BRIDGE HEALTH MONITORING

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www.shm.ce.boun.edu.tr

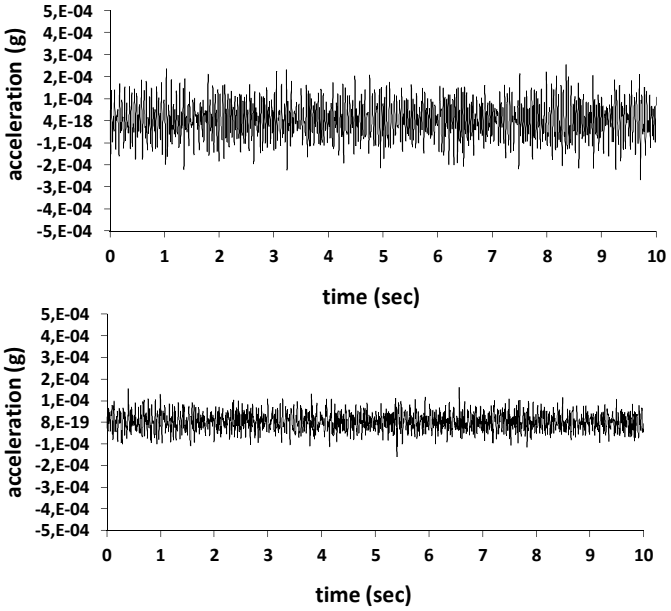
Outline

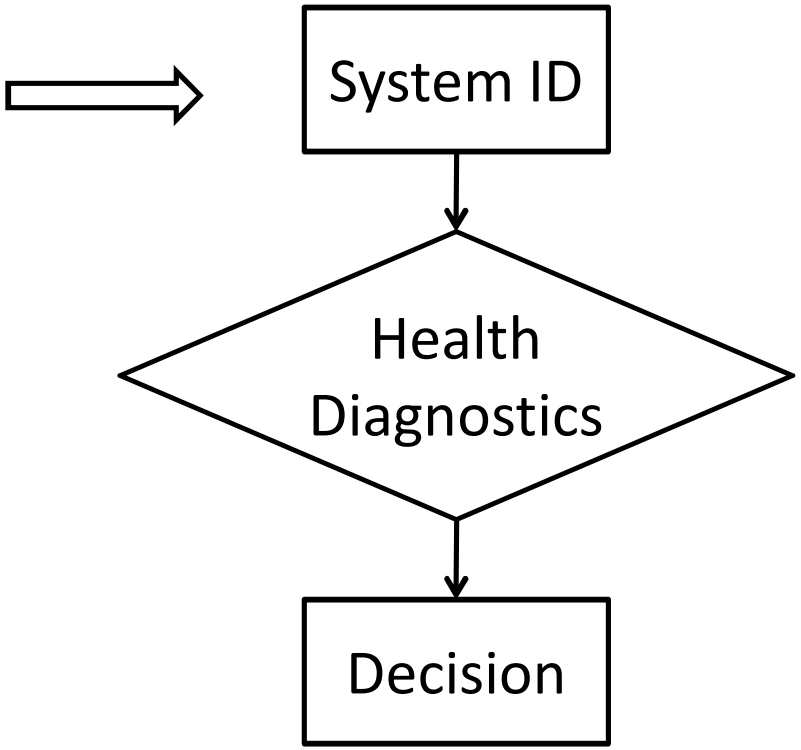
- Structural Health Monitoring
- Some Recents Projects
- Bridge Health Monitoring

Vulnerability of Civil Infrastructure

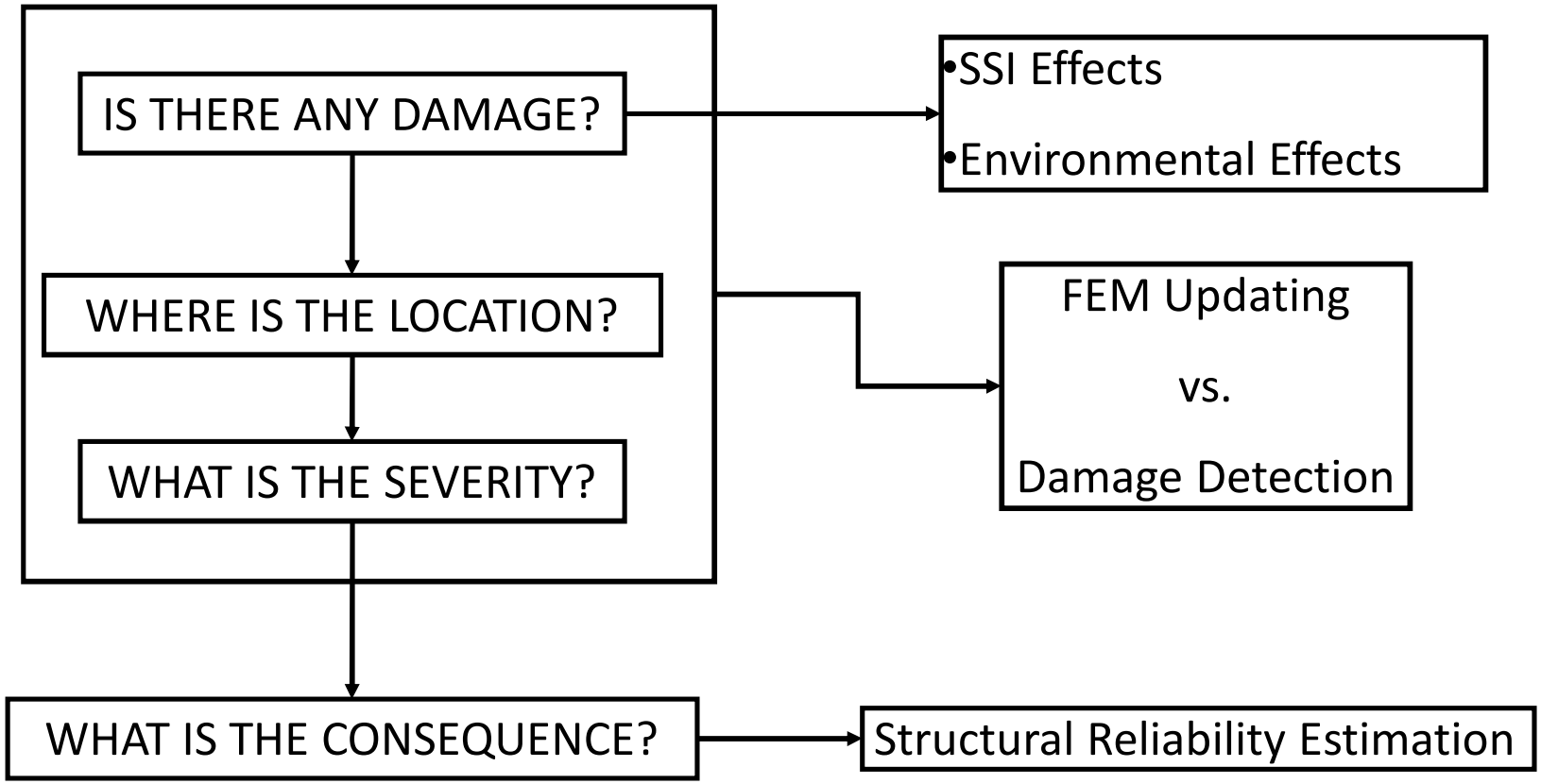
Visual Inspection

Vibration-Based Health Monitoring





SHM Flowchart



Outline

- Structural Health Monitoring
- Some Recents Projects
  - SID of Historical Structures
  - SID of RC Buildings
  - SID of CFS Structures
  - SID of a Chimney
  - SHM of Offshore Platform
  - SHM of a Wind Turbine
  - SHM of a Tall Building
- Bridge Health Monitoring

Outline

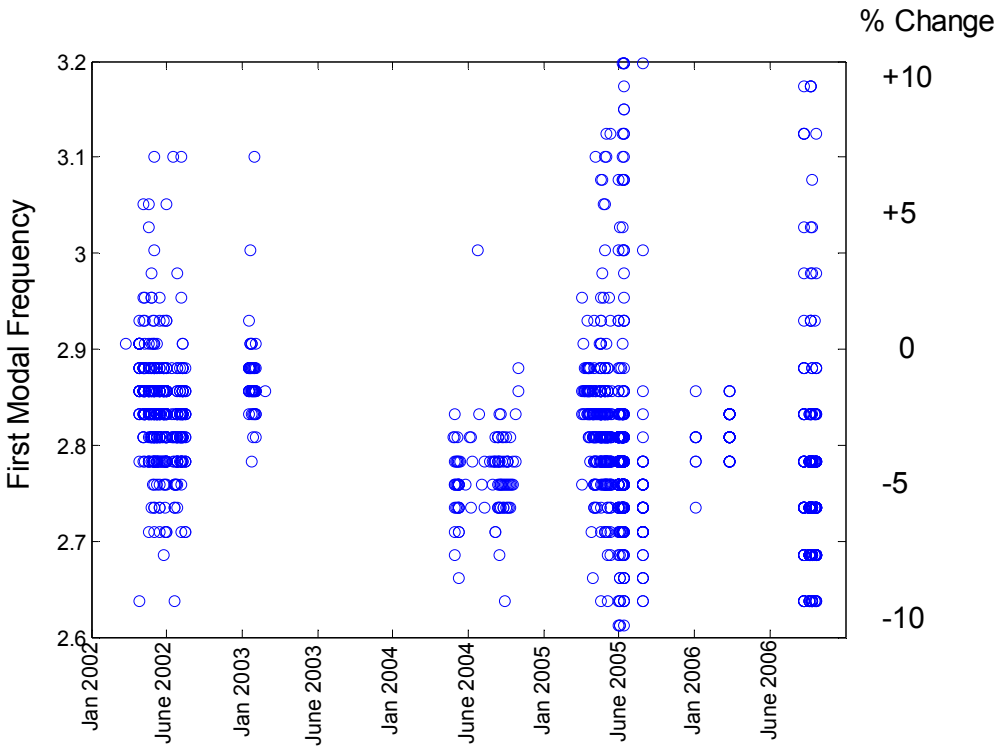
- Structural Health Monitoring
- Some Recents Projects
- Bridge Health Monitoring
  - Highway Bridges
  - Historical Stone Arch Bridges
  - Suspension Bridges

Long-Term Monitoring of Jamboree Bridge

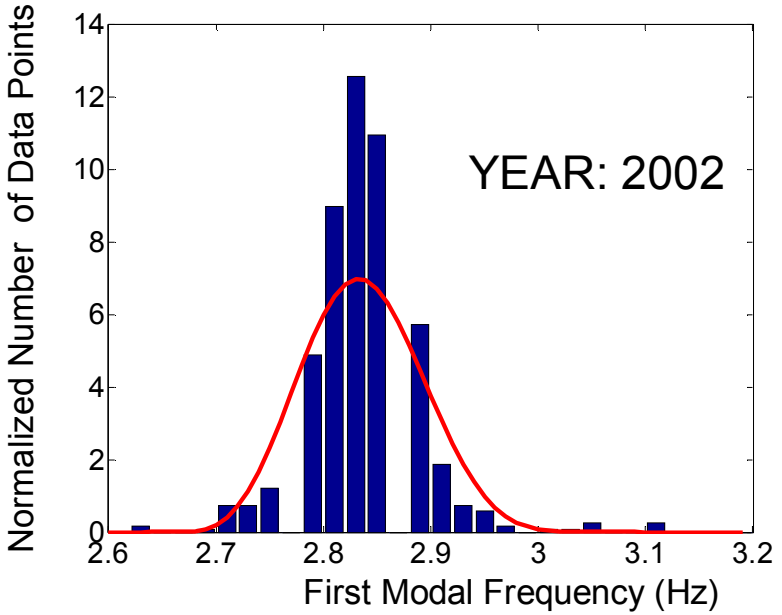
Soyoz S., Feng M.Q. (2009) "Long-term Monitoring and Identification of Bridge Structural Parameters" *Computer-Aided Civil and Infrastructure Engineering*, 24(2): 82-92.

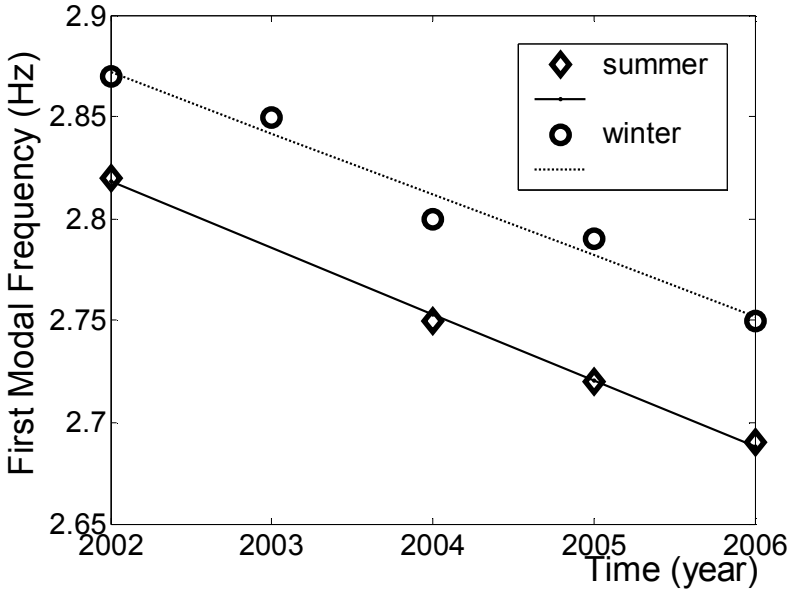
Remote Control and Data Acquisition

Modal Frequency Information

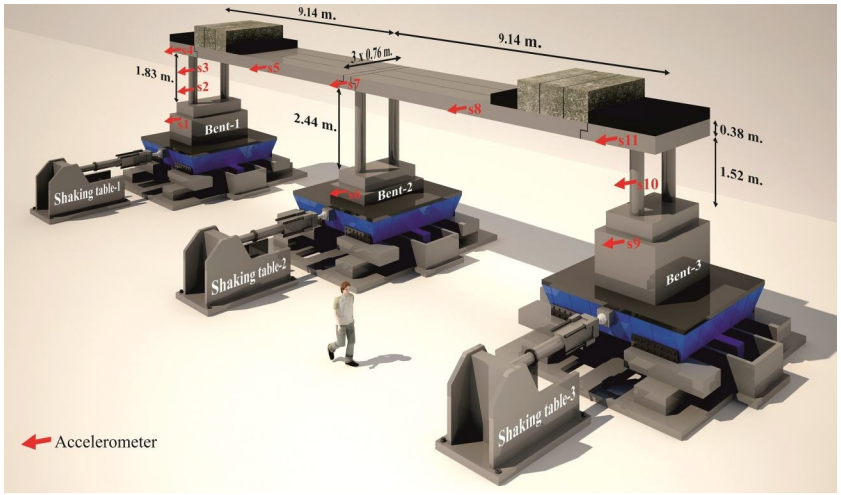


Modal Identification is performed by Singular Value Decomposition





Vibration-based Seismic Reliability Estimation of a Bridge



The shaking table test were conducted at University of Nevada, Reno in conjunction with Prof. Saidii's and Prof. Sander's NSF-NEES project.

