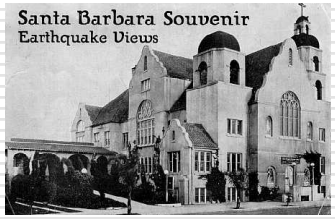


4th IASPEI / IAEE International Symposium:

Effects of Surface Geology on Seismic Motion

August 23–26, 2011 · University of California Santa Barbara

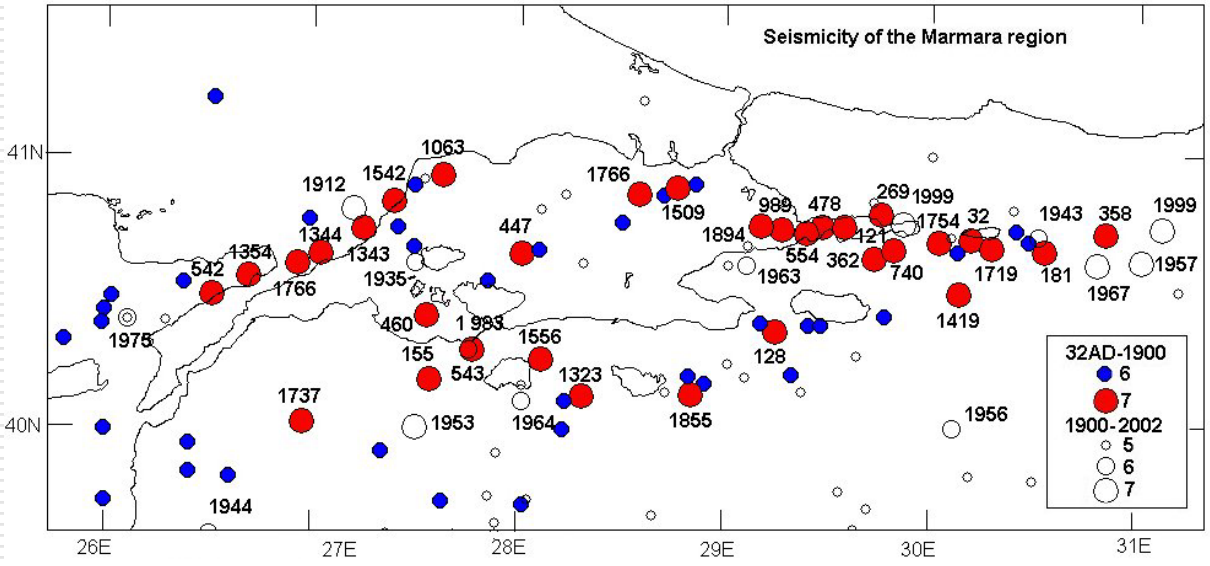
Geotechnical Arrays Recently Deployed in Istanbul

by Asli Kurtuluş, Atilla Ansal and Erdal Safak

Kandilli Observatory and Earthquake Research Institute (KOERI)

Bogazici University, Istanbul, Turkey

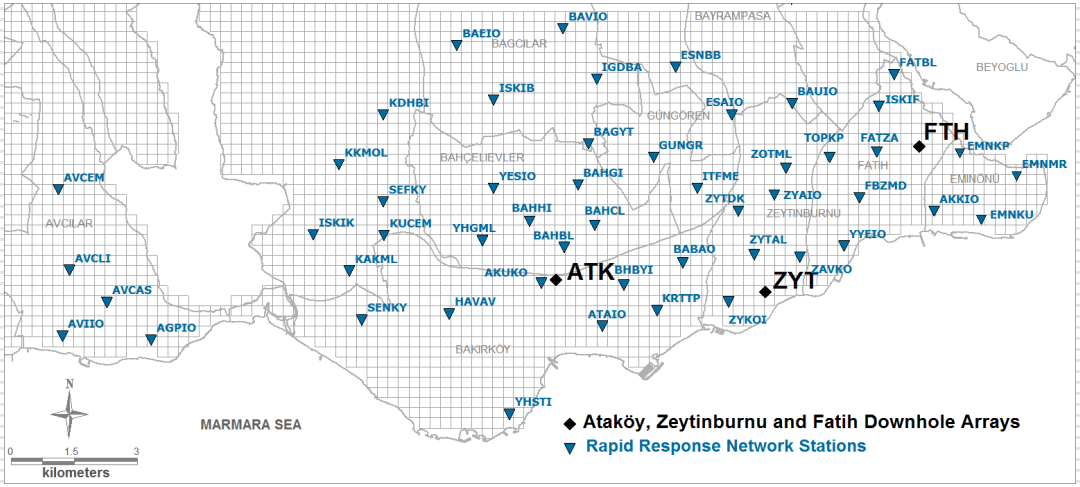
Location



Erdik et al. (2003)

- Tectonics: Marmara Fault System- westward elongation of the strike-slip North Anatolian Fault (NAF)
- Seismic History: At least one medium intensity (Io=VII-VIII) earthquake in every 50 years. Average return period for high intensity (Io=VIII-IX) events 300 years.
- Seismic Risk: 65% probability of M_w>7 in the next 30 years

Istanbul Strong Motion Network



West European Side of Istanbul

- High seismic activity
- Extensive geotechnical investigations (2900 boreholes in an area of about 182 km^2, various field and laboratory tests)

- Three geotechnical downhole arrays

  composed of accelerometers at various depths with deepest at bedrock level

- Rapid Response Network

  composed of 55 surface accelerometers distributed within the area

generate data for development, verification, and calibration of predictive tools and design procedures

Downhole Arrays

- investigate site amplification effects at different soil sites within the city
- provide reference bedrock motion for Rapid Response Network

<u>Site Selection</u>

Depth of bedrock, properties of soil profile, seismic vulnerability of area, security of the site

<u>Site Investigation</u>

SPT, PS Logging and laboratory tests

<u>Borehole Preparation</u>

'Rotary-mud' drilled, PVC cased and grout injected

<u>Instrumentation</u>

3D downhole force-balance accelerometers (±2g)

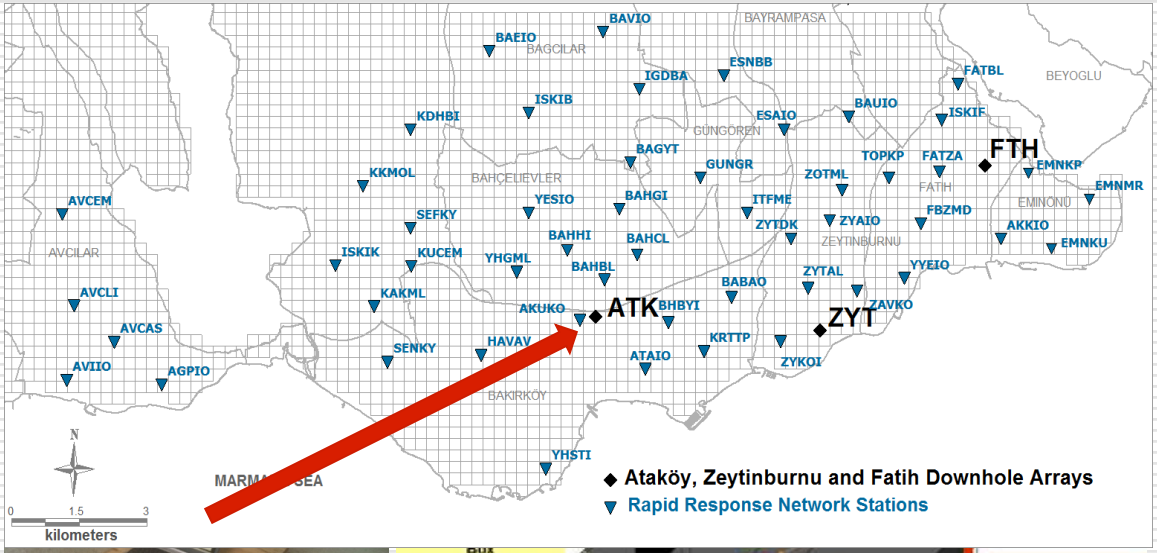
with built-in compass and digital recorders

