Earthquake Performance and Protection of Hagia Sophia

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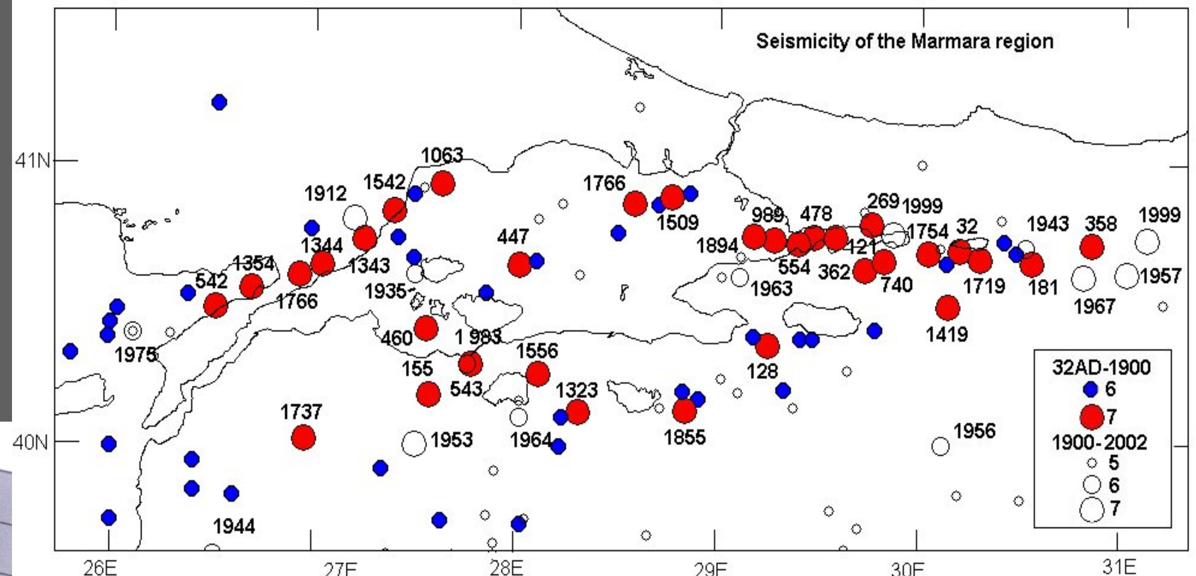
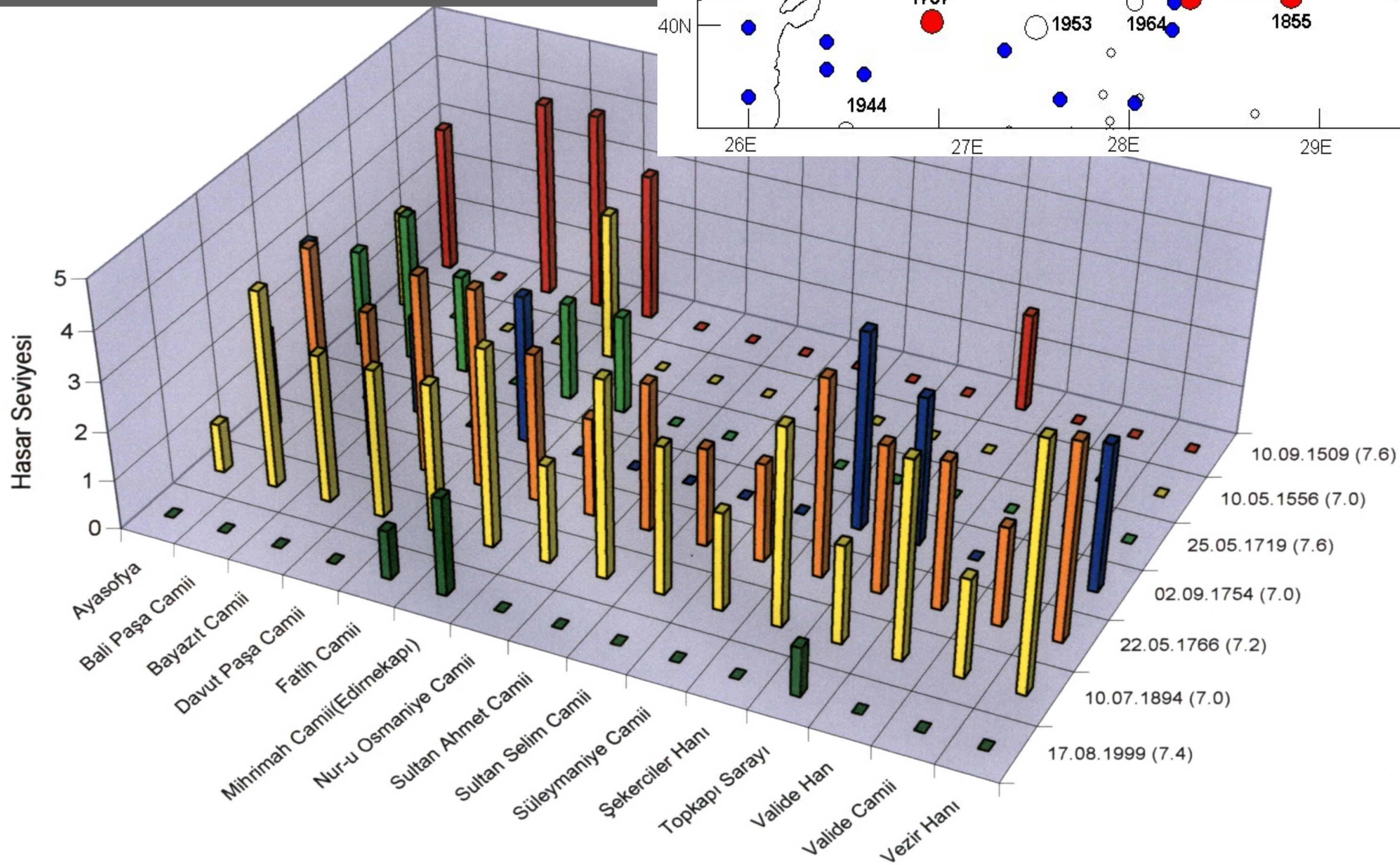
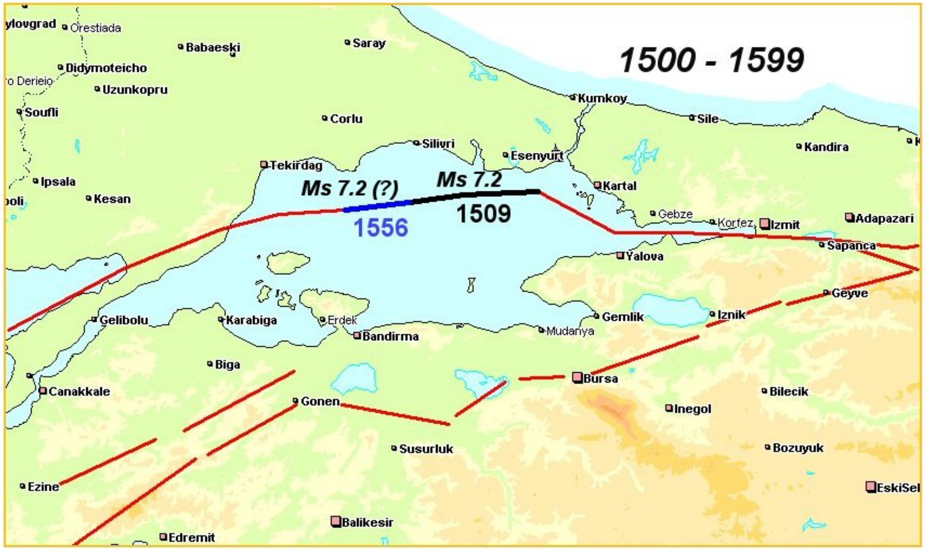
Past damages to historical structures in Istanbul

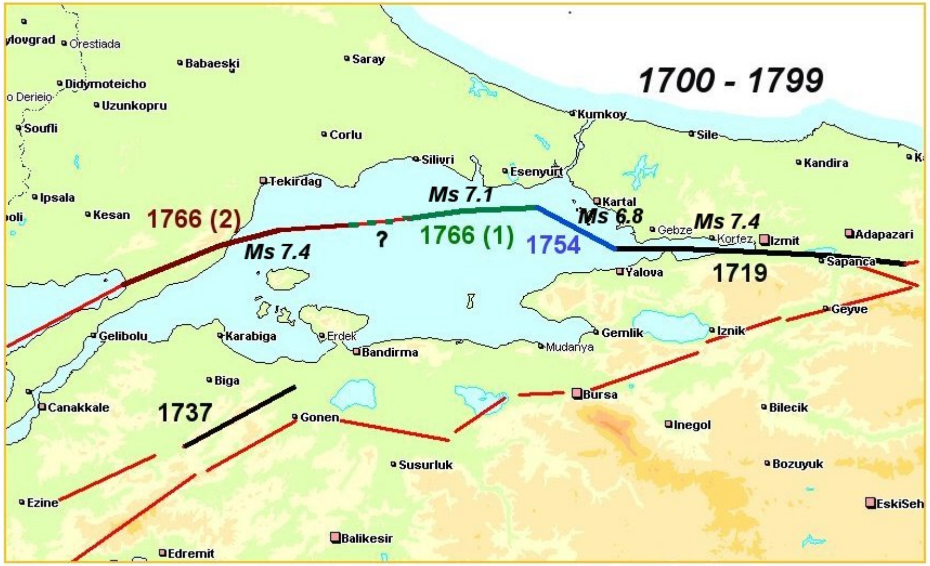


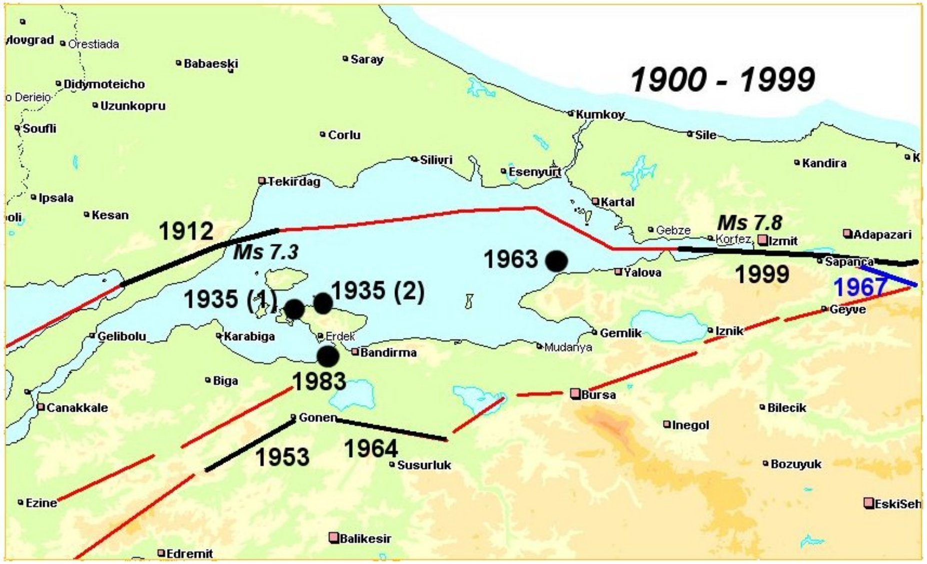


Şekil 2. Istanbul'da tarihi yapılardaki deprem hasarı

Earthquakes with M>7 over the centuries







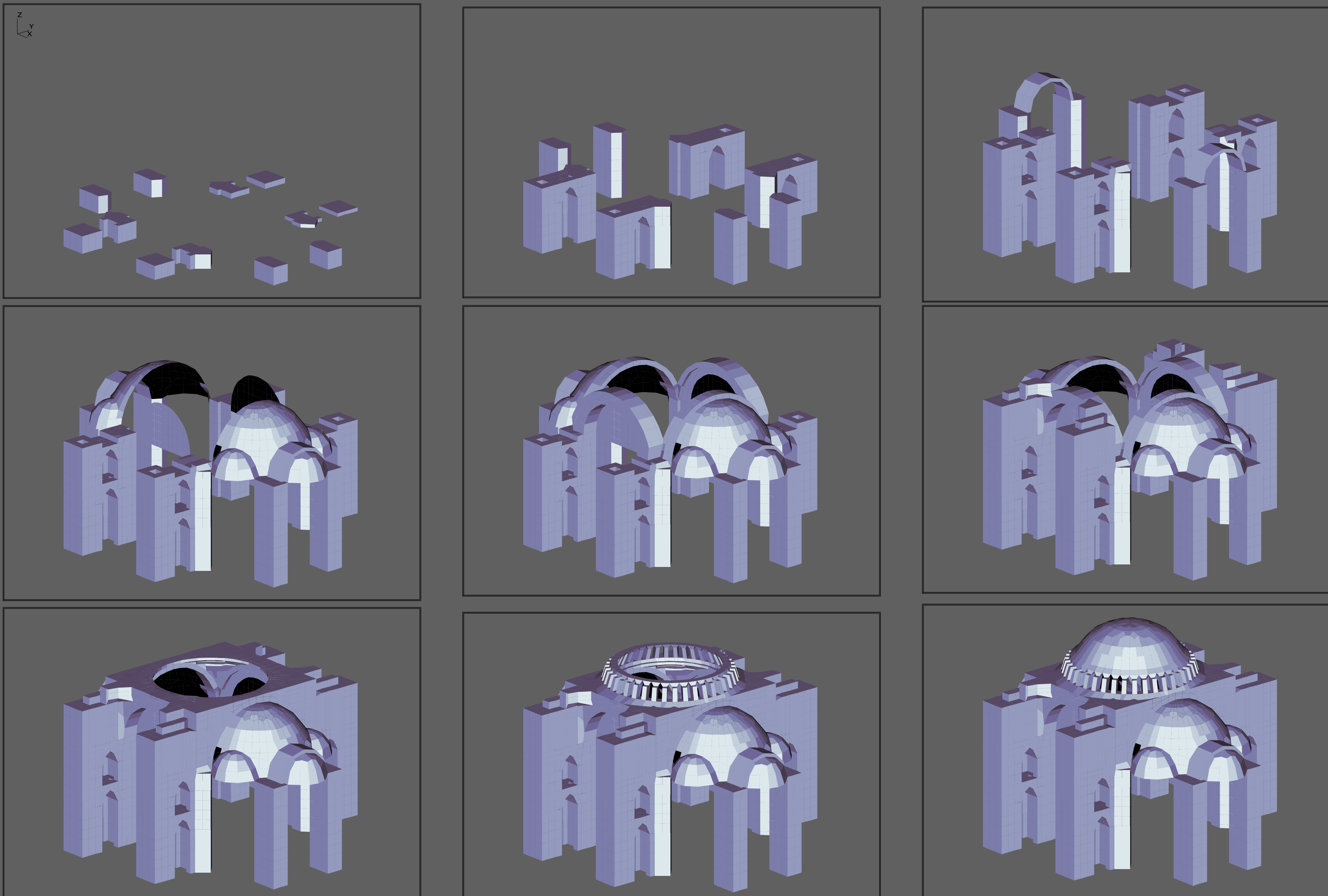
HAGIA SOPHIA
DAMAGE HISTORY

- 23 February 532 — Construction starts
- 27 December 537 — Inauguration
- 554-557 — *Weakening and collapse of the east main arch and part of domes*
- 9 January 869 — Partial damage
- 25 October 989 — *Collapse of the west main arch and part of domes*
- 19 May 1346 — *Collapse of the east main arch and part of domes*
- 10 September 1509 — Partial damage
- 10 May 1556 — Partial damage
- 2 September 1754 — Partial damage
- 22 May 1766 — Partial damage
- 10 July 1894 — Light damage

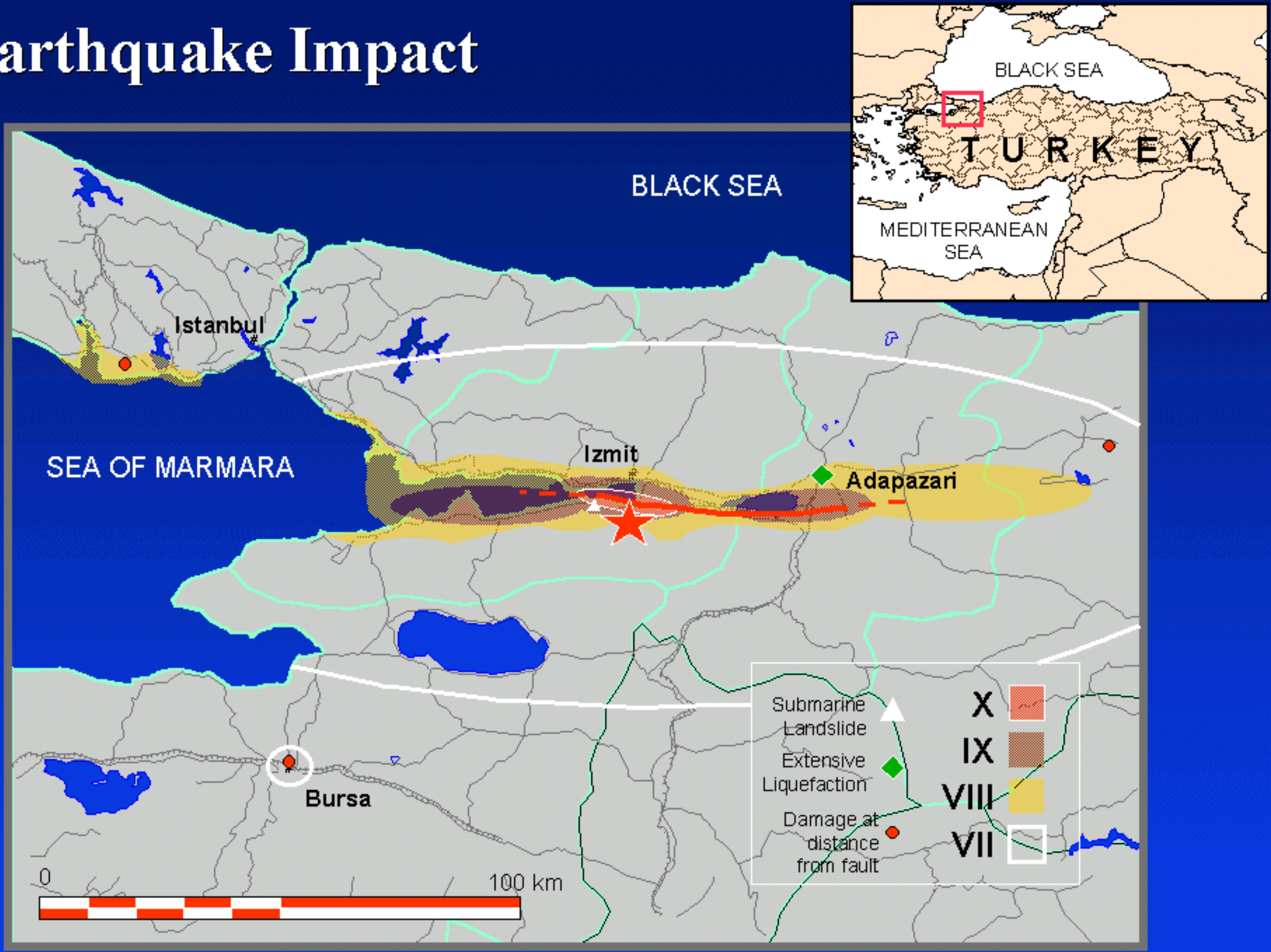
Current Situation

- Along the north south direction main piers have an 85 cm outward inclination from ground level to top of the piers.
- The east west direction the piers exhibit 16 cm outward inclination.
- The crowns of north, south, east and west arches have vertical displacements of 9, 18, 26, 13 cm in the direction of gravity respectively.
- The east and west arches tilt inward 14 and 15 cm due to semidomes attached to them.
- The north and south arches’ crowns also lead outward 60 and 57 cm respectively.
- The high values of displacements should be the result of short construction period and long curing time of mortar. It is believed that the current deformation seen today occurred mostly while the construction was going on.

Hagia Sophia Construction Stages (?)