•Ozer E., Feng M.Q., **Soyoz S.** (2015) **"**SHM-Integrated Bridge Reliability Estimation using Multivariate Stochastic Processes" *Earthquake Engineering Structural Dynamics, 44,* 601-618.

•Ozer E., **Soyoz S.** (2015) "Vibration-based Damage Detection and Seismic Performance Assessment of Bridges", Earthquake Spectra, 31(1), 137-157.

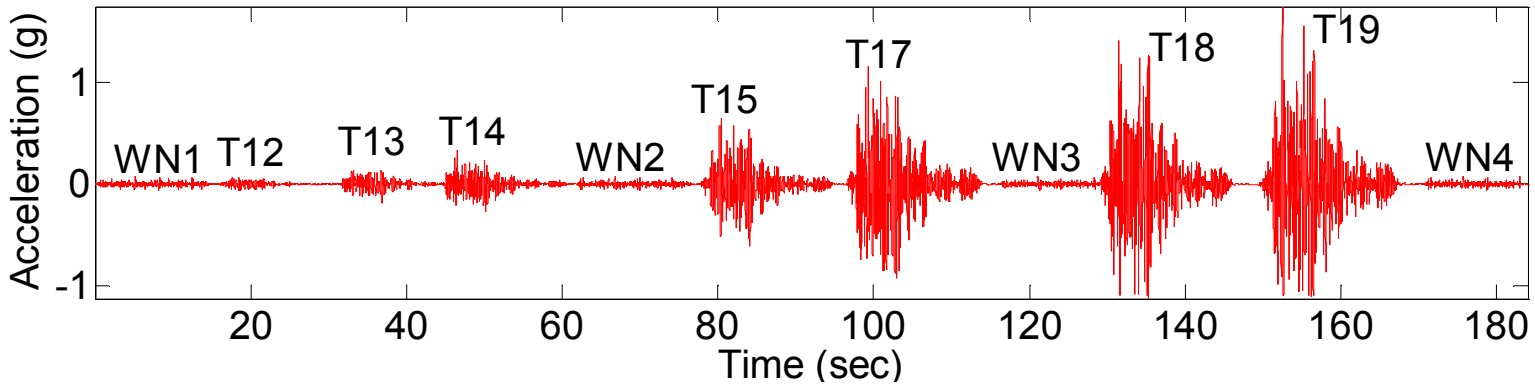
•**Soyoz S.,** Feng M.Q., Shinozuka M. (2010) "Remaining Capacity Estimation Based on Structural Identification Results" *Journal of Engineering Mechanics, ASCE,136(1), 100-106*.

•**Soyoz S.,** Feng M.Q. (2008) "Instantaneous Damage Detection of Bridge Structures and Experimental Verification" *Structural Control and Health Monitoring*, 15(7): 958-973.

•Chen Y., Feng M. Q., **Soyoz S.** (2008) "Large-Scale Shake Table Test Verification of Bridge Condition Assessment Methods" *Journal of Structural Engineering, ASCE*, 134(7):1235-1245.

Test Procedure

Test	Ground Motion Description	PGA (g)	Damage Description
WN-1	White Noise in Transverse		
T-13	Low Earthquake in Transverse	0.17	Bent-1 yields
T-14	Moderate Earthquake in Transverse	0.32	Bent-3 yields
WN-2	White Noise in Transverse		
T-15	High Earthquake in Transverse	0.63	Bent-2 yields
WN-3	White Noise in Transverse		
T-19	Extreme Earthquake in Transverse	1.70	Bent-3 steel buckles
WN-4	White Noise in Transverse		



Observed Damage

on bent-1

T-13

T-14

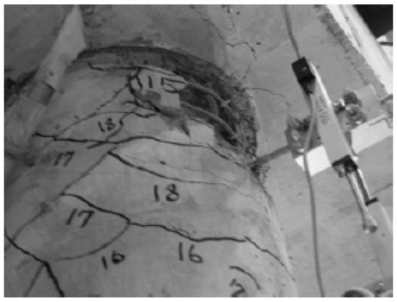
T-15

T-19

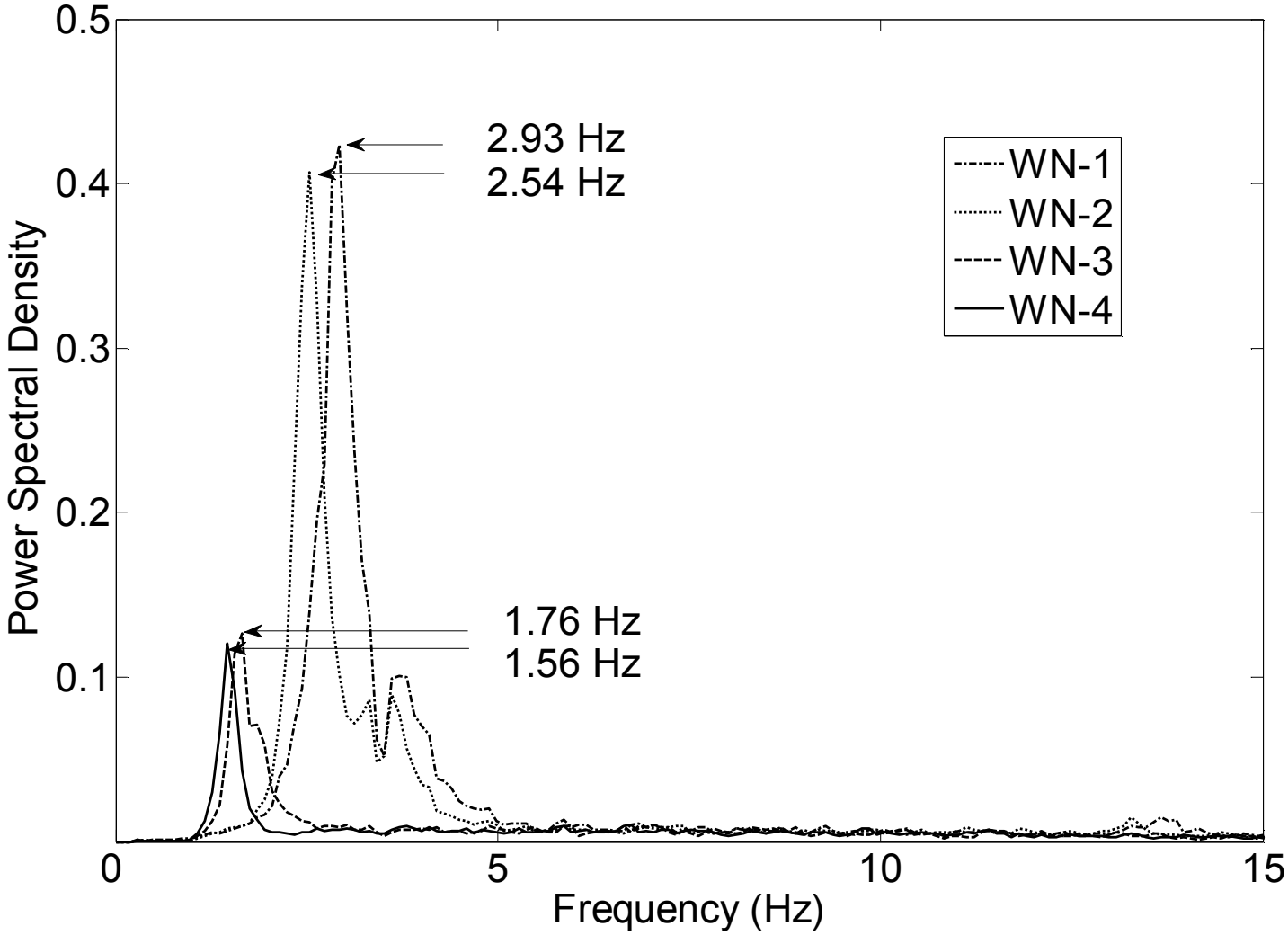
bent-3, T-19

lower (left)

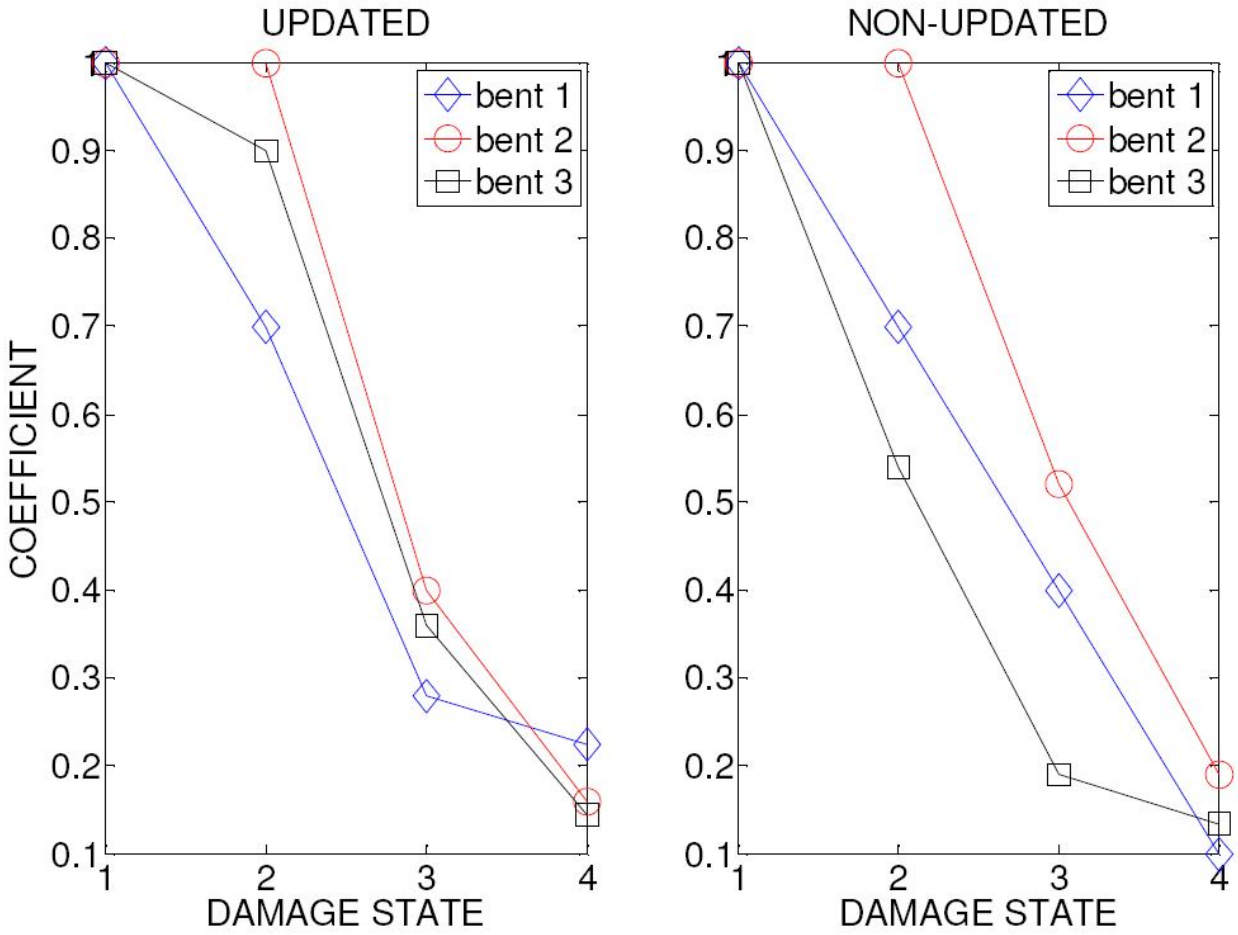
upper (right)



Modal Identification

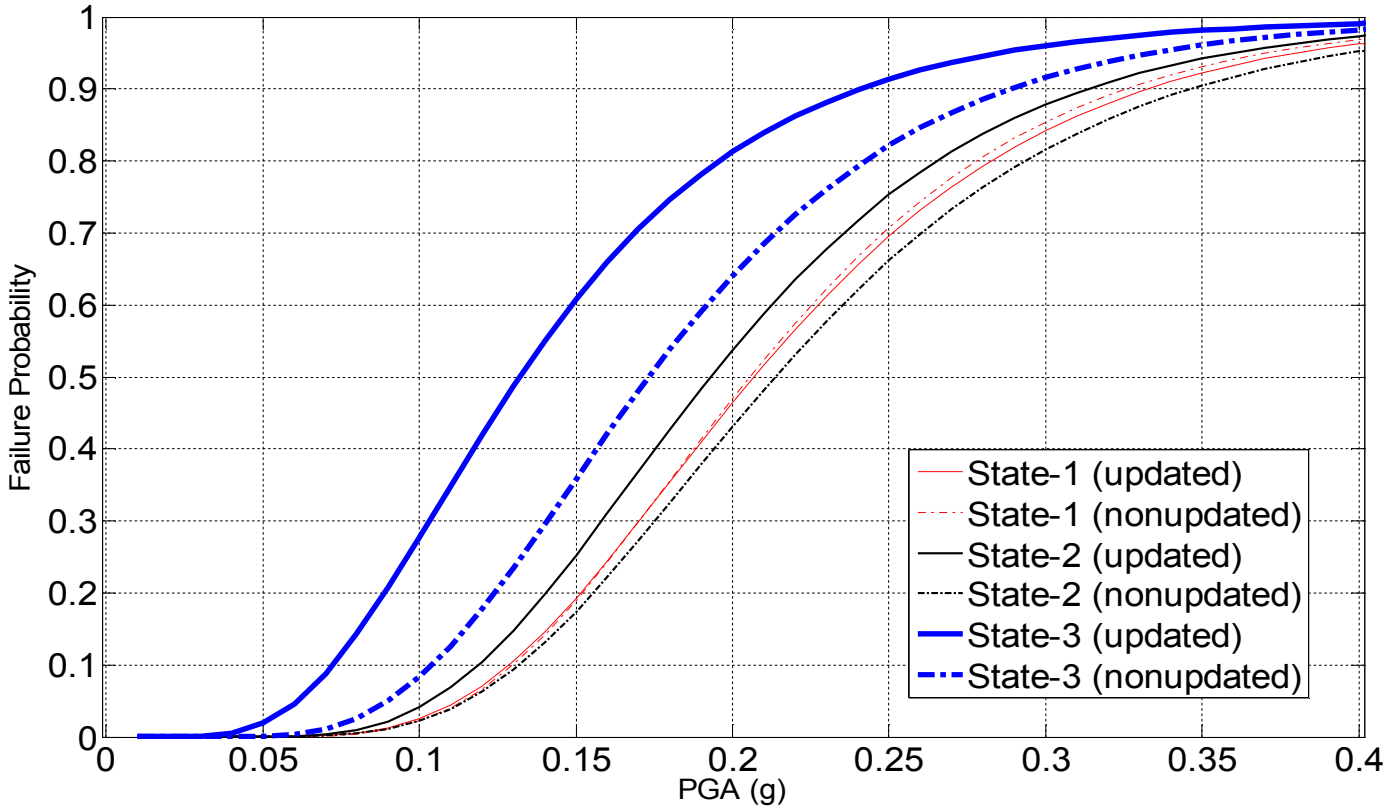


Damage Progress

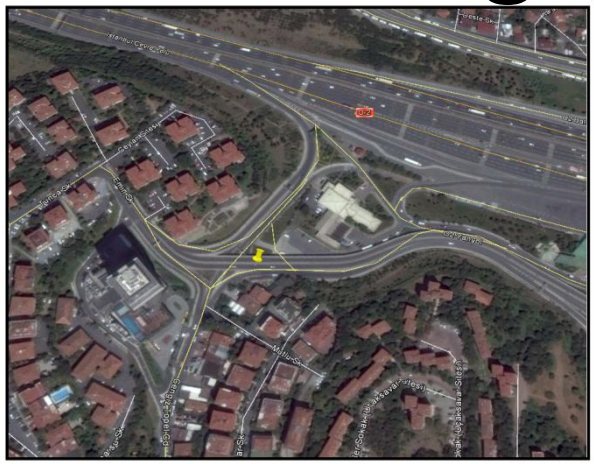


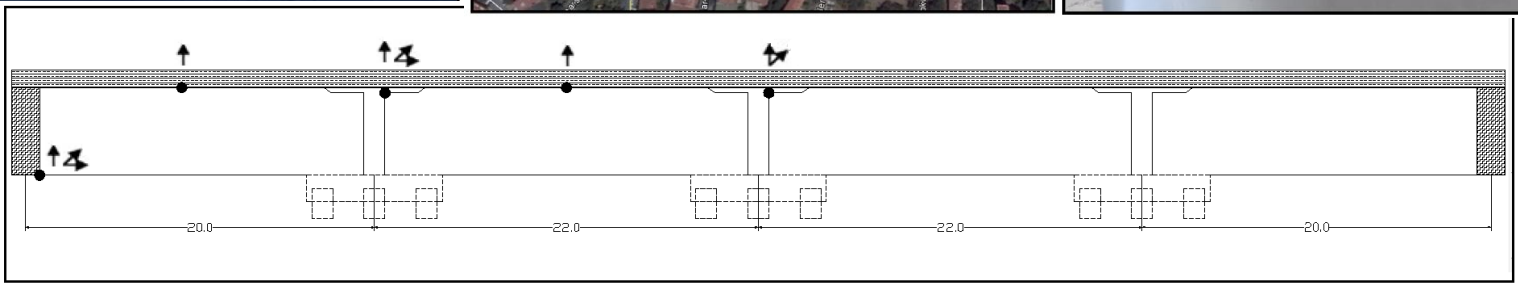
Stiffness values according to different damage states

