Från trådade till trådlösa system för broövervakning. Vilka möjligheter erbjuder framtida teknikutveckling?

Raid Karoumi
Brobyggnad

Contents

- Introduction: why monitor?
- Sensors for civil engineering applications
- What can we get from the measurement data
- Data management: AI & IoT
- Summary

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Introduction

Why bridge monitoring?

- European bridge stock is generally quite old with many structures being over 100 years old (especially for railways).
- As a consequence, the cost of bridge operation & maintenance is increasing across Europe at a very fast rate.
- Trafikverket spend ~1,3 billion kronor per year on bridge operation & maintenance.
- With monitoring we can smarter condition assessment, reduced number of inspections and prolong the service life → reduce total LCC/LCA.

The Forsmo bridge from 1912.

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Typical Bridge Problems

Frequent bridge problems in load bearing members:

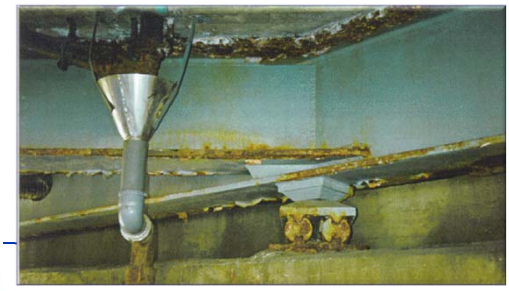
- Concrete bridges: deterioration of concrete and corrosion of reinforcement
- Steel bridges: corrosion of steel beams and fatigue
- Wear in bearings and expansion joints
- Support settlements
- Collision of vehicles, etc. etc.

Foto 404. Knutpunkt K3, avsaknad av skruvförband i rörelsefog.

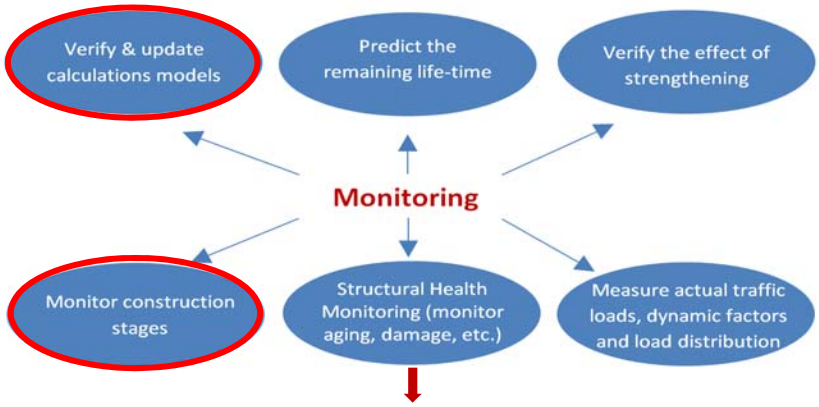
Foto 2599. Avsaknad av skruv i rörelsefog till södra överramsstaget i spann 5-6.

Typical Bridge Problems

Foto 432. Knutpunkt K4, Kraftig korrosion i undre förbindningsplåten samt midjebildning i skruv.



Goals of monitoring



Assist operation & maintenance process. Data can be used as input for optimizing inspection / maintenance strategies.

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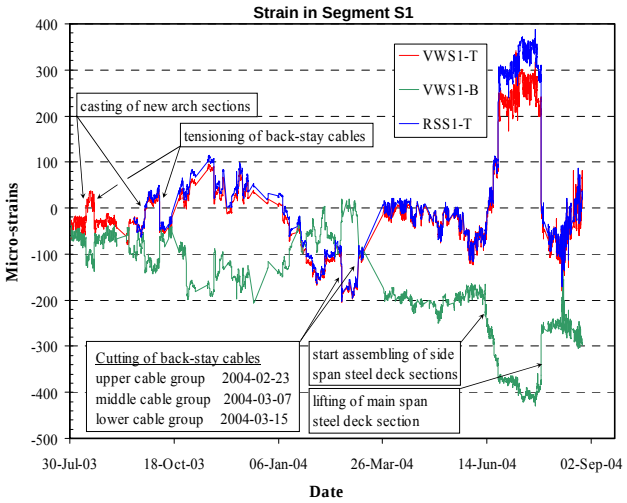
The Svinesund Bridge