Earthquake Impact



Historical Buildings in Istanbul effected by the 17 August 1999 Kocaeli earthquake

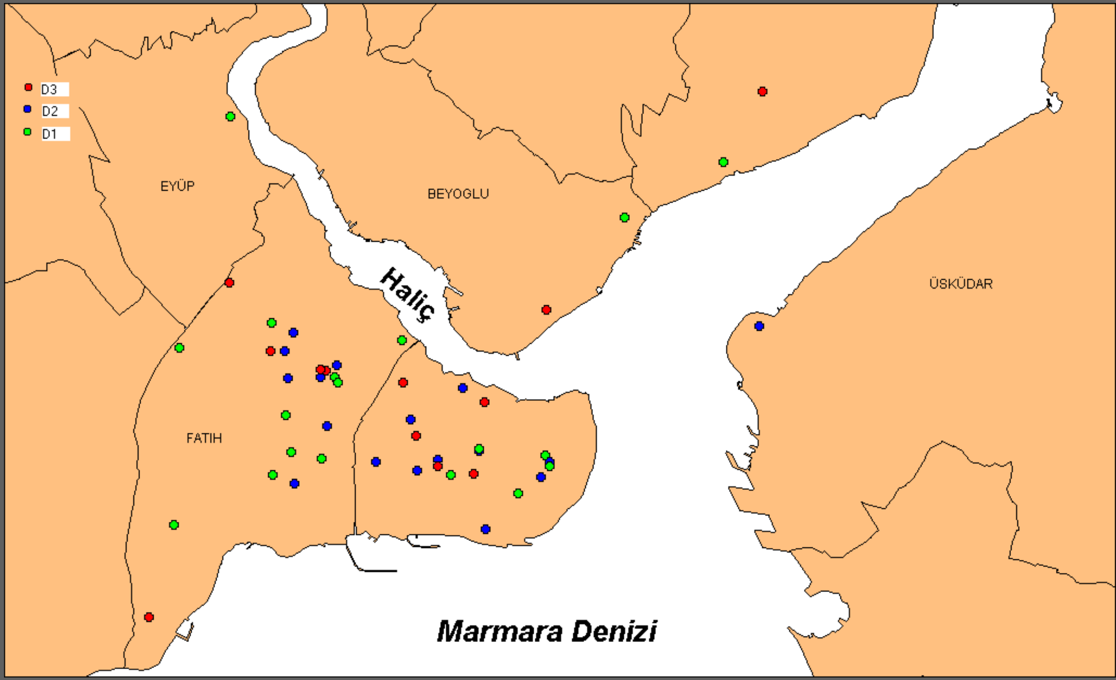
Mihrimah Sultan Mosque

damaged in 1640, 1690, 1719, 1766, 1894 and 1999 eq's

Fatih Mosque

formerly church of Holy Apostels, damaged by eq's in 358, 1010, 1296
collapsed in 1462, damaged in 1509, 1690, 1754, 1766, 1894 and 1999 eq's.

Millet Library
İslam Eserleri Library
Topkapı Palace
Beyazıt Librray
Süleymaniye Library
Dolmabahçe Palace
Ragıp Paşa Library
Hatice Turhan Sultan Tomb
Archeological Museum,
New Bldg



D1: fall of plaster, thin cracks,
D2: localized cracks in the structural system, D3: widespread cracking in the structure

From the structural and earthquake engineering point of view

- **Empirical Assessment of Structural Performance**

  Assessment of subground conditions, foundations and structural properties; structural materials, visible and hidden damages, visible or hidden interventions.

  Monitoring of static and dynamic deformations

- **Analytical Assessment of Structural Performance**

  Numerical modelling for understanding dynamic and static characteristics of structural behaviour, also for understanding the effectiveness of strengthening proposals.

- **Stabilization and Retrofit (Improvement of Earthquake Performance)**

ANALYSIS OF EARTHQUAKE VULNERABILITY OF HAGIA SOPHIA: A TECHNICAL OVERVIEW (1/2)

-

- Structural system properties and dimensions:
  existing drawings, literature and photogrammetric measurements.
- Material properties:
  in-situ non-destructive- and in-situ shear testing.
  Chemical and physical properties of mortar
- Soil and foundation properties and the sub-structure:
  seismic refraction, seismic tomography, geo-radar and microgravimeter methods
- Existence and location of embedded iron ties and rings:
  magnetometric procedures.
- Forces on the tie bars of secondary arches: *dynamic methods.*
- Modal frequencies and shapes: *ambient vibration tests.*

ANALYSIS OF EARTHQUAKE VULNERABILITY OF HAGIA SOPHIA: A TECHNICAL OVERVIEW (2/2)

- Strong-motion instrumentation and analysis of data

  Nine inter-connected three-component accelerometers

- Simulation of expected earthquake ground motions at the site
- 3-D finite element modelling

  calibrated to yield the measured dynamic properties.

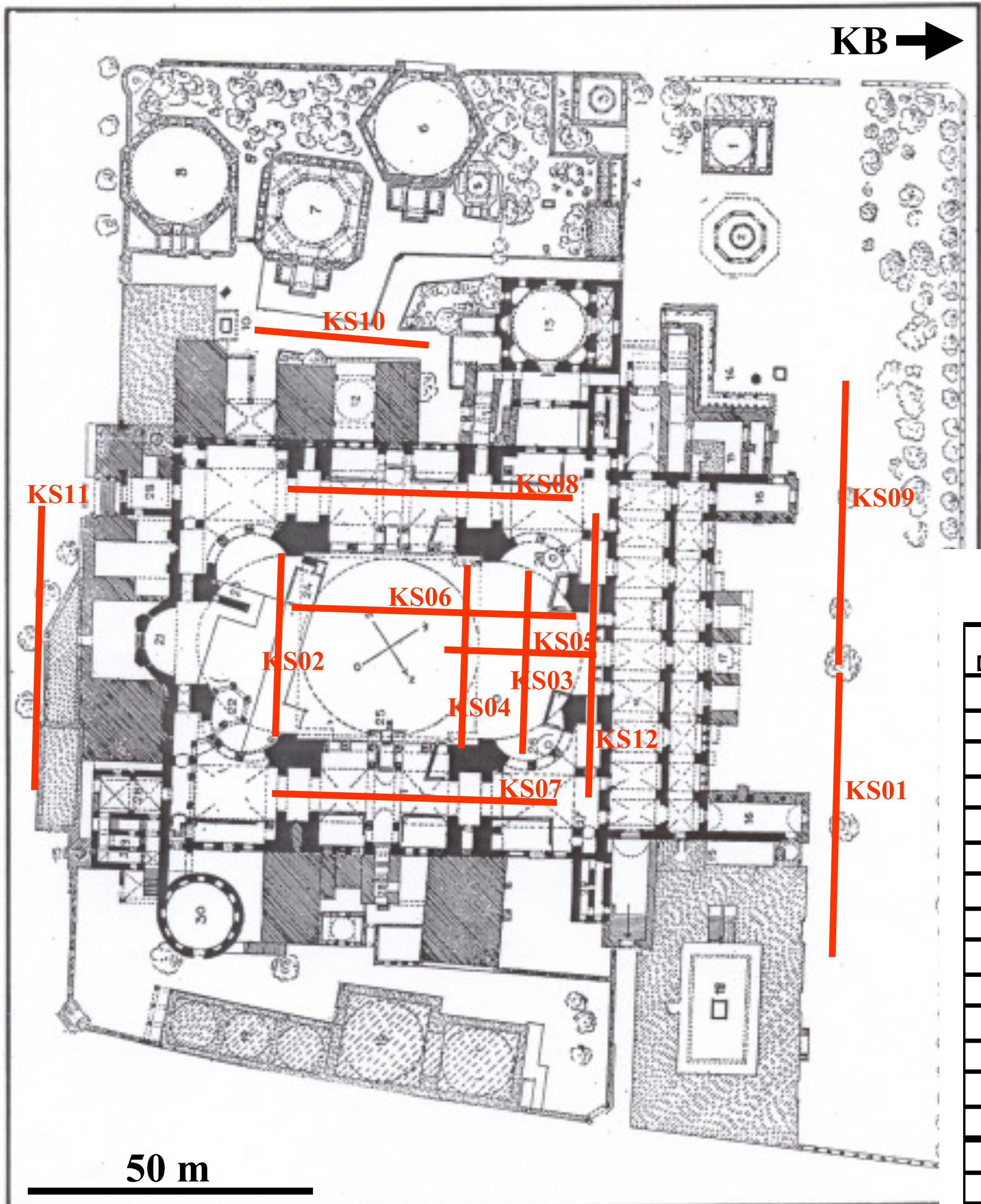
- Non-linear earthquake response analysis:

  determination of failure mechanisms

- Proposals for strengthening.
- Analysis of earthquake data from the 1999 earthquakes

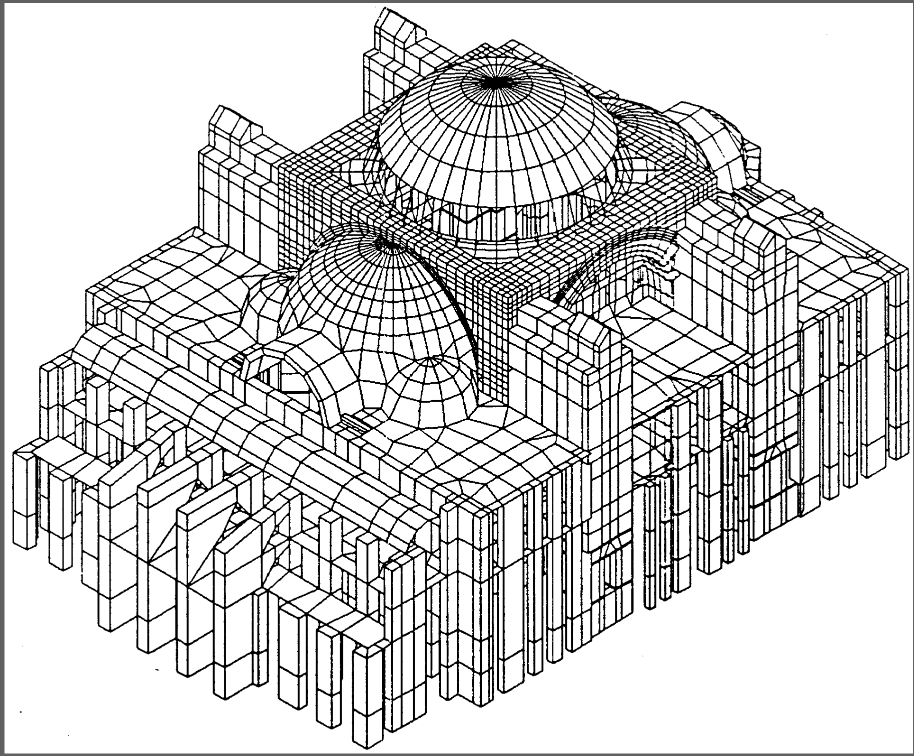
Ground Investigations

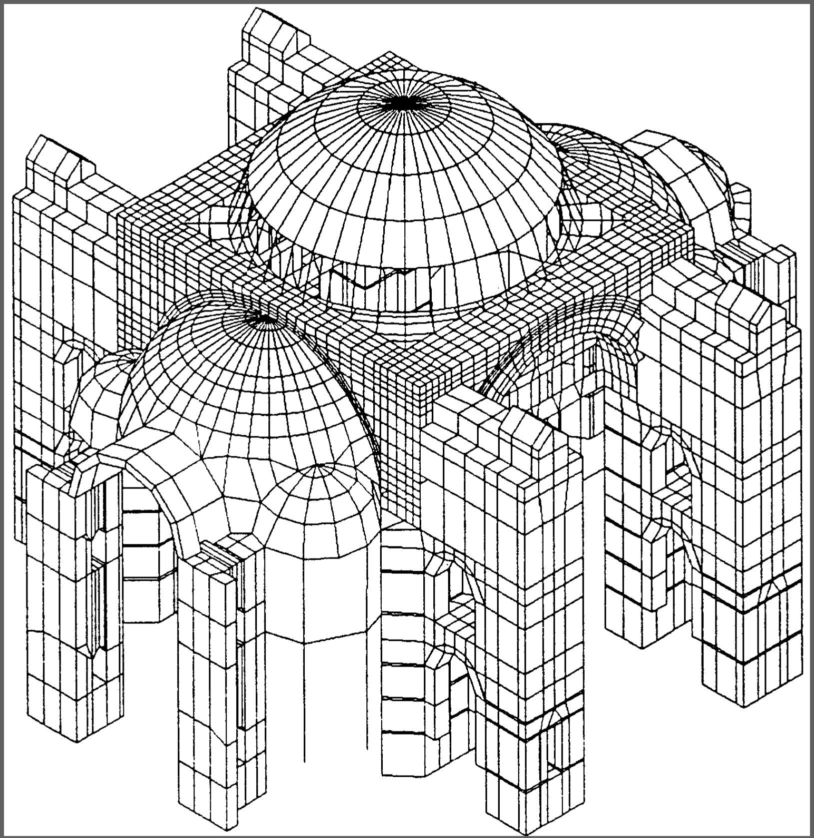
georadar, reflection

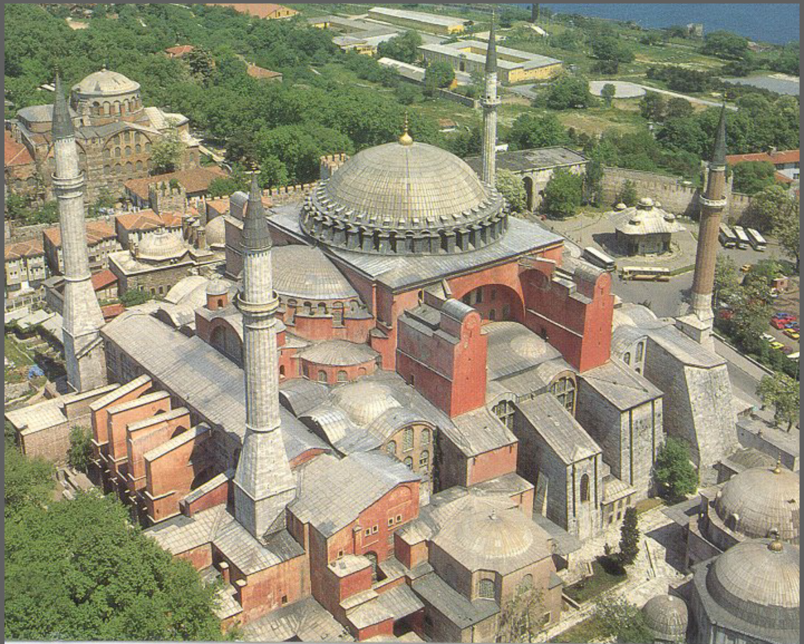


Vs **hız-derinlik değerleri (m/s)**

Metre Derinlik	KS 01	KS 03	KS 04	KS 07	KS 08	KS 09	KS 10	KS 11
0	475	447	394	581	400	447	442	363
1	475	447	394	581	400	447	442	363
2	223	331	337	581	316	275	458	241
3	223	289	337	549	641	275	288	241
4	404	554	622	549	641	292	376	269
5	607	554	769	707	744	292	376	269
6	607	658	902	707	826	539	581	474
7	607	658	902	707	826	539	581	474
8	698	673	1072	635	807	539	595	565
9	698	673	1072	635	807	614	595	565
10	837	766	1072	635	807	614	657	565
11	837	766	1174	622	902	614	657	548
12	837	766	1174	622	902	707	657	548
13	837	975	1174	622	902	707	847	548
14	1070	975	1278	622	964	707	847	548
15	1070	975	1278	934	964	707	847	770
16	1070	975	1278	934	964	707	847	770
17	1070	1122	1278	934	1353	828	930	770
18	1227	1122	1799	934	1353	828	930	770
19	1227	1122	1799	934	1353	828	930	908
20	1227	1122	1799	951	1353	828	930	908







Hagia Sophia Finite Element Model

Ambient Vibration Testing

The ambient vibration and eigenvalue frequencies

Mode Number	Ambient vibration frequencies	Eigenvalue frequencies	Dominant motion
1	1.75*	1.79	East-West
2	2.01*	2.11	North-South including slight torsion
3	2.35**	2.26	Torsional
4	2.50**	3.26	Northeast-Southwest breathing
5	2.80**	3.38	East-West breathing