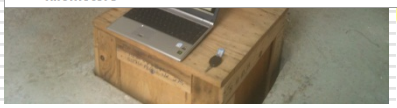
<u>Data Collection</u>

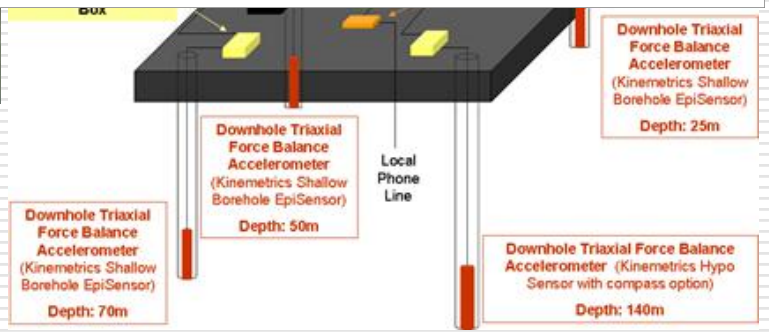
Threshold-triggered recording at 200 sps via ADSL

Ataköy Array (ATK)

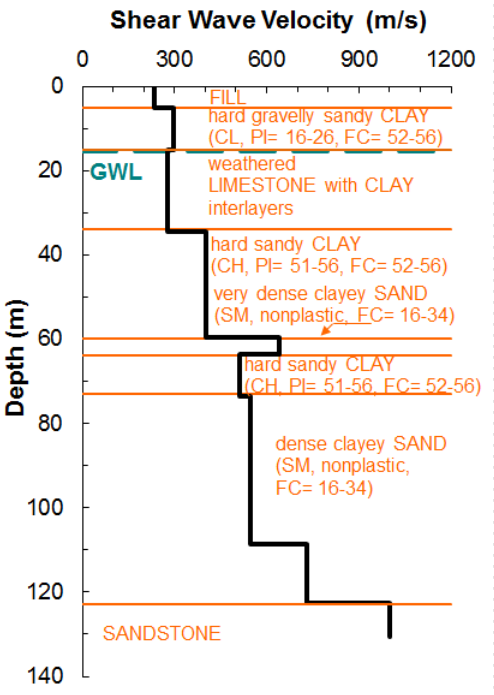
Stiff-soil/rock site







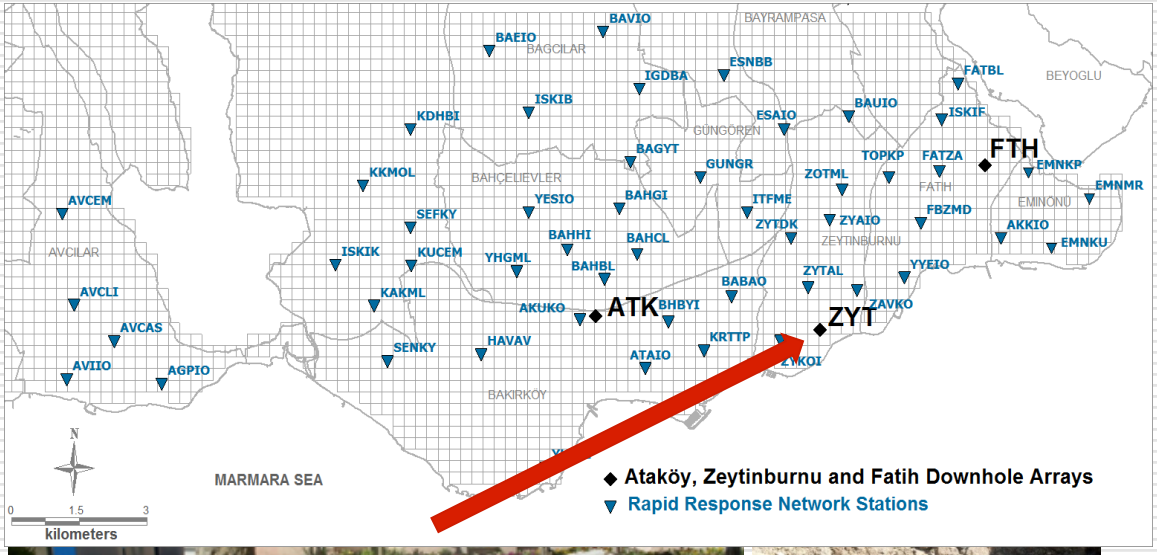
Field Set-Up

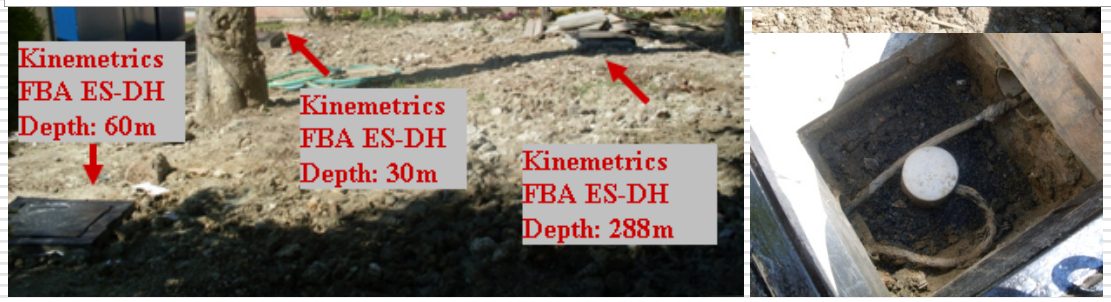


Soil Profile

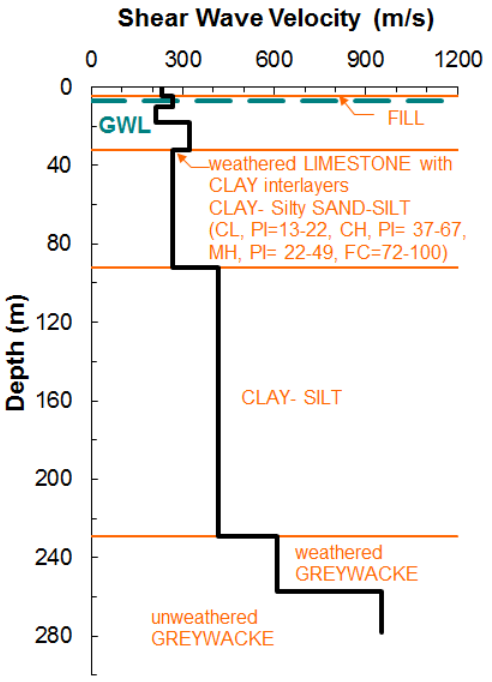
Zeytinburnu Array (ZYT)

