SAMCO

Structural Assessment Monitoring and Control

SAMCO Educational Module 02:

Monitoring and Assessment of Bridges and Structures

Produced by the EC Research Project SAMCO

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SAMCO Case Studies vce

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Structural Assessment Monitoring and Control

- **Responsibility** driven, which means the new methods to become standard applications supported by codes, standards and guidelines
- **Economy** driven motivations, such as situations where a ranking of structures to be rehabilitated is necessary because of insufficient budget available
- **Curiosity** (Interest) driven motivations comprise those cases where clients would like to know more about their structures.

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Motivation for Health Monitoring vce

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- **Spot Observations** shall comprise a quick measurement campaign with a few sensors only. It shall enable a ranking.
- **Periodic Assessment** is a repeated measurement campaign on a structure, to generate information on the performance over time.
- **Permanent Observation** and assessment of structures becomes necessary when certain limits are passed and can help to implement quick decision making.
- **Online Observation** and assessment allows warning through electronic media. These alert systems will only be applied at rare and extremely critical structures. (Beware of false alarms).

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Bridge Observation Concept Hierarchy vce

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Motivation: **Responsibility** Observation Concept: **permanent** (since 1994)

Westend Bridge - Germany

The 38 years old and 243 m long superstructure is a pre-stressed concrete bridge. In the past the bridge had to be strengthened multiple times due to cracks and open connecting joints within the floor slab.

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Submitted by: Federal Institute for Materials Research and Testing (BAM) BAM

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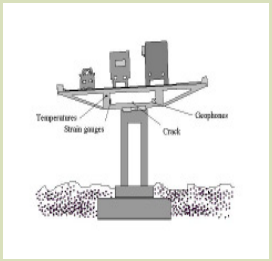
The **purpose** of the **inspection** of the Westend bridge was to assess their condition with respect to the presence of multiple cracks within the girder.

→The inspection was performed by using a monitoring system that records permanently the current traffic loads, stresses and the structure's health.



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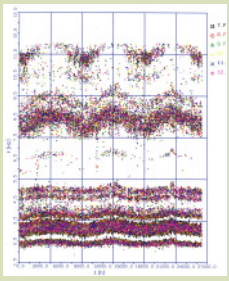
Examples of outcomes:

- In case of the Westendbridge it could be shown, that the increasing dynamic loads are correlated to the quality of the road surface.
- Global condition monitoring found out, that the natural frequencies of the bridge are varying with respect to changes of the structural temperature what means that changes of the bearing capacity can be assumed.



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Motivation: **Responsibility** Observation Concept: **permanent** (since 2003)

Europabrücke - Austria

Currently the bridge is stressed by more than 40.000 motor vehicles per day. The combination of measuring and analytical calculation over the past years has led to a detailed system identification. Due to the requirement to assess the prevailing vibration intensities with regard to fatigue problems and possible damage, a permanent measuring system has been installed in 2003.


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Submitted by: Vienna Consulting Engineers (VCE)

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Purpose of Inspection:

The superior goal is to determine the relation between the randomly induced traffic loads (vehicles per day) and the fatigue-relevant, dynamic response of the structure.

It is going to be focused on three ranges:

- Global behavior in dependence of all relevant loading cases.
- Cross-sectional behavior under special consideration of the cantilever regions.
- Local systems analyzing the interaction between tires and the beam-slab connections.

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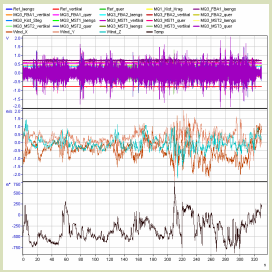
Examples of outcomes:

An indispensable requirement is to reduce the data of the complete load-time history to a few statistical data (Rainflow-Counting) describing the remaining fatigue-relevant recurring response-cycles in different categories of intensity and occurrence.



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Submitted by: Vienna Consulting Engineers (VCE)

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Motivation: **Quality Control** Observation Concept: **periodic** (since 2001)

RAMA IX Bridge - Thailand

The Rama IX is a single plane cable stayed bridge with steel box girder and orthotropic deck and steel pylons. It total span length is about 615,0 m.

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Submitted by: EMPA, Swiss Federal Laboratories for Materials Testing and Research

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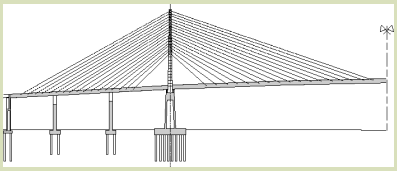
Purpose of Inspection:

The purpose of the inspection of the RAMA IX stay cables was to assess their condition with respect to the presence of fractured wires and possibly of corrosion in the cross-section of the free length of the cables. The inspection was performed using the magnetic flux leakage (MFL) method.