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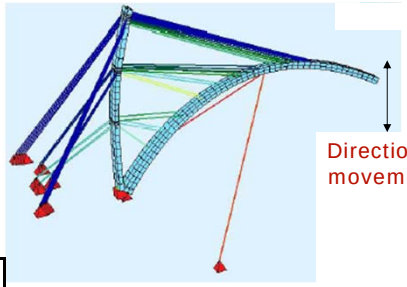
Arch Frequencies

Theoretical and measured frequencies of vibration of the arch prior to the construction of the arch stone.



Direction of movement

Mode No.	Frequency Theoretical [Hz]	Swe./ Norw. arch	Frequency Measured [Hz]	Mode type
1	0.30	N	**0.29**	1 H
2	0.32	S	**0.33**	
3	0.47	S	**0.48**	1 V
4	0.50	N	**0.45**	
5	0.96	S	**0.96**	2 V
6	0.96	N	**0.92**	
7	1.14	N	**1.12**	2 H
8	1.18	S	**1.22**	

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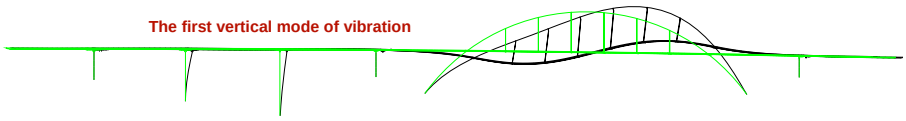
Frequencies & Structural Damping

Comparison of the measured and the theoretical natural frequencies of the bridge after completion of the deck.

Mode no	Original FE-model: Theoretical f [Hz]	Measured f [Hz]	Measured ξ [%]	Description of mode type relevant to arch	Revised FE-model: Theoretical f [Hz]
1	0.41	0.43	0.39 ± 0.15	Symmetric bending horizontal	0.41
2	0.46	0.88	0.58 ± 0.24	Anti-symmetric bending vertical	0.86
3	0.96	0.96	0.55 ± 0.14	Anti-symmetric bending horizontal	0.96
4	1.02	1.05	0.53 ± 0.18	Complex mode horizontal in arch	1.03
8	1.19	1.53	0.62 ± 0.29	Symmetric bending vertical	1.48

The first vertical mode of vibration



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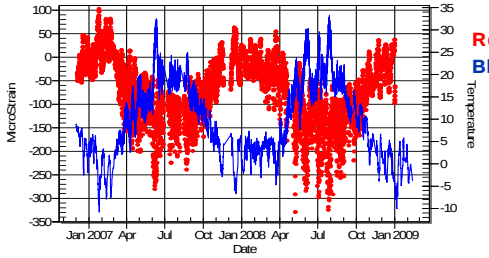
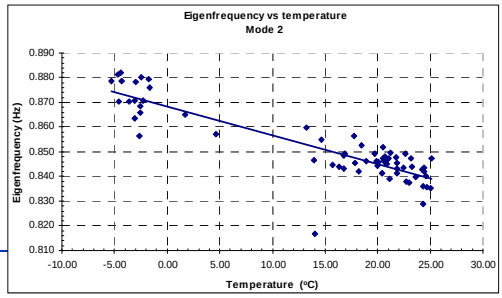
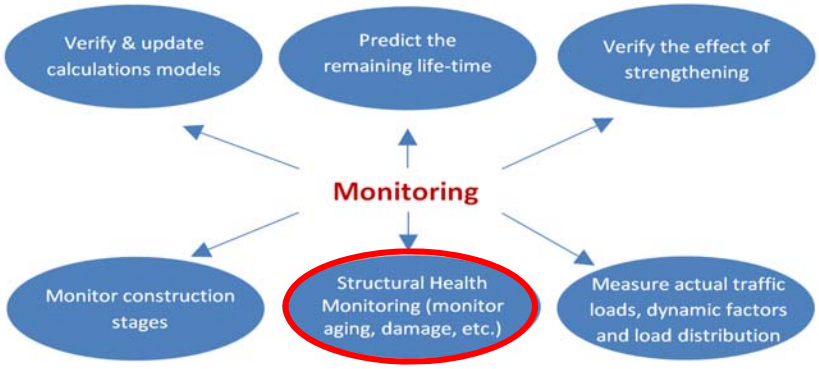
Long-term statistical data