Soft-soil/rock site





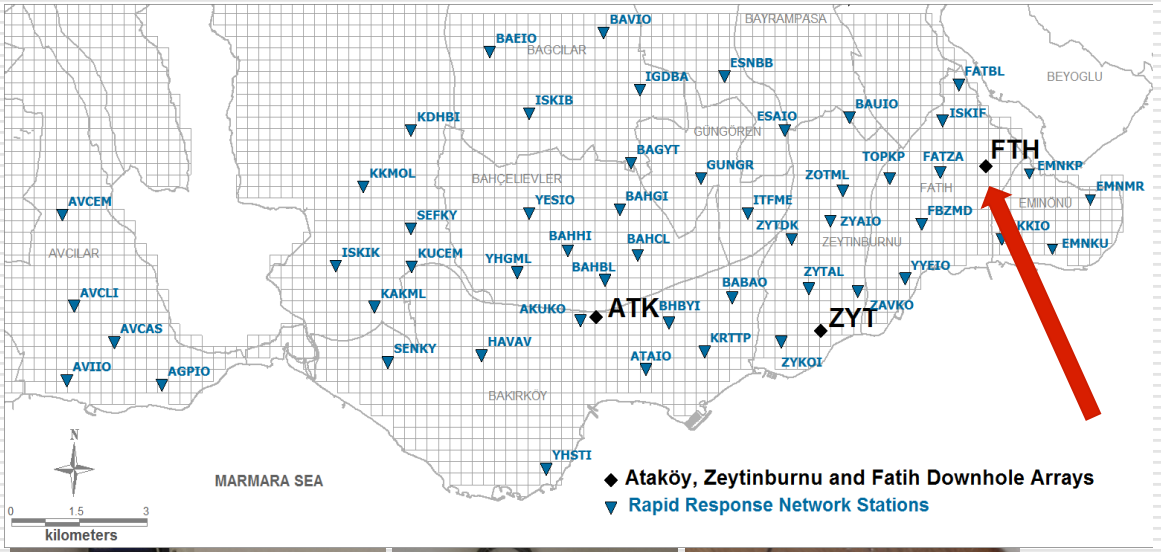
Field set-up

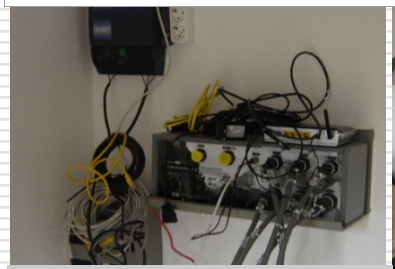


Soil profile

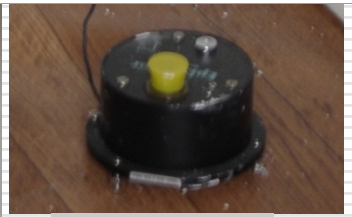
Fatih Array (FTH)