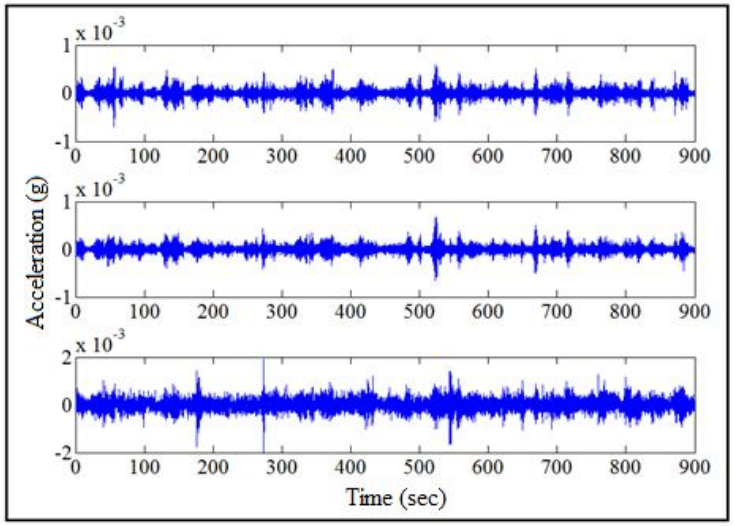
Effect of System Identification on Reliability Estimation

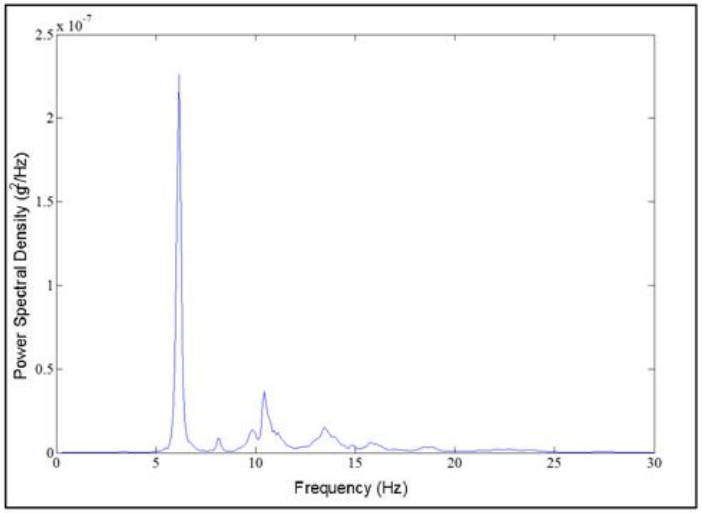


Etiler Bridge





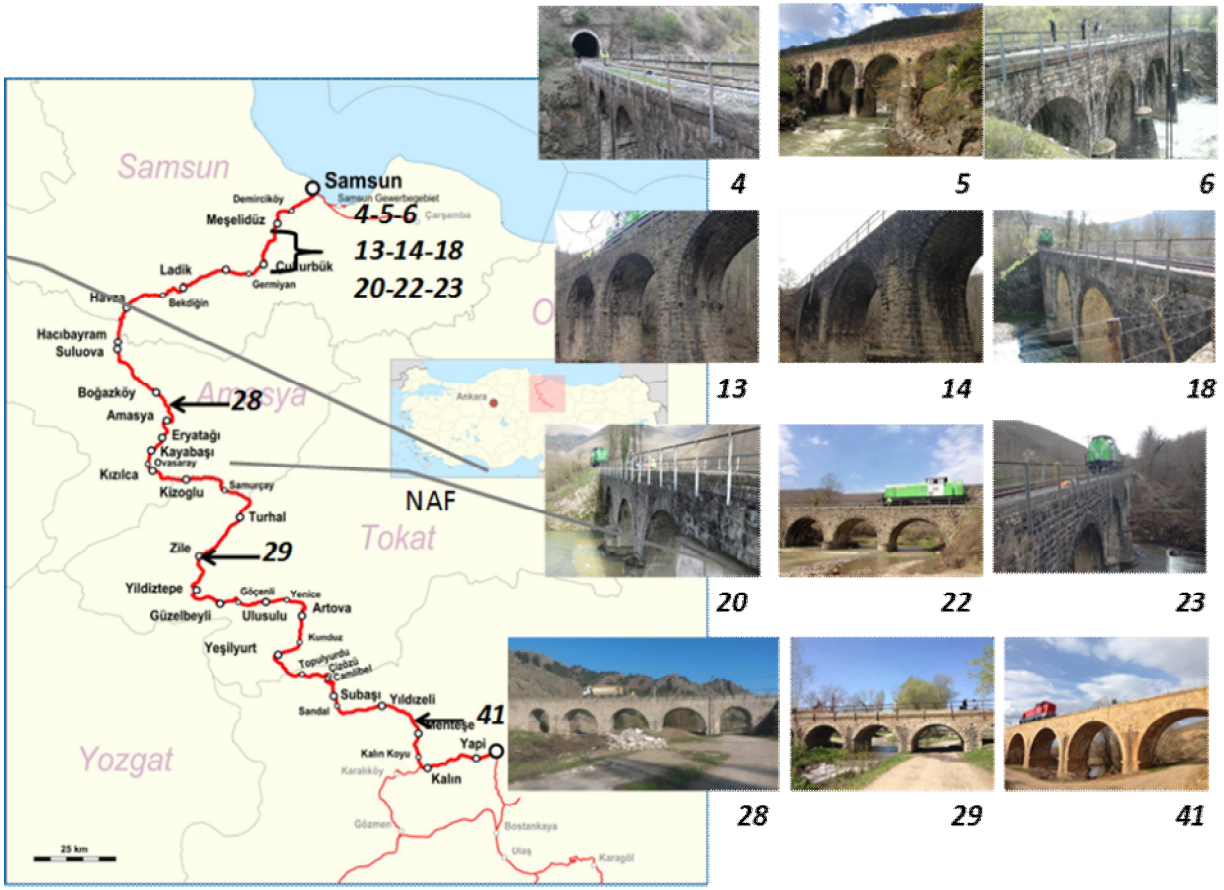




Outline

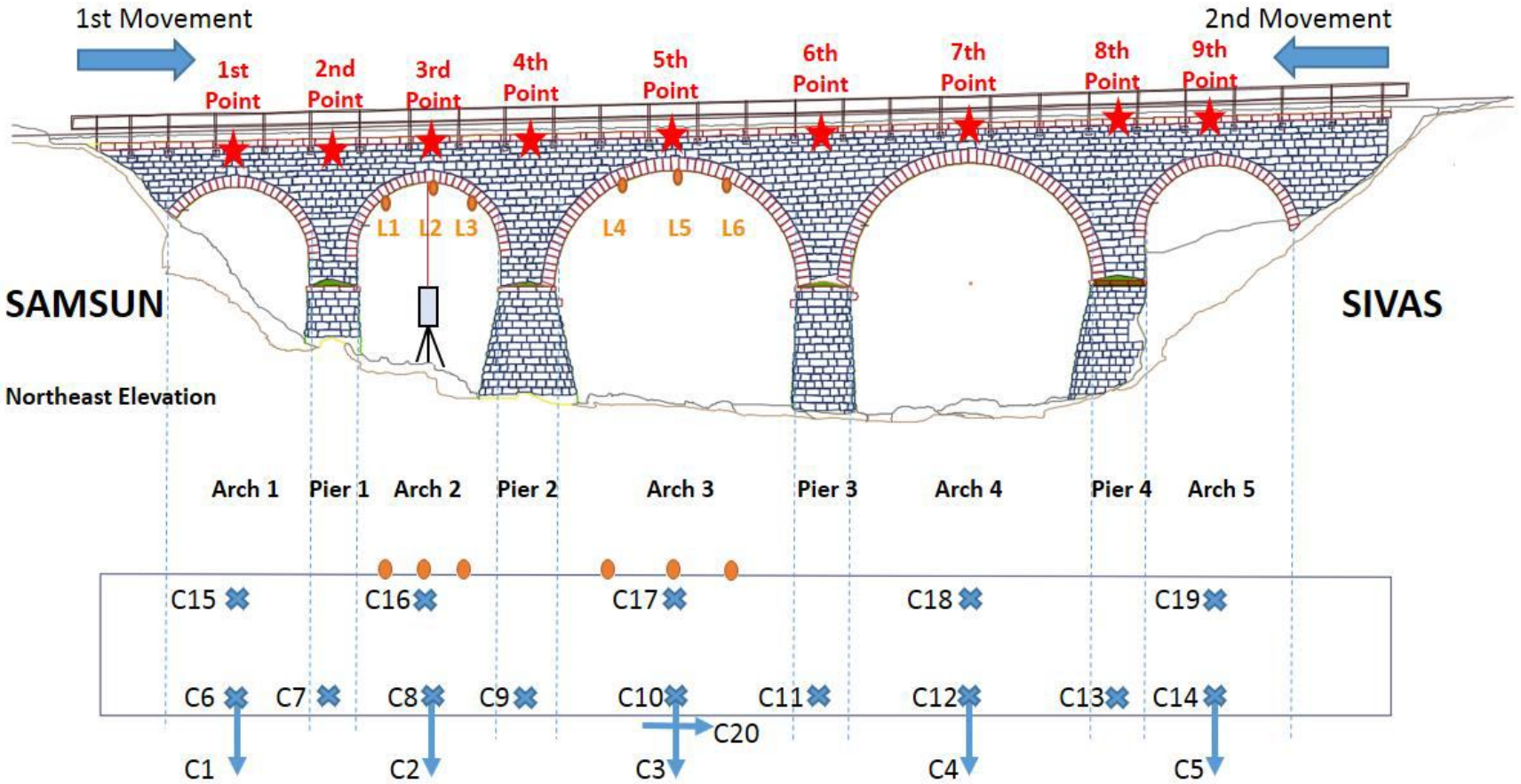
- Structural Health Monitoring
- Some Recents Projects
- Bridge Health Monitoring
  - Highway Bridges
  - Historical Stone Arch Bridges
  - Suspension Bridges

Stone Arch Bridges



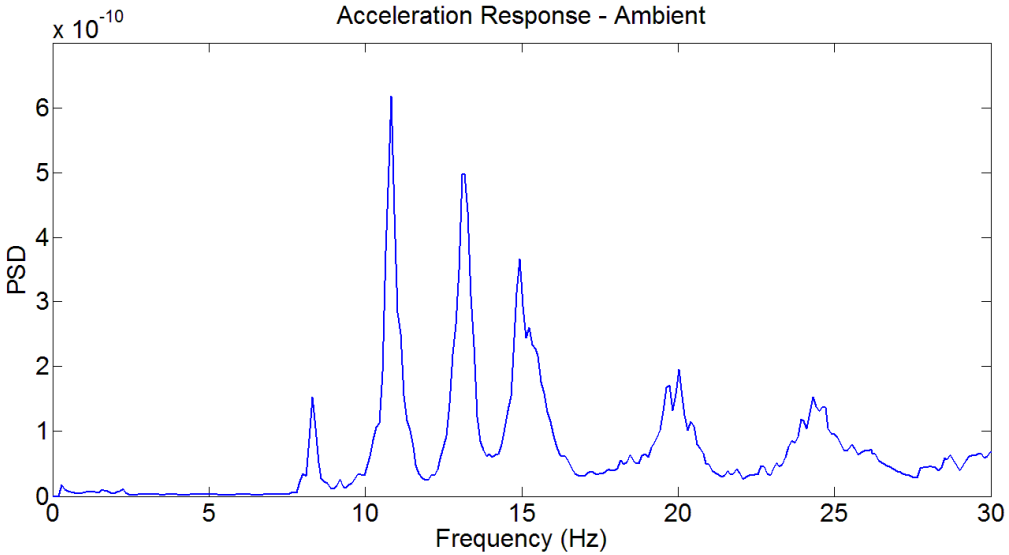
Soyoz S. et al (2017) "Dynamic identification-model updating-seismic performance assessment of stone arch bridges" *4th Conf on Smart Monitoring Assessment and Rehabilitation of Civil Structures*, Zurich, Switzerland.