*Durukal, 2000
**Durukal, 1992

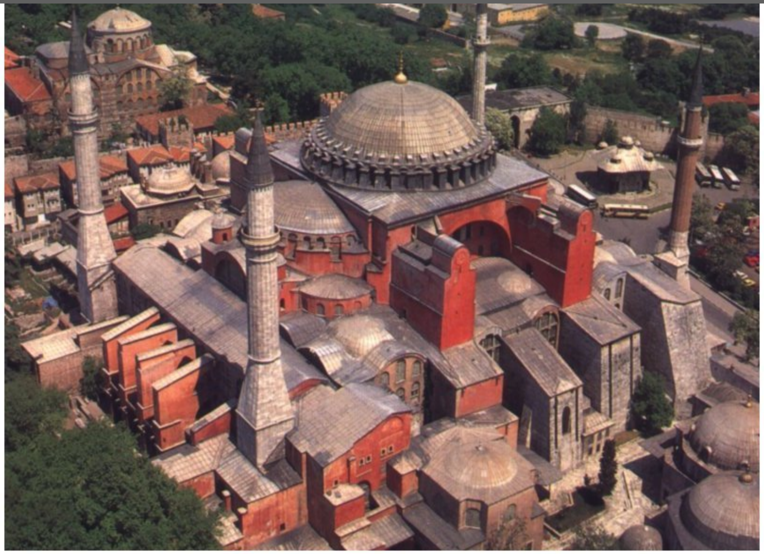
HS f1= 1.8 Hz, f2= 2.01 Hz

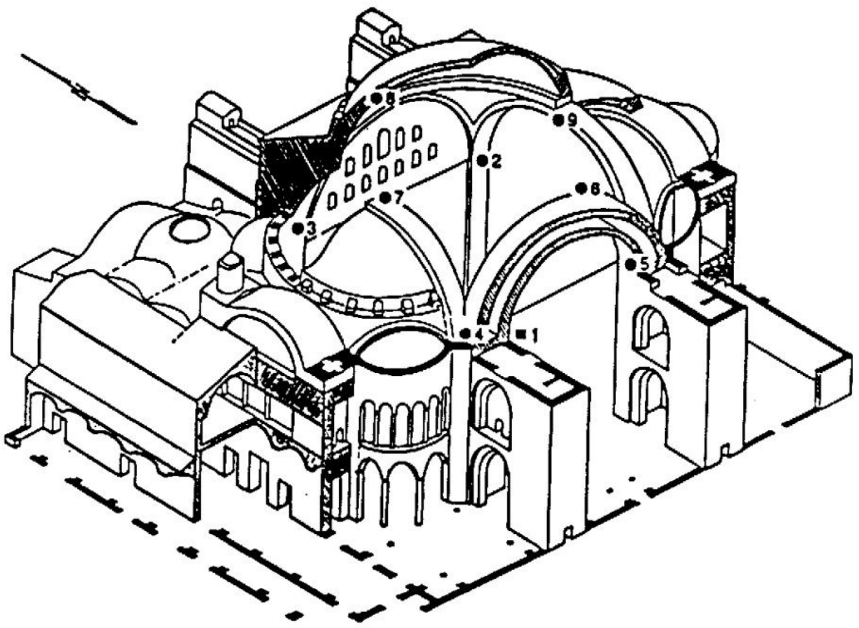
Süleymaniye M. f1= 3.35 Hz, f2= 3.50 Hz

Sultanahmet M,f1= 1.83 Hz, f2= 1.93 Hz

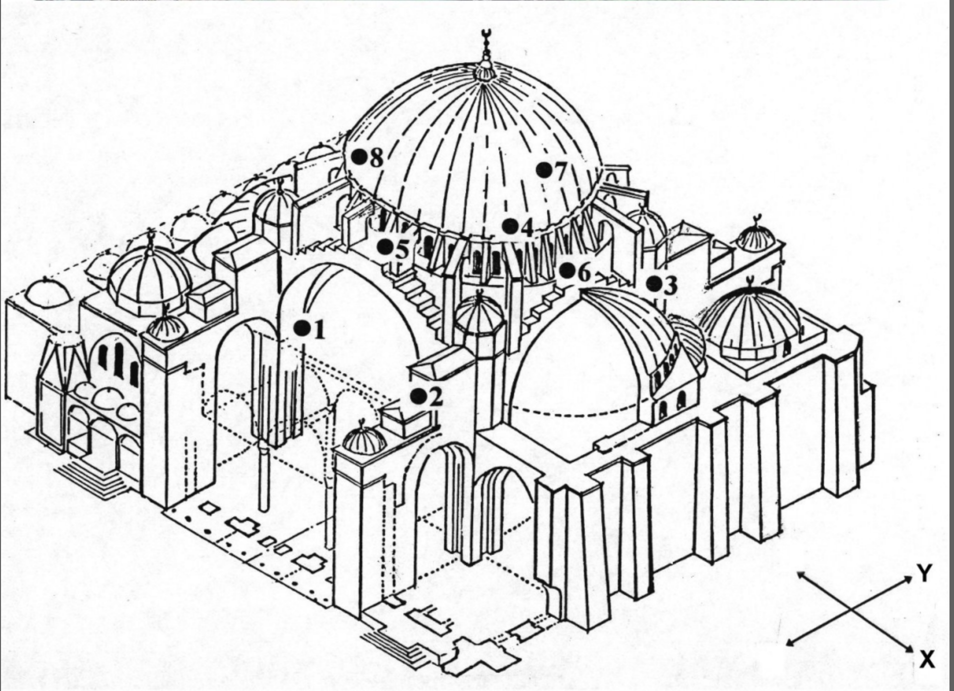
Mihrimah S.M. f1= 2.23 Hz, f2= 2.60 Hz

Strong Motion Instrumentation



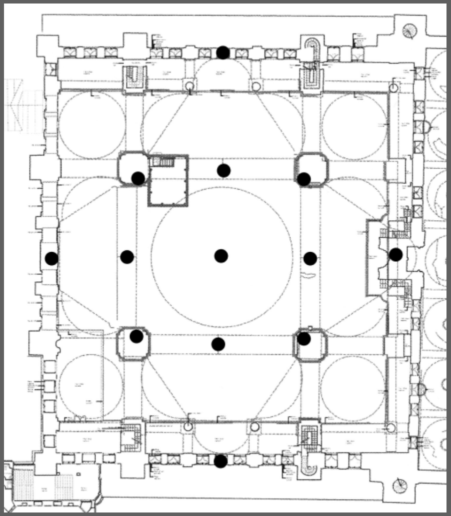


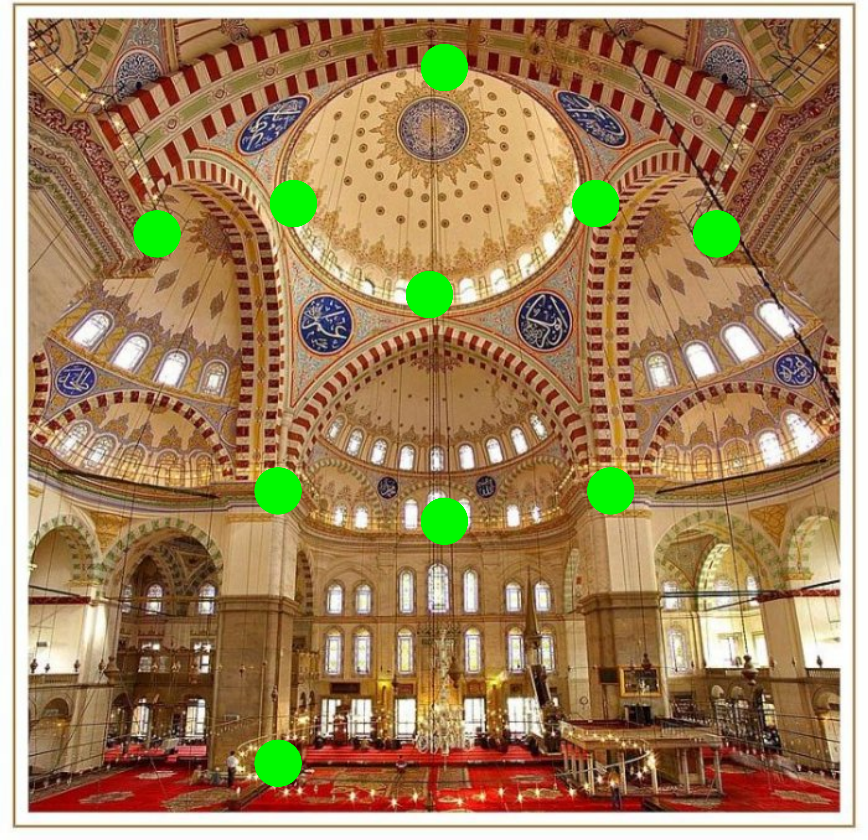

4
5
2
3
1

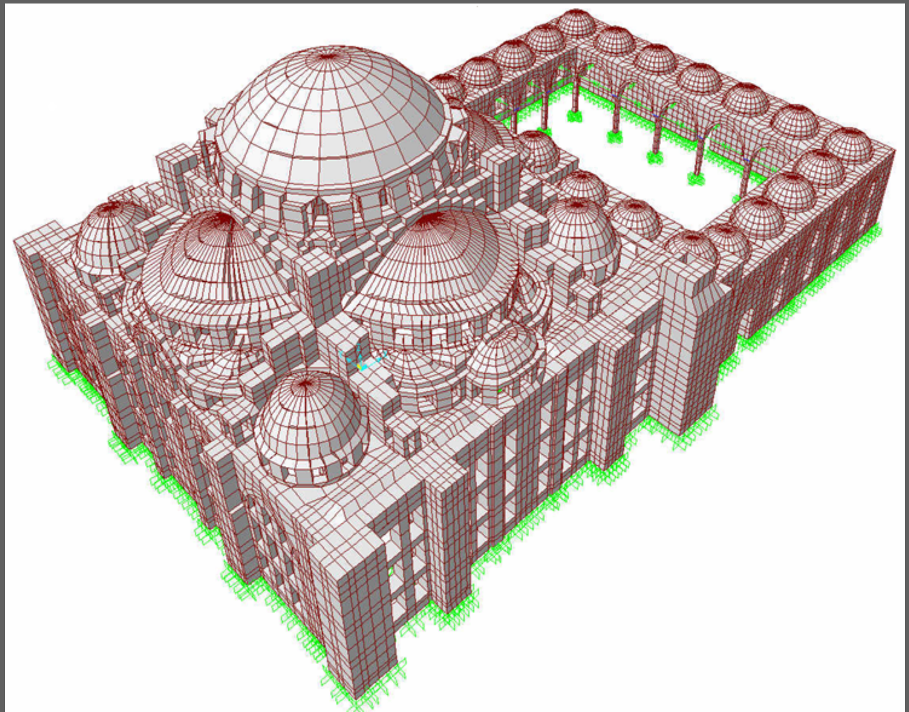


Süleymaniye

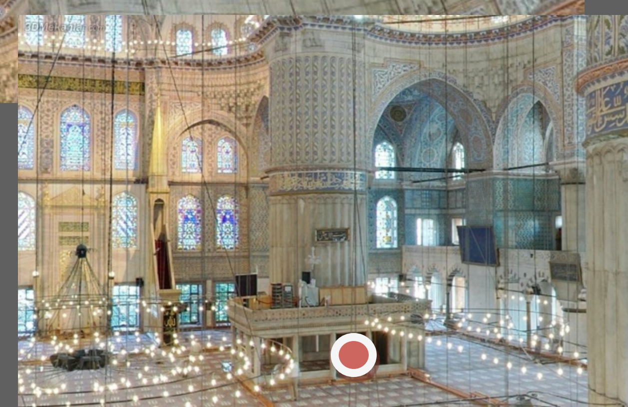
FATIH MOSQUE EARTHQUAKE MONITORING SYSTEM



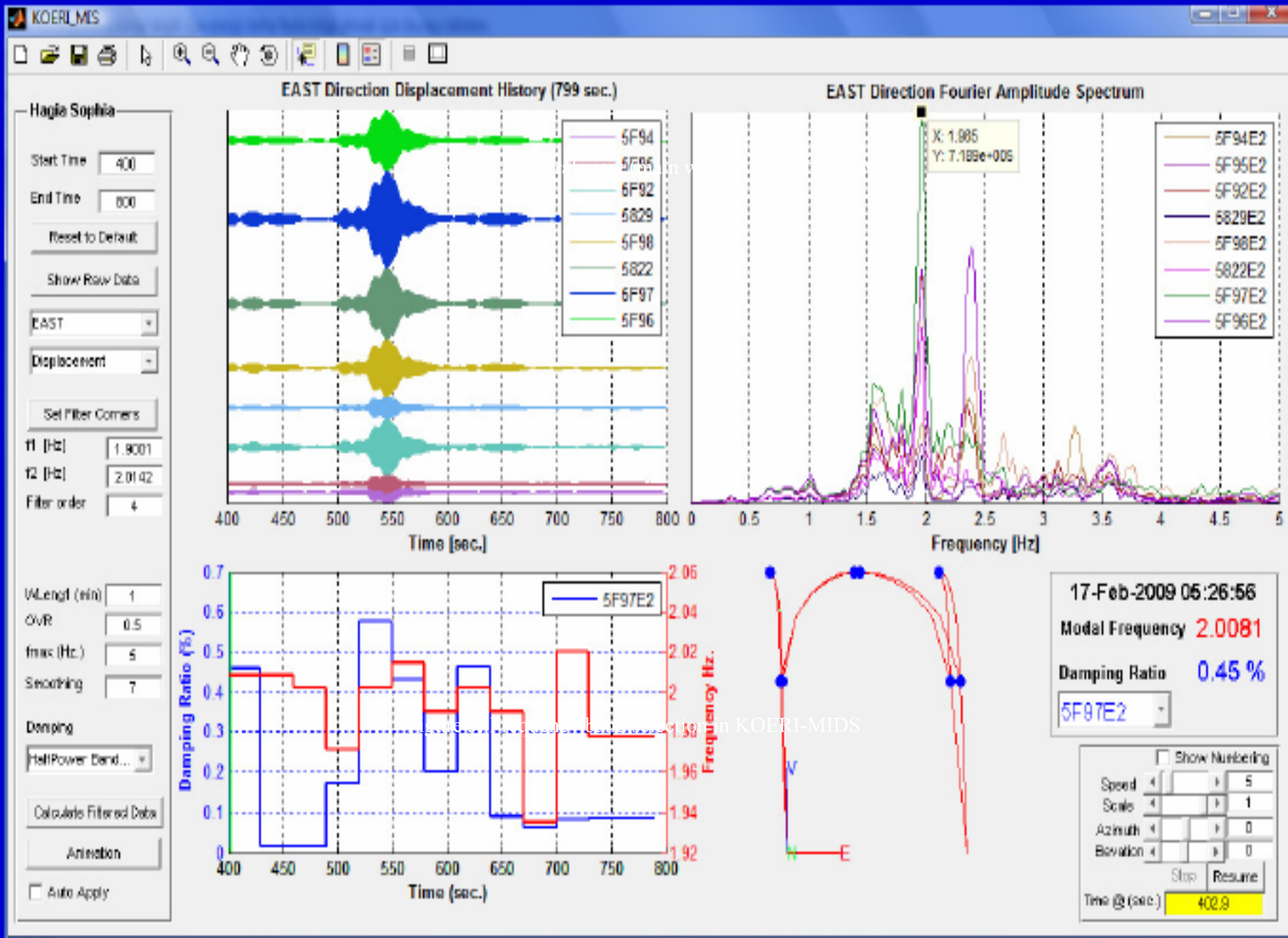




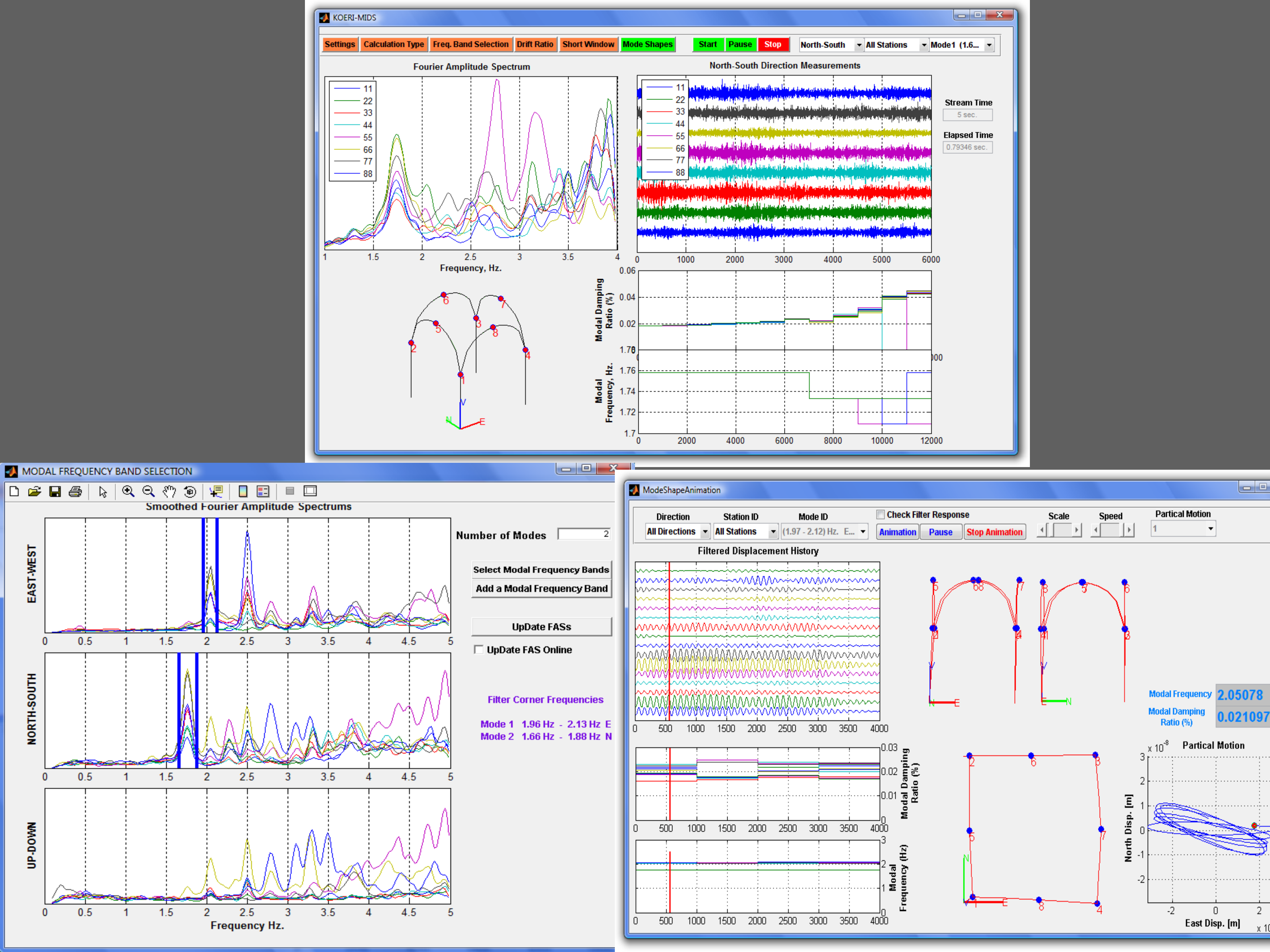
Sultanahmet Mosque



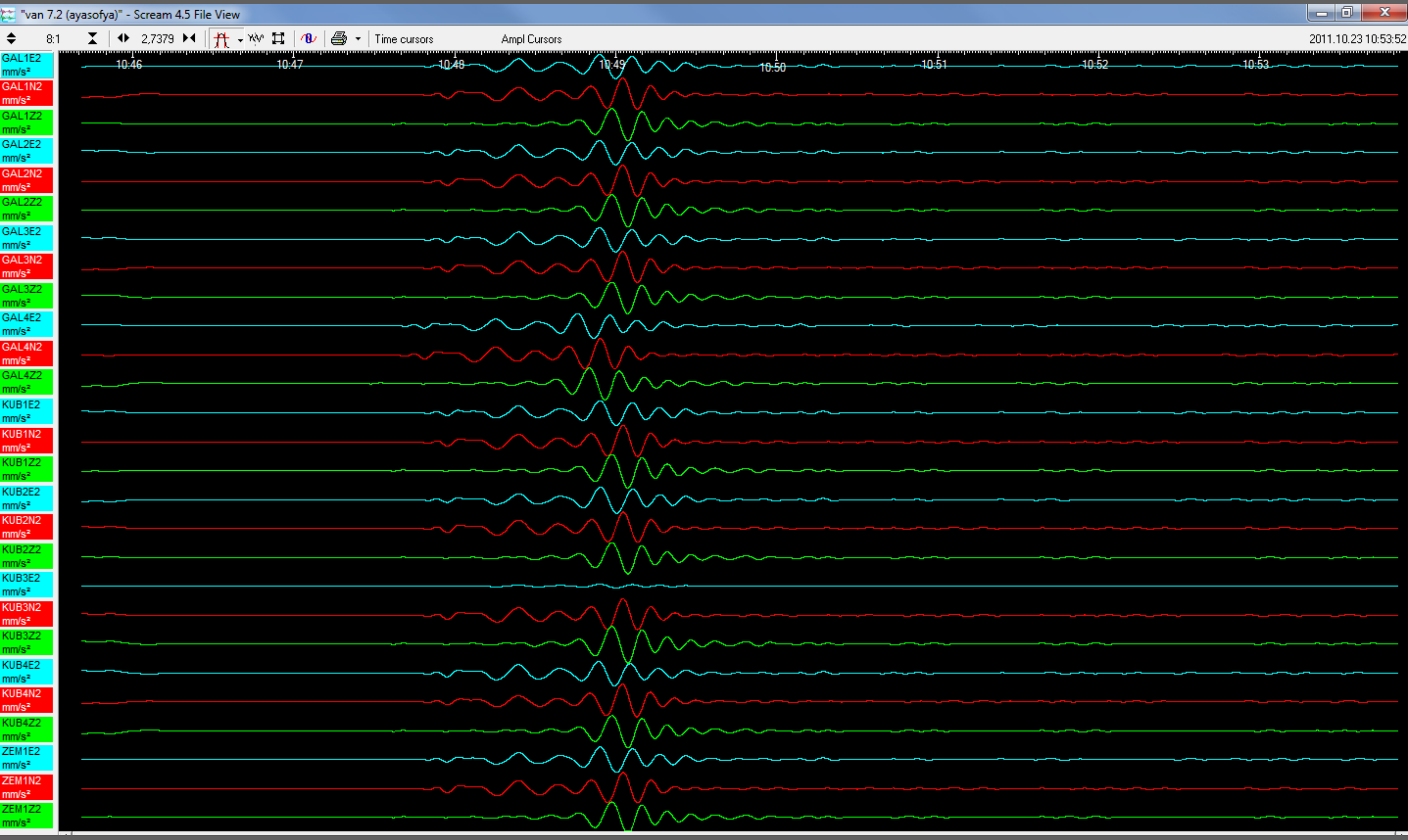
KOERI_MIS



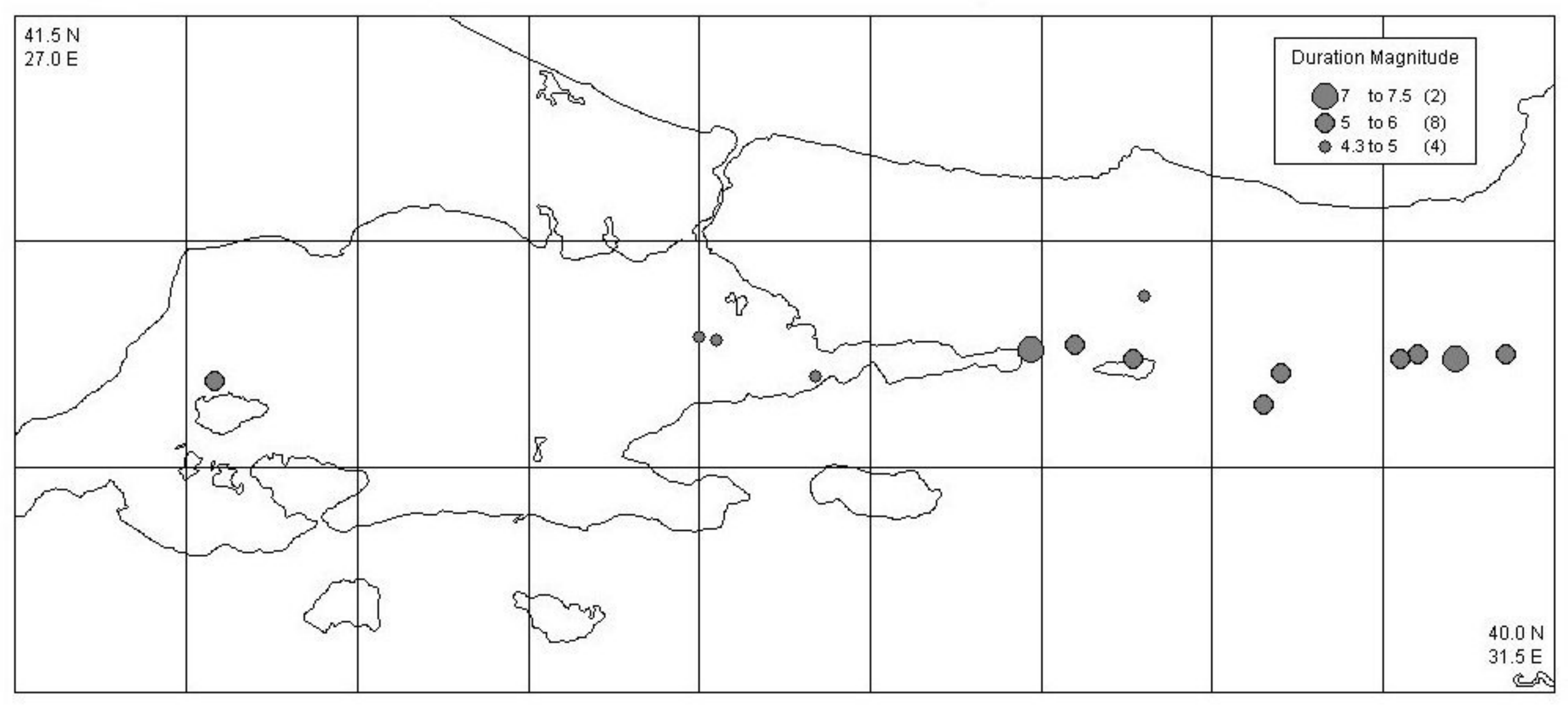
KOERI_MIS
EAST Direction Displacement History (799 sec.)
EAST Direction Fourier Amplitude Spectrum
Hagia Sophia
Start Time
400
End Time
800
Reset to Default
Show Raw Data
EAST
Displacement
Set Filter Corners
f1 [Hz]
1.9001
f2 [Hz]
2.0142
Filter order
4
W.Lengt (min)
1
OVR
0.5
fmax (Hz.)
5
Smoothing
7
Damping
HalfPower Band...
Calculate Filtered Data
Animation
Auto Apply
5F94
5F95
5F92
5829
5F98
5822
5F97
5F96
Time [sec.]
X: 1.985
Y: 7.189e+006
5F94E2
5F95E2
5F92E2
5829E2
5F98E2
5822E2
5F97E2
5F96E2
Frequency [Hz]
Damping Ratio (%)
Frequency Hz.
5F97E2
Time (sec.)
17-Feb-2009 05:26:56
Modal Frequency 2.0081
Damping Ratio 0.45 %
5F97E2
Show Numbering
Speed
5
Scale
1
Azimuth
0
Elevation
0
Stop
Resume
Time @ (sec.)
402.9