Red curve: strain at S1-T
Blue curve: temperature



Goals of monitoring



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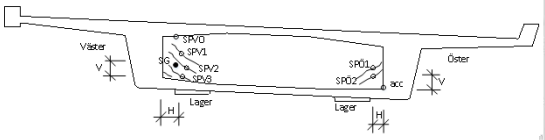
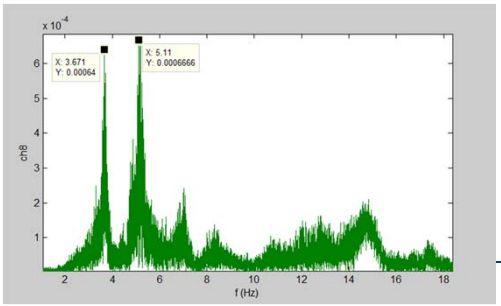
The Essinge Bridge

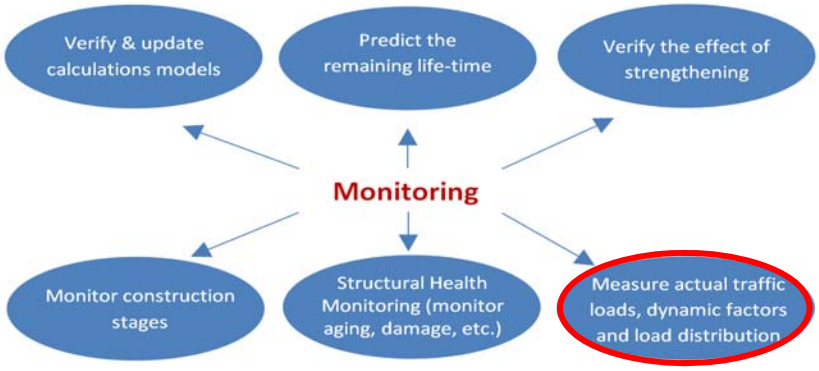
Kontroll av sprickor och armeringsspänning på tvärbalk i stödlinje E13 (västra anslutningsbron)





Friktion i lager som byggs upp och släpps?

Goals of monitoring



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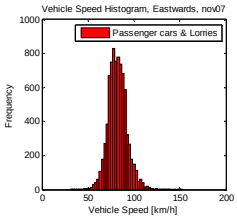
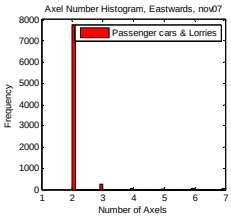
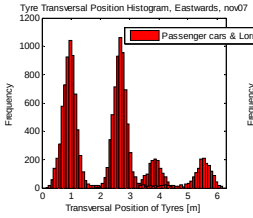
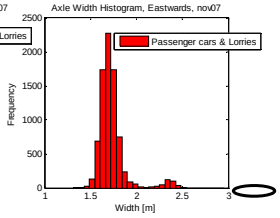
The Öland Bridge









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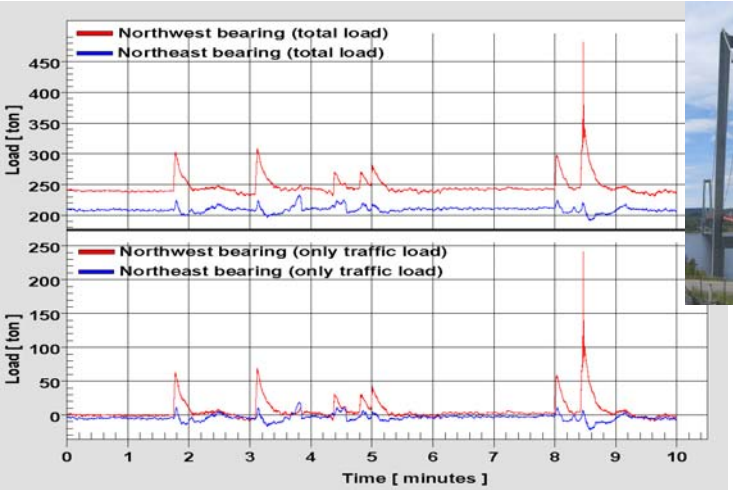
The Högakusten Bridge



