

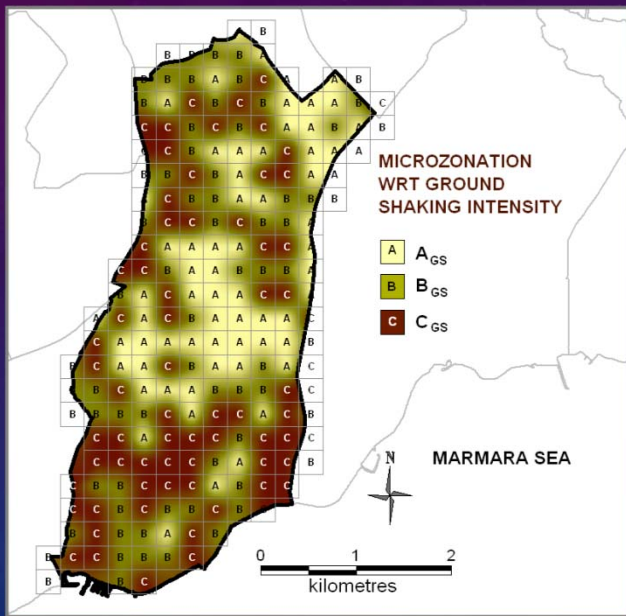


Microzonation with respect to peak spectral accelerations based on Borcherdt (1994) empirical amplification relationships



Microzonation with respect to average spectral accelerations calculated by site response site response analyses

MICROZONATION WRT GROUND SHAKING INTENSITY BY SUPERPOSITION



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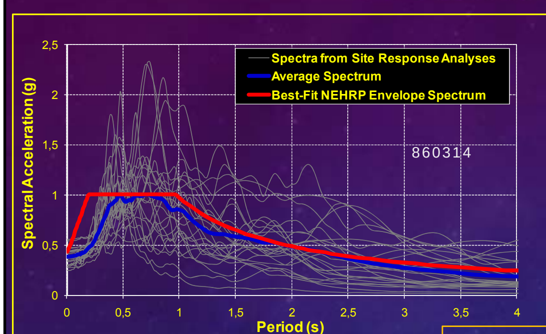
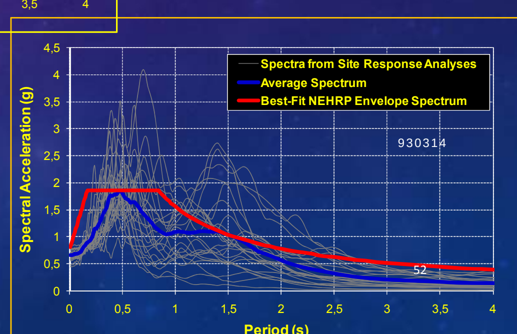
BEST FIT NEHRP ENVELOPE SPECTRUM





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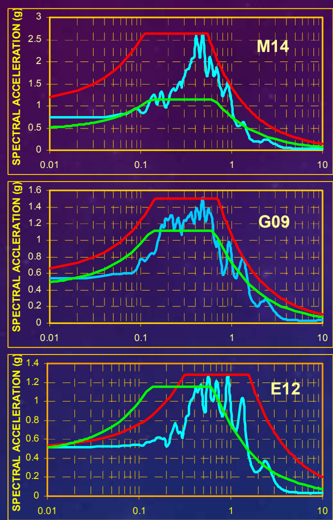
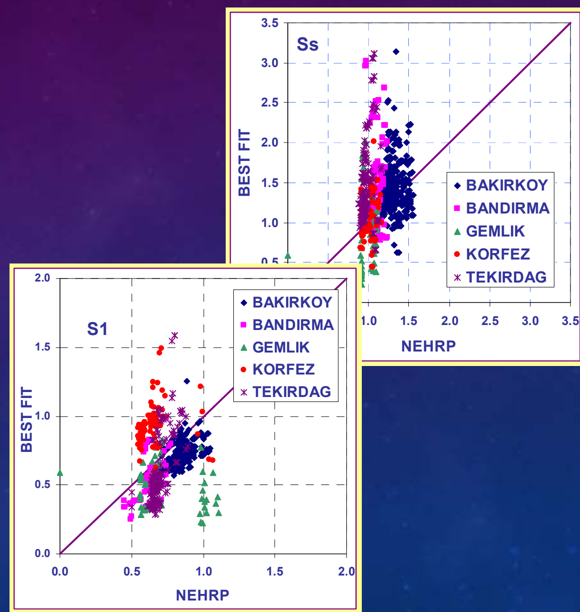
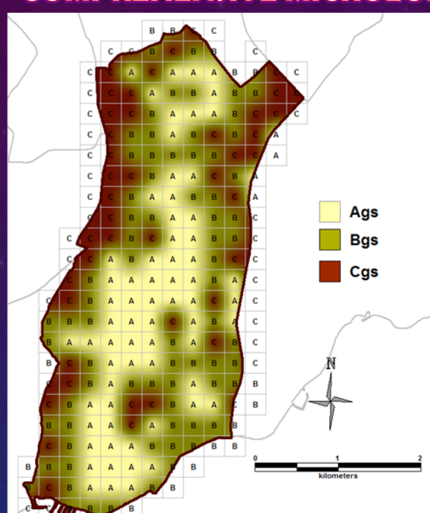
COMPARISON OF SPECTRAL ACCELERATIONS