KOERI-MIDS
Settings
Calculation Type
Freq. Band Selection
Drift Ratio
Short Window
Mode Shapes
Start
Pause
Stop
North-South
All Stations
Mode1 (1.6...
Fourier Amplitude Spectrum
Frequency, Hz.
North-South Direction Measurements
Stream Time
5 sec.
Elapsed Time
0.79346 sec.
Modal Damping Ratio (%)
Modal Frequency, Hz.
MODAL FREQUENCY BAND SELECTION
Smoothed Fourier Amplitude Spectrums
EAST-WEST
NORTH-SOUTH
UP-DOWN
Frequency Hz.
Number of Modes
Select Modal Frequency Bands
Add a Modal Frequency Band
UpDate FASs
UpDate FAS Online
Filter Corner Frequencies
Mode 1 1.96 Hz - 2.13 Hz E
Mode 2 1.66 Hz - 1.88 Hz N
ModeShapeAnimation
Direction
Station ID
Mode ID
Check Filter Response
Scale
Speed
Partical Motion
All Directions
All Stations
(1.97 - 2.12) Hz. E...
Animation
Pause
Stop Animation
Filtered Displacement History
Modal Damping Ratio (%)
Modal Frequency (Hz)
Modal Frequency
2.05078
Modal Damping Ratio (%)
0.021097
Partical Motion
North Disp. [m]
East Disp. [m]

23 October 2011, Mw 7.2 Van, Turkey earthquake
as recorded by the Hagia Sophia network in Istanbul, about 1250 km west of Van



1999 Kocaeli (Mw=7.4) and Düzce (Mw=7.2) Earthquake Records in Hagia Sophia and Suleymaniye



HAGIA SOPHIA

Table 1. Records obtained during the Kocaeli and Düzce earthquakes in Hagia Sophia

Event Date	Event Time	Event Location	Event Coordinates		Magnitude	Max.Acc-EW*	Max.Acc.-NS*	Max.Acc.-z*	Triggered Stations								
		local	North	East	Md	cm/s2	cm/s2	cm/s2	S1	S2	S3	S4	S5	S6	S7	S8	S9
8/17/1999	3.02	Izmit	40.76	29.97	7.4	53,6 (4)	76,5 (2)	53,7 (2)	-	Y	-	Y	-	-	-	-	-
8/17/1999	3.17					5,4 (2)	6,1 (4)	2,4 (4)	-	Y	-	Y	-	-	-	-	-
8/17/1999	4.34					6,7 (2)	9,4 (4)	5,1 (2)	-	Y	-	Y	-	-	-	-	-
8/17/1999	4.49					5,4 (4)	3,5 (4)	3,1 (4)	-	Y	-	Y	-	-	-	-	-
8/17/1999	5.52					18,6 (4)	16,4 (4)	9,4 (4)	-	Y	-	Y	-	-	-	-	-
8/17/1999	6.15	Akyazı-Adapazarı	40.64	30.65	5.5	6,4 (4)	8,8 (4)	2,9 (4)	-	Y	-	Y	-	-	-	-	-
8/17/1999	7.15					5,6 (2)	6,2 (4)	5,3 (4)	-	Y	-	Y	-	-	-	-	-
8/17/1999	8.55	Adalar	40.78	29.05	4.3	7,0 (4)	7,1 (4)	2,3 (2)	-	Y	-	Y	-	-	-	-	-
9/13/1999	14.55	Izmit	40.77	30.1	5.8	67,8 (9)	57,5 (6)	74,2 (7)	Y	Y	Y	Y	Y	Y	Y	Y	Y
9/21/1999	0.28	Marmara Sea	40.69	27.58	5	12,9 (7)	12,3 (9)	14,7 (7)	Y	-	Y	Y	Y	Y	Y	Y	Y
9/29/1999	3.13	Yalova	40.7	29.34	4.8	31,6 (9)	14,2 (8)	14,4 (9)	Y	-	-	Y	Y	Y	Y	Y	Y
10/21/1999	2.08	Adalar	40.79	29	4.4	30,1 (9)	35,7 (8)	37,5 (7)	Y	Y	Y	Y	Y	Y	Y	Y	Y
11/7/1999	19.55	Hendek-Adapazari	40.71	30.7	5	2,7 (7)	4,9 (8)	4,6 (7)	Y	-	Y	-	-	-	Y	Y	-
11/11/1999	16.41	Sapanca-Adapazari	40.74	30.27	5.7	16,7 (7)	21,4 (8)	20,5 (7)	Y	Y	Y	Y	Y	Y	Y	Y	Y
11/11/1999	16.56	Sapanca-Adapazari	40.88	30.3	4.4	3,0 (7)	2,2 (6)	2,5 (7)	-	-	-	-	-	Y	Y	-	-
11/12/1999	18.57	Duzce-Bolu	40.74	31.21	7.2	22,6 (7)	35,1 (6)	26,4 (7)	Y	Y	Y	Y	Y	Y	Y	Y	Y
11/12/1999	19.07					2,8 (7)	3,5 (7)	2,7 (7)	-	-	-	-	-	Y	Y	-	-
11/12/1999	19.17	Duzce-Bolu	40.75	31.1	5.2	4,3 (9)	4,5 (8)	5,3 (7)	-	-	-	Y	-	Y	Y	Y	Y
11/12/1999	19.18	Duzce-Bolu	40.74	31.05	5.4	5,6 (7)	8,5 (6)	5,1 (9)	Y	Y	Y	Y	Y	Y	Y	Y	Y
11/12/1999	20.15	Kaynasli-Bolu	40.75	31.36	5	2,0 (7)	3,3 (7)	2,4 (7)	-	-	-	-	-	Y	Y	-	-

** Values in paranthesis indicate the stations where the relevant PGA is recorded,*

Note: Event information from Kandilli Observatory and Earthquake Research Institute

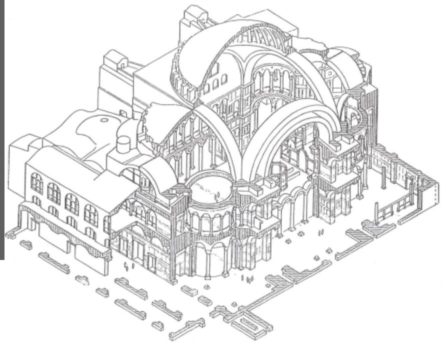
SULEYMANIYE

Table 2. Records obtained during the Kocaeli and Düzce earthquakes in Süleymaniye

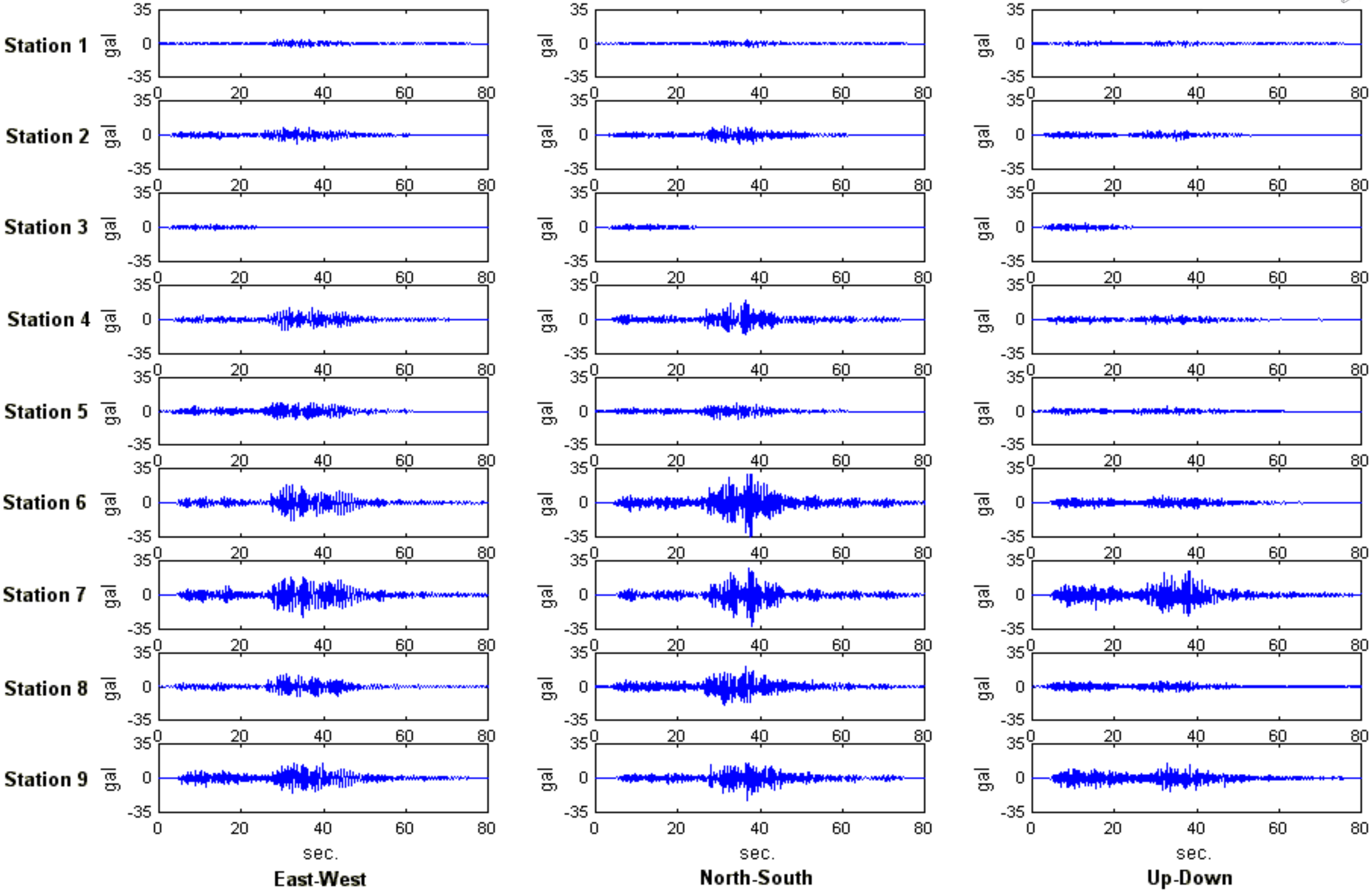
Event Date	Event Time	Event Location	Event Coordinates		Magnitude	Max.Acc.-x*	Max.Acc.-y*	Max.Acc.-z*	Triggered Stations								
	local		North	East	Md	cm/s2	cm/s2	cm/s2	S0	S1	S2	S3	S4	S5	S6	S7	S8
8/17/1999	3.02	Izmit	40.76	29.97	7.4	227,2 (5)	161,7 (5)	165,1 (5)	-	Y	Y	Y	Y	Y	Y	Y	Y
8/17/1999	3.17					12,8 (5)	10,8 (6)	6,8 (5)	-	Y	Y	Y	Y	Y	Y	Y	Y
8/17/1999	4.34					20,2 (5)	20,9 (8)	13,3 (6)	-	Y	Y	Y	Y	Y	Y	Y	Y
8/17/1999	4.49					7,8 (5)	11,0 (6)	4,9 (5)	-	Y	Y	Y	Y	Y	Y	Y	Y
8/17/1999	5.52					29,6 (5)	18,8 (6)	10,3 (7)	-	Y	Y	Y	Y	Y	Y	Y	Y
8/17/1999	6.15	Akyazı-Adapazarı	40.64	30.65	5.5	10,9 (4)	8,5 (2)	4,0 (5)	-	Y	Y	Y	Y	Y	Y	Y	Y
8/17/1999	7.15					9,2 (5)	10,9 (6)	20,8 (5)	-	Y	Y	Y	Y	Y	Y	Y	Y
8/17/1999	8.55	Adalar	40.78	29.05	4.3	13,1 (5)	11,1 (8)	9,9 (5)	-	Y	Y	Y	Y	Y	Y	Y	Y
9/13/1999	14.55	Izmit	40.77	30.1	5.8	83,8 (5)	97,1 (6)	52,1 (8)	-	Y	Y	Y	Y	Y	Y	Y	Y
9/21/1999	0.28	Marmara Sea	40.69	27.58	5	14,6 (7)	15,7 (6)	5,8 (6)	-	Y	Y	Y	Y	Y	Y	Y	Y
9/29/1999	3.13	Yalova	40.7	29.34	4.8	14,5 (5)	12,8 (6)	9,3 (5)	-	Y	Y	Y	Y	Y	Y	Y	Y
10/21/1999	2.08	Adalar	40.79	29	4.4	38,0 (5)	43,8 (8)	28,3 (6)	-	Y	Y	Y	Y	Y	Y	Y	Y
11/7/1999	19.55	Hendek-Adapazari	40.71	30.7	5	7,8 (5)	4,7 (6)	2,2 (5)	-	Y	Y	Y	Y	Y	Y	Y	Y
11/11/1999	16.41	Sapanca-Adapazari	40.74	30.27	5.7	29,1 (5)	19,9 (6)	9,7 (6)	Y	Y	Y	Y	Y	Y	Y	Y	Y
11/11/1999	16.56	Sapanca-Adapazari	40.88	30.3	4.4	5,6 (4)	4,9 (6)	2,1 (5)	-	Y	Y	Y	Y	Y	Y	Y	Y
11/12/1999	18.57	Duzce-Bolu	40.74	31.21	7.2	19,1 (5)	20,4 (6)	7,1 (4)	Y	Y	Y	Y	Y	Y	Y	Y	Y
11/12/1999	19.17	Duzce-Bolu	40.75	31.1	5.2	4,9 (5)	4,3 (6)	2,1 (5)	-	Y	Y	Y	Y	Y	Y	Y	Y
11/12/1999	19.18	Duzce-Bolu	40.74	31.05	5.4	5,6 (5)	5,6 (8)	2,3 (5)	-	Y	Y	Y	Y	Y	Y	Y	Y

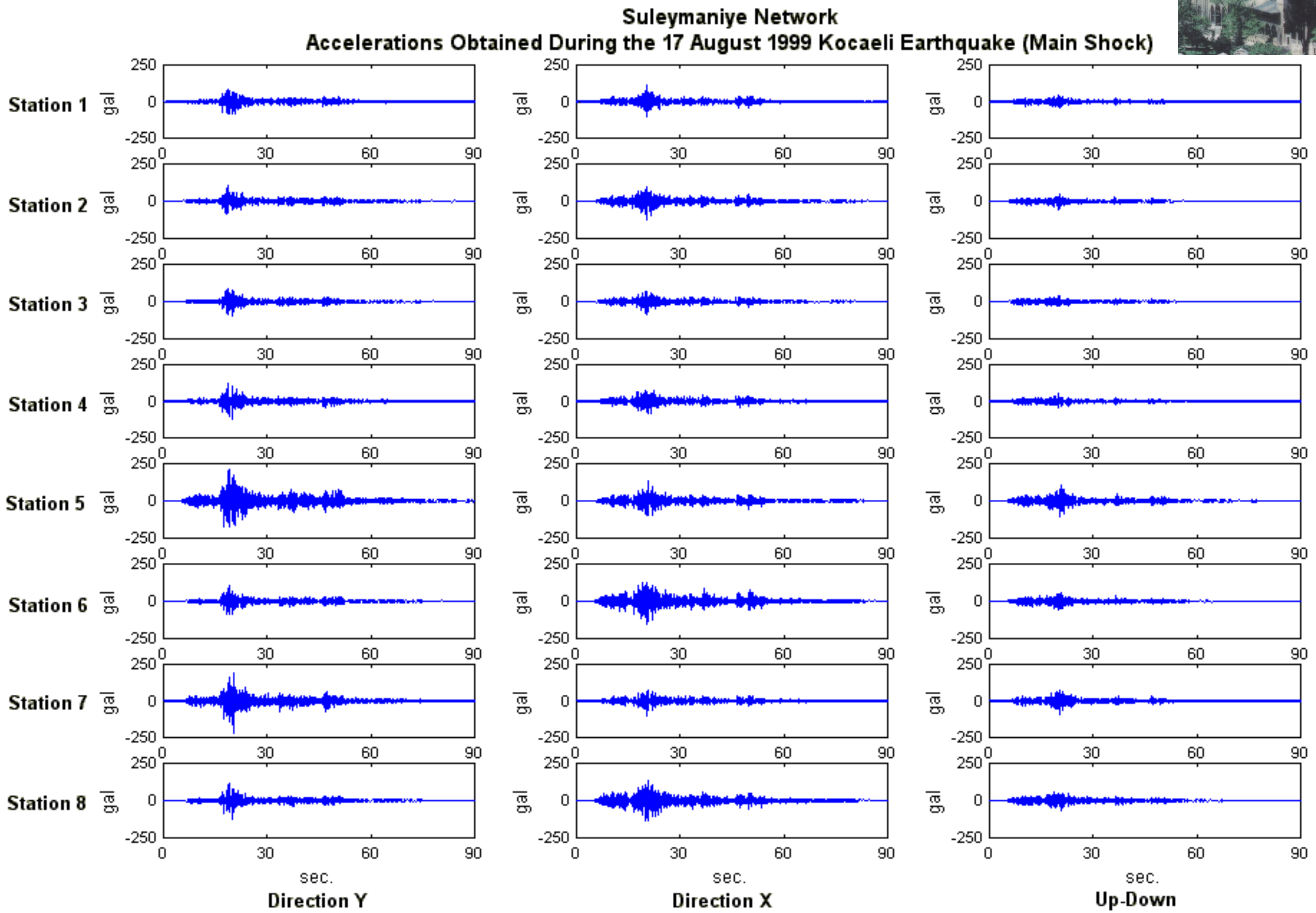
** Values in paranthesis indicate the stations where the relevant peak acceleration is recorded*

Note: Event information from Kandilli Observatory and Earthquake Research Institute

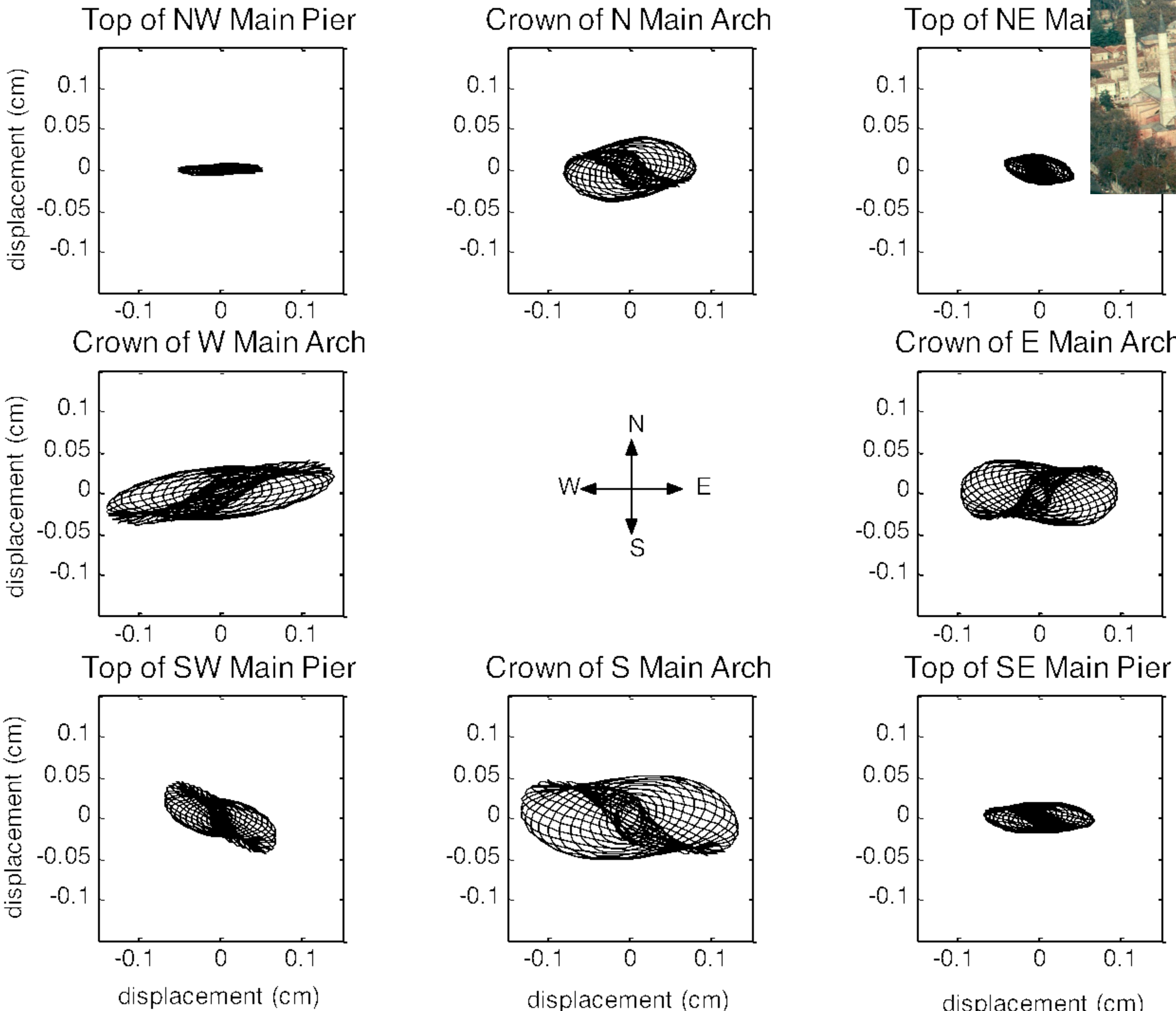


Hagia Sophia Network
Accelerations Obtained During the 12 November 1999 Duzce Earthquake