Stiff-soil/rock site

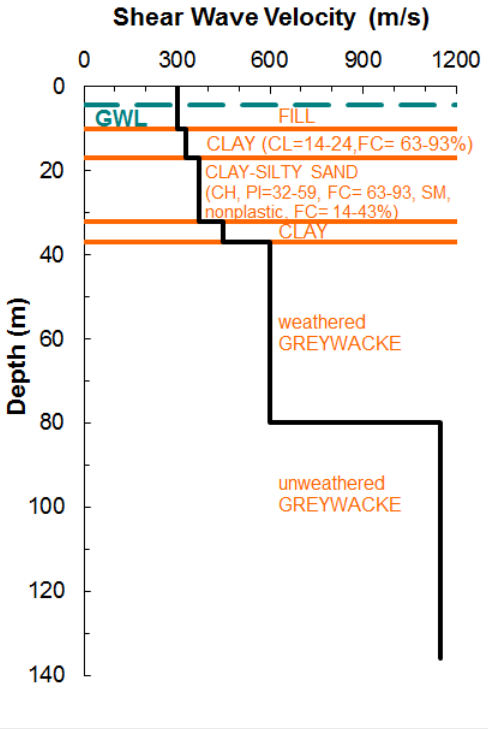




12-ch Kinemetrics Rock Digitizer



Kinemetrics ES-T

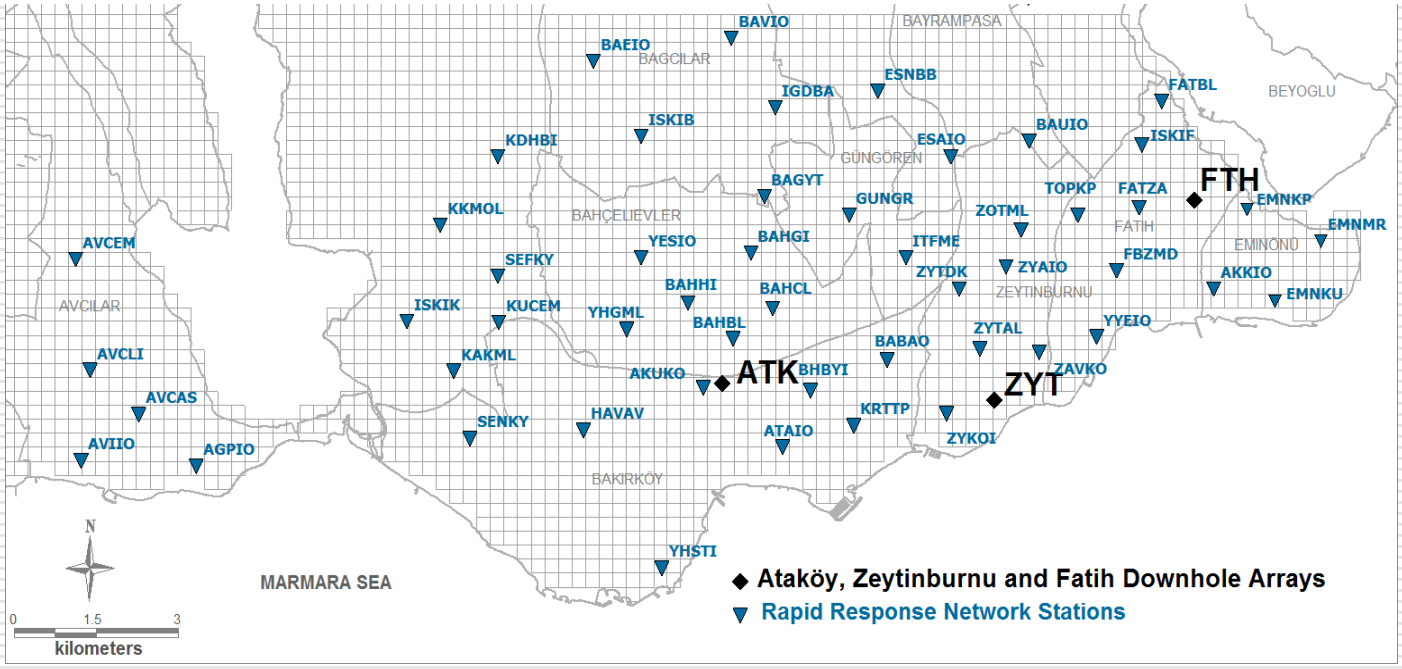


Field set-up

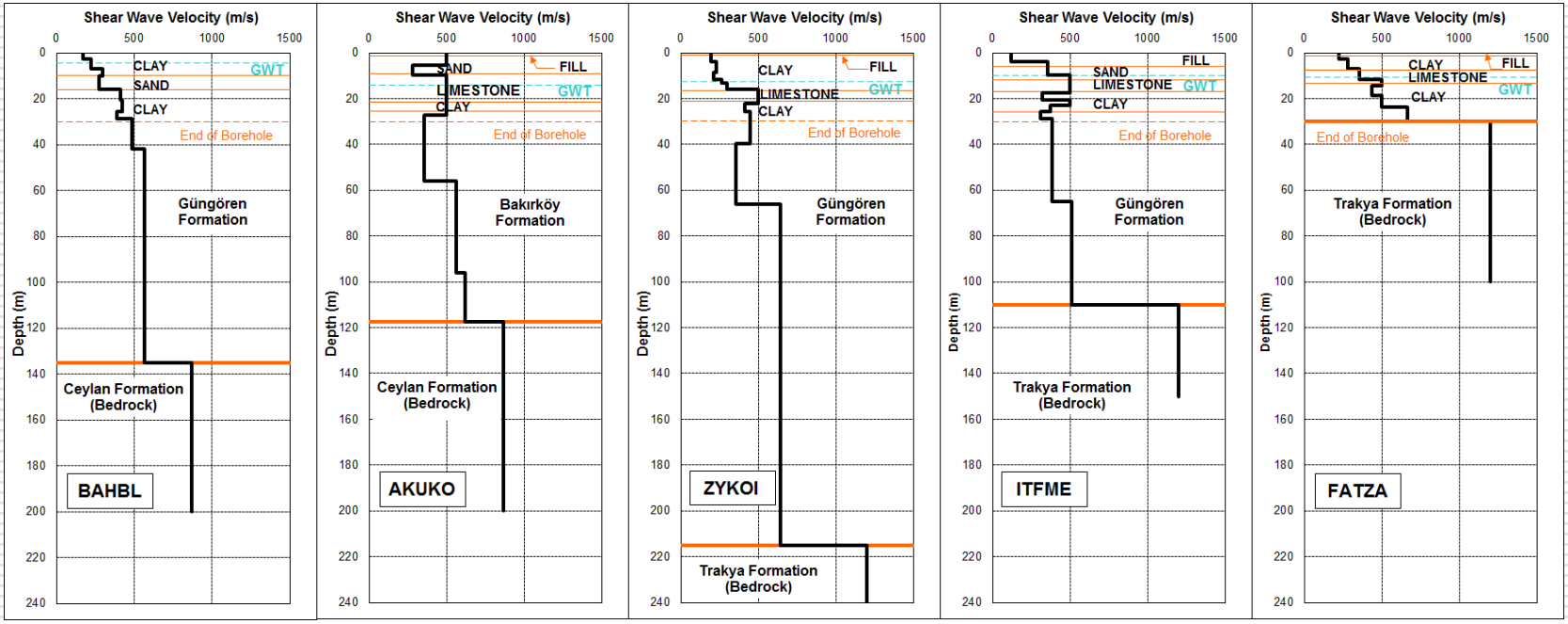
Soil profile

Istanbul Rapid Response Network (IRRN)

- 100 strong-motion instruments (Güralp CMG-5T) installed at grade level in small- to medium-sized buildings
- Continous recording, data retrieval through GSM and GPRS modems
- Out of 100 rapid response network strong motion stations, 55 stations are located in the west European side of Istanbul



Soil Conditions at IRRN Stations



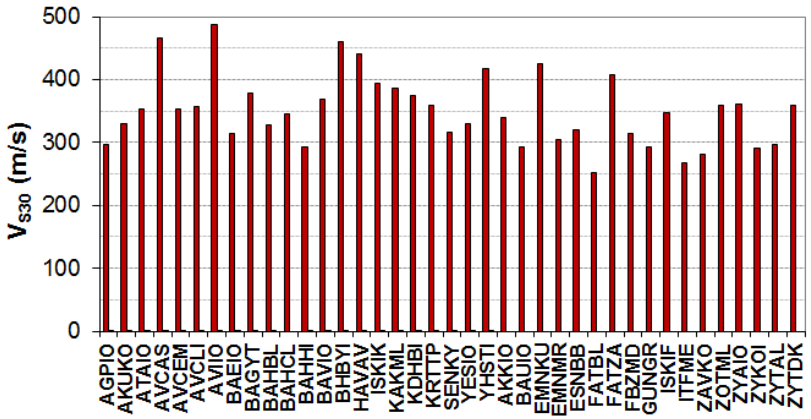
- Istanbul Microzonation Study (initiated by Metropolitan Municipality)

  2900 borings in 189 km^2, SPT, CPT, seismic reflection, refraction, PS-Logging, laboratory tests

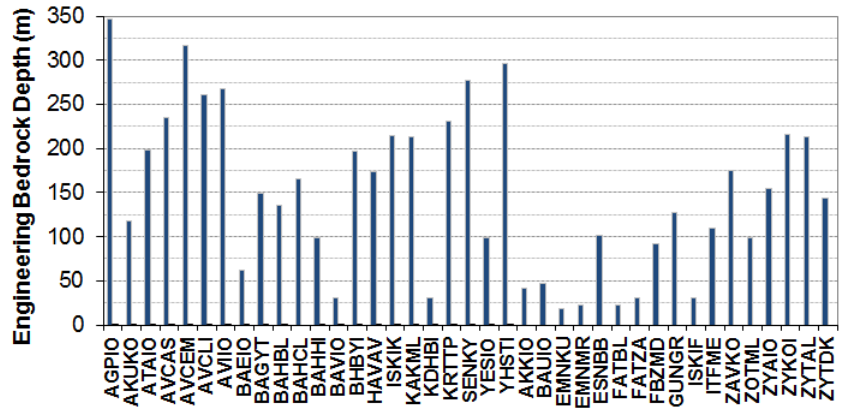
  3D bedrock model based on geology and geophysical measurements (OYO, 2007)

- Representative soil profile at each IRRN station using data from borings conducted in the near vicinity (<200m)

Soil Conditions at IRRN Stations



- Comparable V_{S30} (NEHRP Site Class D and C)