Measured loads on the northeast and the northwest bearings during 10 minutes on 2006-02-28 The lower plot shows the results excluding permanent loads

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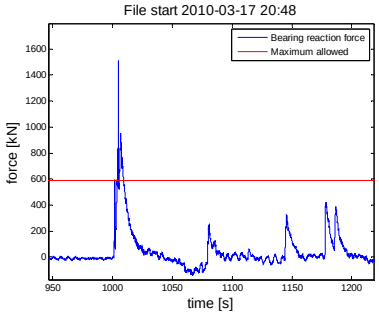
Results



Vehicle with static weight over 60 ton

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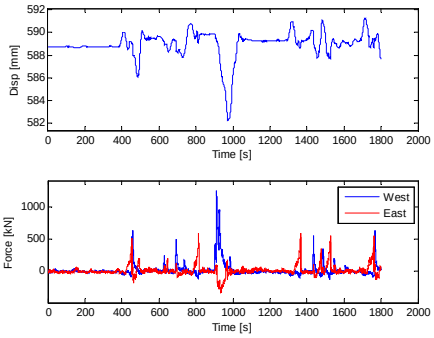
The Högakusten Bridge



Longitudinal displacement and force on the bearings

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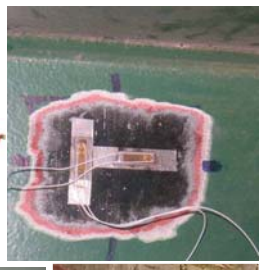
Sensors for civil engineering applications

Sensors for civil engineering applications

We need sensors to measure:

- Strains
- Displacements
- Accelerations
- Forces
- Corrosion
- Temperatures
- …

Sensors can be wired or wireless



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Wireless sensors?

Advantages when cabling is

- complicated
- expensive & time consuming
- sometimes not applicable (e.g during construction)

Challenges

- power supply
- distance to base
- limited memory & cpu

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Kostnad för sladdlöst bevakningssystem

Cirka kostnad för sensorer	Kostnad/SEK
Accelerometer (3-axlig, inkl. temp)	10 000 – 15 000
Modul för trådtöjningsmätning (för 4st givare)	10 000 – 15 000
Trådtöjningsgivare / mätare	1 000 – 6 000
Basenhet	20 000 – 30 000
4G Router och antenn	5 000 – 10 000

Tillkomande kostnader	Kostnad/SEK
Förberedelser, installation, testning	
Utvärdering & rapportering (årliga kostnad) [via App?]	
4G abonnemang (årliga kostnad)	
Drift och underhåll av mätsystem (årliga kostnad)	

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Bevakningssystem till gamla Lidingöbron

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What can we get from the measurement data

What can we get from the measurement data

How is the data used

- Displacement sensors → direct check
- Strains → direct (stress) & indirect (applied load)
- Accelerations → in direct (frequencies → stiffness, cable force…)

Beam frequencies

$$\omega_k = \lambda_k^2 \cdot \sqrt{\frac{EI}{m \cdot L^4}}$$

Cable frequencies

$$\omega_k = \gamma_k \cdot \sqrt{\frac{N}{m}}$$

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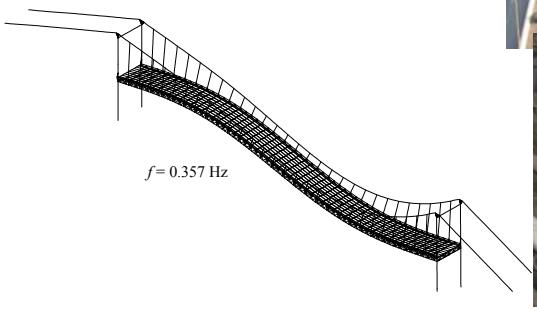
What can we get from the measurement data