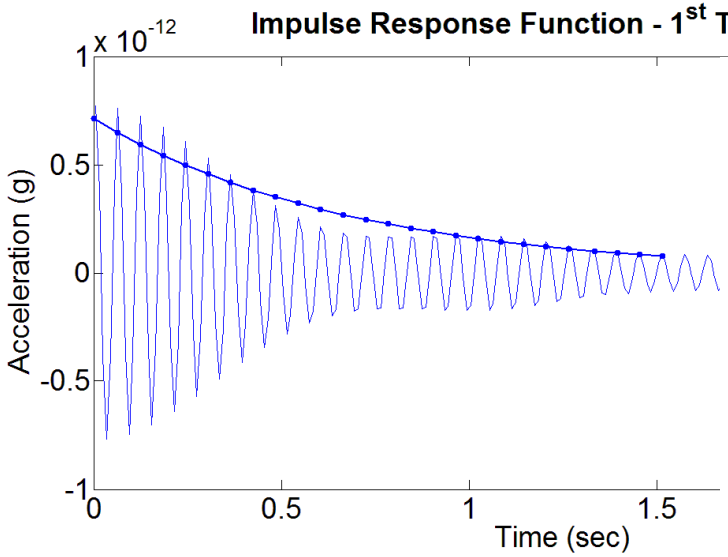
Bridge 6

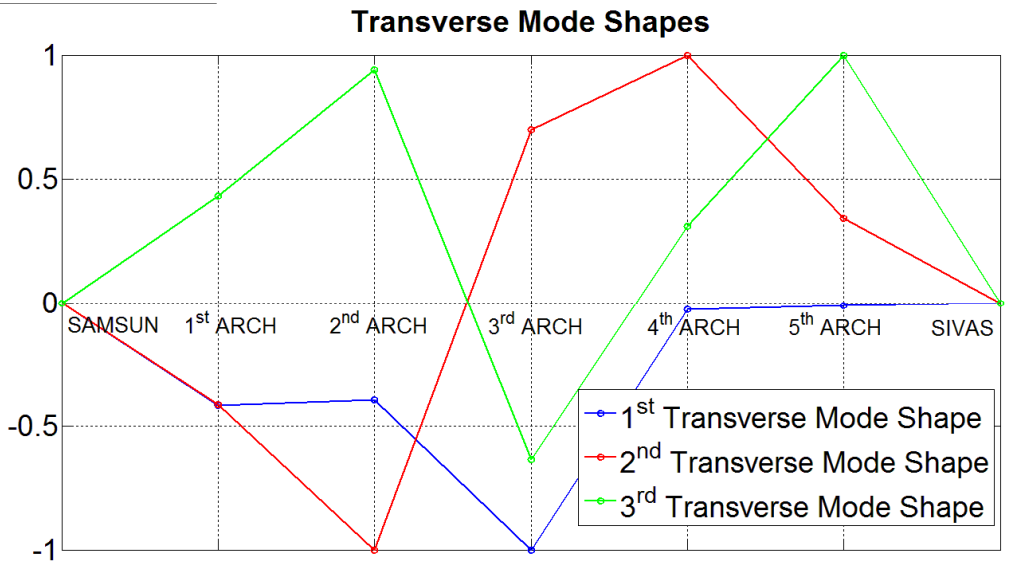

1st Movement
2nd Movement
1st Point
2nd Point
3rd Point
4th Point
5th Point
6th Point
7th Point
8th Point
9th Point
L1
L2
L3
L4
L5
L6
SAMSUN
SIVAS
Northeast Elevation
Arch 1
Pier 1
Arch 2
Pier 2
Arch 3
Pier 3
Arch 4
Pier 4
Arch 5
C15
C16
C17
C18
C19
C6
C7
C8
C9
C10
C11
C12
C13
C14
C20
C1
C2
C3
C4
C5

Ambient Vibration Test

Dynamic Properties







FEM Updating

Modal assurance criteria

$$MAC = \frac{\left|\psi_*^T \cdot \psi\right|^2}{\left(\psi_*^T \cdot \psi_*\right) \cdot \left(\psi^T \cdot \psi\right)}$$

Error function

$$E = \sum_{i=1}^{4} \left(k_i \cdot \left[\left(f_i^* - f_i \right) / f_i^* \right]^2 + h_i \cdot \left[1 - MAC_i \right]^2 \right)$$

Parameters to be identified

- Young's modulus of stone + mortar
- Soil Springs

FEM Updating

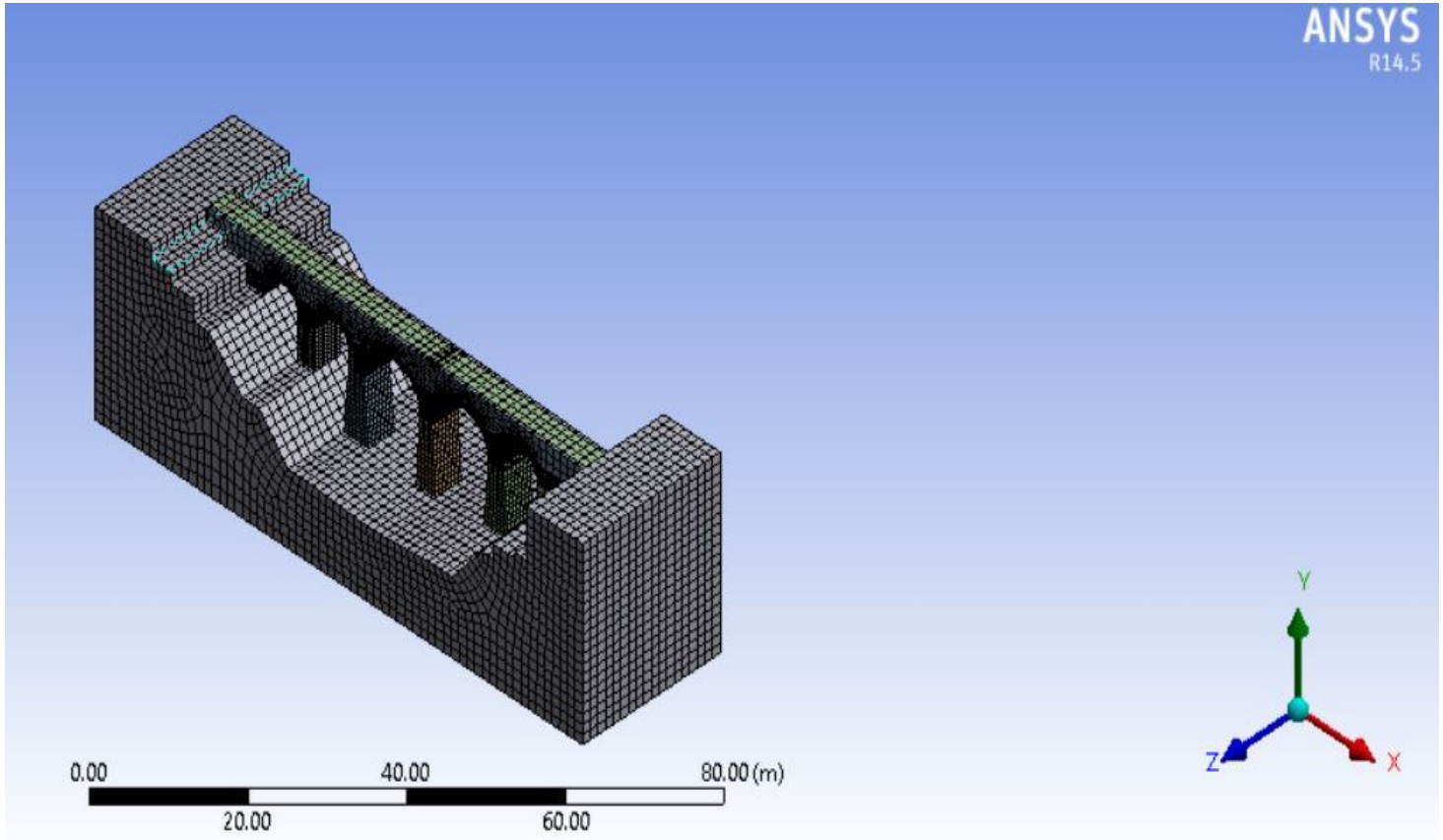
Modal Frequencies

Mode	Non-updated Frequency (Hz)	Updated Frequency (Hz)	Identified Frequency (Hz)
Trans-1	3.28	7.33	8.31
Trans-2	5.79	10.8	10.9
Trans-3	9.29	15.3	13.2
Vert-1	13.0	23.6	20.0
Vert-2	13.8	25.8	24.3

Parameters

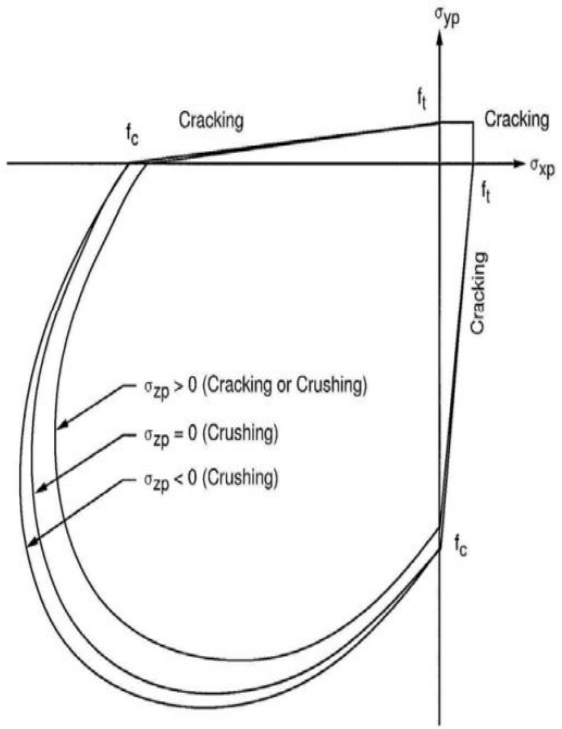
	Non-updated	Updated
E (Gpa)	7.8	12.3
Soil Spring (MN/m)	75	Fixed