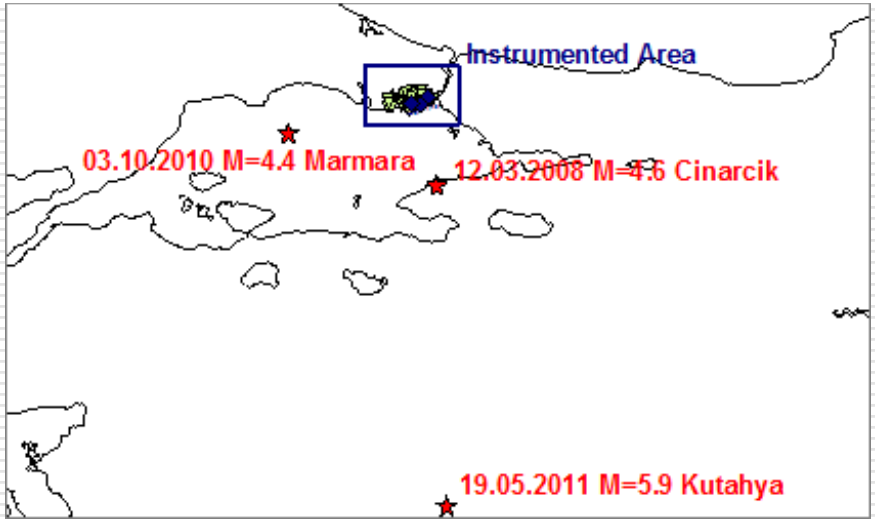


- Significantly different bedrock depths

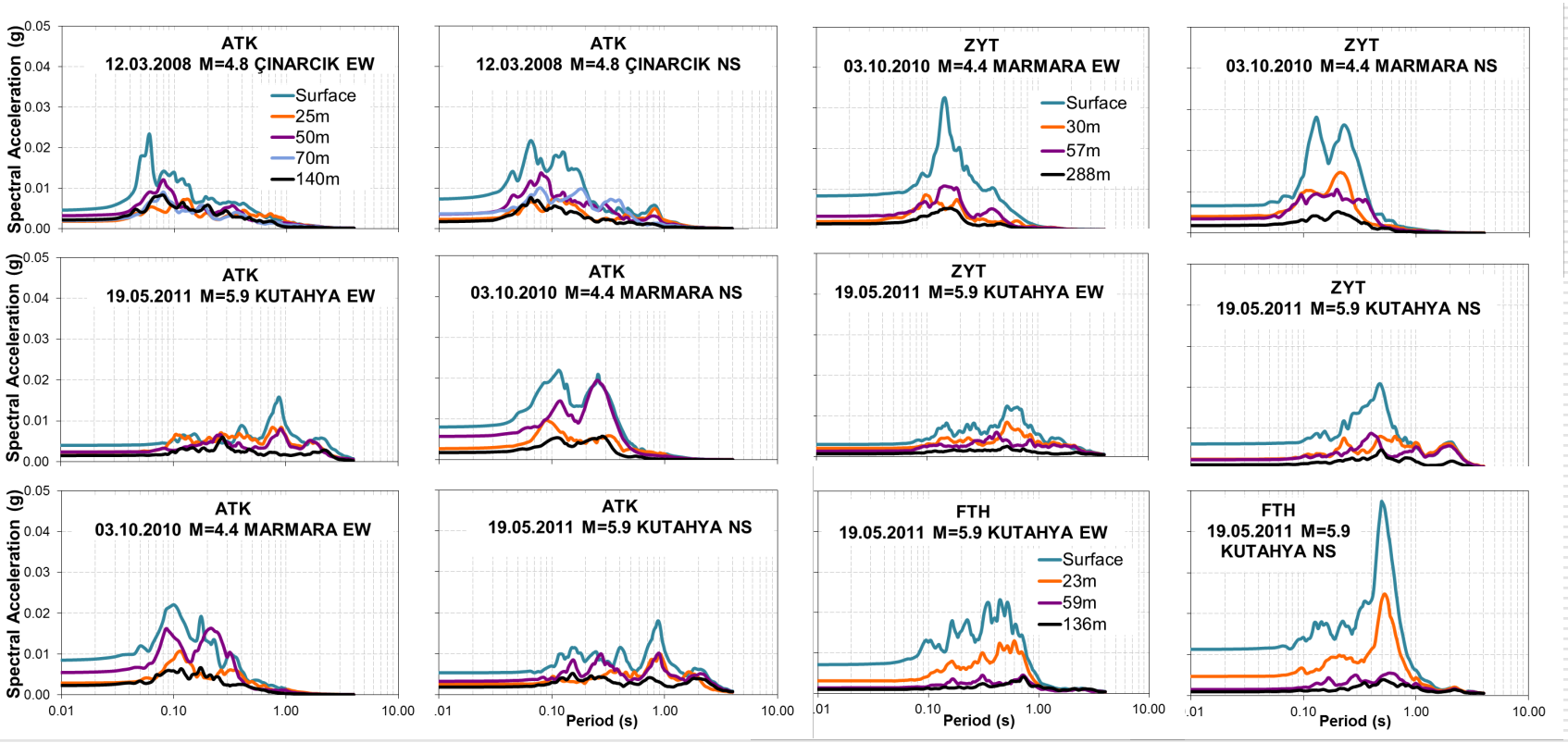
Recorded Motions

- M_L>4 local events recorded by downhole arrays in Istanbul

Eq. No	Date/Local Time	Local Name	Lat. °	Long. °	Depth (km)	M_L	Station	Distance (km)	$PGA_{surface}$(g)
1	12/03/2008/18:53:39	Çınarcık	40.620	29.004	11.2	4.8	ATK	43.4	0.008
2	05/10/2008/09:04:05	-	40.650	29.017	8.5	4.1	ATK	41.6	0.002
3	24/01/2009 15:58:38	-	40.803	27.785	11.2	4.2	ATK	91.7	0.001
4	27/04/2009 19:03:06	-	40.759	27.543	18.2	4.1	ATK	115.5	0.003
5	01/08/2009 16:42:38	-	40.366	28.274	9.1	4.1	ATK	85.3	0.001
6	08/08/2009 13:52:38	-	40.328	27.411	15.6	4.4	ATK	141.8	0.001
7	03/10/2010 20:49:02	Marmara	40.846	28.110	11.2	4.4	ATK, ZYT	64.2, 68.8, 73.2	0.008, 0.008
8	19/05/2011 23:15:23	Kütahya	39.152	29.088	7.6	5.9	ATK, ZYT, FTH	205.5, 204.8, 208.2	0.005, 0.006, 0.011

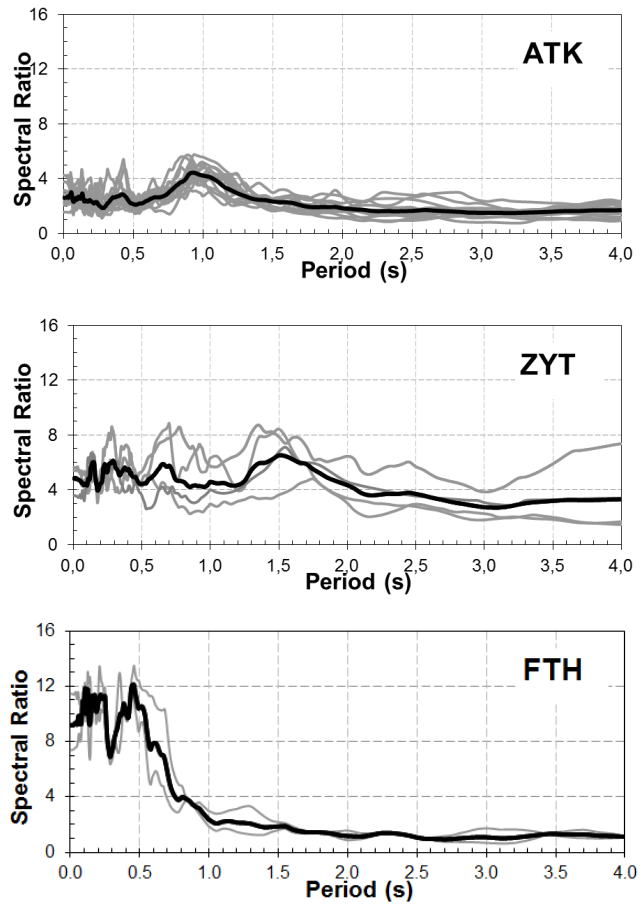


Recorded at Downhole Arrays



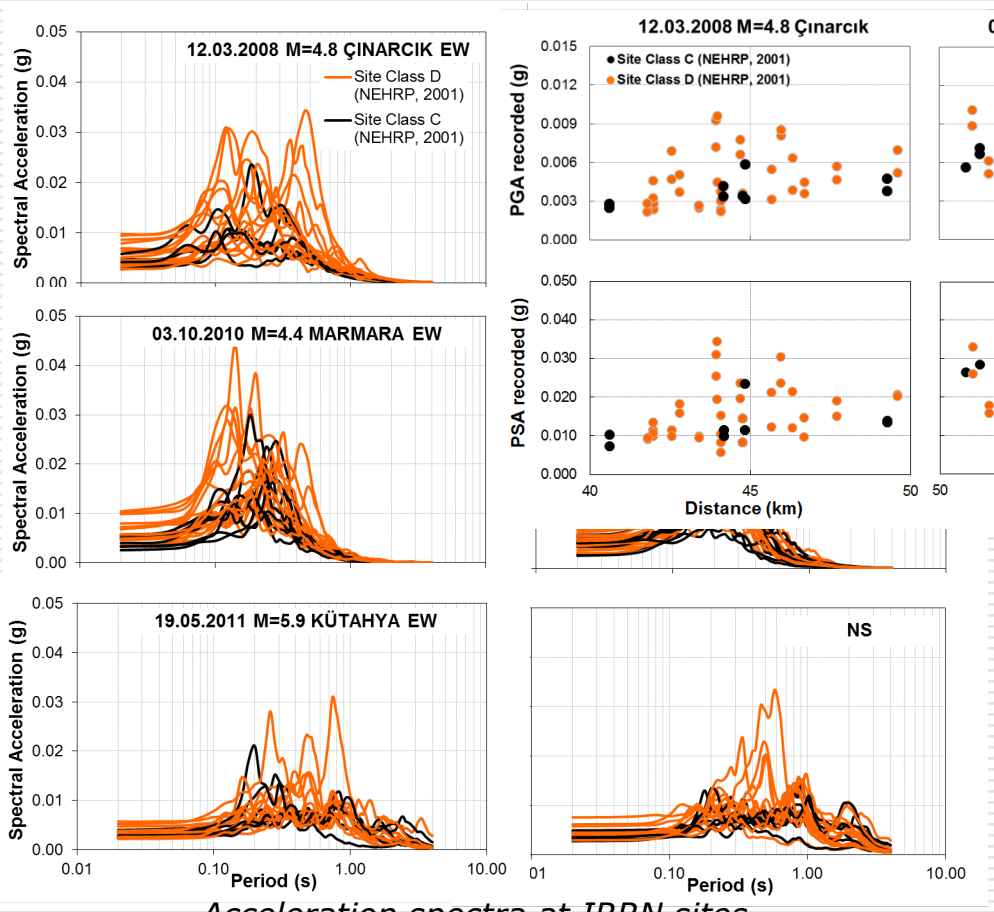
Acceleration spectra of downhole records during the 12/03/2008 M=4.8 Çınarcık, 03/10/2010 M=4.4 Marmara and 19/05/11 M=5.9 Kütahya events