Evaluate forces in cables

- Älvsborg bridge
- Högakusten bridge
- Svinesund bridge
- Strömsund bridge



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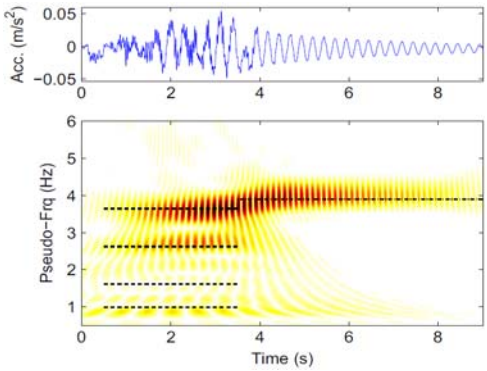
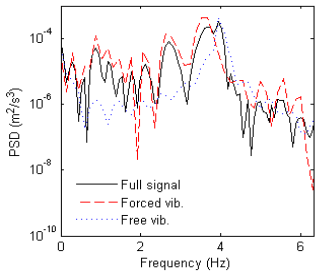
What can we get from the measurement data

För några fordonpassager per dag beräkna de lägsta frekvenser från fria vibrationer





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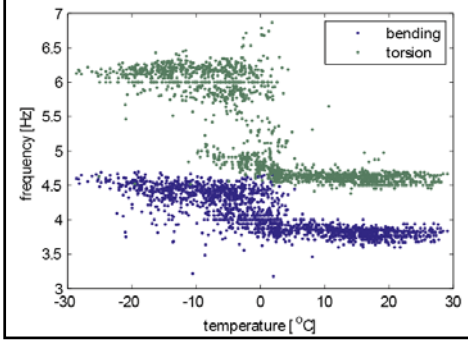
Data management
Model-free methods with AI & IoT

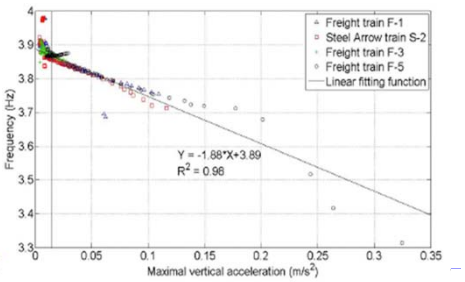
Why model-free methods?

The Skidträsk bridge, variations in bridge properties

We need model-free methods as

- Bridges are complex structures
- Very difficult to capture real behavior (SSI, bearings…) in models
- Our models can be on unsafe side





Vad ska vi göra med all data?

Lösningen: AI + IoT

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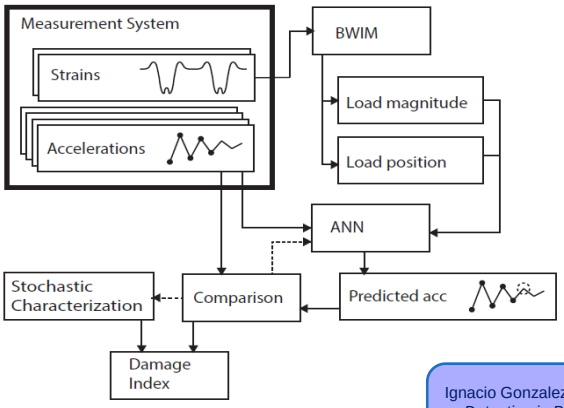
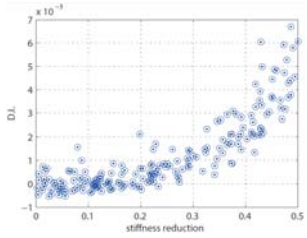
Damage detection using Artificial Neural Network





Ignacio Gonzalez and Raid Karoumi, *BWIM Aided Damage Detection in Bridges Using Machine Learning*, Journal of Civil Structural Health Monitoring, 2015.