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Submitted by: EMPA, Swiss Federal Laboratories for Materials Testing and Research

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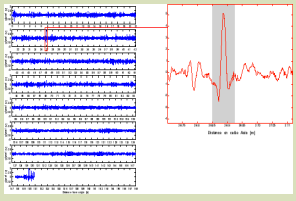
Examples of outcomes:

- 100% of the free length of the cables was inspected. The output from the global MFL sensor yielded overall information about the presence of fractures within the cable cross-section as a function of the distance along the cable axis.
- For multi-strand systems, the mapping of the magnetic flux leakage maps on the surface of the cable can be used to localize the position of flaws within the cross-section of a cable.



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Submitted by: EMPA, Swiss Federal Laboratories for Materials Testing and Research

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Motivation: Damage Scenarios Observation Concept: periodic (Start 1998)

Bridge Z24 - Switzerland

The condition of the bridge was relatively good but the bridge had to be demolished to allow the construction of new railway tracks. Within the SIMCES project the influence of the environment on the Dynamic characteristics was investigated as well as the changes of the dynamic characteristics due to progressive damage tests.

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Submitted by: Katholieke Universiteit Leuven

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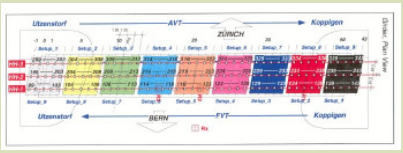
Purpose of Inspection:

The purpose of the SIMCES project was to prove the feasibility of assessing the integrity of civil structures by means of evaluating their vibration. Several damage scenarios were applied and the resulting changes in dynamic characteristics were recorded and used to detect and identify the corresponding structural damage. Full-scale ambient (AVT) as well as forced vibrations (FVT) were carried out.



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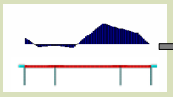
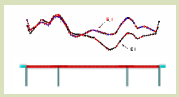
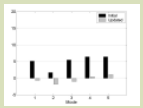
Examples of outcomes: The box bridge is modeled by a beam model with equivalent stiffness properties. The damage is represented by a Reduction in bending and torsional stiffness of the constituting beam elements.



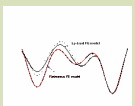
Reduction factor of bending stiffness



Identified bending stiffness



Eigenfrequency differences



Mode shape 5

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Motivation: Construction Observation Concept: temporary (since 2003)

The New Svinesund Bridge - Sweden

The world's largest bridge with a single arch is an elegant but structurally complicated bridge as it combines a very slender construction with a special structural form.
Due to the uniqueness of design and the importance of the bridge a monitoring project was initiated. The monitoring project, including measurements during the construction phase, the testing phase, and the first 5 years of operation,

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Submitted by: Royal Institute of Technology (KTH)

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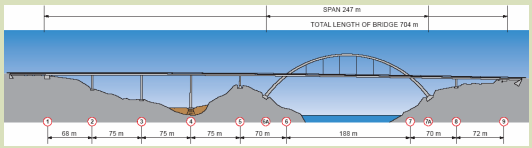
Purpose of Inspection:



The primary objective of the monitoring programme is to check that the bridge is built as designed and to learn more about the as-built structure. This will be achieved by comparing the measured structural behaviour of the bridge with that predicted by theory.

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Submitted by: Royal Institute of Technology (KTH)

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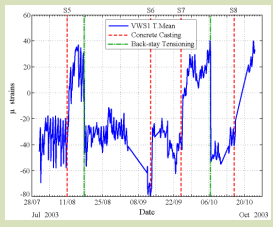
Examples of outcomes:

The figure shows the strains measured at the roof of a segment close to the arch base on the swedish side. The casting of each subsequent segment causes an elongation of the reinforcement bars. This is to be expected as the arch behaves as a cantilever and the extra weight at the end of the structure caused by the newly cast arch segments will cause tension in the top of the section at the base of the arch. In a similar manner, tensioning the support cables, represented by the green dot-dashed lines, causes a contraction of the same reinforcement bars.



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Motivation: **Responsibility** Observation Concept: **permanent** (since 2000)

Øresund Bridge – Denmark/Sweden

The bridge is equipped with a PC-based continuous monitoring system, capable of measuring both static and dynamic quantities such as temperatures, wind characteristics, air humidity, strains and accelerations. The challengesfor the design of the monitoring system were the long distances between the monitoring points and the variety of sensors.