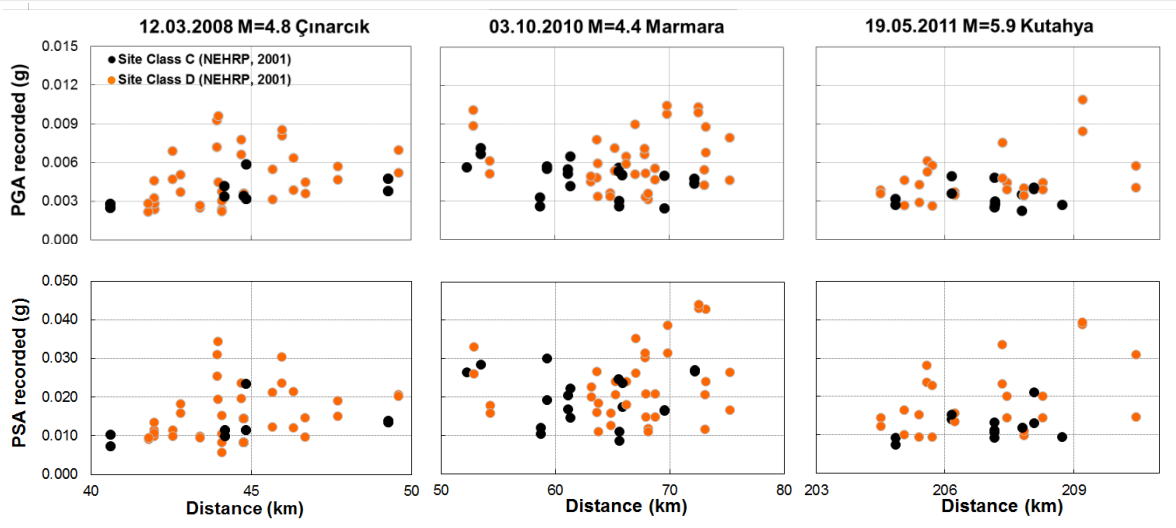
Recorded at Downhole Arrays



- Max Amplification: 4
  T_{max}: 0.9s
  $T_o = 4H/V_S$ =1.1s
- Max Amplification: 7
  T_{max}: 1.5s
  T_o = 2.7s
- Max Amplification: 12
  T_{max}: 0.5s
  T_o = 0.6s

Recorded at IRRN Stations

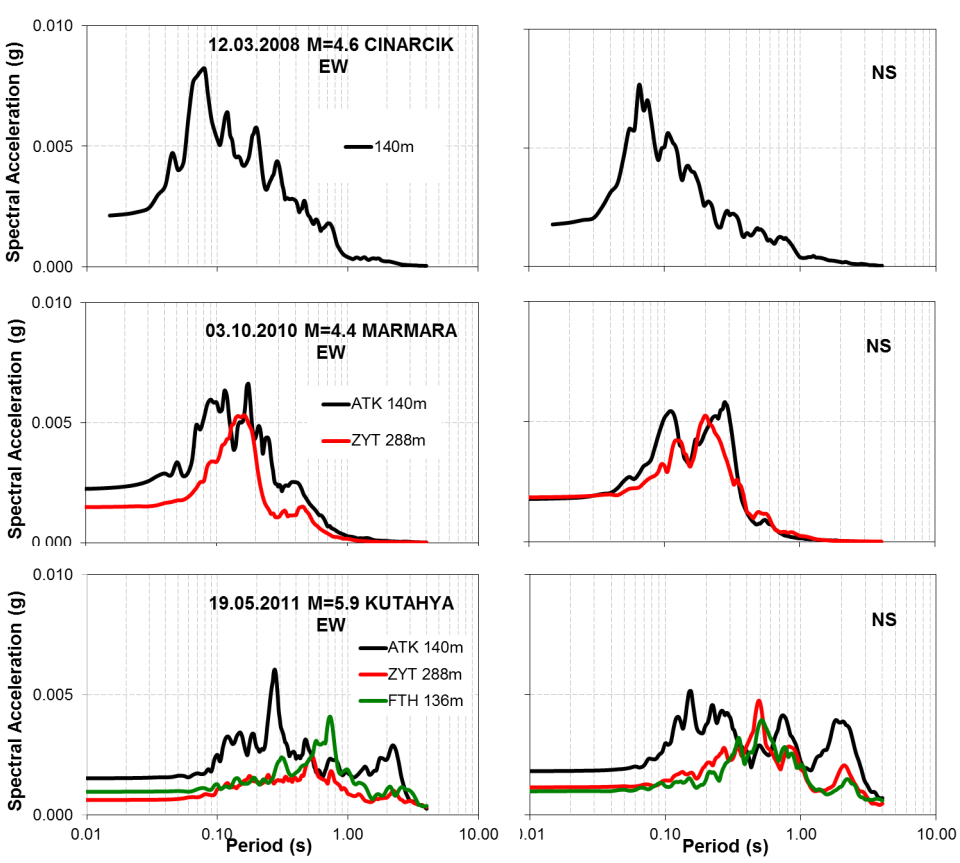




Acceleration spectra at IRRN sites

- High scatter within each event
- All sites have comparable V_{S30}

Recorded and Modeled Response

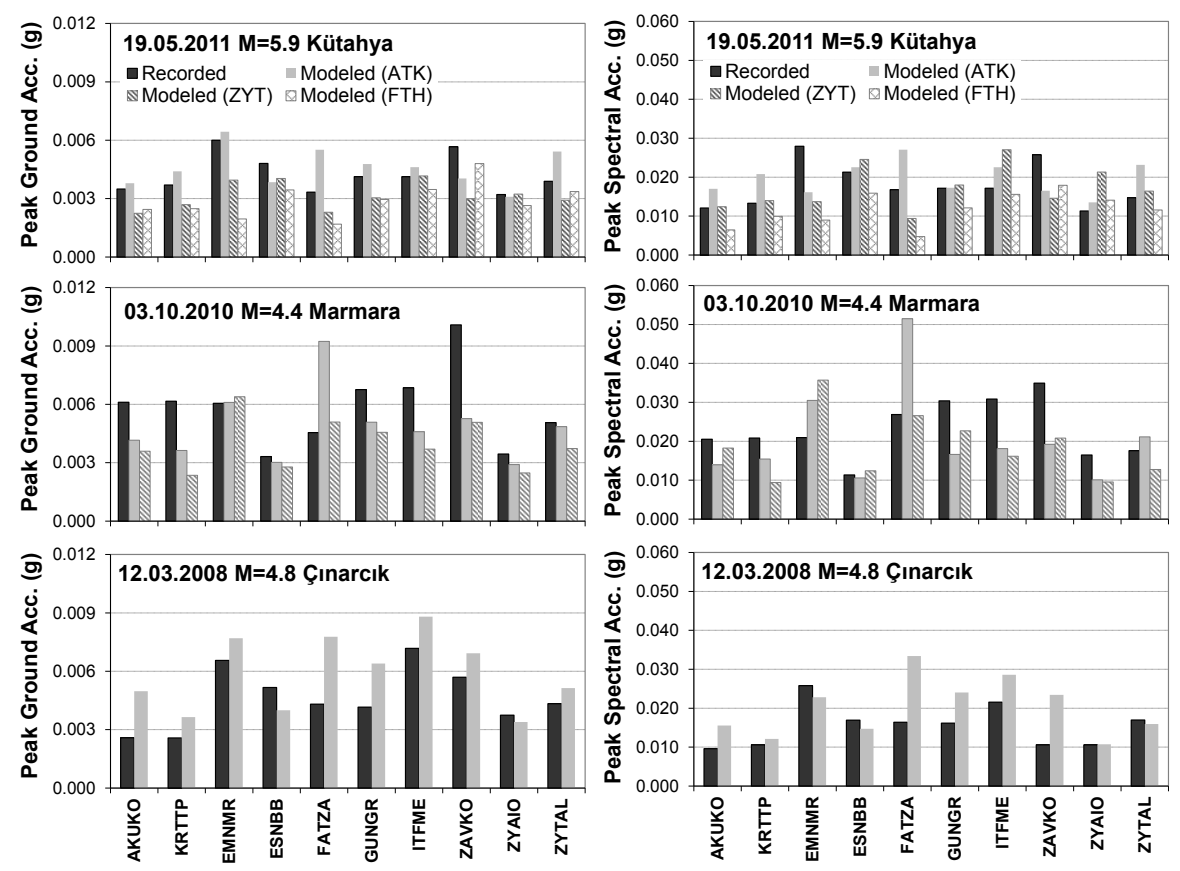


Acceleration spectra of the deepest accelerometers at ATK, ZYT, and FTH sites

Modeling recorded respose at IRRN sites:

- 1-D analysis using Shake91
- Input motion as recorded by deepest accelerometers at ATK, ZYT, FTH sites

Recorded and Modelled Response



Differences in calculated ground motion parameters depending on the input acceleration time history

- Different bedrock geology
- Measured V_S in the range of 1000 m/s not sufficiently representing the engineering bedrock

Application of Seismic Interferometry

- Deconvolution to separate the response of soil layers from the incoherent waveforms. Once isolated from interacting up and downgoing waves, travel times can be calculated.

- The two standard approach to calculate wave travel times:

  time differences between characteristics peaks

  time lag where the cross-correlation has a maximum

  acceptable for non-dispersive, non-attenuating media.

- Waves do change their shapes due to attenuation while travelling through soil layers. Phase shifts caused by the combined effect of wave travel times plus the phase distortions due to damping.

- Phase shifts introduced by damping can be eliminated by using the envelope functions. Envelope functions are not affected by dispersive medium.

- The travel times from envelope functions are smaller; the difference representing the phase shift due to material damping.

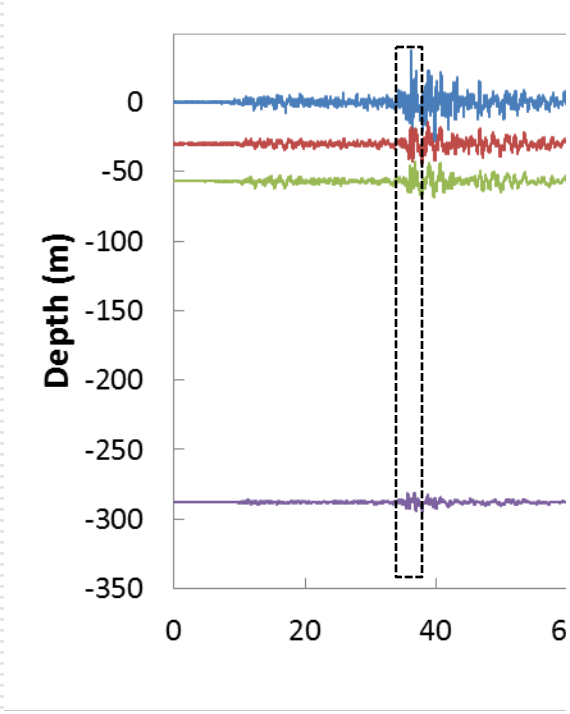
Application of Seismic Interferometry

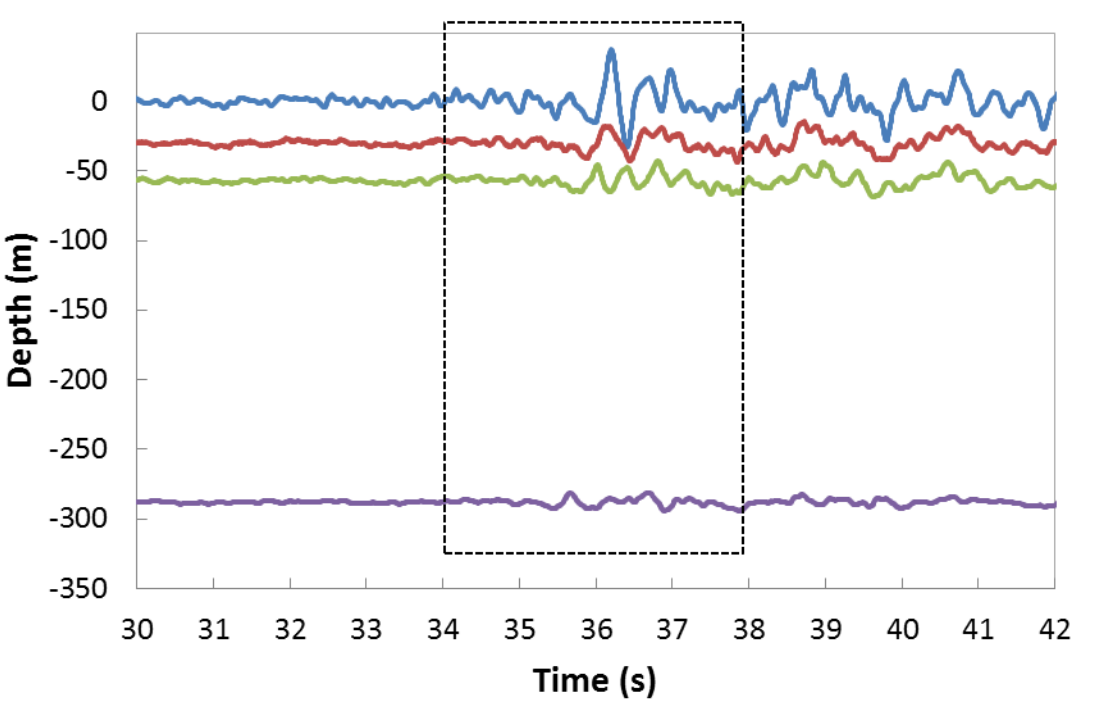
Approach:

- Deconvolution instead of cross-correlation to separate the response of soil layers from the incoherent waveforms
- Deconvolution with surface record instead of deepest: to obtain a simple downgoing wave
- Regularized deconvolution: to avoid instability $D(\varpi) = A(\omega) * B(\omega) / (|B(\omega)|^2 + \varepsilon)$
- Hilbert transform and corresponding analytic signal to calculate envelope of deconvolved waveforms $E[d(t)] = d(t) + iH[d(t)]$
- Cross-correlation to calculate travel times for the deconvolved waves and their envelopes
- Travel-time difference to obtain Q and corresponding material damping ratio $\tau' \approx (1 - i(1/2Q))\tau$