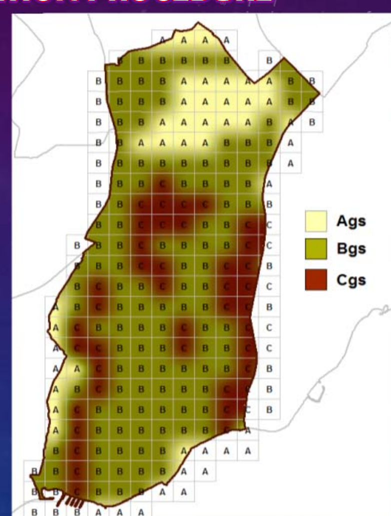




IMPORTANCE OF DETAILED SITE INVESTIGATION & COMPREHENSIVE MICROZONATION PROCEDURE

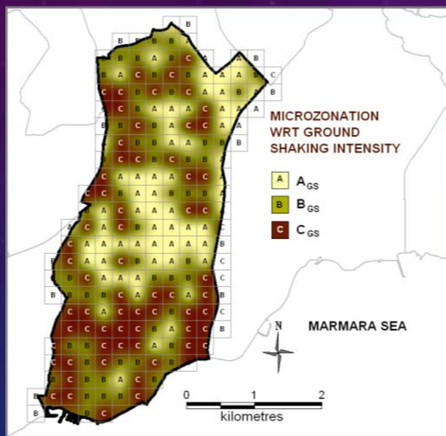


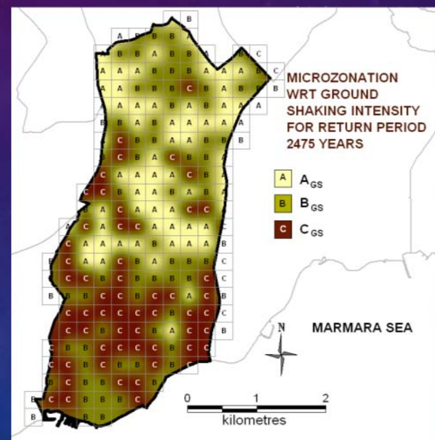
Limited number of borings and site response analysis based on 3 simulated acceleration time histories (Ansal et al., 2005)



Limited number of borings and site response analysis based on PGA scaled 28 real acceleration time histories (Ansal et al., 2007)

475 AND 2475 YEAR RETURN PERIODS





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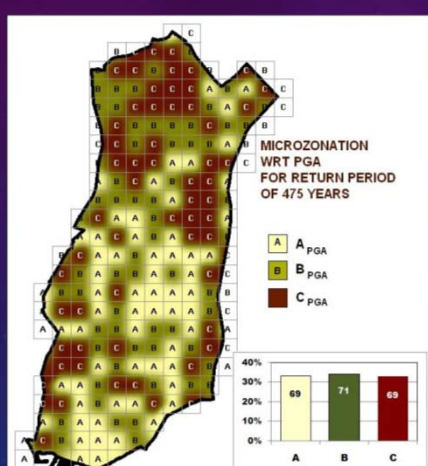
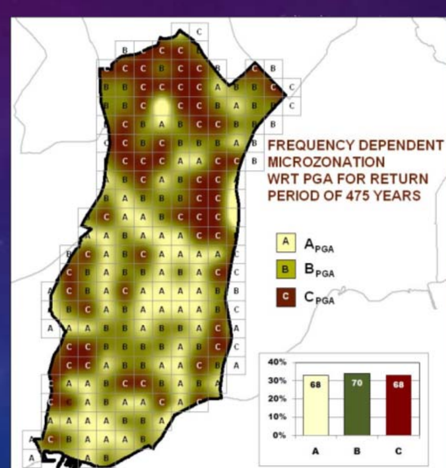
EFFECT OF FREQUENCY CORRECTION





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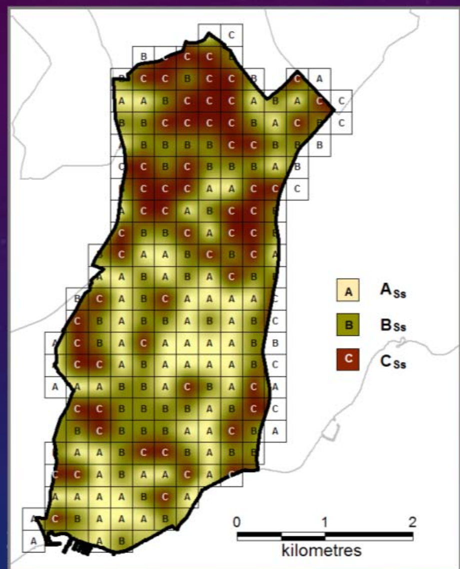
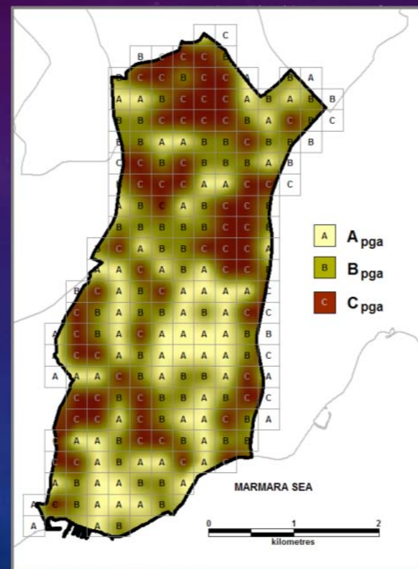
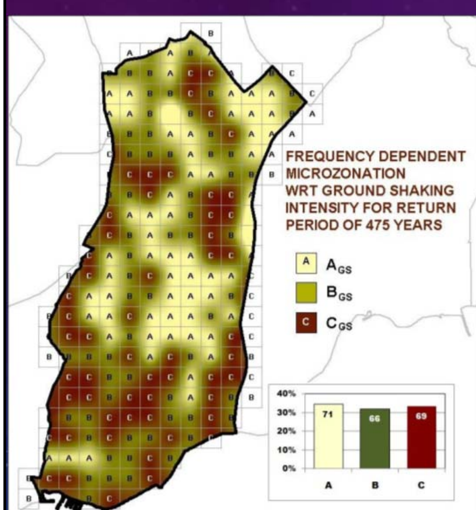
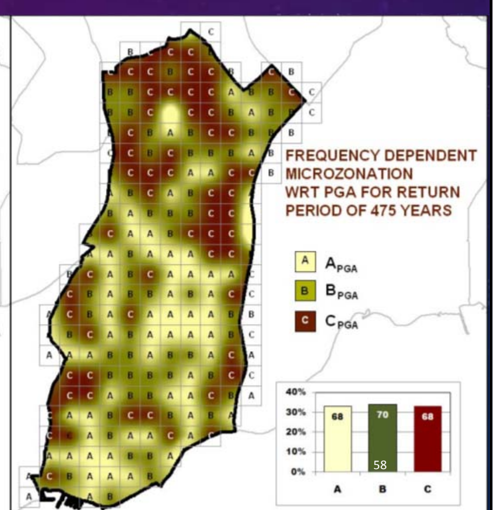
MICROZONATION WRT SS, PGA, PGV