ANSYS Model



Nonlinear Model Definition

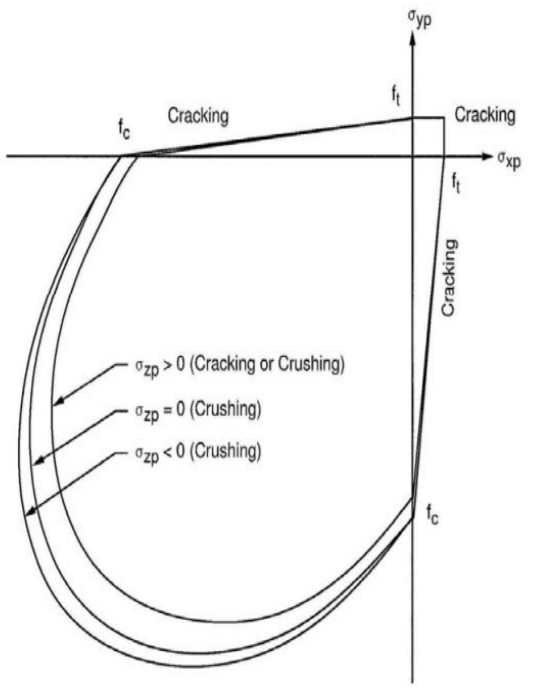
Structure



ft=0.8 MPa

fc=56.5 MPa

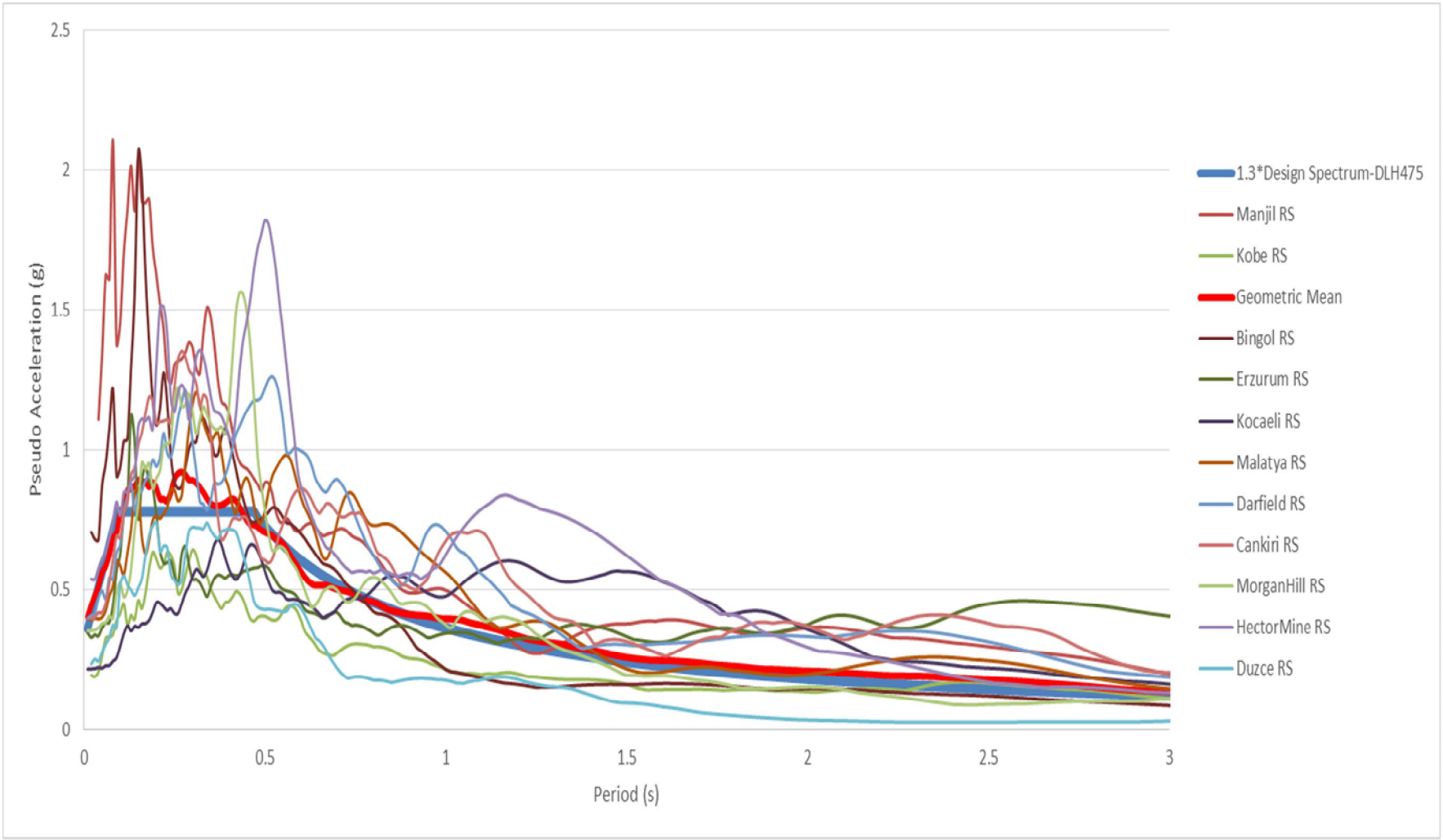
Soil



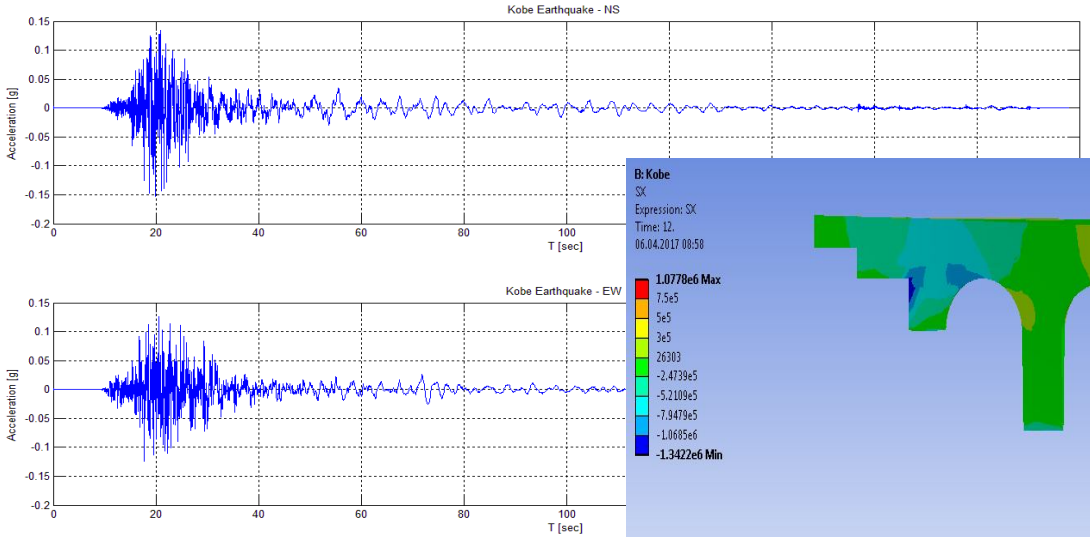
ft=0.1 MPa

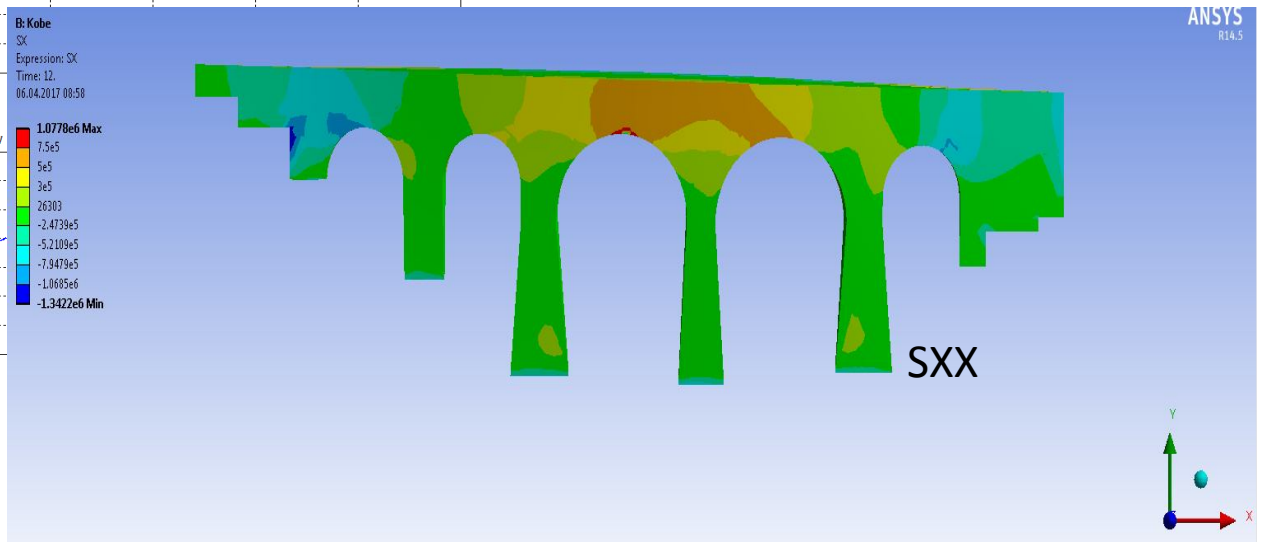
fc=10 MPa

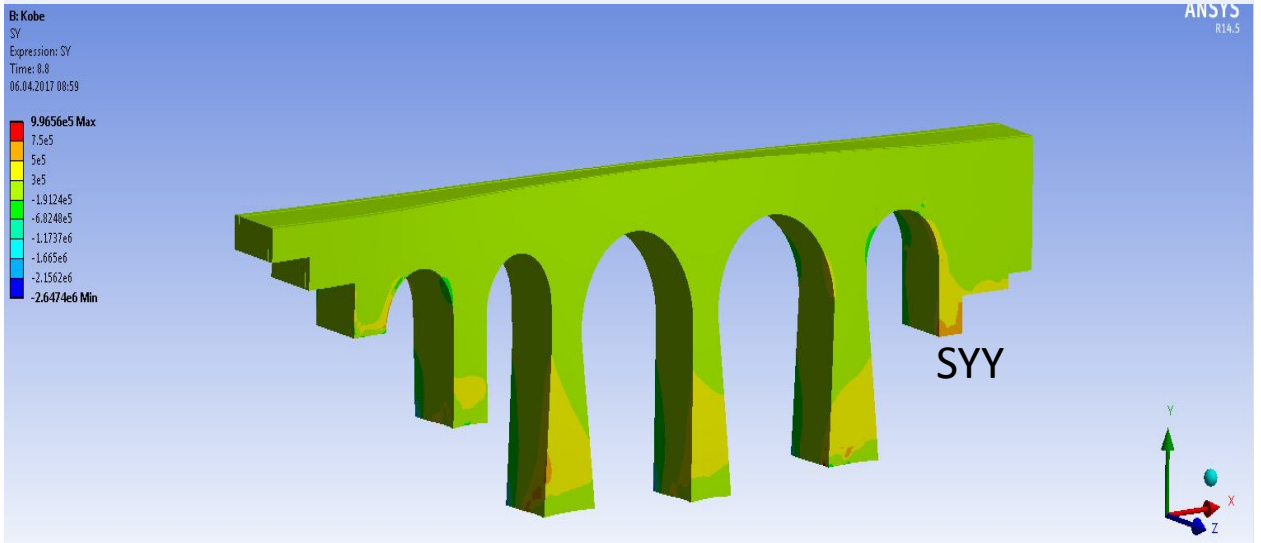
Seismic Input



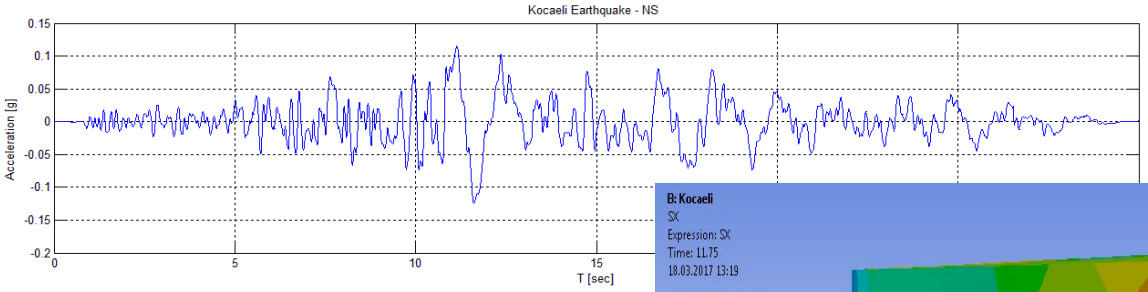
Kobe Earthquake

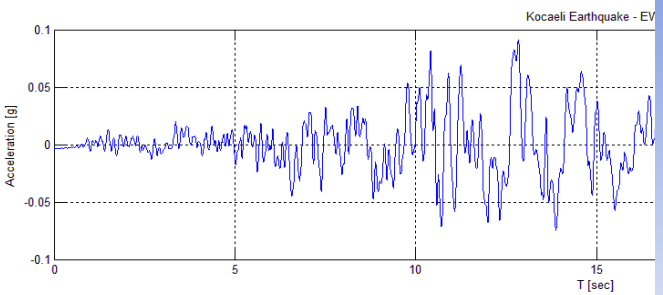


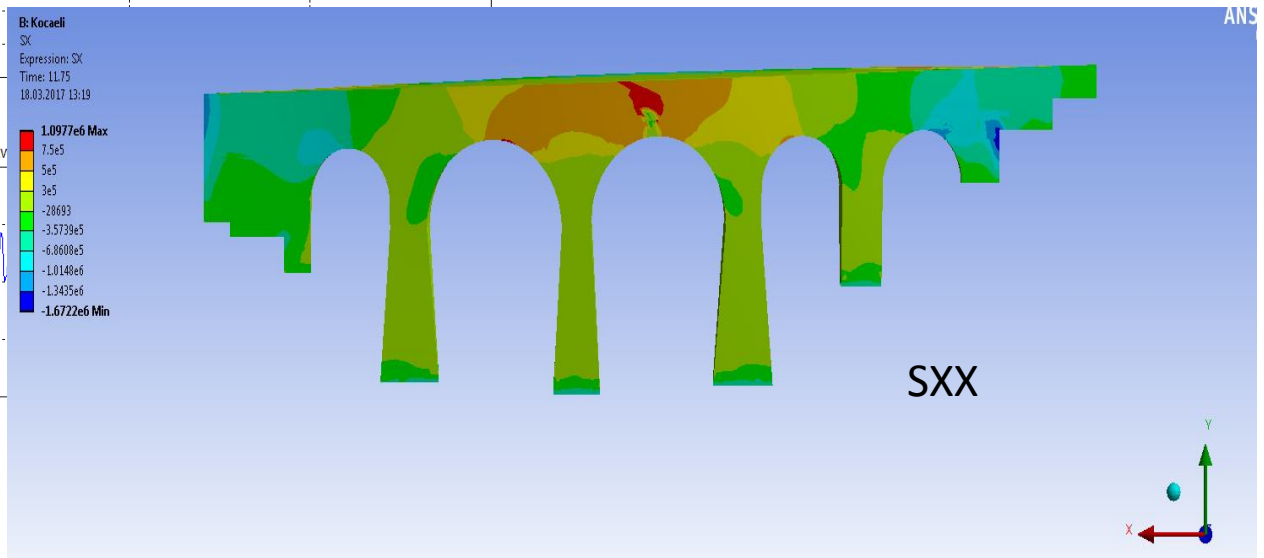


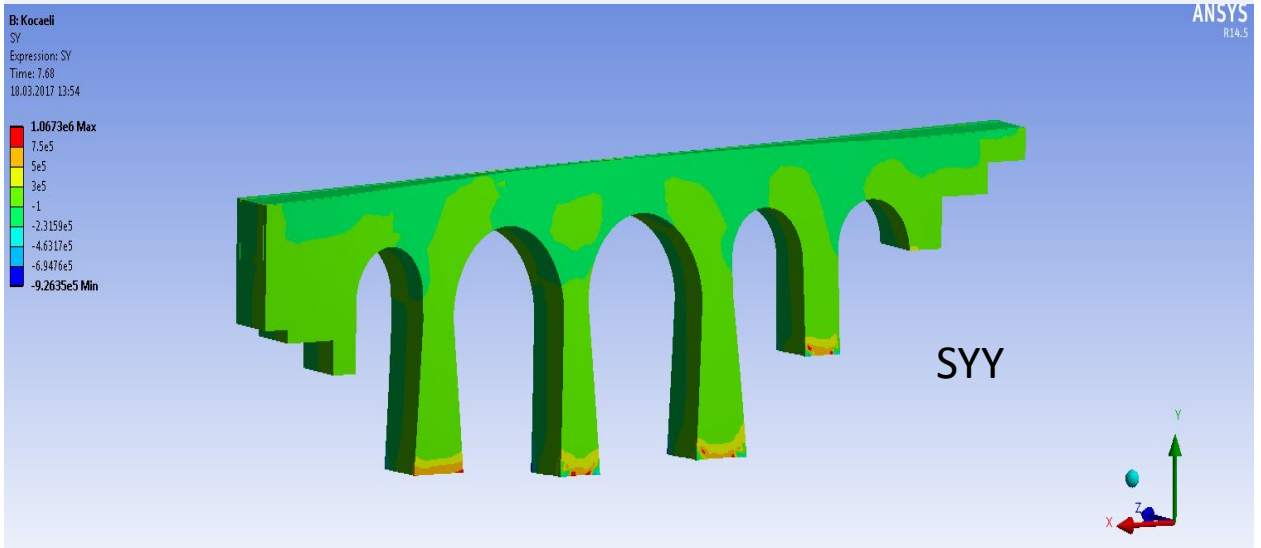


Kocaeli Earthquake









Conclusion

- System identification for “global” structural condition assessment
- Vibration-based FEM updating of structures
- Seismic Reliability Analysis with updated FEM

Outline

- Structural Health Monitoring
- Some Recents Projects
- Bridge Health Monitoring
  - Highway Bridges
  - Historical Stone Arch Bridges
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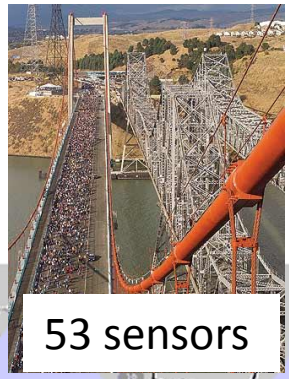
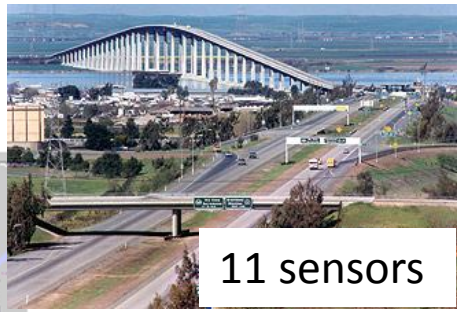
Suspension Bridges-California