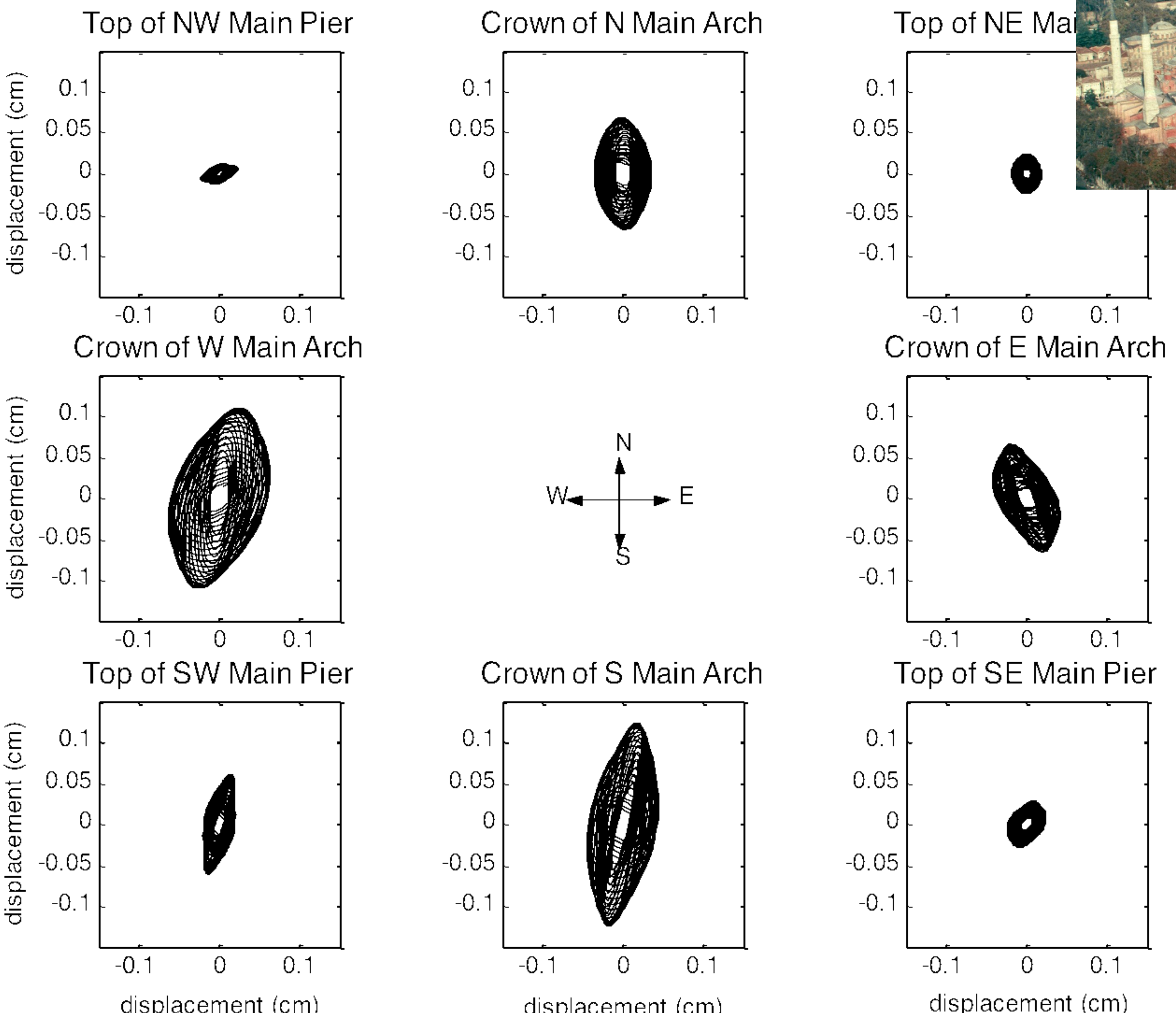




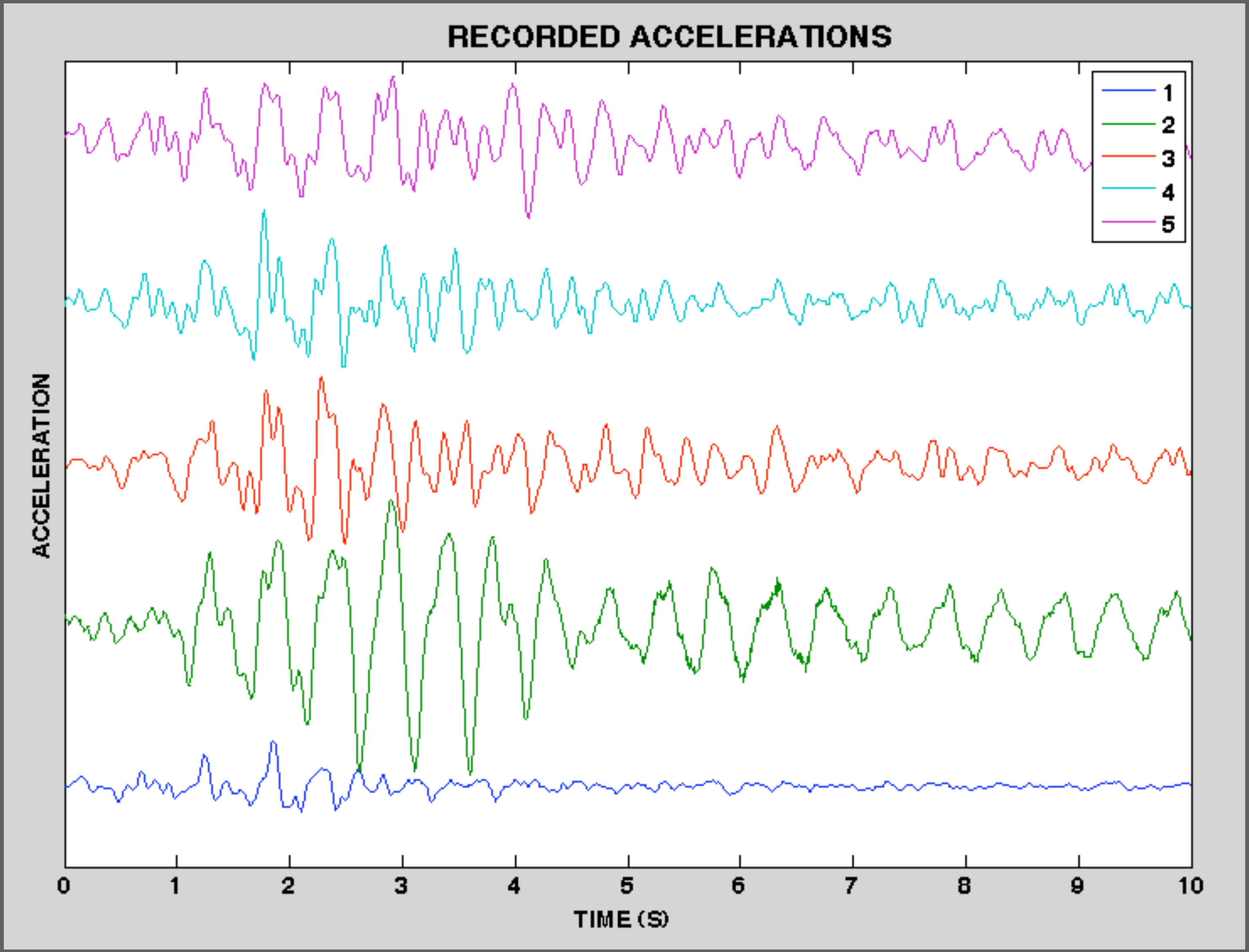
Suleymaniye Network
Accelerations Obtained During the 17 August 1999 Kocaeli Earthquake (Main Shock)
Station 1
Station 2
Station 3
Station 4
Station 5
Station 6
Station 7
Station 8
gal
250
0
-250
0
30
60
90
sec.
Direction Y
Direction X
Up-Down



Hagia Sophia, first mode shape, dominantly EW



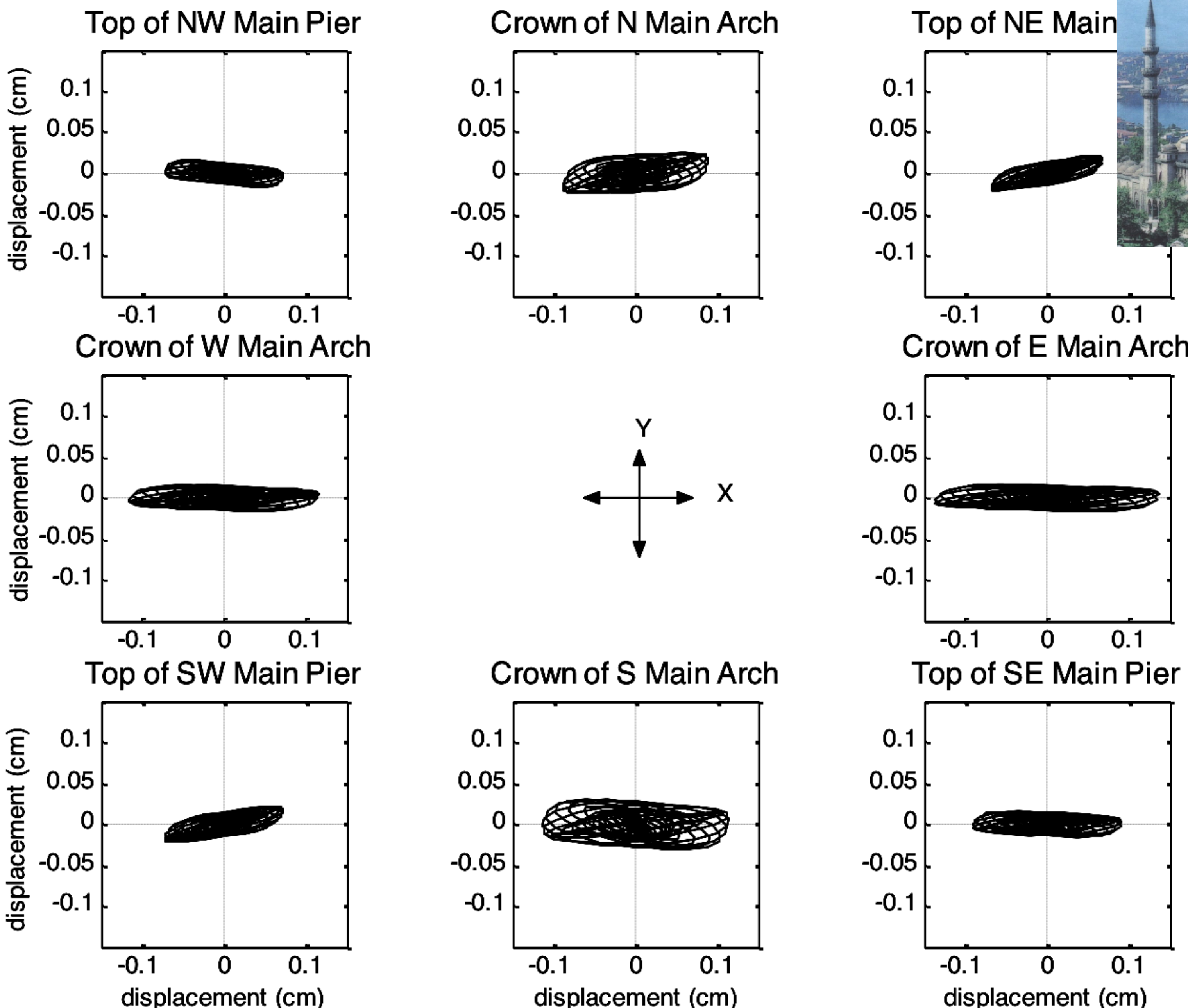
Hagia Sophia, second mode shape, dominantly NS



Hagia Sophia, filtered accelerations

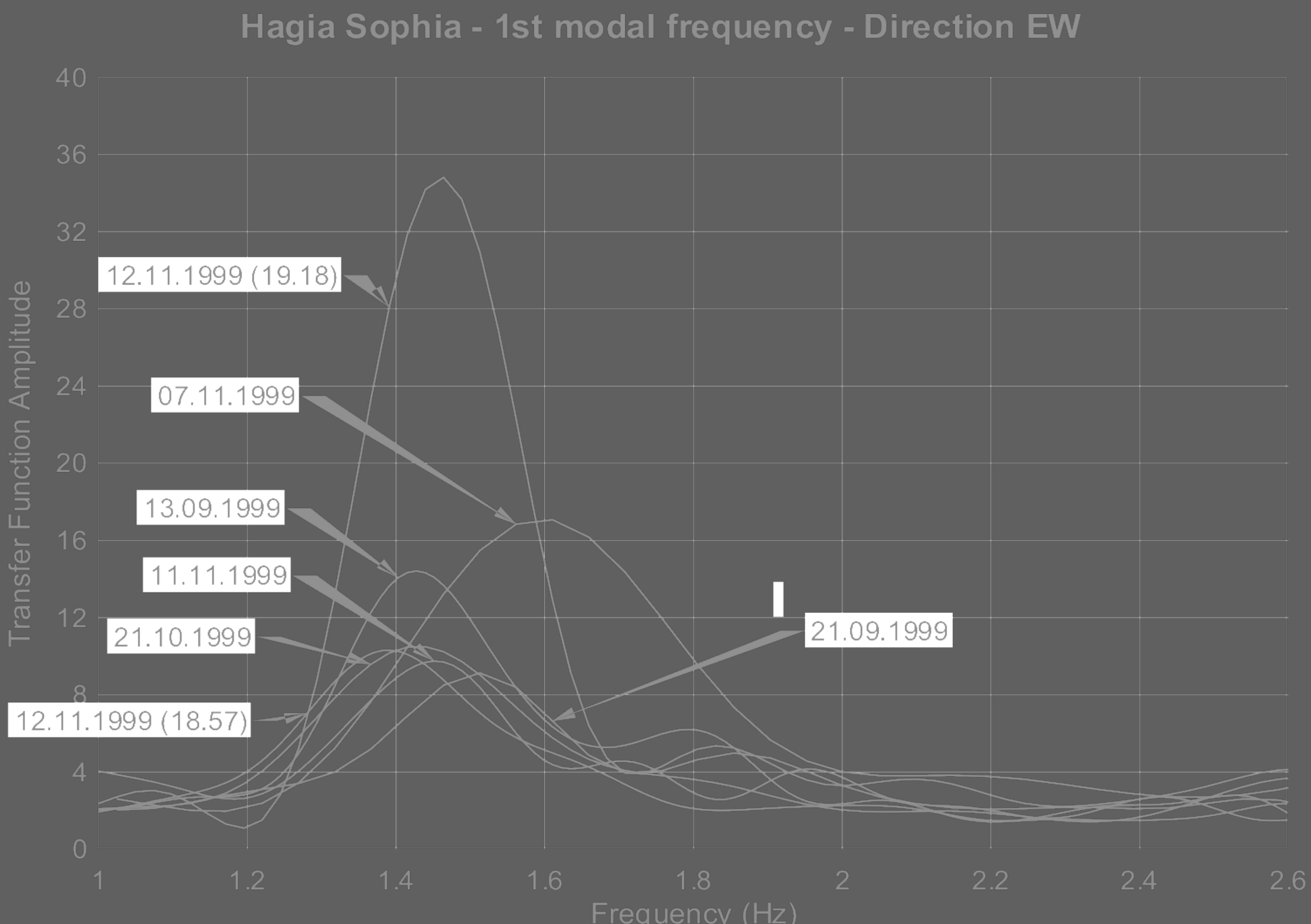
Station 1 is at the ground floor, stations 2-5 are at the top the main piers,

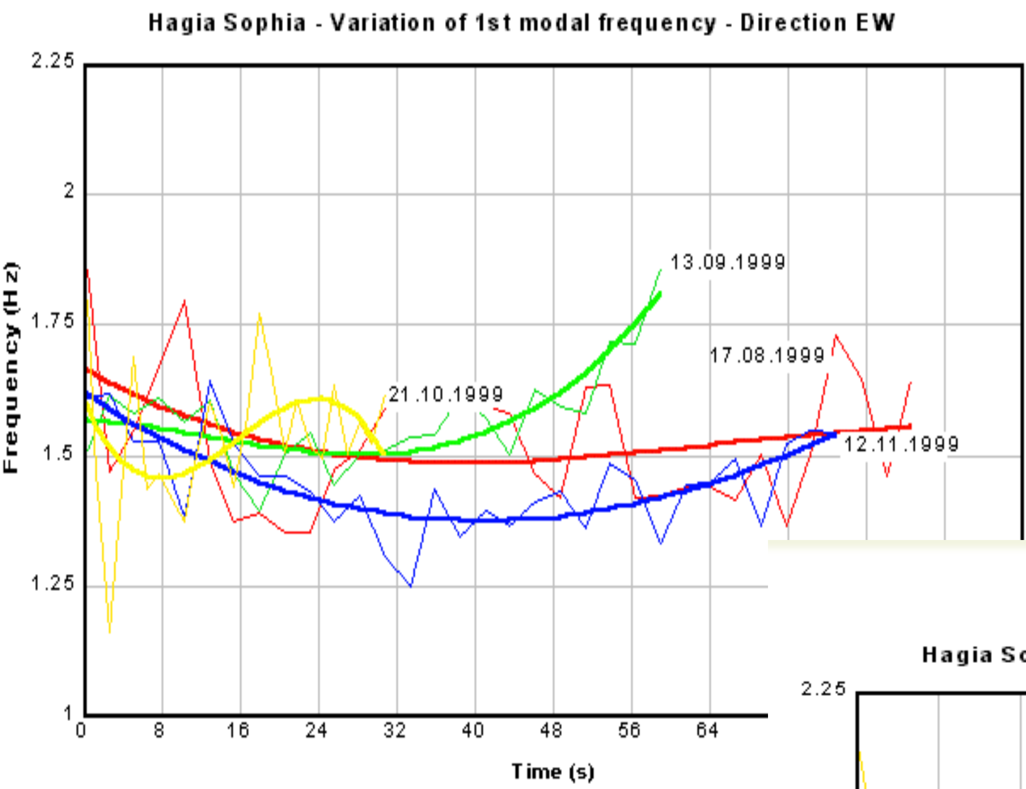
note the different vibration characteristics at station 2, which correponds to SW main pier.