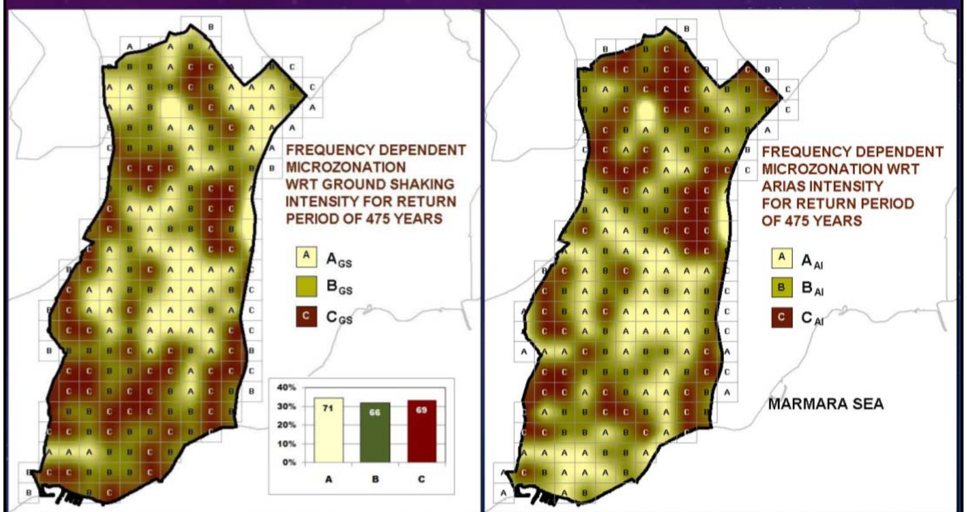


COMPARISON OF MICROZONATION WRT TO GS AND PGA

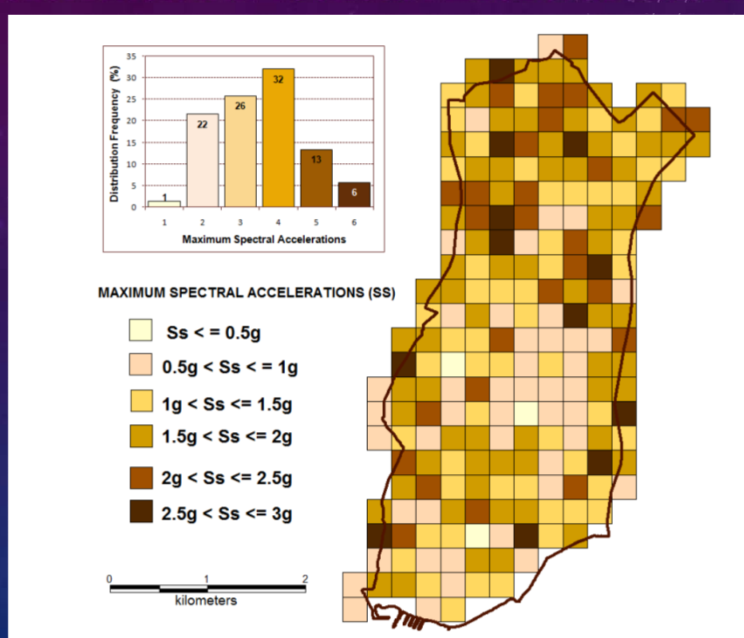


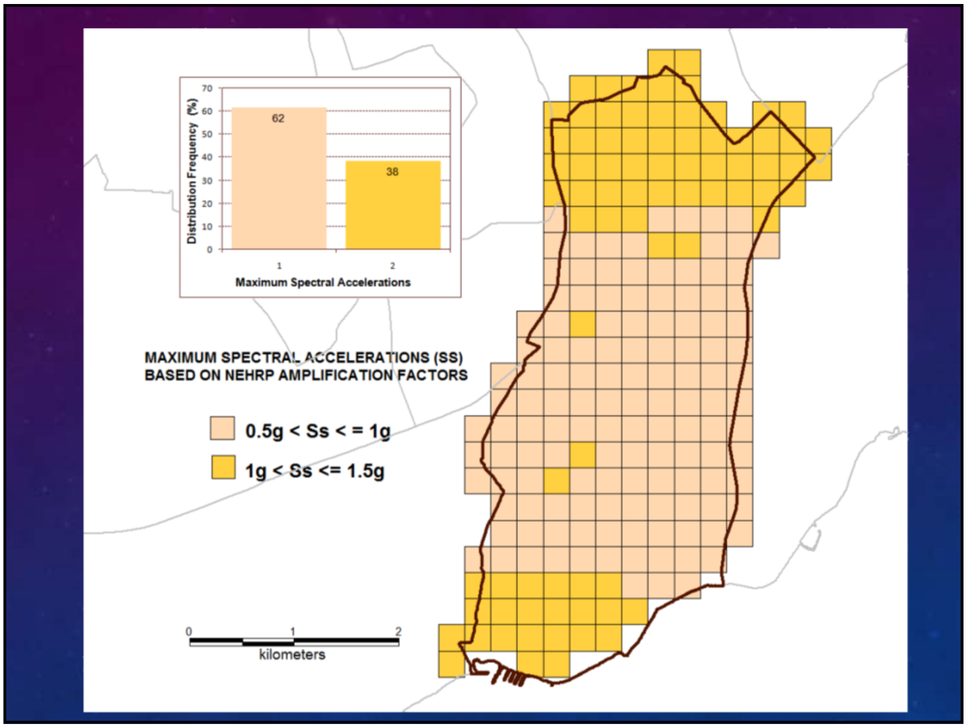


COMPARISON OF MICROZONATION WRT TO GS AND ARIAS INTENSITY

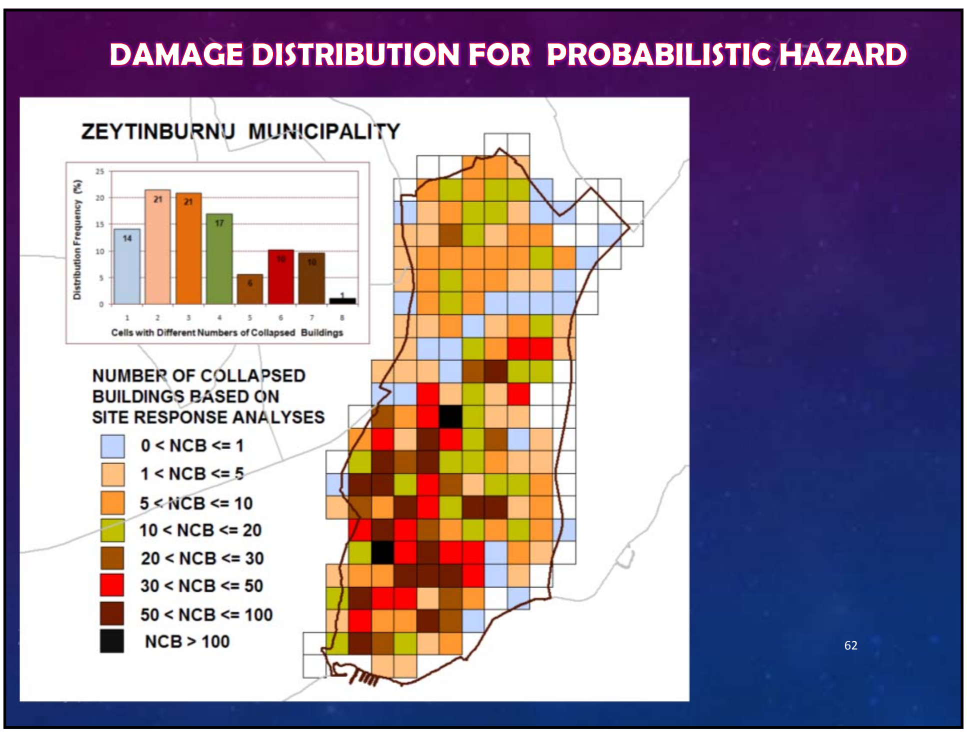