53 sensors

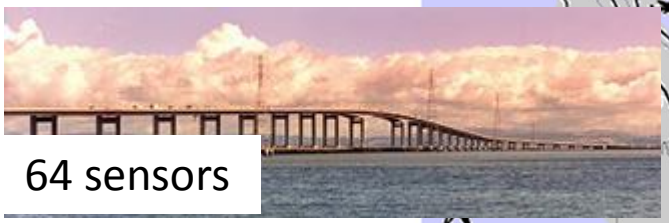


11 sensors

81 sensors

71 sensors

26 sensors

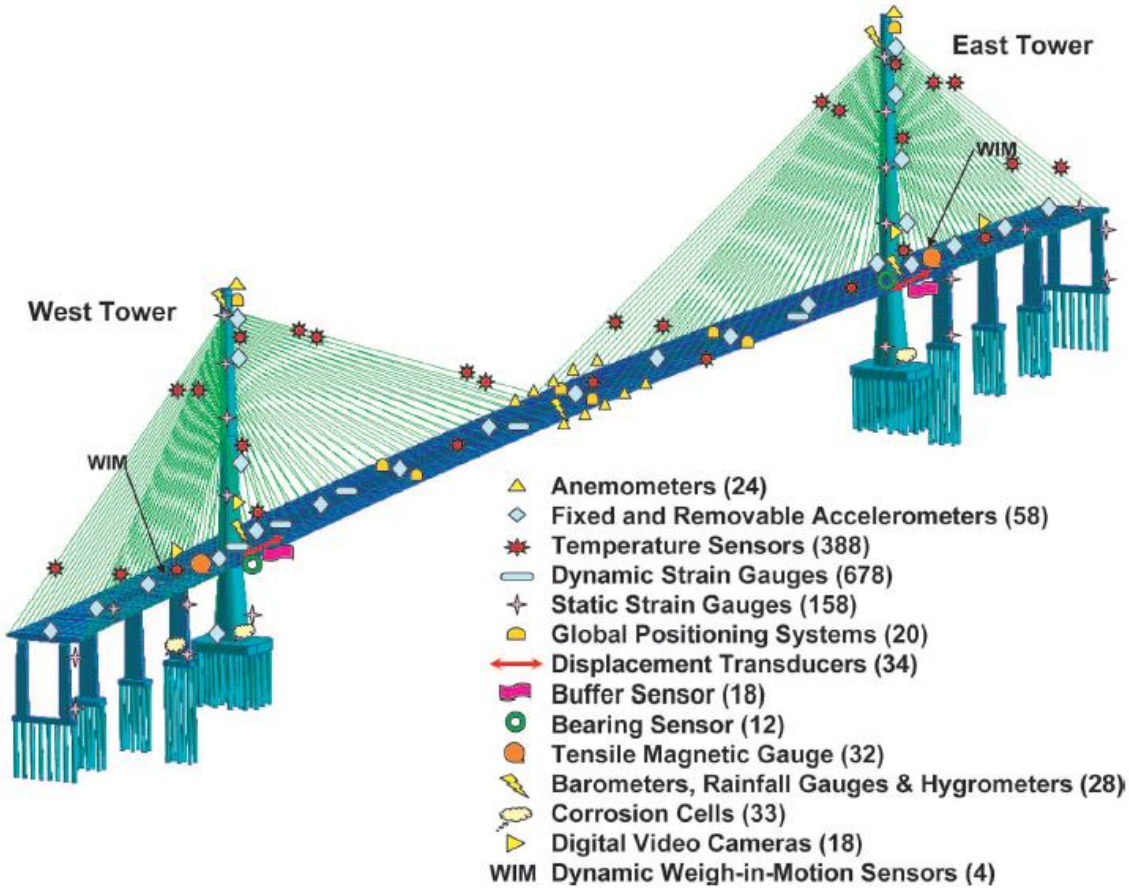


64 sensors

Design of SHM systems for long-span bridges

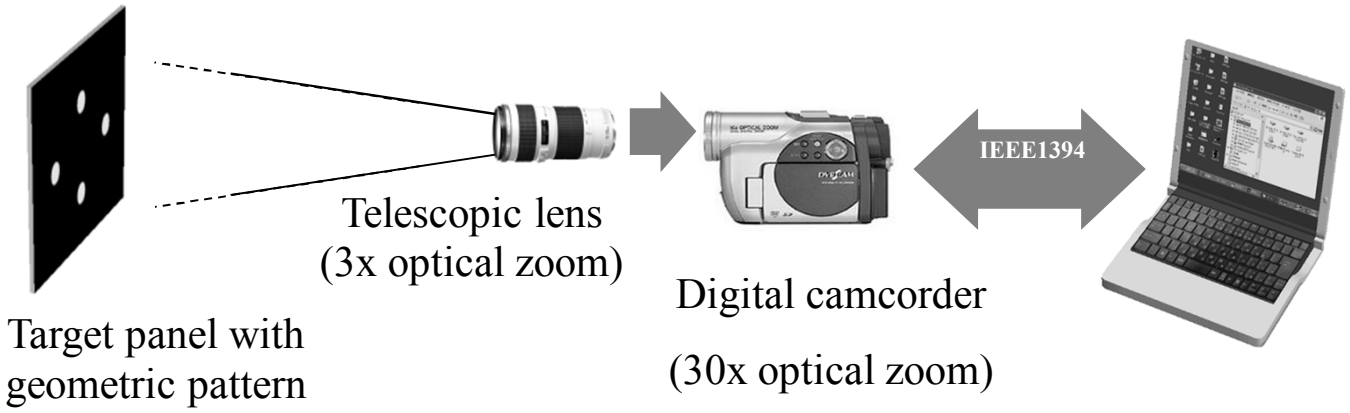
Wong K-Y

Structure and Infrastructure Engineering, 2007



Stonecutters bridge

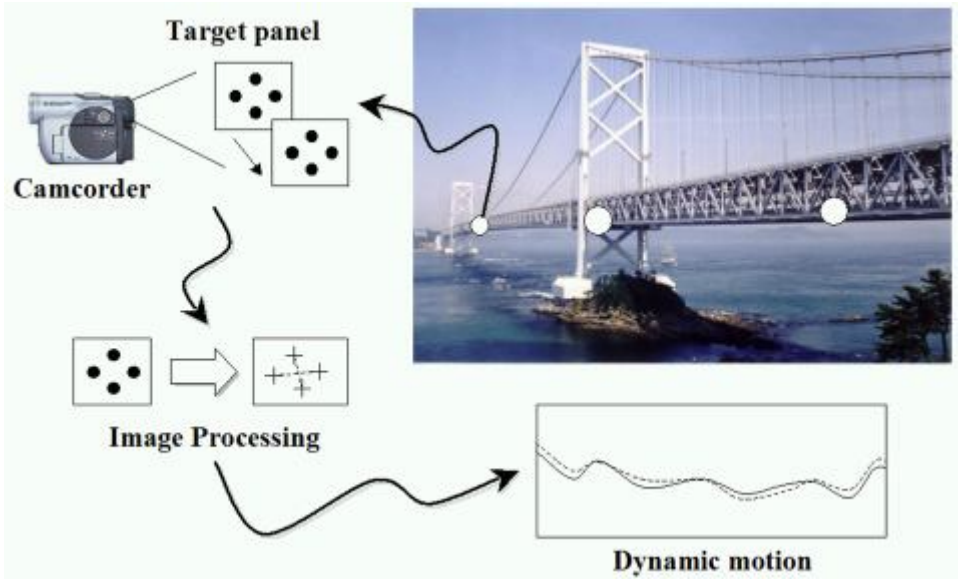
Optical Sensors



Target panel with geometric pattern

Telescopic lens (3x optical zoom)

Digital camcorder (30x optical zoom)



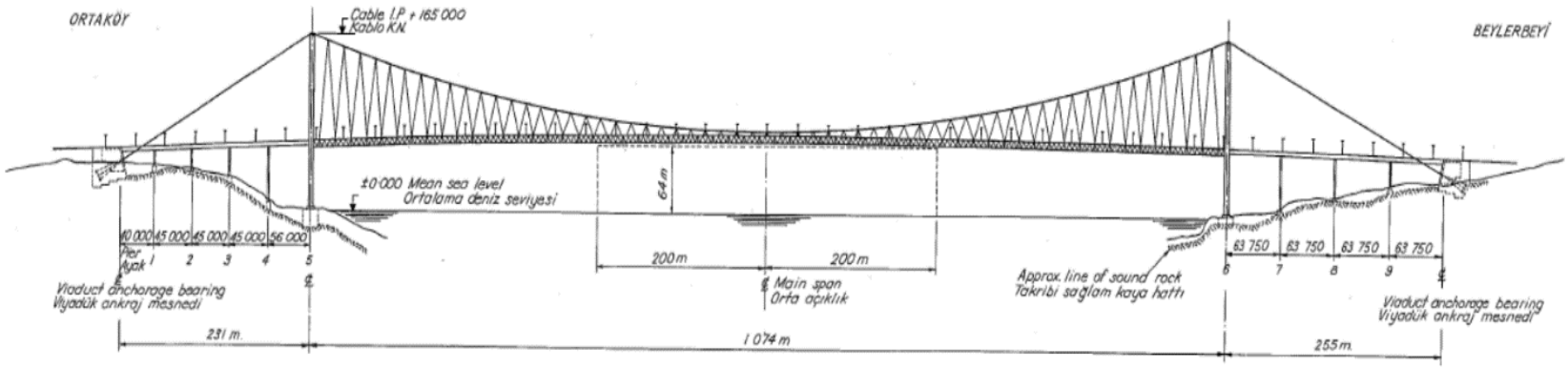
Suspension Bridges in Turkey

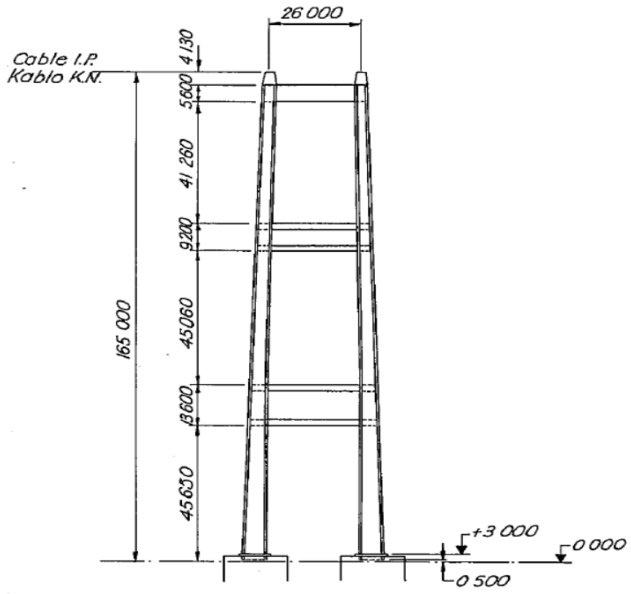
Hanger Replacement of Bogazici Bridge

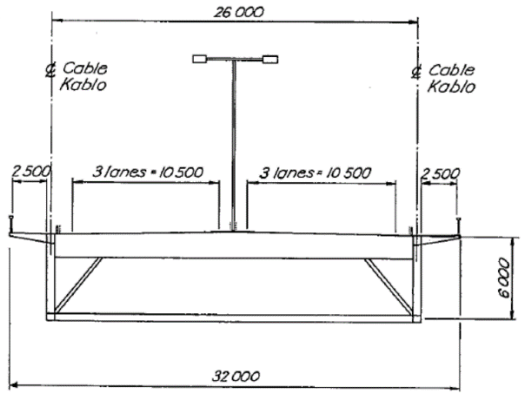
Soyoz S. et al (2017) “System identification of Bogazici suspension bridge during hanger replacement” *10th Conf on Structural Dynamics*, Rome, Italy.

Bogazici Bridge

-Completed in 1974-





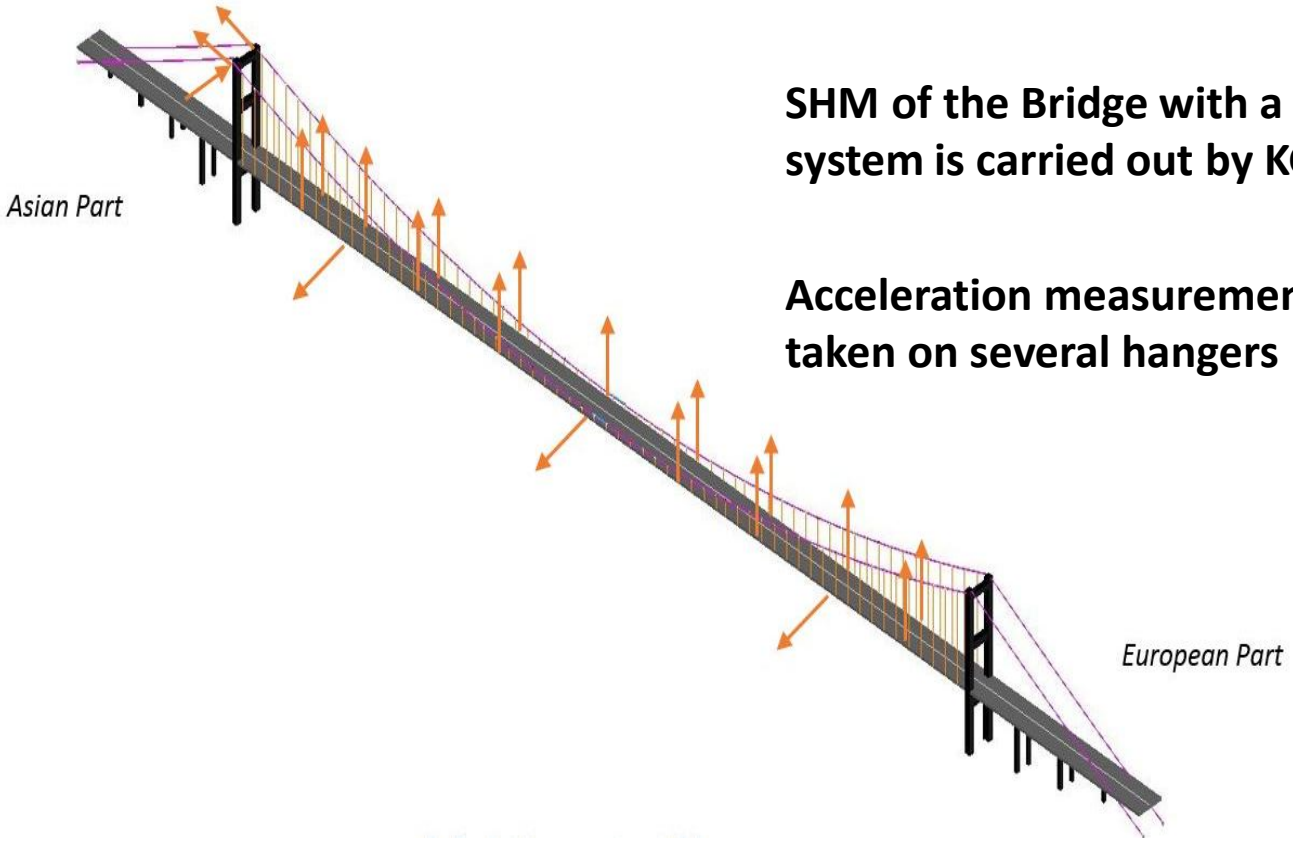


Change of Hangers-Inclined to Vertical

Change of Hangers-Inclined to Vertical

System Identification

Instrumentation

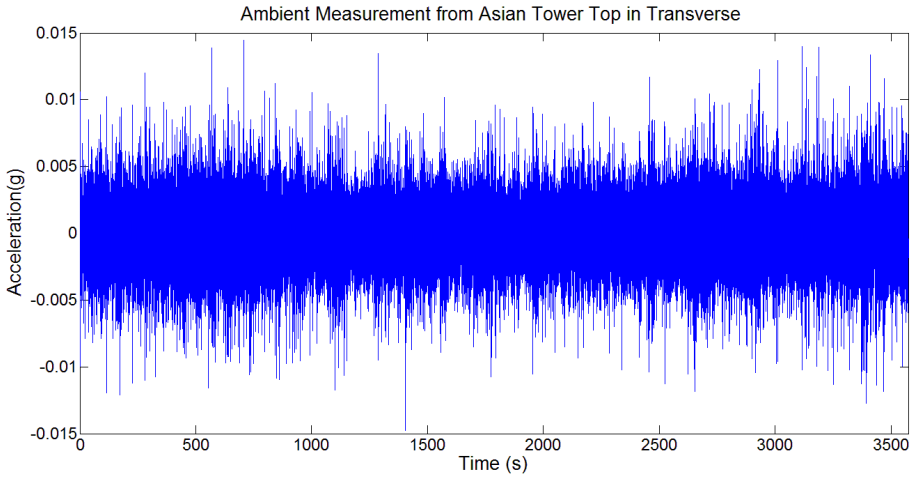


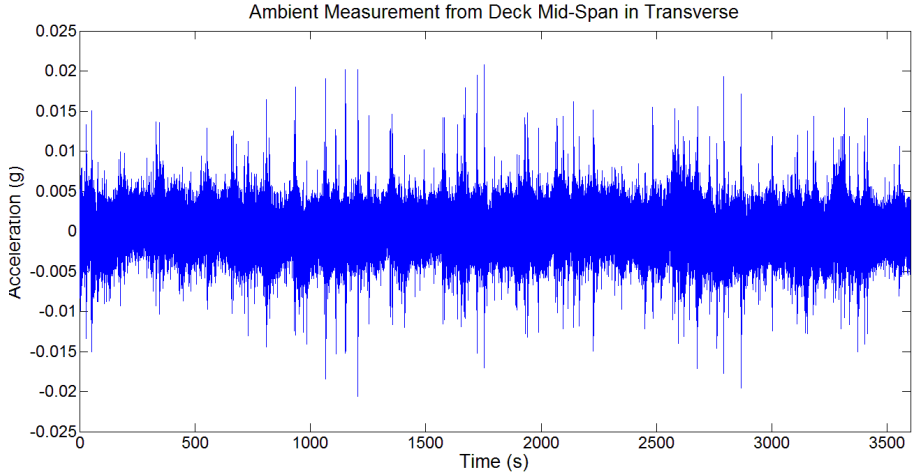
SHM of the Bridge with a permanent system is carried out by KGM