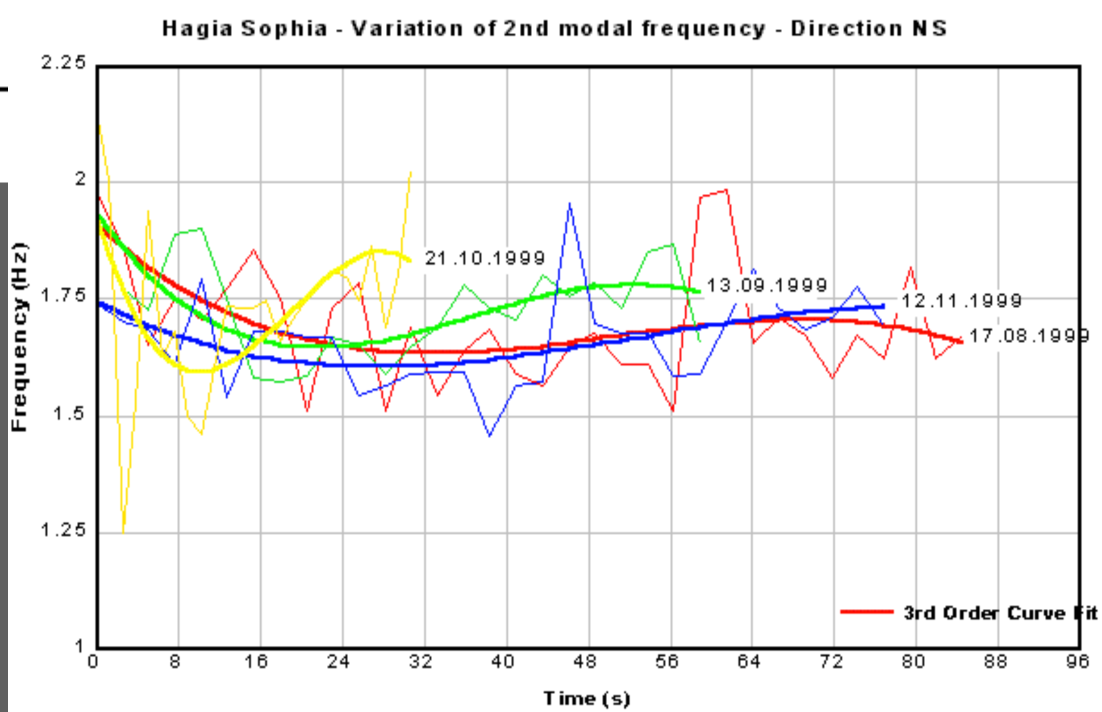


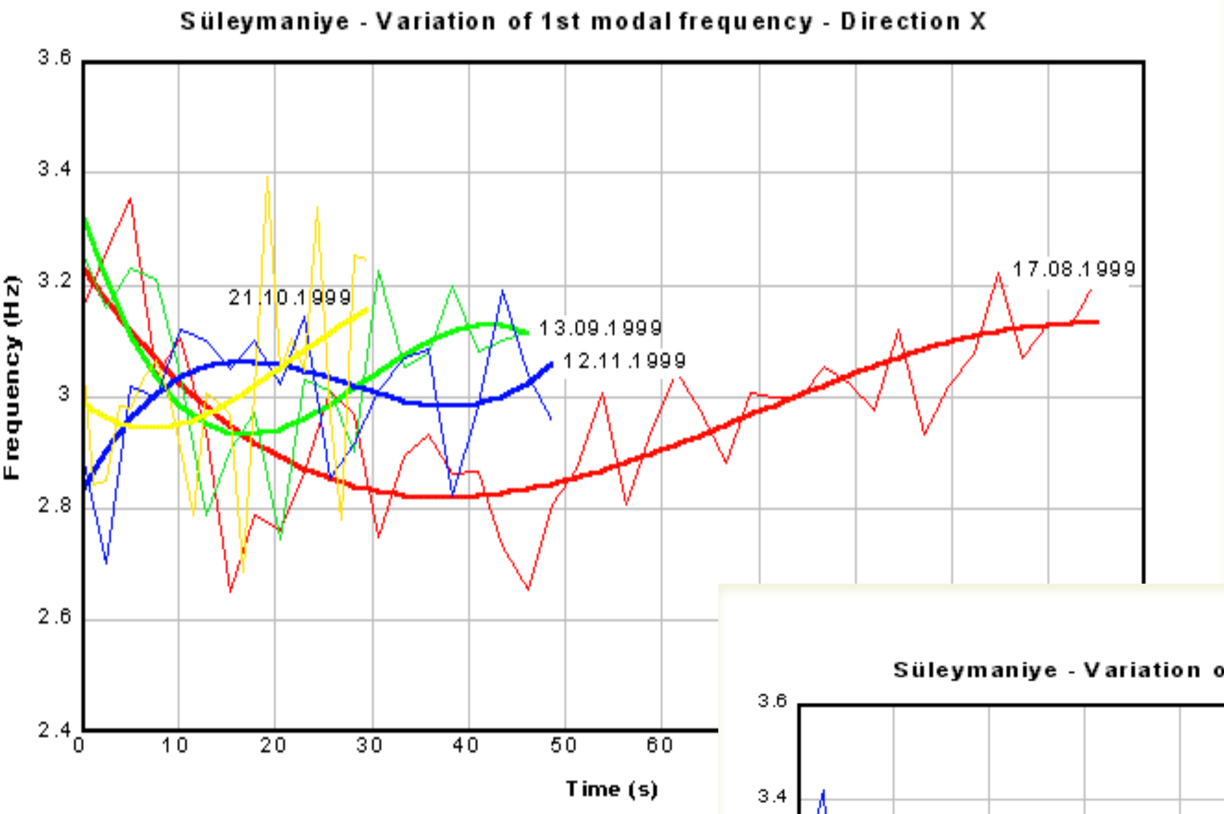
Süleymaniye, first mode shape

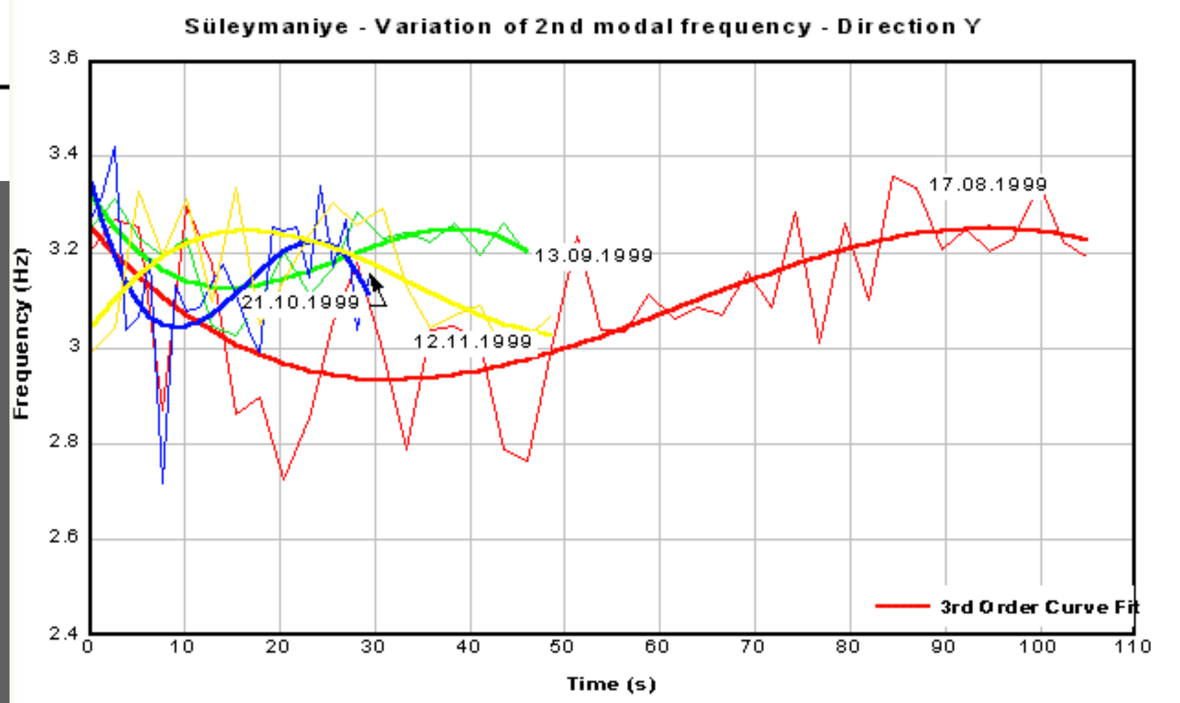
Transfer Functions in EW Direction

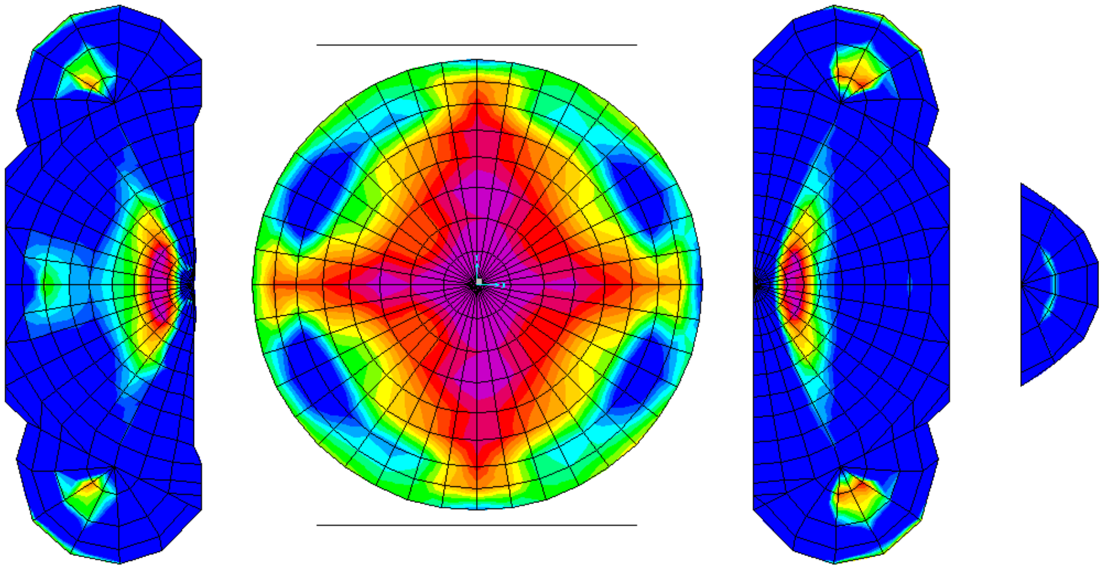



Hagia Sophia - Variation of 1st modal frequency - Direction EW
Frequency (Hz)
Time (s)
13.09.1999
17.08.1999
21.10.1999
12.11.1999
2.25
2
1.75
1.5
1.25
1
0
8
16
24
32
40
48
56
64


Hagia Sophia - Variation of 2nd modal frequency - Direction NS
Frequency (Hz)
Time (s)
21.10.1999
13.09.1999
12.11.1999
17.08.1999
3rd Order Curve Fit
2.25
2
1.75
1.5
1.25
1
0
8
16
24
32
40
48
56
64
72
80
88
96

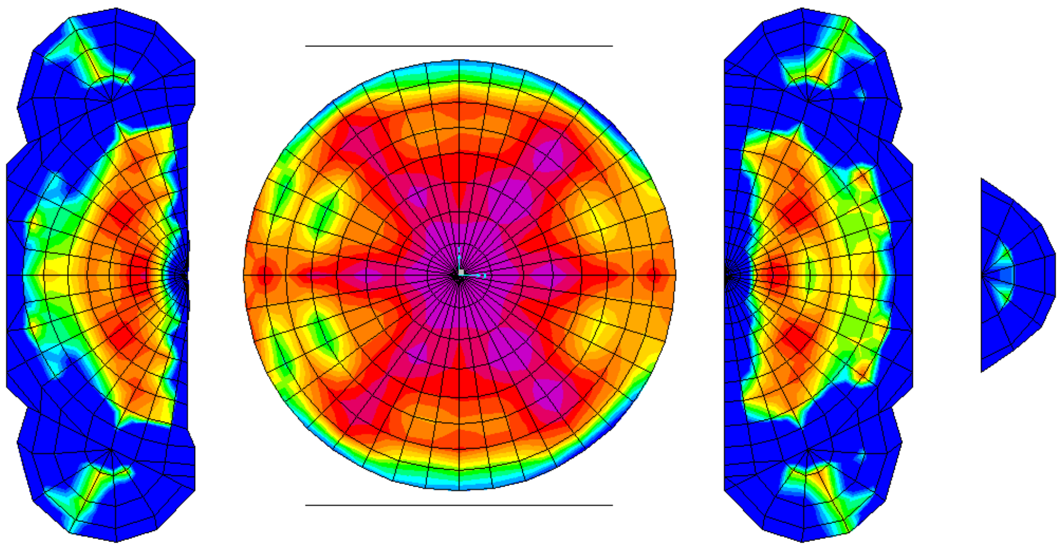

Süleymaniye - Variation of 1st modal frequency - Direction X
Frequency (Hz)
Time (s)
21.10.1999
13.09.1999
12.11.1999
17.08.1999
3.6
3.4
3.2
3
2.8
2.6
2.4
0
10
20
30
40
50
60


Süleymaniye - Variation of 2nd modal frequency - Direction Y
Frequency (Hz)
Time (s)
17.08.1999
13.09.1999
21.10.1999
12.11.1999
3rd Order Curve Fit
3.6
3.4
3.2
3
2.8
2.6
2.4
0
10
20
30
40
50
60
70
80
90
100
110

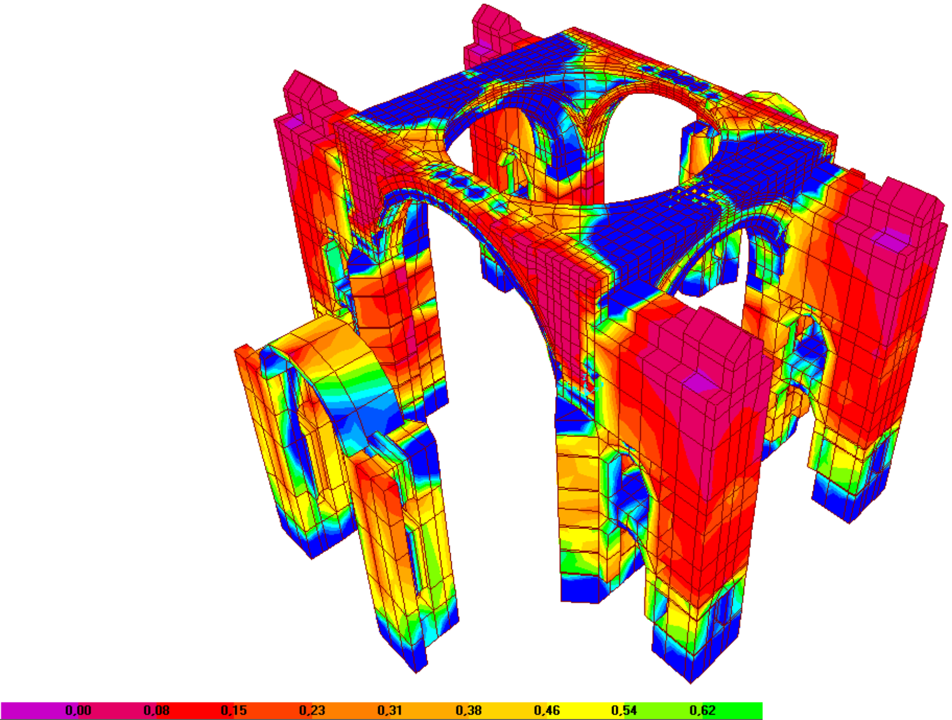


Hoop stresses
under the combination of
self-weight and resp.
spec. analysis

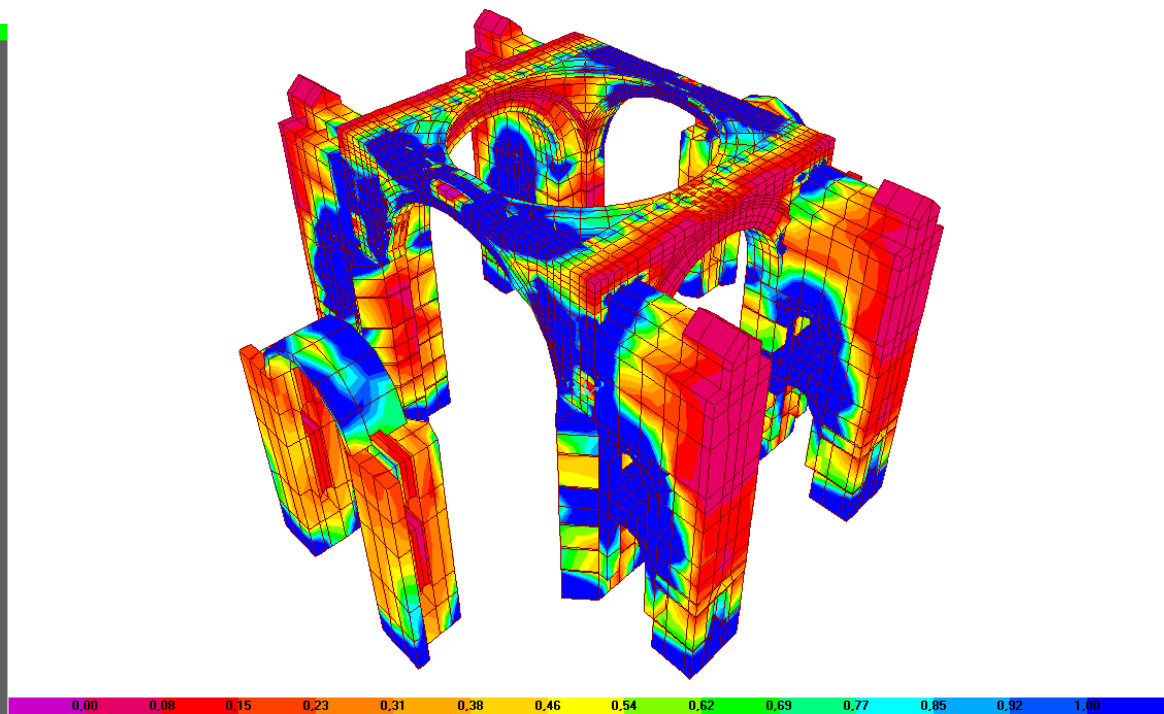
Radial stresses
under the combination of
self-weight and resp.
spec. analysis



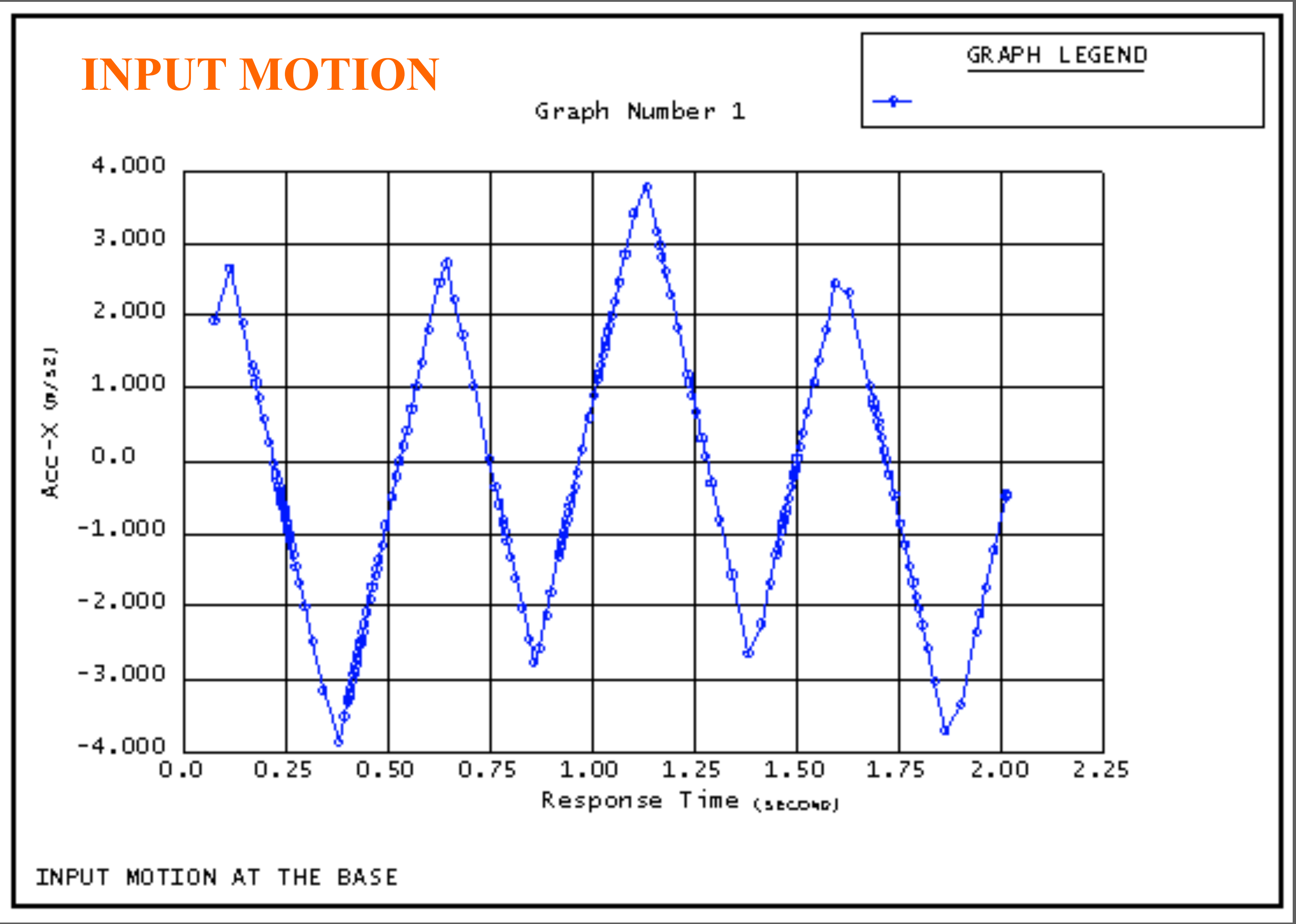
Stresses in X direction under the combination of self-weight and resp. spec. analysis