MICROZONATION WRT TO SHORT PERIOD SPECTRAL ACC.



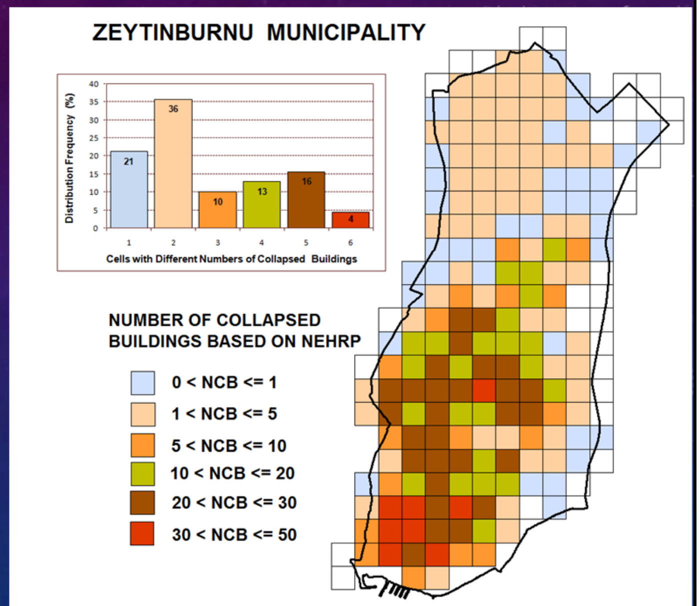


Distribution Frequency (%)
Maximum Spectral Accelerations
MAXIMUM SPECTRAL ACCELERATIONS (SS)
BASED ON NEHRP AMPLIFICATION FACTORS
0.5g < Ss < = 1g
1g < Ss <= 1.5g
kilometers