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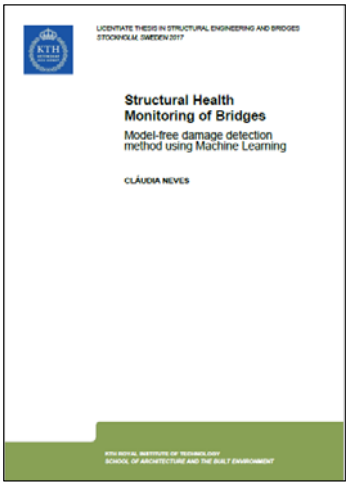
Licentiate Seminar 30 May



New BBT project (2017-2019)
Monitoring as a tool for optimal management of critical bridges

http://kth.diva-portal.org/smash/get/diva2:1089610/FULLTEXT01.pdf

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IoT – Årsta Bridge

IoTBridge iPhone App

Twitter

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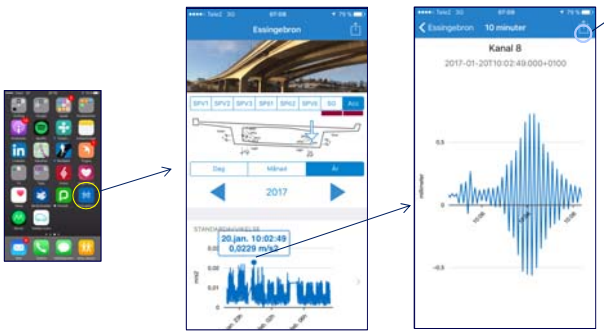
Essinge Bridge App

Send report by Email



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Summary and final words

- With continuous monitoring we can make smarter condition assessment and reduced number of costly inspections
- Wireless sensor networks are becoming an alternative to conventional wired monitoring
- We need model-free methods
- To reach this goal, we need to:
  - develop AI that will analyze the data from the sensor system
  - develop sensors and algorithms that are able to detect gradual deterioration
  - develop decision support methodology that can be used for implementing maintenance strategies on a rational basis
  - develop sensors that have a lifespan comparable to that of the bridge
  - Enhance power management, e.g. local power using vib. harvester

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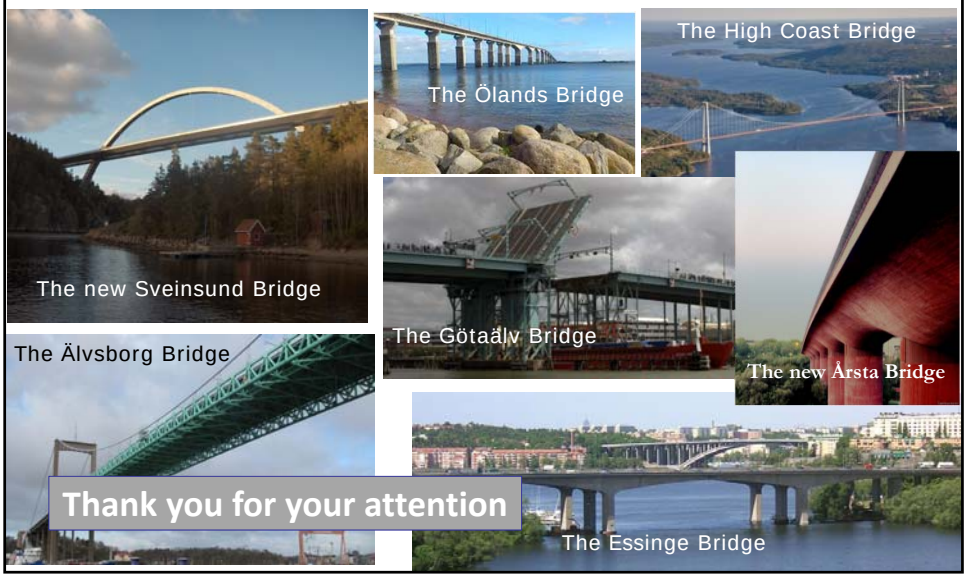
Some of KTH instrumented bridges