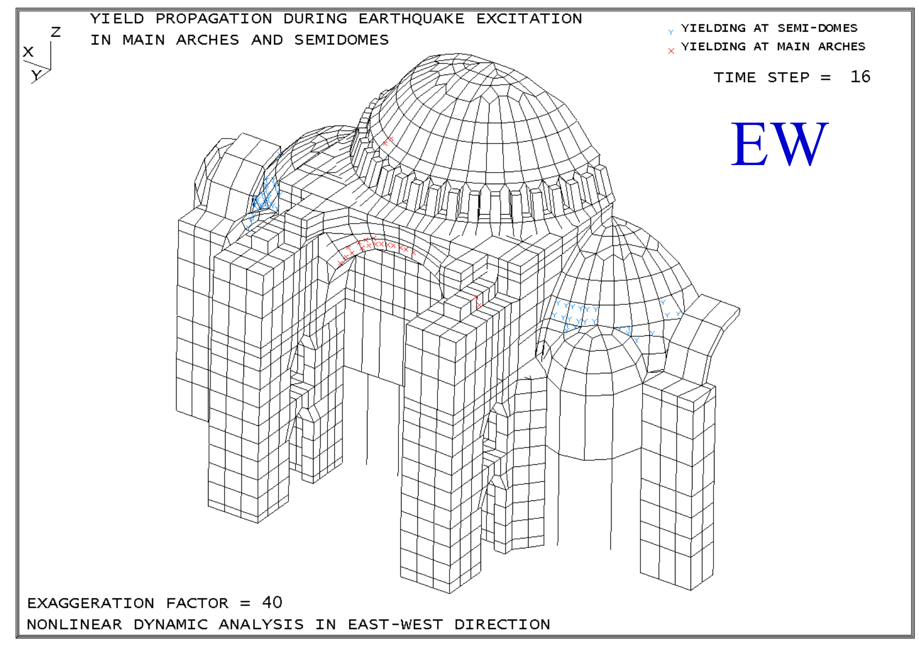


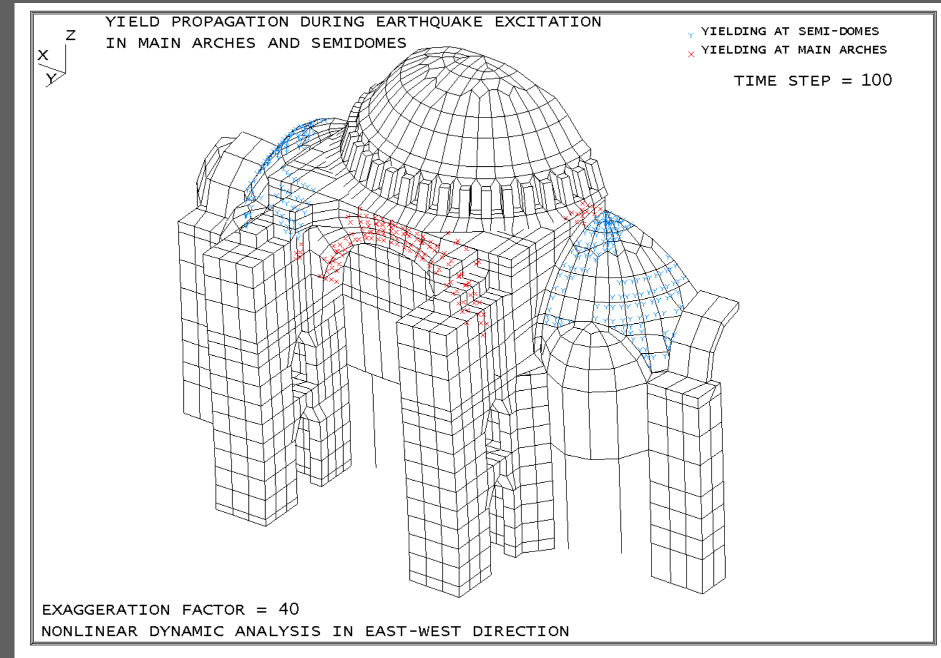
Stresses in Y direction under the combination of self-weight and resp. spec. analysis

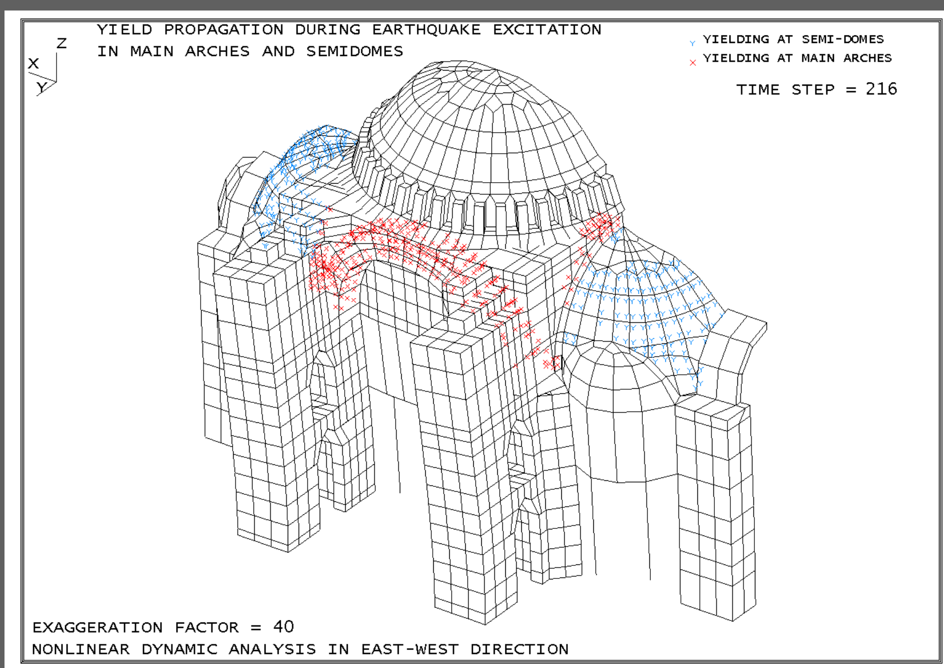


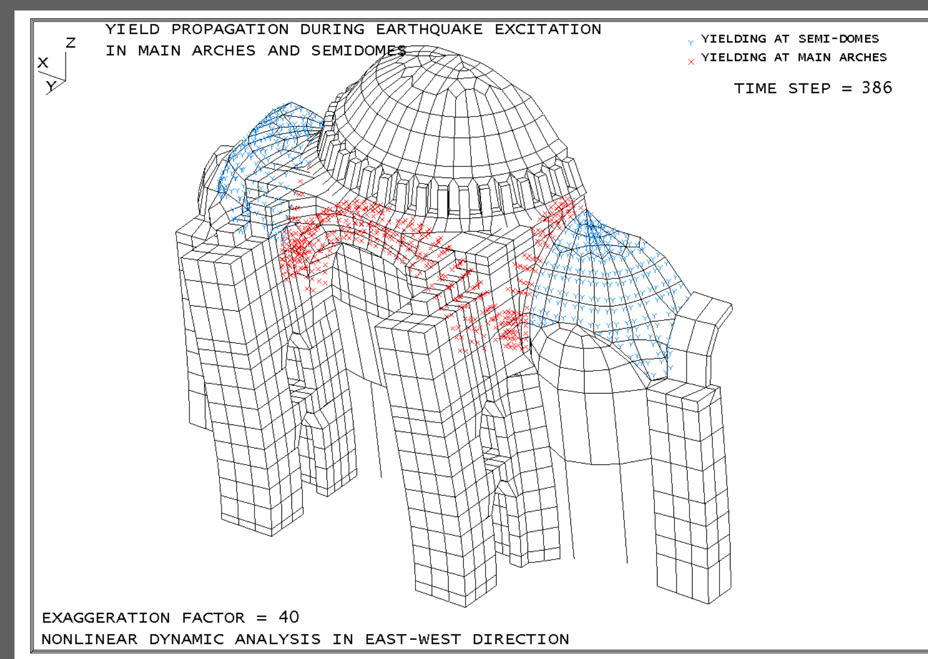
Nonlinear Analysis

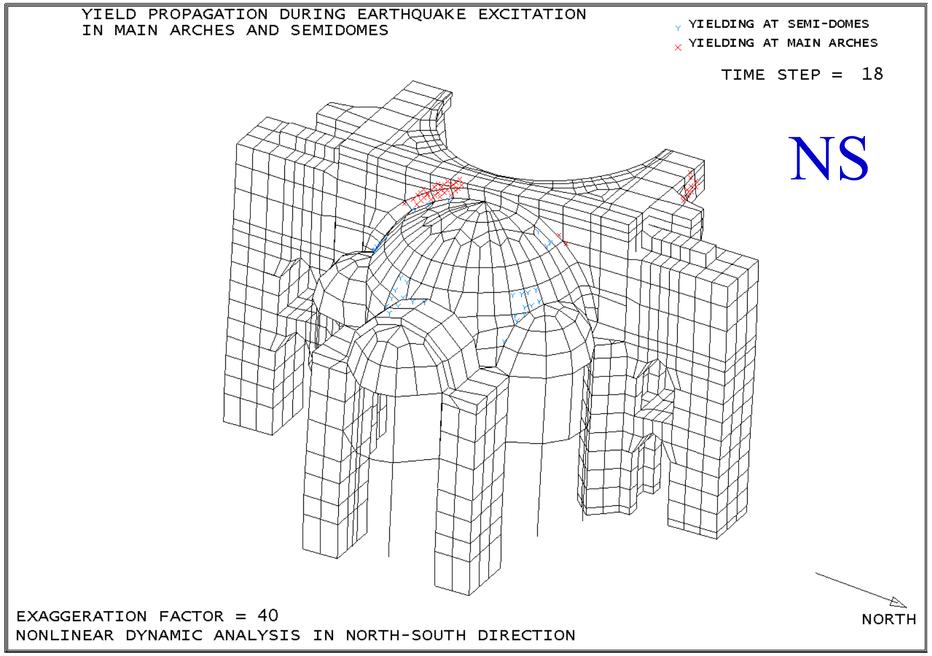


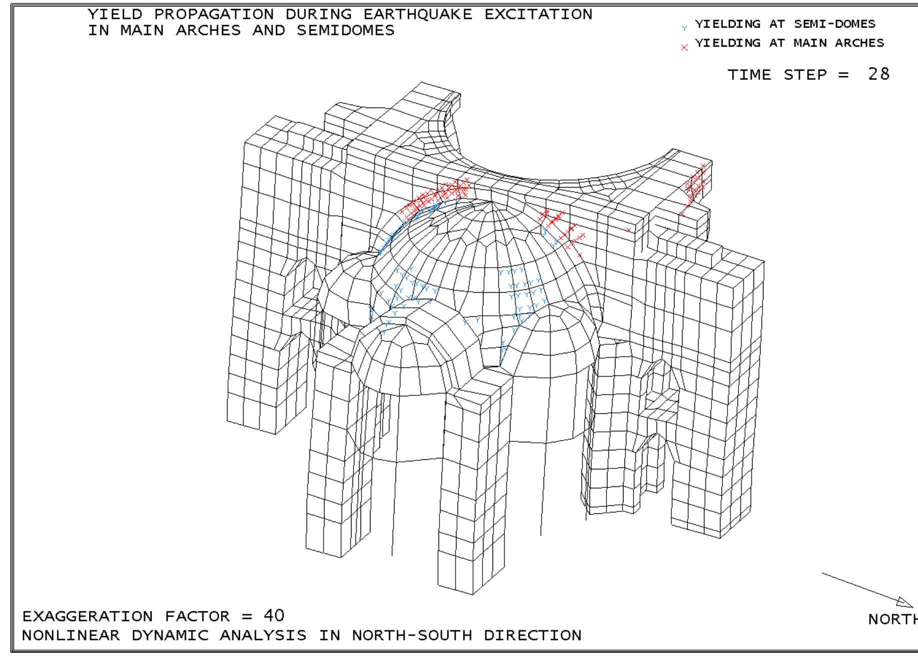

YIELD PROPAGATION DURING EARTHQUAKE EXCITATION
IN MAIN ARCHES AND SEMIDOMES
YIELDING AT SEMI-DOMES
YIELDING AT MAIN ARCHES
TIME STEP = 16
EW
EXAGGERATION FACTOR = 40
NONLINEAR DYNAMIC ANALYSIS IN EAST-WEST DIRECTION

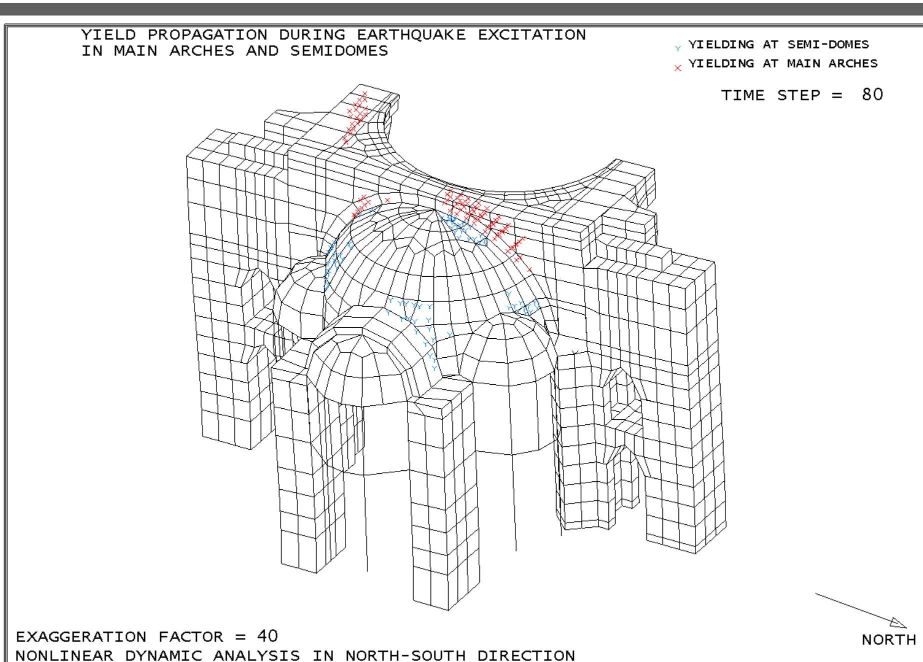

YIELD PROPAGATION DURING EARTHQUAKE EXCITATION
IN MAIN ARCHES AND SEMIDOMES
YIELDING AT SEMI-DOMES
YIELDING AT MAIN ARCHES
TIME STEP = 100
EXAGGERATION FACTOR = 40
NONLINEAR DYNAMIC ANALYSIS IN EAST-WEST DIRECTION

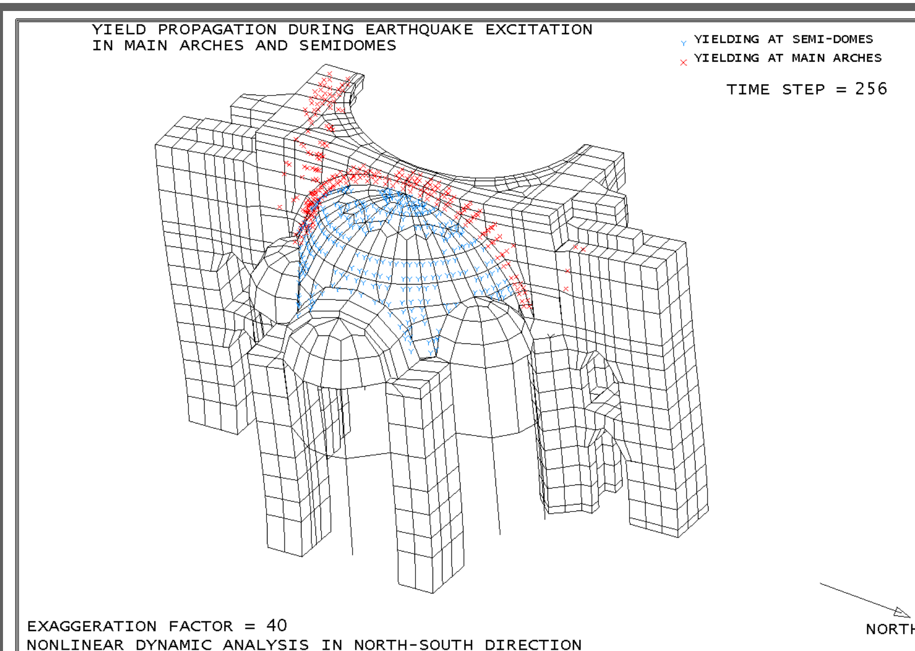

YIELD PROPAGATION DURING EARTHQUAKE EXCITATION
IN MAIN ARCHES AND SEMIDOMES
YIELDING AT SEMI-DOMES
YIELDING AT MAIN ARCHES
TIME STEP = 216
EXAGGERATION FACTOR = 40
NONLINEAR DYNAMIC ANALYSIS IN EAST-WEST DIRECTION


YIELD PROPAGATION DURING EARTHQUAKE EXCITATION
IN MAIN ARCHES AND SEMIDOMES
YIELDING AT SEMI-DOMES
YIELDING AT MAIN ARCHES
TIME STEP = 386
EXAGGERATION FACTOR = 40
NONLINEAR DYNAMIC ANALYSIS IN EAST-WEST DIRECTION


YIELD PROPAGATION DURING EARTHQUAKE EXCITATION
IN MAIN ARCHES AND SEMIDOMES
YIELDING AT SEMI-DOMES
YIELDING AT MAIN ARCHES
TIME STEP = 18
NS
EXAGGERATION FACTOR = 40
NONLINEAR DYNAMIC ANALYSIS IN NORTH-SOUTH DIRECTION
NORTH


YIELD PROPAGATION DURING EARTHQUAKE EXCITATION
IN MAIN ARCHES AND SEMIDOMES
YIELDING AT SEMI-DOMES
YIELDING AT MAIN ARCHES
TIME STEP = 28
EXAGGERATION FACTOR = 40
NONLINEAR DYNAMIC ANALYSIS IN NORTH-SOUTH DIRECTION
NORTH


YIELD PROPAGATION DURING EARTHQUAKE EXCITATION
IN MAIN ARCHES AND SEMIDOMES
YIELDING AT SEMI-DOMES
YIELDING AT MAIN ARCHES
TIME STEP = 80
EXAGGERATION FACTOR = 40
NONLINEAR DYNAMIC ANALYSIS IN NORTH-SOUTH DIRECTION
NORTH


YIELD PROPAGATION DURING EARTHQUAKE EXCITATION
IN MAIN ARCHES AND SEMIDOMES
YIELDING AT SEMI-DOMES
YIELDING AT MAIN ARCHES
TIME STEP = 256
EXAGGERATION FACTOR = 40
NONLINEAR DYNAMIC ANALYSIS IN NORTH-SOUTH DIRECTION
NORTH

Probability of occurrence of a Mw=7.0+ Earthquake In Marmara Sea is 65% in the next 30 Years

Strengthening ?

No implementation to date, however some studies for the earthquake performance assessment of proposed strengthening schemes to improve earthquake performance have been carried out.

The Retrofit Strategies for Hagia Sophia

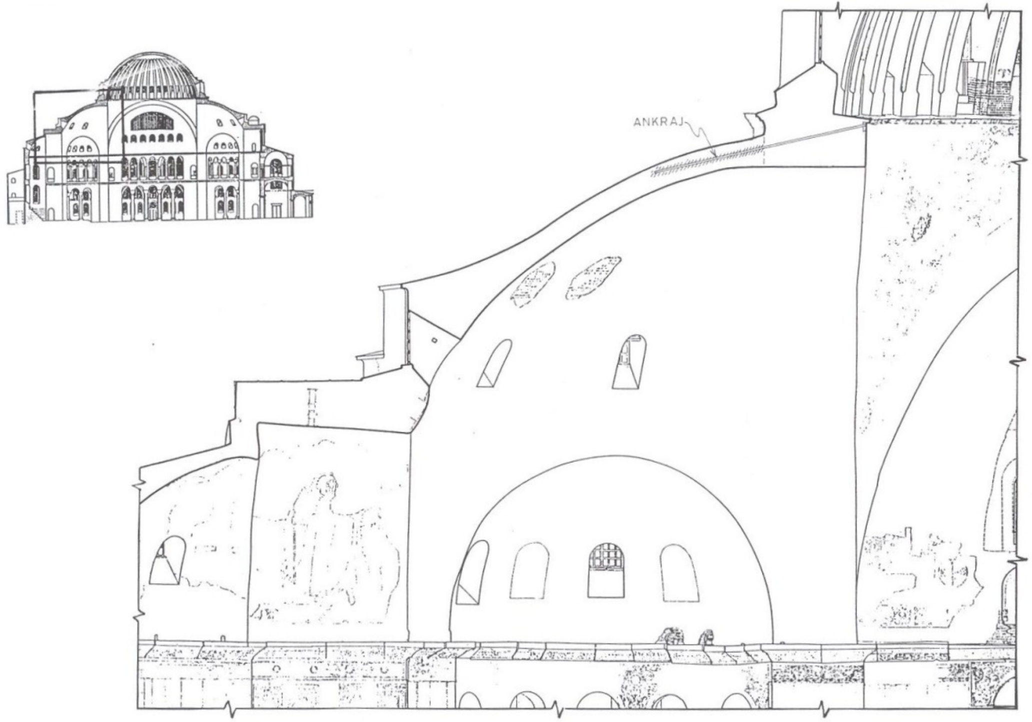
Following retrofitting methods are considered to reduce tensile stress:

- **Post-tensioned steel bars** are used to strengthen the domebase. Additional compression stress to counteract high tension is purposed.
- **Fiber reinforced polymers (FRPs)** are tried out to improve resistance of the semidomes. Tension is intended to be carried by FRP laminates rather than the brick-masonry.
- **Shape memory alloys** turn out difficult to implement due to the small thickness of the semidomes.

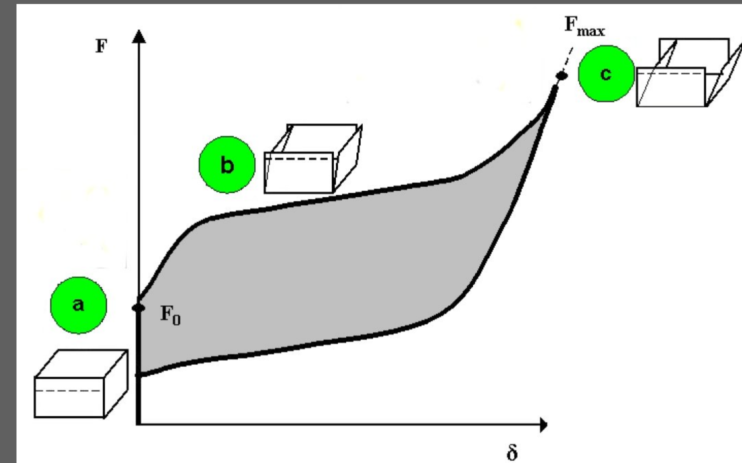
Self-weight, modal-eigenvalue, response spectrum analyses are performed.