DAMAGE DISTRIBUTION FOR PROBABILISTIC HAZARD
ZEYTINBURNU MUNICIPALITY
Distribution Frequency (%)
Cells with Different Numbers of Collapsed Buildings
NUMBER OF COLLAPSED
BUILDINGS BASED ON
SITE RESPONSE ANALYSES
0 < NCB <= 1
1 < NCB <= 5
5 < NCB <= 10
10 < NCB <= 20
20 < NCB <= 30
30 < NCB <= 50
50 < NCB <= 100
NCB > 100
62

DAMAGE DISTRIBUTION FOR PROBABILISTIC HAZARD



LIQUEFACTION EVALUATION

- Seismic demand in terms of cyclic stress ratio, CSR
  - Empirical approach (Seed & Idriss, 1971)

$$CSR = 0.65 \frac{a_{\max}}{g} \frac{\sigma_v}{\sigma'_v} r_d$$

Stress Reduction Factor, r_d

Youd et al., 2001

Cetin et al., 2004

  - Site response analysis

$$CSR = \frac{\tau_{av}}{\sigma'_v}$$

- Capacity of the soil layers to resist liquefaction, expressed in terms of cyclic resistance ratio, CRR

LIQUEFACTION SUSCEPTIBILTY -YOUD ET AL. (2001)

$$CSR = \frac{\tau_{av}}{\sigma'_v} = 0.65 \frac{a_{max}}{g} \frac{\sigma_v}{\sigma'_v} r_d$$

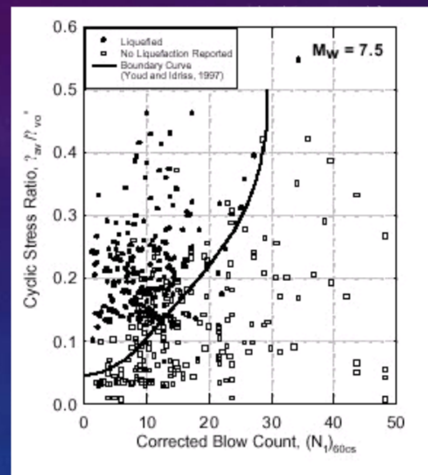
a_{max}= peak horizontal ground surface acceleration
g = acceleration of gravity
σ_v= total vertical overburden stress
σ'_v= effective vertical overburden stress
r_d= stress reduction factor.

$$r_d = \frac{(1.00 - 0.4113z^{0.5} + 0.04052z + 0.001753z^{1.5})}{(1.00 - 0.4177z^{0.5} + 0.05729z - 0.006205z^{1.5} + 0.001210z^2)}$$

Corrected $N_{1,60}$ values are calculated as,

$$N_{1,60} = NC_N C_R C_S C_B C_E$$

C_N = factor to normalize N to a common reference effective overburden stress
C_R = correction for rod length,
C_S = correction for non-standardized sampler configuration,
C_B = correction for borehole diameter,
C_E = correction for hammer energy ratio.

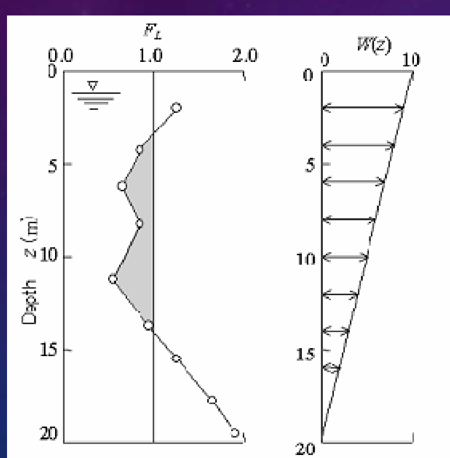


$$CRR_{7.5} = \frac{1}{34 - N_{1,60}} + \frac{N_{1,60}}{135} + \frac{50}{(10N_{1,60} + 45)^2} - \frac{1}{200}$$

$$FS = (CRR_{7.5} / CSR) MSF$$

LIQUEFACTION SUSCEPTIBILTY

LIQUEFACTION POTENTIAL INDEX, PI
Iwasaki et al (1982)