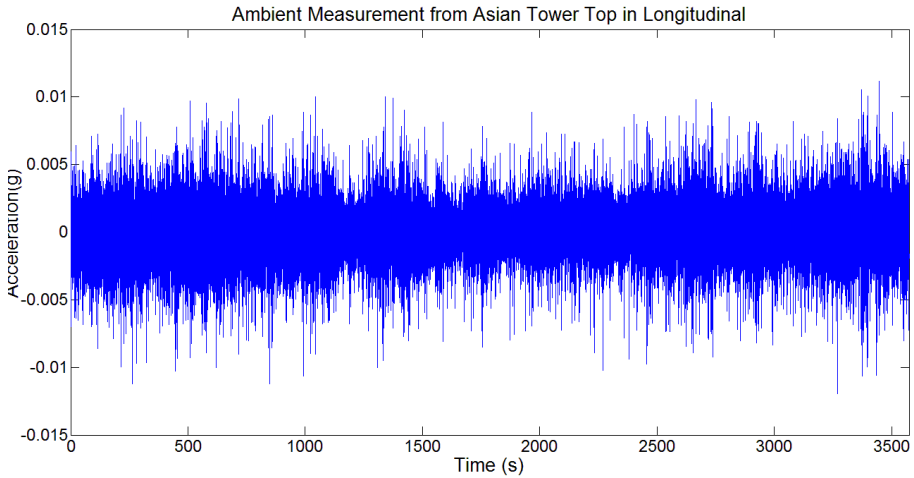
Acceleration measurements were taken on several hangers

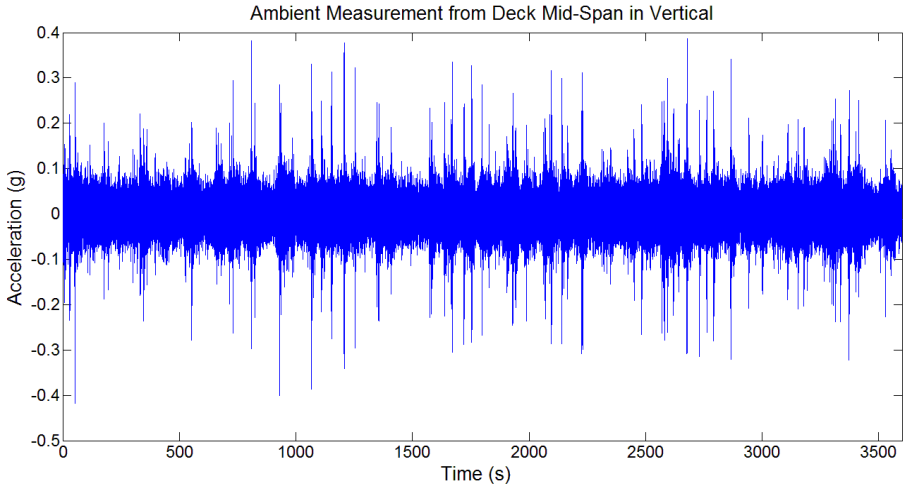
System Identification

Measurement



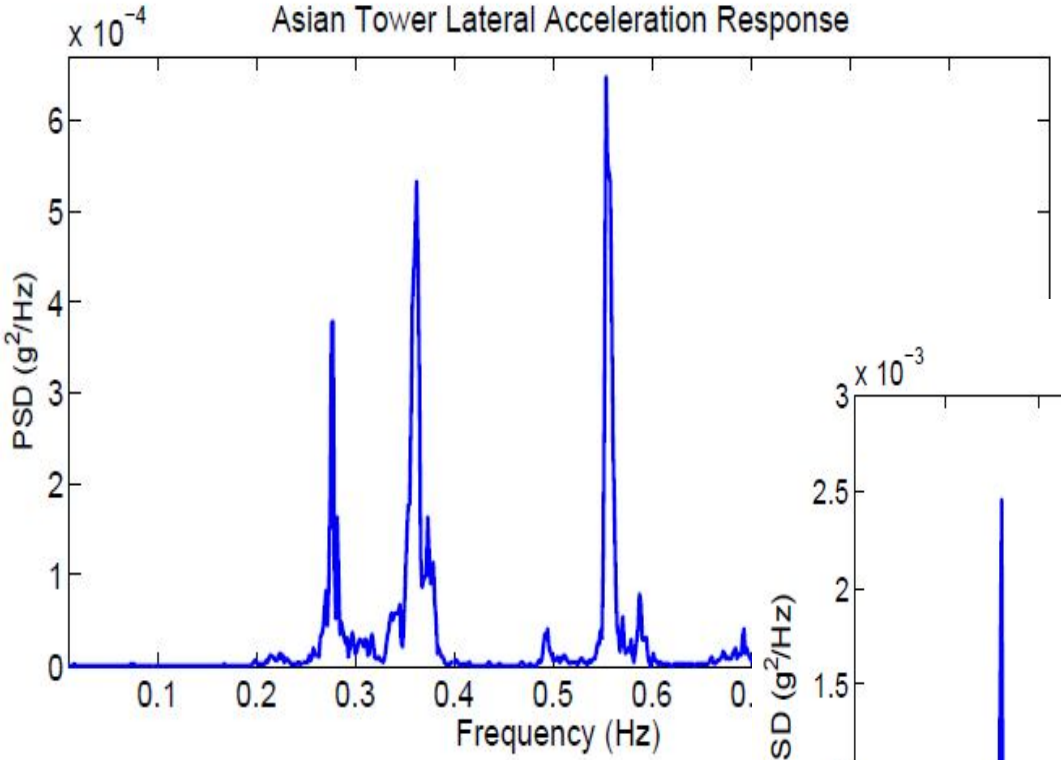


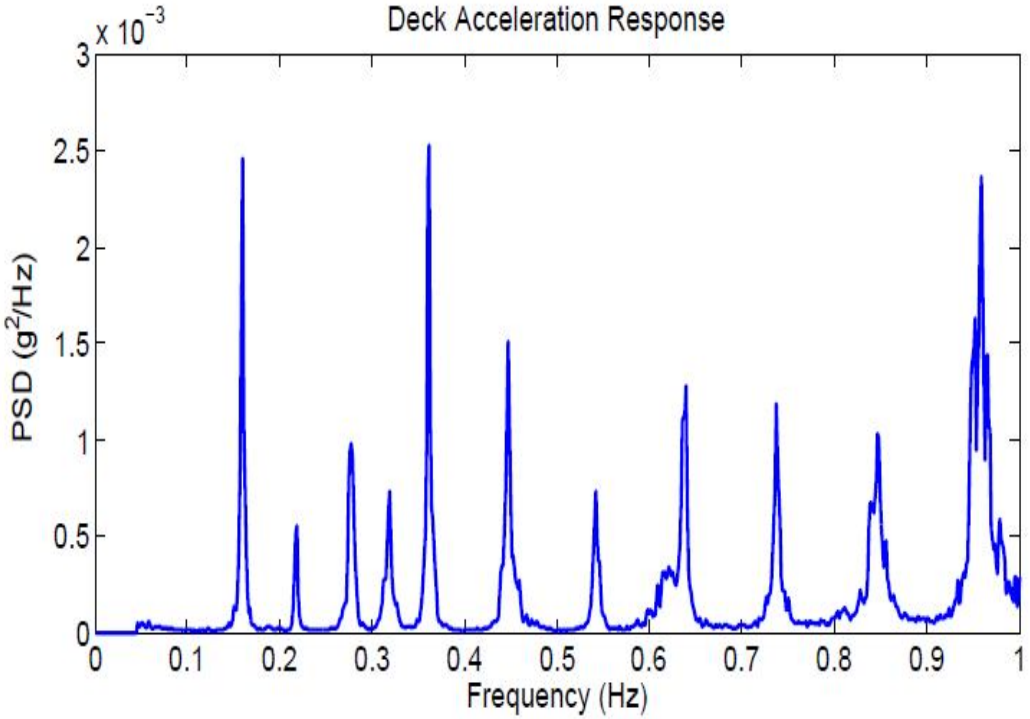




System Identification

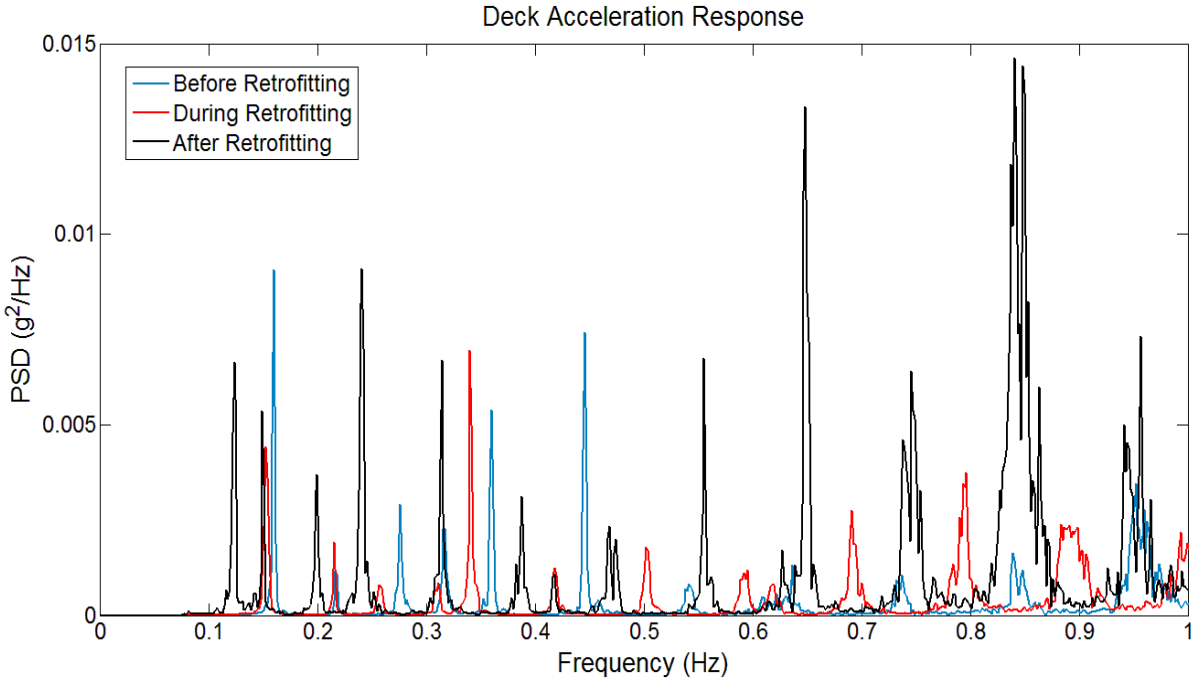
Frequency Response





System Identification

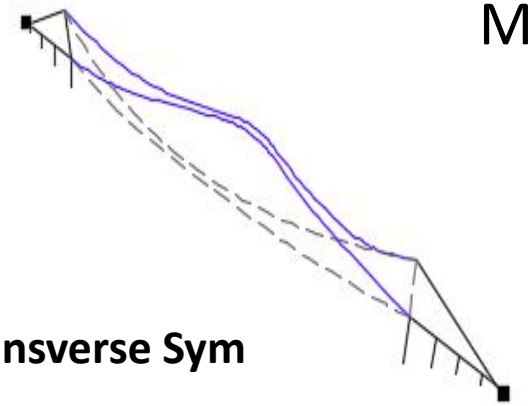
Effect of Retrofitting



Mod Number	Before Retrofitting	During Retrofitting	After Retrofitting	Difference (%)
1 (1st Trans)	0.074 Hz	0.076 Hz	0.081 Hz	9.5
2 (1st Vasym)	0.149 Hz	0.137 Hz	0.125 Hz	16.1
3 (1st Vsym)	0.159 Hz	0.154 Hz	0.149 Hz	6.3
4 (2nd Vsym)	0.217 Hz	0.215 Hz	0.201 Hz	7.4
5 (3rd Vasym)	0.276 Hz	0.262 Hz	0.243 Hz	12.0