Reinforcements with different post-tension values, cross sections and material properties are investigated until the most reasonable responses are obtained.

The stresses calculated in the intervened models are wanted to ensure the range of 10 MPa for compression and 1 MPa for tension.

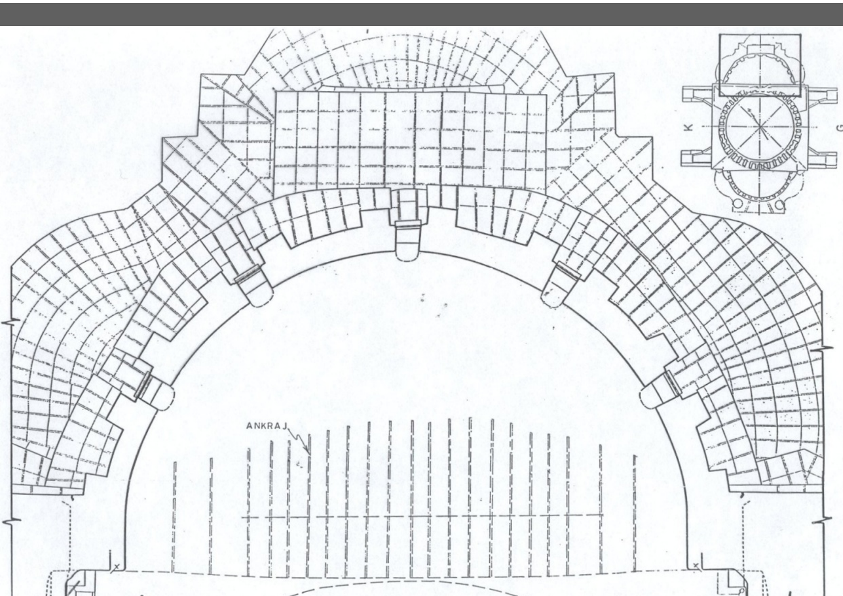


AYASOFYA DOĞU YARIM KUBBE KESİTİ (KUZEYDEN GÜNEYE BAKIŞ)

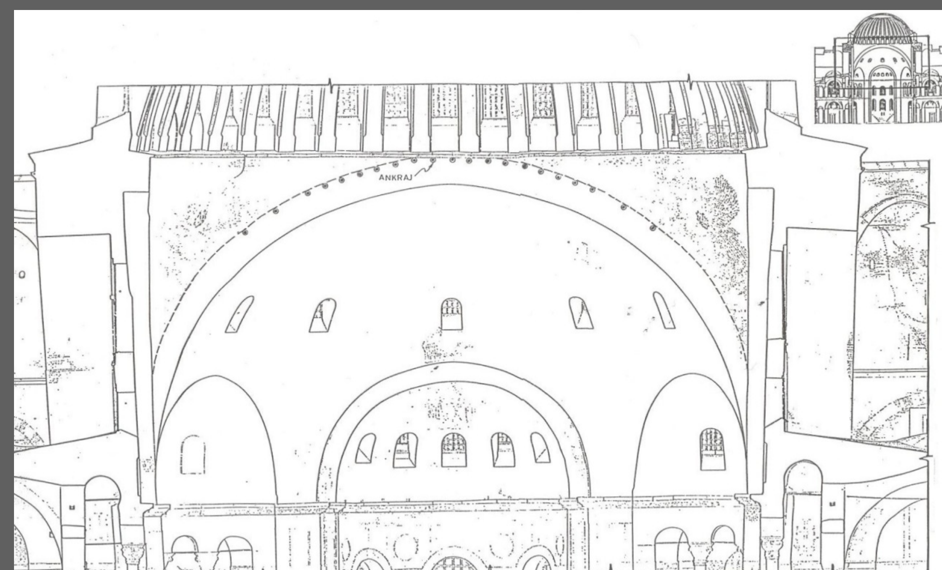


AyaSofya Retrofit Proposal

Shape Memory Alloys



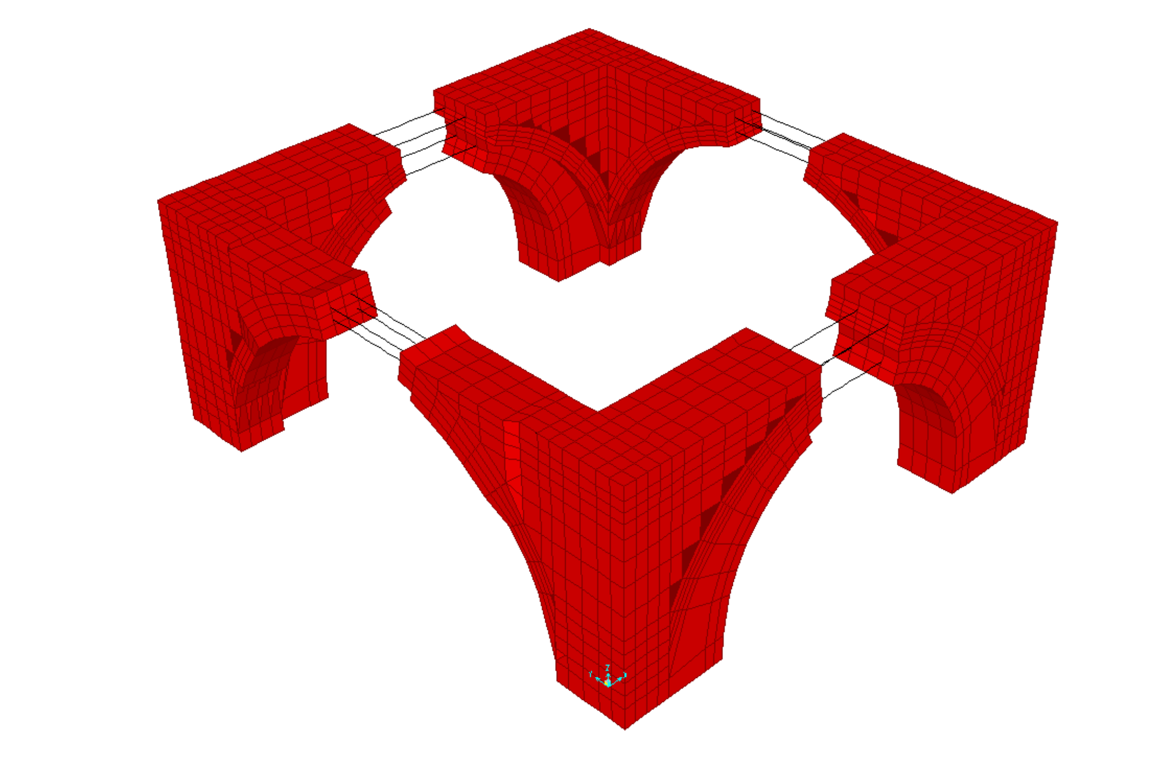
AYASOFYA DOĞU YARIM KUBBE PLANI (ETEK HİZASINDA, TEPEDEN BAKIŞ)



AYASOFYA DOĞU YARIM KUBBE İÇ CEPHESİ GÖRÜNÜŞÜ

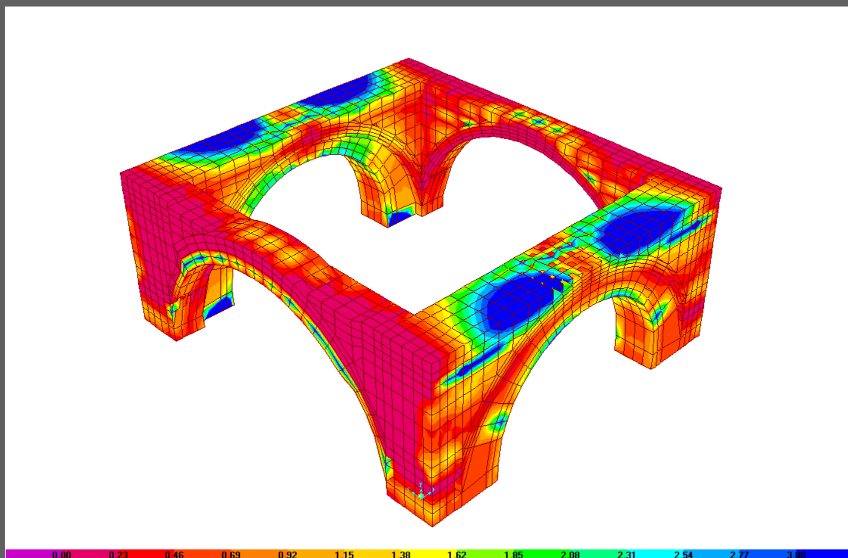
Post-tensioned Bars

- 3 tendons in each arches, 12 tendons totally
- 10 MN post-tension force for each tendon in East & West arches
- 20 MN post-tension force for each tendon in North & South arches
- Modeled as element
- Steel’s material properties
- 5 cm diameter
- Maximum discretization: 50 cm
- No tendon profile
- Jacking location at both ends of tendon
- Wobble coefficient: 8,333e-7 1/cm
- Anchorage set slip: 25 cm

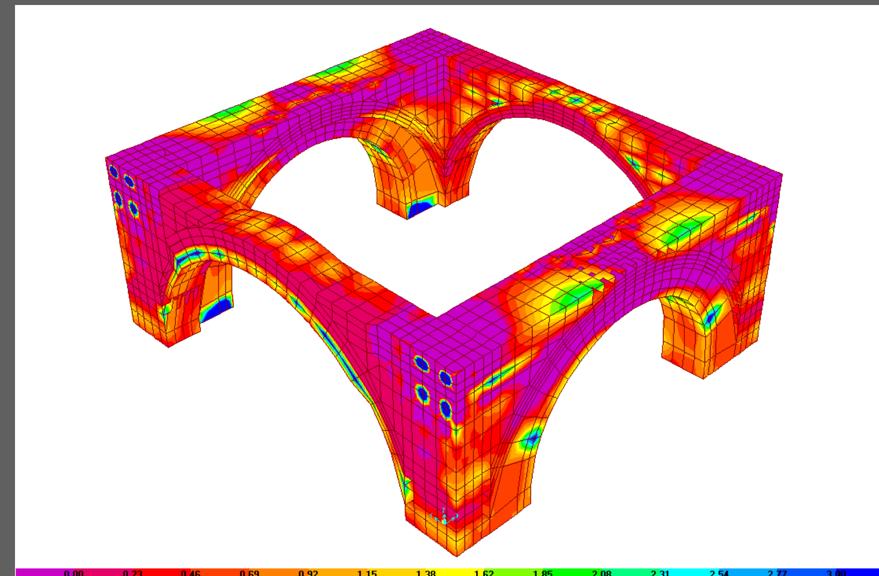


SXX stress distribution under self-weight, response spectrum & post-tension force

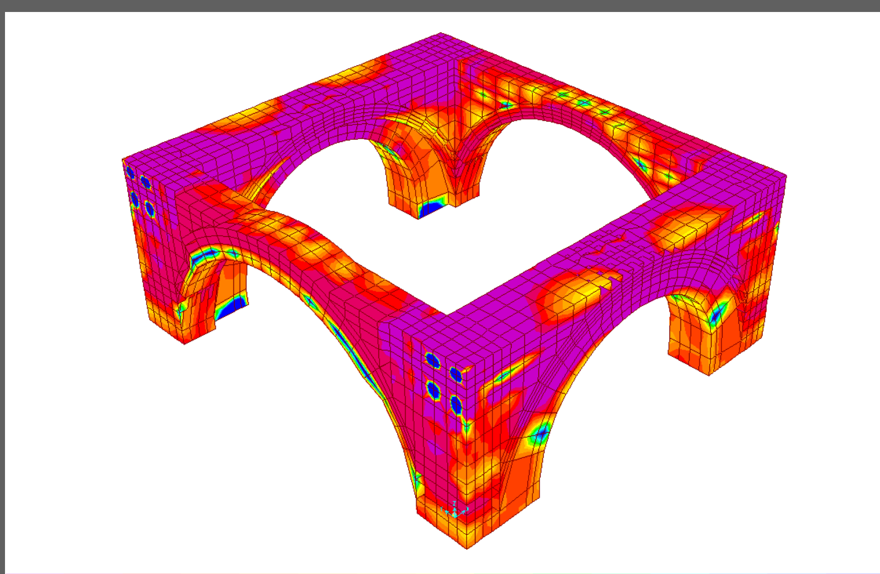
Self-weight & Response Spectrum



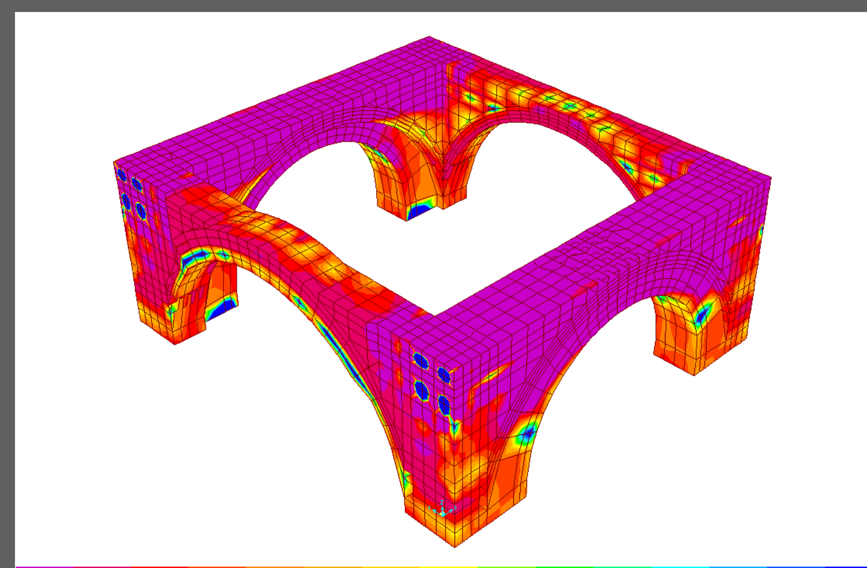
Self-weight & Resp. Spec. & 60 MN Post-tension force



Self-weight & Resp. Spec. & 80 MN Post-tension force

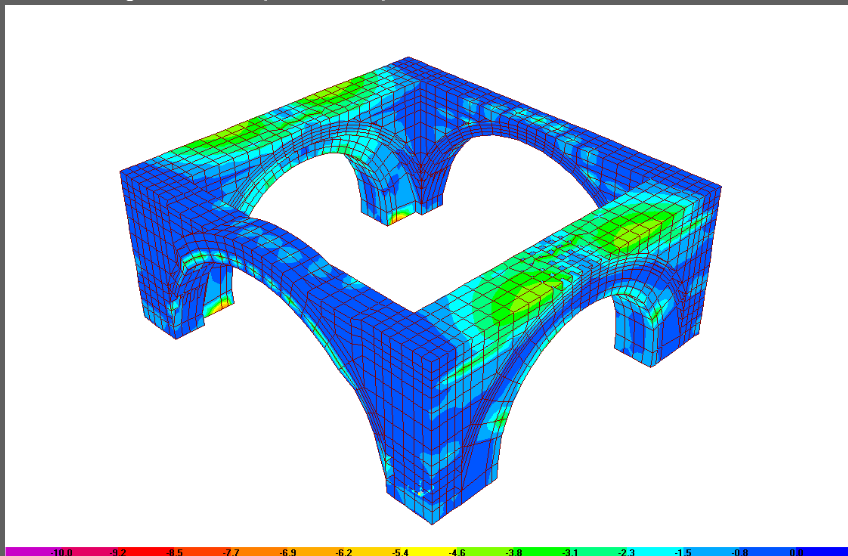


Self-weight & Resp. Spec. & 120 MN Post-tension force

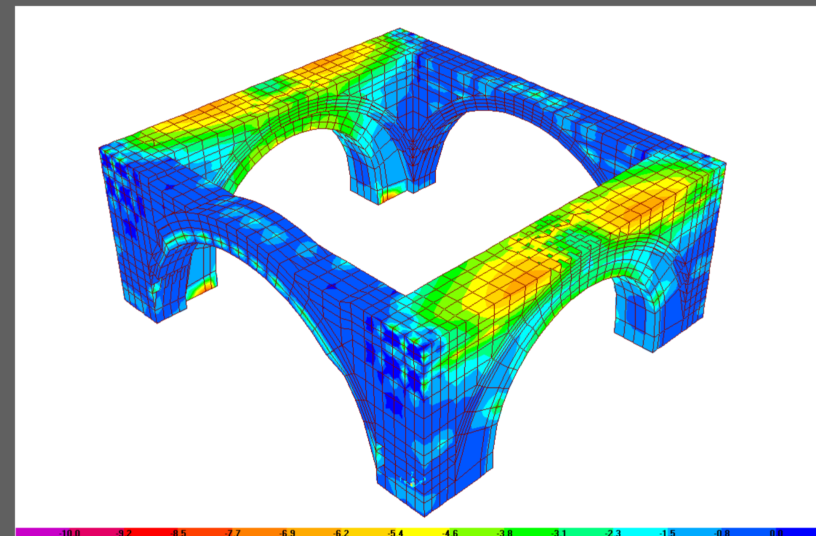


SXX stress distribution under self-weight, response spectrum & post-tension force

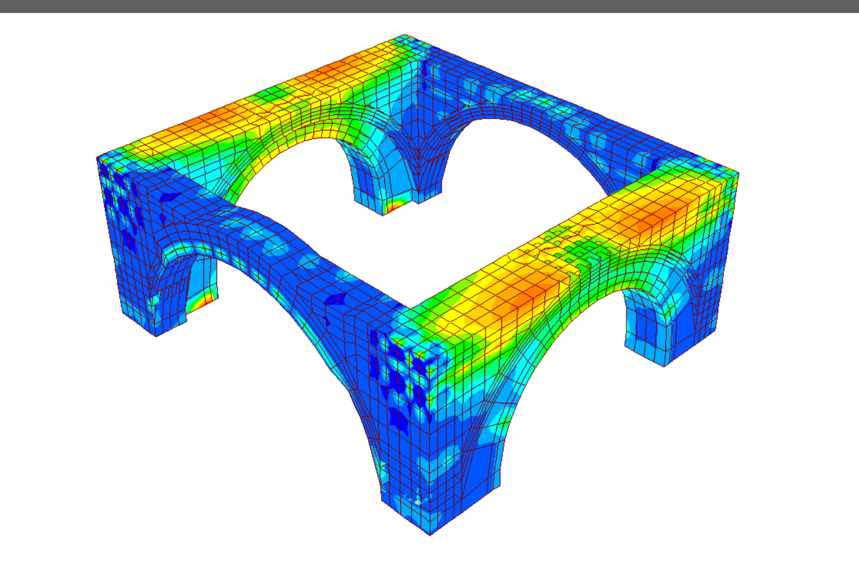
Self-weight & Response Spectrum



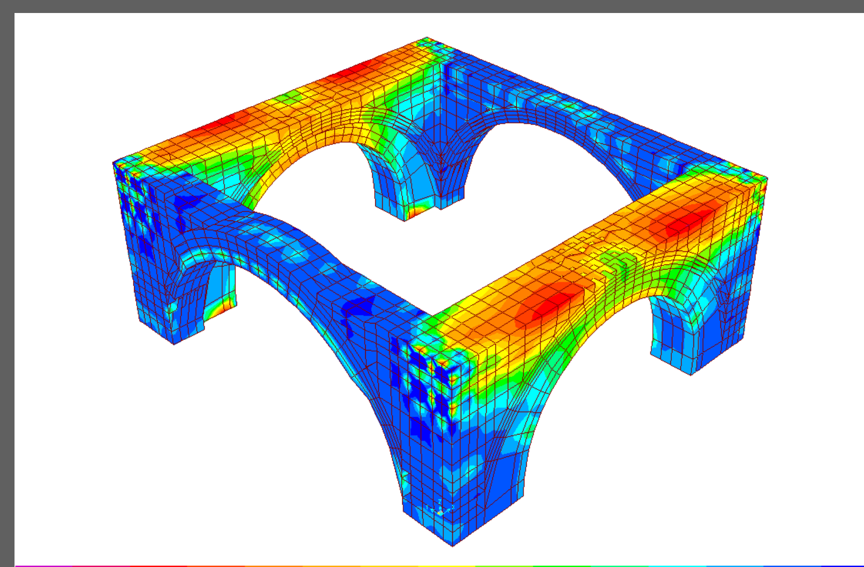
Self-weight & Resp. Spec. & 60 MN Post-tension force



Self-weight & Resp. Spec. & 80 MN Post-tension force



Self-weight & Resp. Spec. & 120 MN Post-tension force



*Response spectrum analyses displayed for negative directions.

Comments

Protection of cultural heritage form the effects of earthquakes is a very delicate issue which requires a multidisciplinary approach.

The most important rule to follow is to choose experimental, analysis and intervention methods and technologies in such a way, to cause minimum damage to the historical structure.

Construction techniques and material properties in historical structures vary from building to building, past damages and interventions make a healthy diagnosis substantially harder. Thus any assessment should only be carried out by those with a certain background.

Wrong decisions often mean harm to structures rather than any improvement of structural performance and increase the possibility of damage in an earthquake.