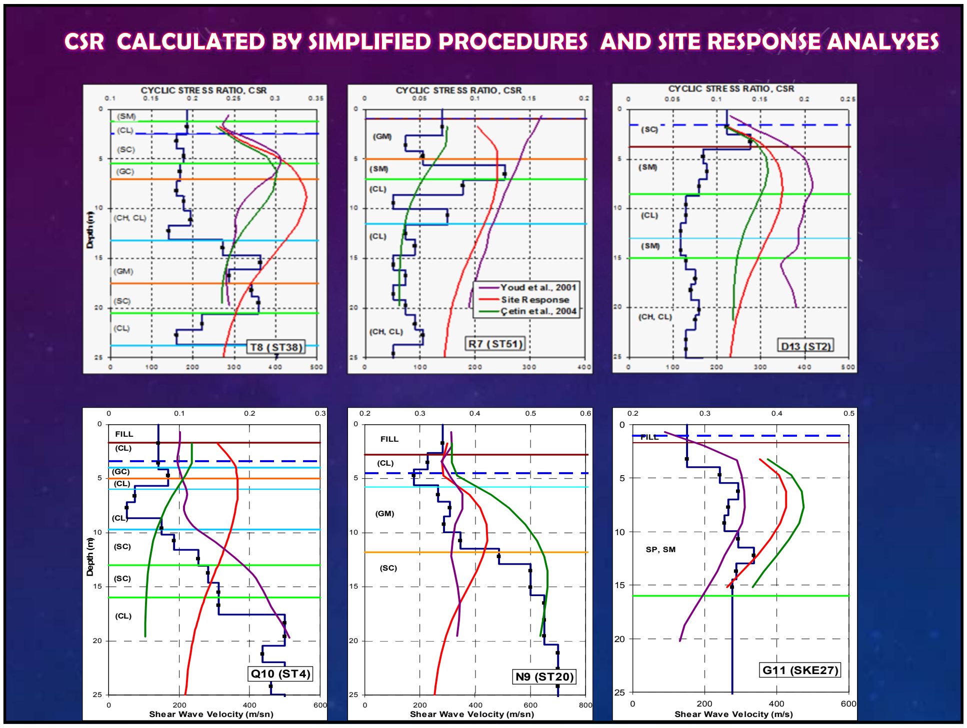


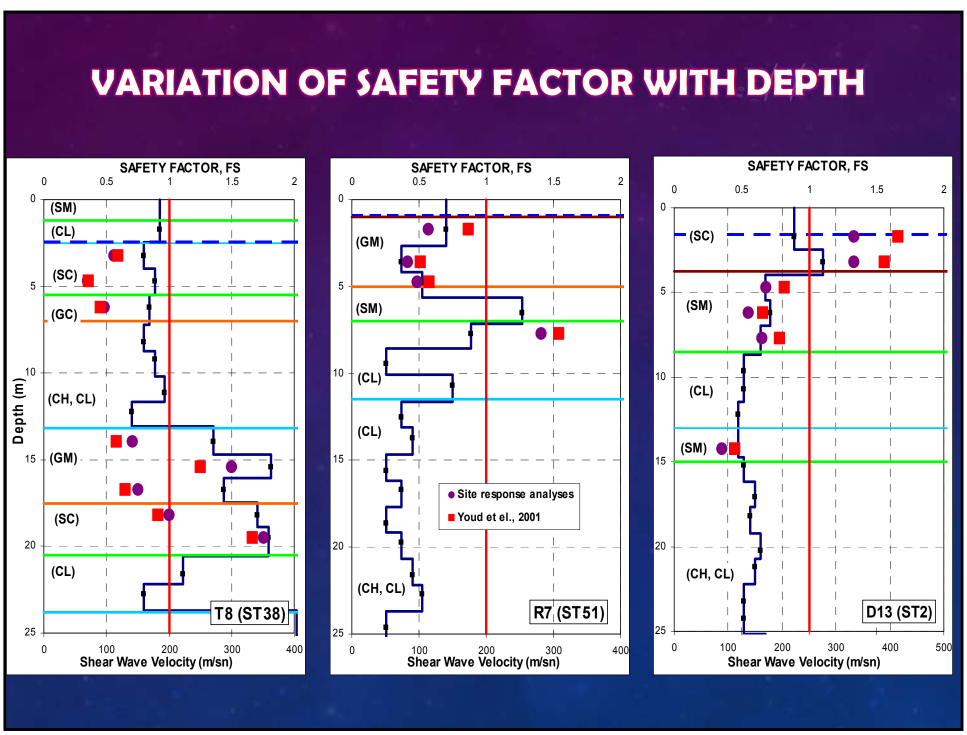
$$P_L = \int F(z) w(z) dz$$

F(z) = 1 - FS, For *FS* >1.0 *F(z)=0*

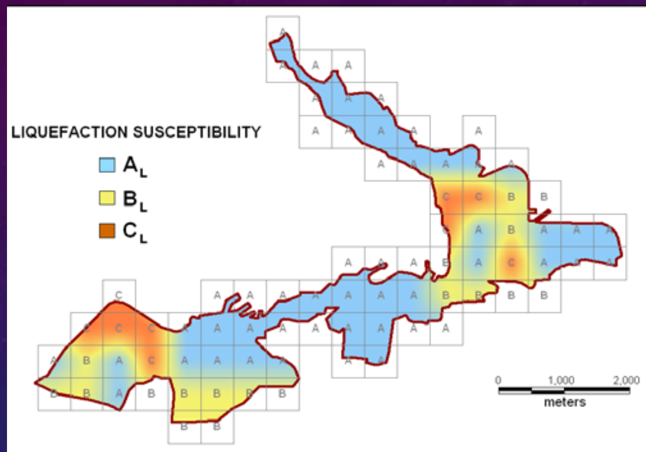
w(z) = 10 - 0.5z

PL>15	***ZONE C_L***
5 ≤ PL≤15	***ZONE B_L***
PL<5	***ZONE A_L***

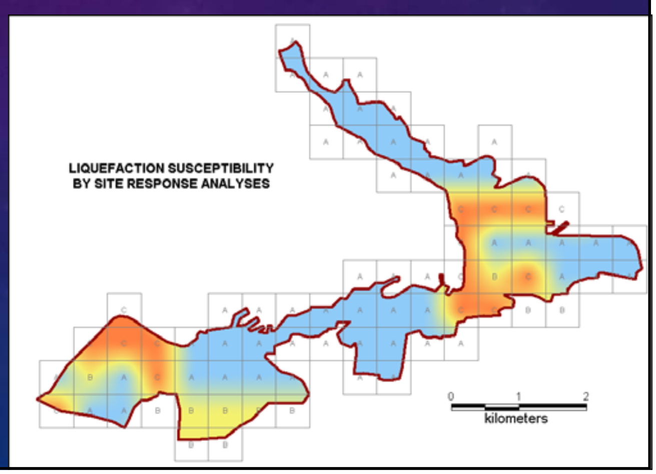

CSR CALCULATED BY SIMPLIFIED PROCEDURES AND SITE RESPONSE ANALYSES
CYCLIC STRESS RATIO, CSR
Depth (m)
Shear Wave Velocity (m/sn)
Shear Wave Velocity (m/s)
Youd et al., 2001
Site Response
Çetin et al., 2004
T8 (ST38)
R7 (ST51)
D13 (ST2)
Q10 (ST4)
N9 (ST20)
G11 (SKE27)
FILL
SP, SM
(SM)
(CL)
(SC)
(GC)
(CH, CL)
(GM)

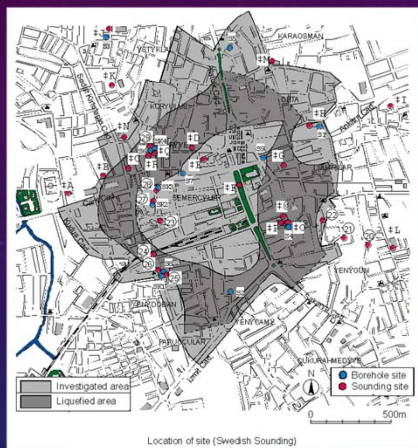

VARIATION OF SAFETY FACTOR WITH DEPTH
SAFETY FACTOR, FS
Depth (m)
Shear Wave Velocity (m/sn)
Site response analyses
Youd et al., 2001
T8 (ST38)
R7 (ST51)
D13 (ST2)
(SM)
(CL)
(SC)
(GC)
(CH, CL)
(GM)