System Identification

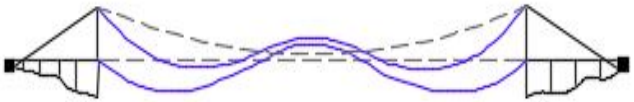
Mode Shapes



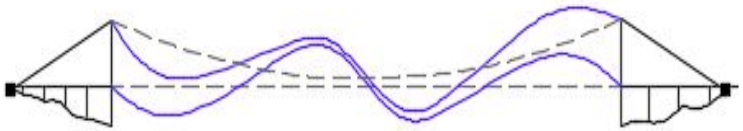
1st Transverse Sym

1st Vertical Asym

1st Vertical Sym



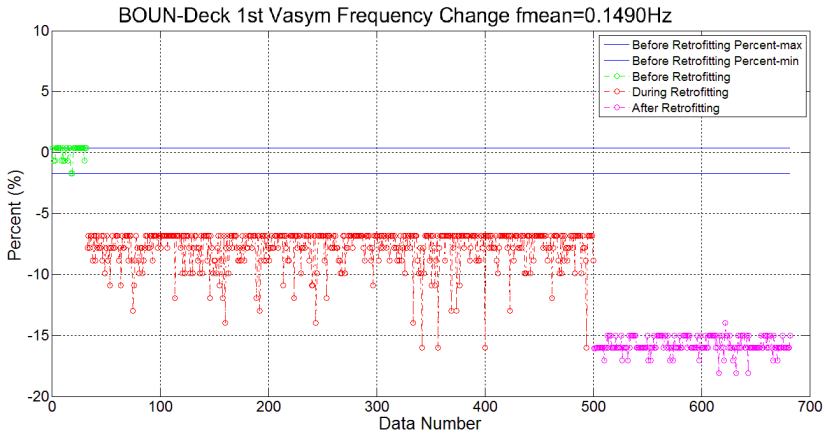
2nd Vertical Sym

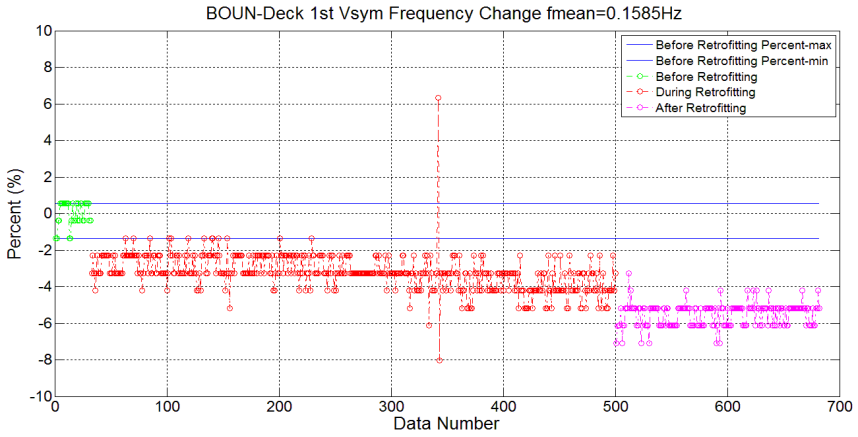


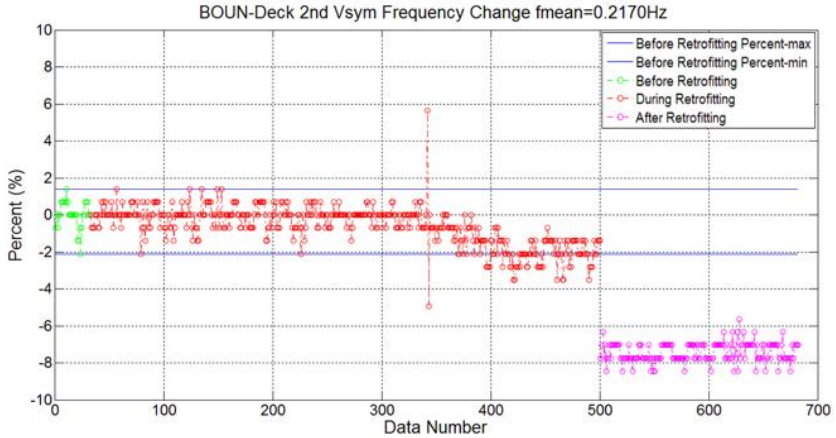
2nd Vertical Asym

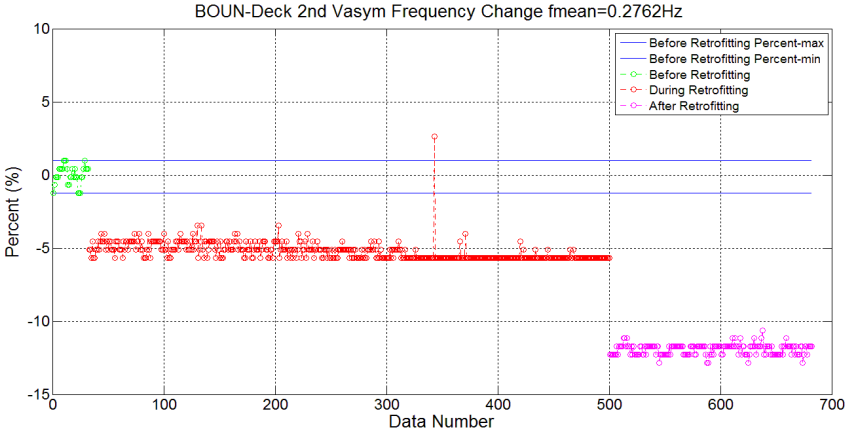
System Identification

Long-Term Monitoring



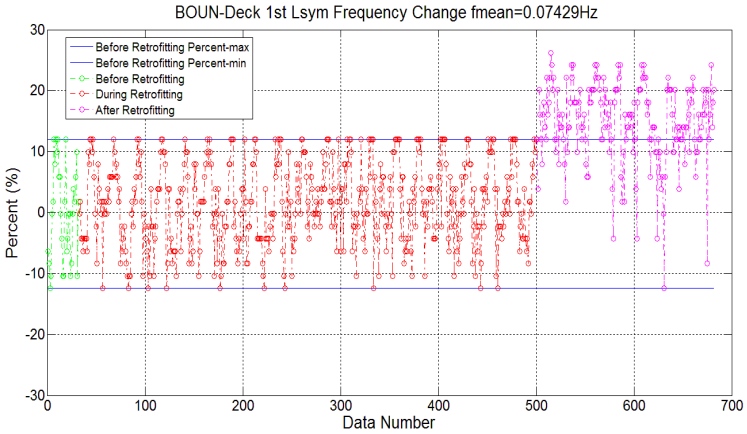


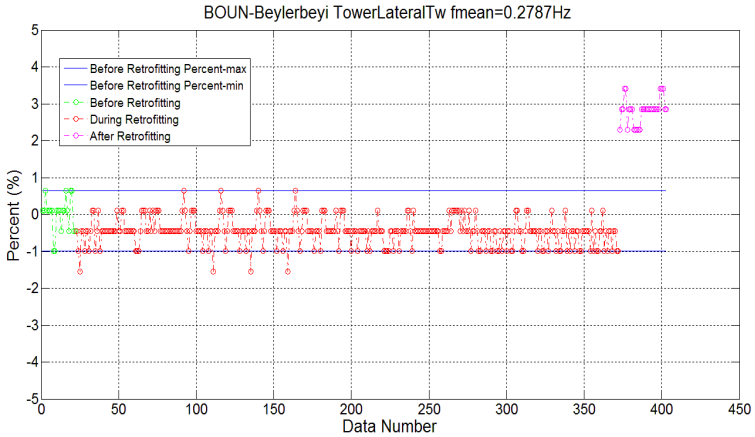


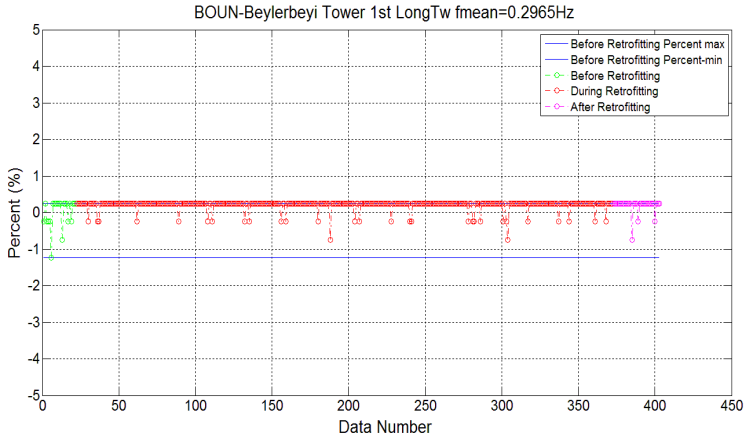


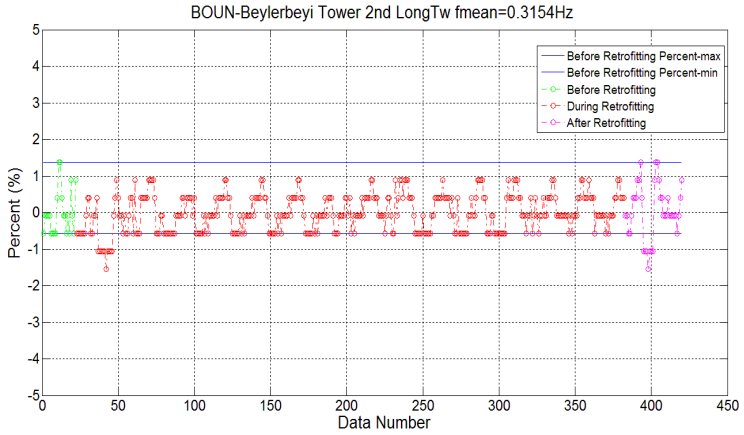
System Identification

Long-Term Monitoring



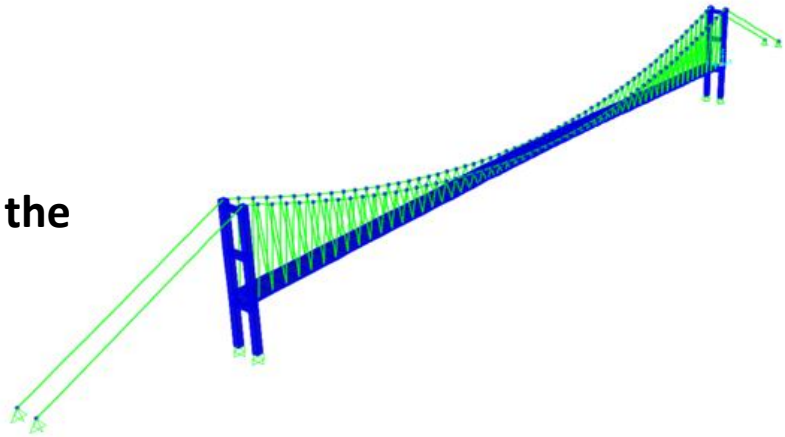




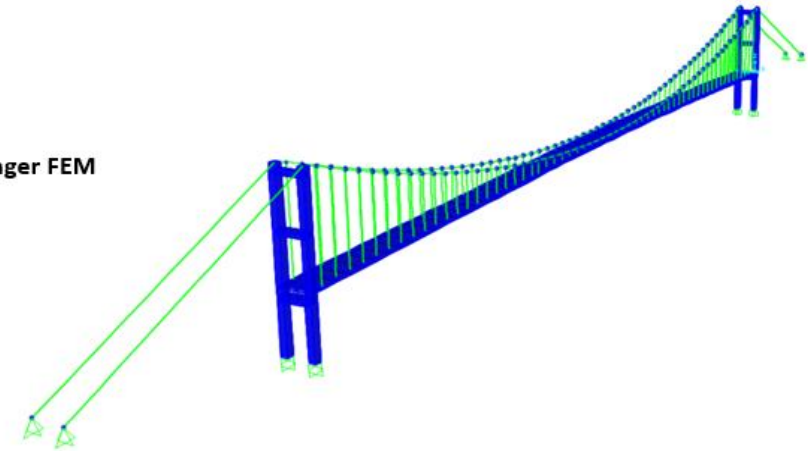


Finite Element Model

Initial strains were introduced to cables and hangers to obtain representative deformed shape of the bridge after dead load analysis



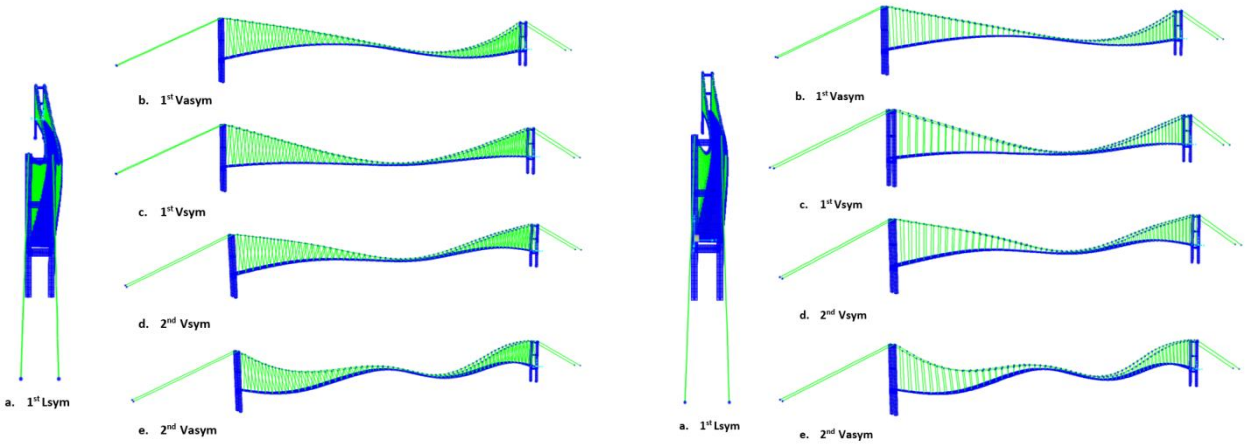
a. Inclined Hanger FEM



b. Vertical Hanger FEM

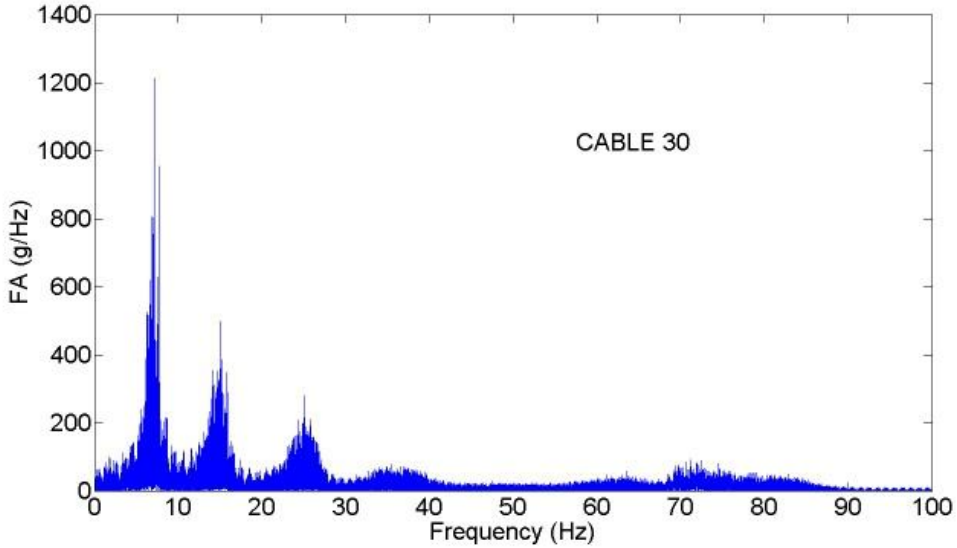
Tension forces of inclined cables at the forth pair are 449.5 kN and 776.8 kN.
And, those of each vertical cable at the same pair are equal and 599.1 kN.

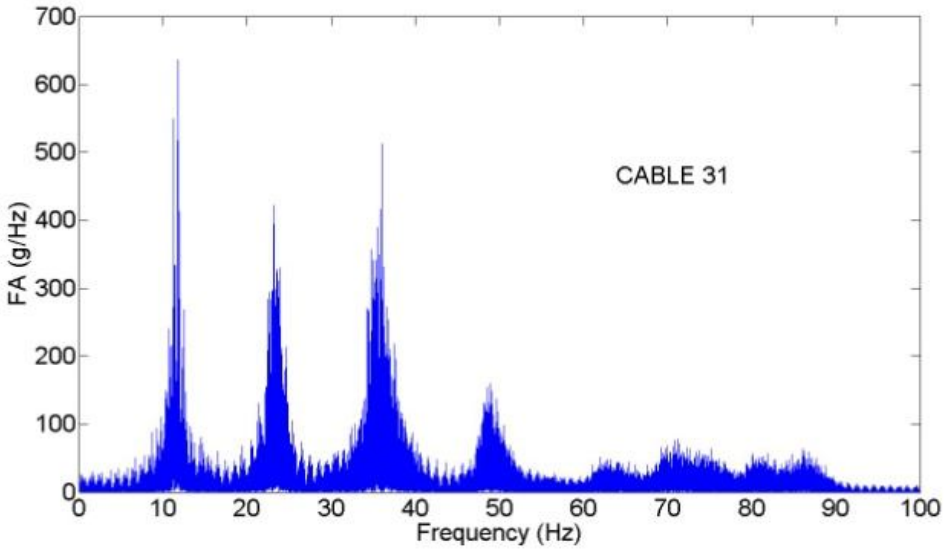
Finite Element Model



Mode Shapes	Natural Modal Frequencies (Hz)		Difference (%)
	Inclined Hanger FEM	Vertical Hanger FEM	
1 (1st Trans)	0.073	0.072	1.4
2 (1st Vasym)	0.138	0.129	6.5
3 (1st Vsym)	0.174	0.165	5.2
4 (2nd Vsym)	0.234	0.219	6.4
5 (2nd Vasym)	0.296	0.269	9.1

Hanger Frequencies





Conclusions

- Vibration based monitoring of Bogazici Bridge during change of hangers from inclined to vertical was carried out almost for one year
- Clear decrease in the vertical modal frequencies of the deck
- Good agreement between FEM and System ID results

Thank you for your attention