Application of Seismic Interferometry

- NS component of 19.05.2011 Kütahya event recorded at ZYT site



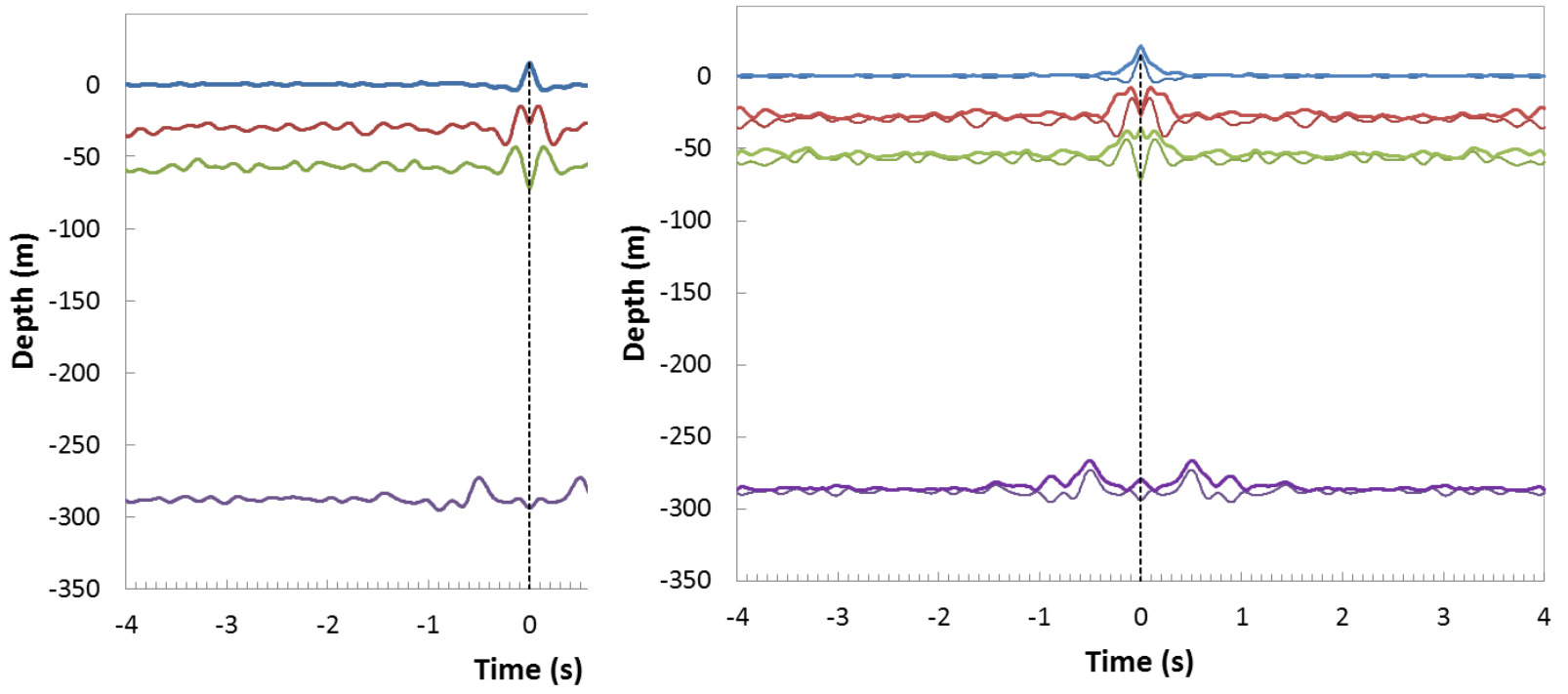


raw acceleration-time histories

time-window for S-wave arrival

Application of Seismic Interferometry

- Deconvolution with the surface record



deconvolution after narrow-bandpass filtering *envelope of deconvolved signals*

Application of Seismic Interferometry

- Dynamic properties of soil layers at ZYT extracted from downhole records

Sensor Depth (m)	Thickness (m)	V_S measured (m/s)	V_S from deconvolved waveforms (m/s)	V_S from envelope of deconvolved waveforms (m/s)	Q	Damping Ratio (%)
0	30	268	287	295	18	2.71
30	27	272	298	302	38	1.32
57	231	478	610	612	153	0.33
288	-	-	-	-	-	-

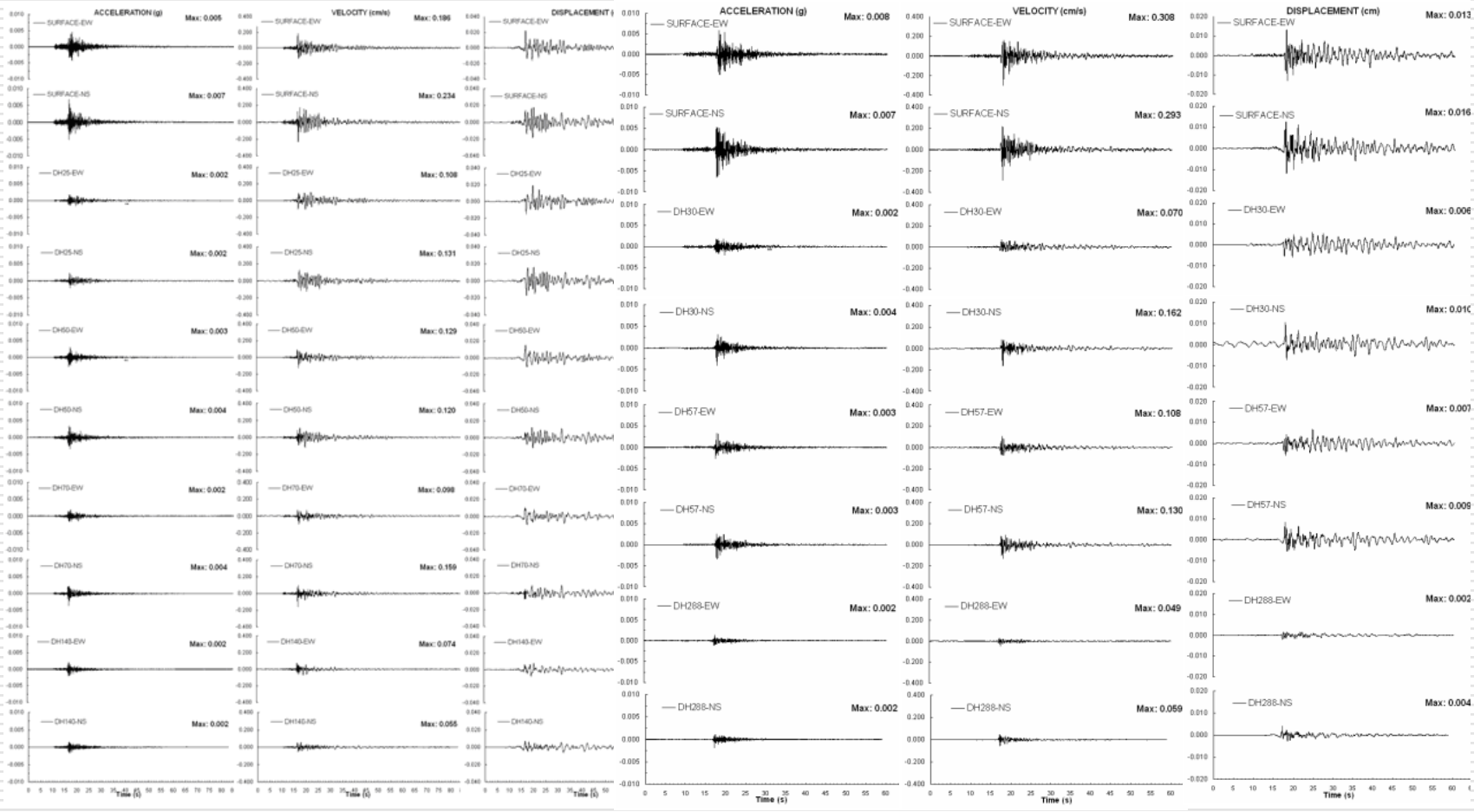
Conclusions

- Arrays are expected to provide valuable data for site response modeling given the existing high seismic activity of the region.
- More records of varying intensities would enable better understanding of soil response at these sites, particularly the shallow 'limestone' layer.
- Analysis of weak ground motions recorded at 39 strong motion stations located at sites with comparable V_{S30} demonstrates that V_{S30} alone is not a sufficient indicator of site amplification potential.
- Seismic interferometry technique can be used to extract dynamic properties of soil layers from downhole records.

Acknowledgements

- TÜBİTAK (The Scientific and Technological Research Council of Turkey)
- Boğaziçi University, Turkey
- Istanbul Metropolitan Municipality, Turkey
- Potsdam GFZ, Germany

Recorded at Downhole Arrays



ATK 12/03/2008 M_L=4.6 Çınarcık **ZYT 03/10/2010 M_L=4.4 Marmara**

Recorded and Modelled Response