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Submitted by: LMS International

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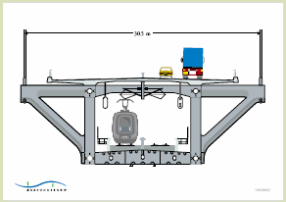
Purpose of Inspection:

The bridge owner was concerned about the stay cable oscillations under heavy wind conditions, as well as the deformation of the bridge when trains or heavy trucks are passing. Therefore a monitoring system called CR-4 Central Recorder was installed that is able to acquire both dynamic and static data.



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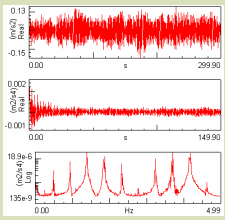
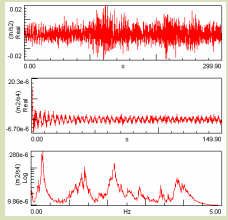
Examples of outcomes:



Dynamic data analysis of cable vibrations:
Time history, auto-correlations, auto spectrum.



Dynamic data analysis of tower vibrations:
Time history, auto-correlations, auto spectrum

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Submitted by: LMS International

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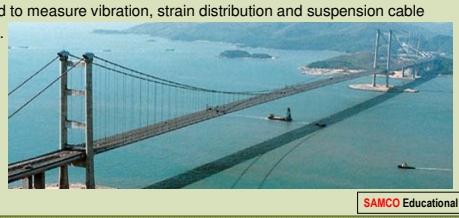
Motivation: **Quality Control** Observation Concept: **permanent**

Tsing Ma Bridge – Hong Kong (PRC)

The Tsing Ma Bridge (TMB) is the longest suspension bridge (2.2 km) in the world for carrying both vehicle and railway traffic.
Besides the existing conventional sensors, Fiber Bragg Grating sensors are installed to measure vibration, strain distribution and suspension cable tension.



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Submitted by: TNO TPD

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Purpose of Inspection:

The sensors are the early warning system for the TMB and provide the essential information that helps the Hong Kong Highways Department to accurately monitor: the general health conditions of the bridge, in terms of structural durability, reliability and integrity.
The sensors include strain gauges, GPS position sensors, accelerometers, level sensors, temperature sensors and weight-in-motion sensors.

→This project is focused on the application of Fiber Bragg Grating for strain measurement and the comparison with conventional strain gauges.

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Submitted by: TNO TPD

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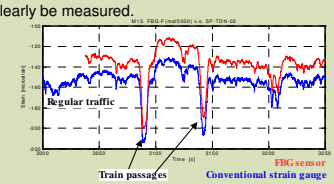
Examples of outcomes:

The results of the FBG sensor are compared with that of the existing strain gauge. Although the sensors are not located at exactly the same location, great resemblance in the results has been found. Train passages and heavy traffics can clearly be measured.



Comparison of strain measurement between FBG sensor and existing strain gauge.

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Submitted by: TNO TPD

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Motivation: Responsibility Observation Concept: permanent (since 1998)

COMMODORE BARRY BRIDGE – USA

The bridge has five traffic lanes, currently serves more than six million vehicles annually and has a totally lenght of 4240m.

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Submitted by: Drexel Intelligent Infrastructure and Transportation Safety Institute

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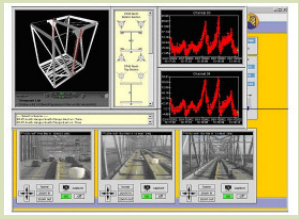
The purpose of monitoring the truss bridge is to evaluate the:

- actual stresses of the critical elements
- ambient environmental conditions at the bridge.
- effectiveness and condition of approximately 1,000 vibration dampers…



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Examples of outcomes:

- The damper should have a useful life of at least 50 years if controlled by the durability of neoprene.
- No changes were observed in the conditions of any of the defects that were identified a decade ago.
- A closer scrutiny of the measured strain and temperature histograms indicated that the hanger intrinsic strains were affected by the complex movement and force-release systems at and in the vicinity of these members. A distinctly unsymmetrical behavior at the long-term strains of the two-instrumented hangers was attributed to a difference in the behavior of the movement systems.

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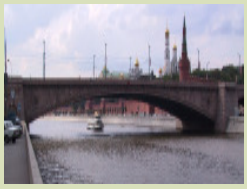
Motivation: Responsibility Observation Concept: permanent (since 2003)

Bolshoj Moskvoretsky Bridge

Two types of degradation are noticed on the bridge: settlement of an abutment provoking cracking of the stone lining as well as the structural elements and chlorides penetration into the structures leading to reinforcement corrosion.