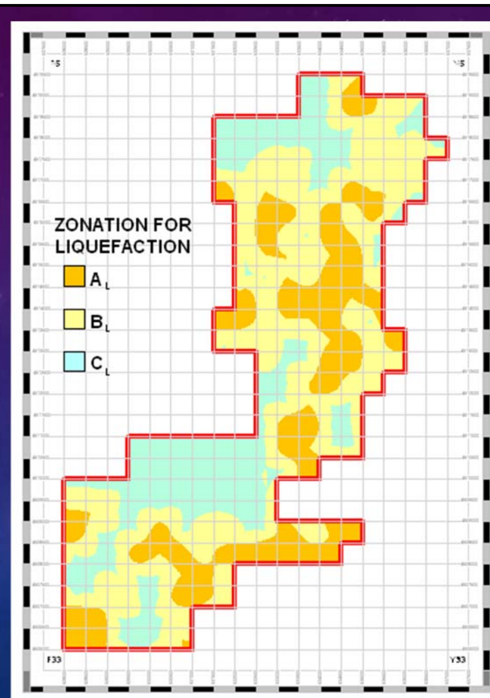
LIQUEFACTION SUSCEPTIBILTY FOR GEMLIK



LIQUEFACTION SUSCEPTIBILTY FOR GEMLIK

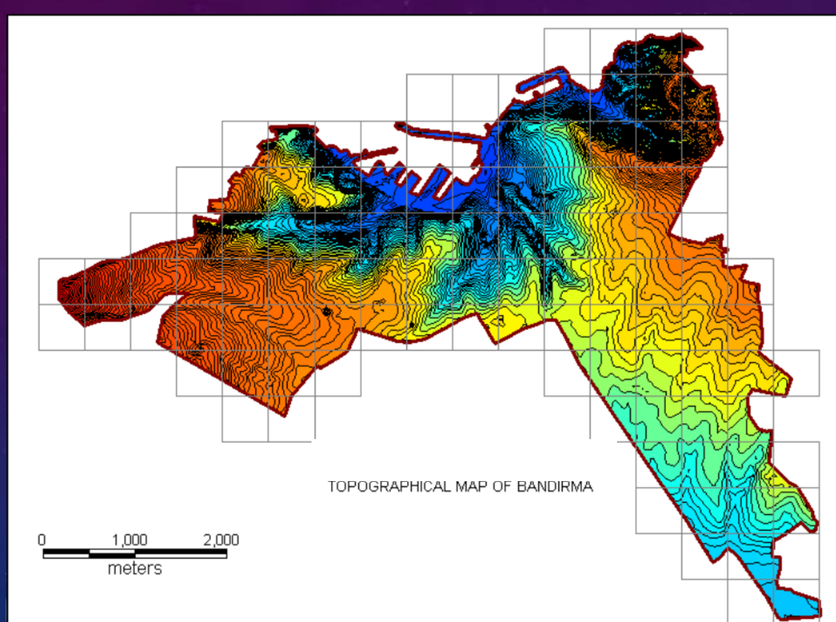


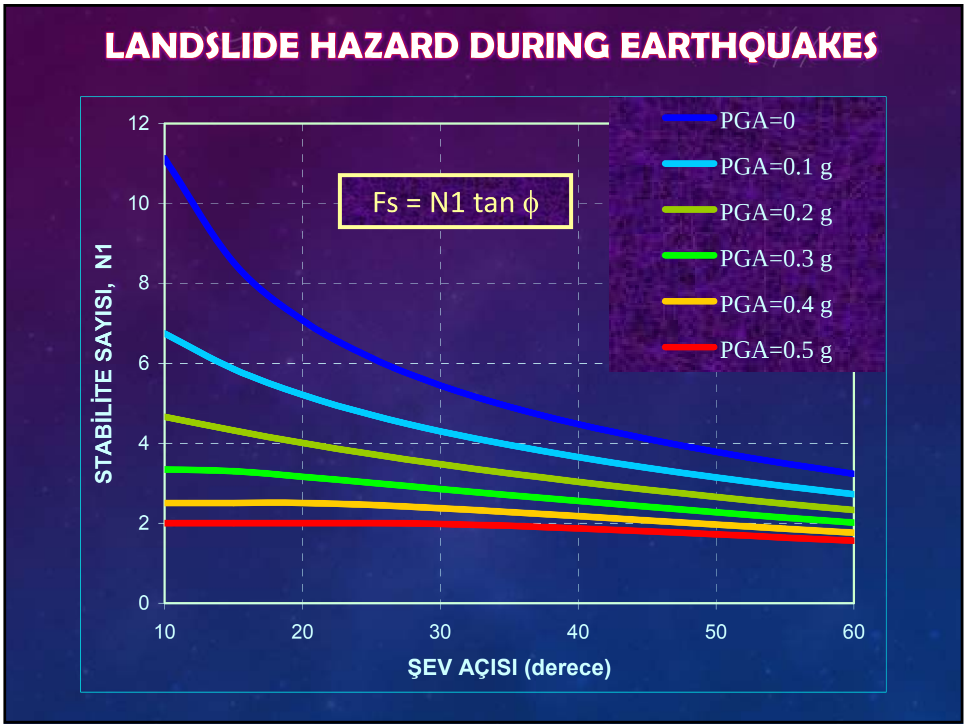


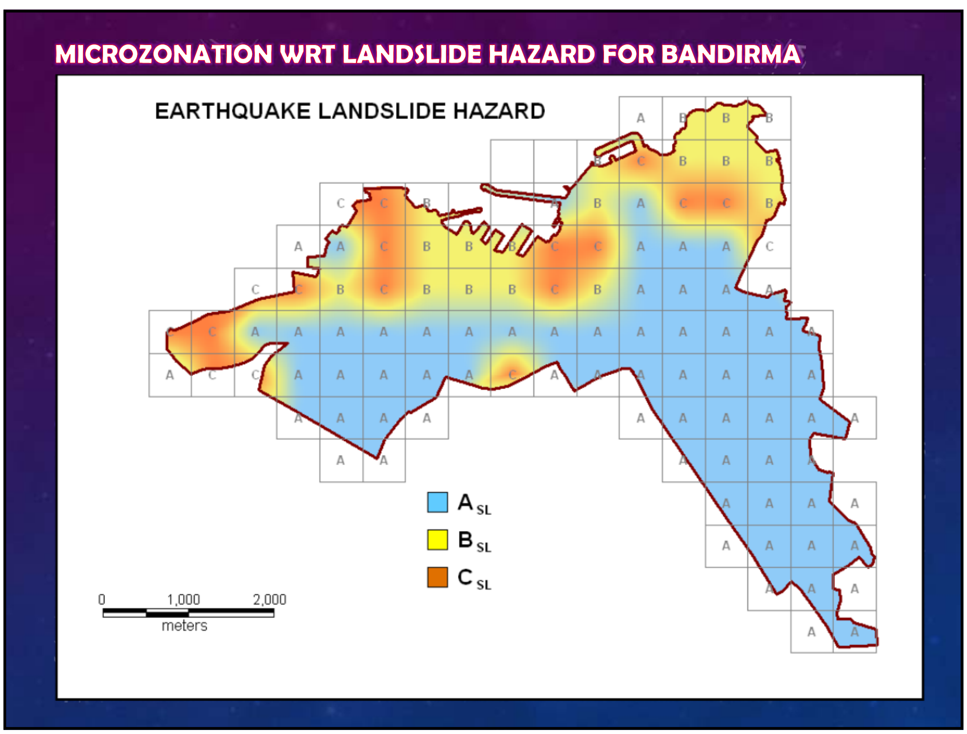


OBSERVED LIQUEFACTION SUSCEPTIBILTY FOR ADAPAZARI

TOPOGRAPHICAL MAP FOR BANDIRMA




LANDSLIDE HAZARD DURING EARTHQUAKES
Fs = N1 tan ϕ
PGA=0
PGA=0.1 g
PGA=0.2 g
PGA=0.3 g
PGA=0.4 g
PGA=0.5 g
STABİLİTE SAYISI, N1
ŞEV AÇISI (derece)
0
2
4
6
8
10
12
10
20
30
40
50
60


MICROZONATION WRT LANDSLIDE HAZARD FOR BANDIRMA
EARTHQUAKE LANDSLIDE HAZARD
A SL
B SL
C SL
0
1,000
2,000
meters

CONCLUSIONS

- Earthquake hazard determination based on regional scale with respect to intended performance levels,
- Use of large number of hazard compatible real acceleration time histories for site response analysis,
- 1D site response analyses appears to be sufficient to model the observed ground motion characteristics.
- Microzonation with respect to average spectral accelerations by site response analysis and spectral acceleration based on equivalent shear wave velocity.
- Microzonation with three relative levels of hazard (high, medium, low) with flexible baundaries.
- Detailed site characterization plays an important role on site response analysis.

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THE END

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