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Submitted by: Smartec

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Example of defects: cracks on structural elements and external facing purpose of instrumentation:

Purpose of Instrumentation:

The aim of monitoring is to increase the knowledge concerning structural behavior. Standard SOFO sensors have been installed to continuously monitor average strain along the arch, curvature in both horizontal and vertical direction. Thermocouples have been installed to distinguish thermal influences.

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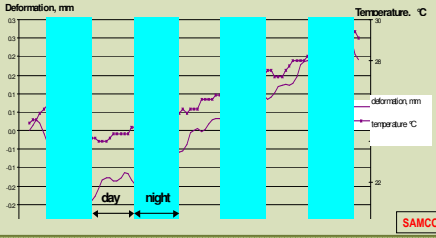
Examples of Outcomes:

The installation of the SOFO System was finished in July 2003. The long-term monitoring started.



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Submitted by: Smartec

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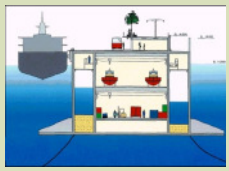
Motivation: Safety Observation Concept: permanent (since 2002)

La Condamine floating dock – Spain / Monaco

The Condamine Marina in Monaco enlarged its surface area in 60.000 m². This enlargement was achieved by means of a floating caisson 352.72 m which was built in a dry dock prepared for this purpose in Algeciras Bay.

Floating dock, Mónaco, during transport



Transversal section of the floating dock

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Purpose of Inspection:

- The owner required the contractor to assure that bending moments induced by sea action during the whole transport process do not surpass the maximum values foreseen in the design.
- Besides that, for safety reasons during transport the contractor wished to control the water level inside the liquid ballast tanks and the owner consulting engineering was also interested in controlling the hydrodynamic pressure applied by sea waves.

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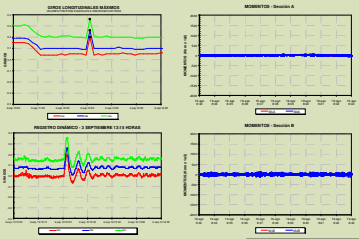
Examples of outcomes:

Maximum tilts every 10´ during hinge coupling operation (left-top) showing a sudden peak; detail of the dynamic record in the 10´period of that peak (left-bottom); evolution of bending moments in sections A/B during a 10' period on 19 August 2002 (right).



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Submitted by: GEOCISA

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Motivation: Responsibility (since 1998) Observation Concept: long-term monitoring

Ting Kau Bridge – Hong Kong, China

The 1,177m long Ting Kau Bridge was 44 months in design and construction and opened to public traffic in 1998.

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Submitted by: The Hong Kong Polytechnic University

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Purpose of Instrumentation:

A sophisticated long-term monitoring system has been devised to monitor the structural health and performance under inservice condition. This on-line monitoring system consists of about 800 permanently installed sensors of various types.
The main objectives of devising this system are:

- to monitor the structural health (safety) conditions of the three bridges,
- to provide information for facilitating the planning of inspection and maintenance activities and
- to verify design assumptions and parameters for future construction of cablesupported bridges.

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Submitted by: The Hong Kong Polytechnic University

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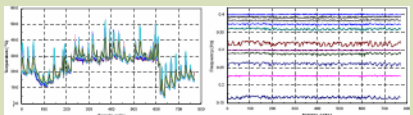
Examples of Outcomes:

The influence of operational and environmental factors on modal characteristics of the bridge has been investigated.
For the reliable performance of damage detection methods, it is of paramount importance to discriminate abnormal changes in dynamic features due to structural damage from normal changes due to the natural variability.



Variation in measured temperatures Variation in identified frequencies

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Motivation: Safety Observation Concept: permanent (since 2001)

Putlitz Bridge - Germany

Currently the bridge is stressed by the transport of heavy gas turbines with maximum loads of 500 t, which is much more than the design loads. To ensure the bearing capacity experimental investigations including SHM have to be carried out.

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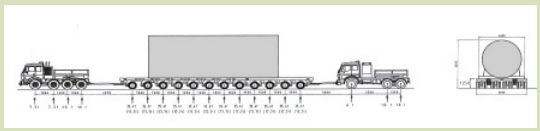
Purpose of Inspection:



- Static calculations show that the ultimate limit state of the bridge is reached under those heavy loads. These results have to be verified by experimental investigations measuring continuously maximum strains due to heavy loads and temperature.
- Additional fatigue stresses at endangered points of the bridge are of interest.

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Submitted by: Federal Institute for Materials Research and Testing (BAM)

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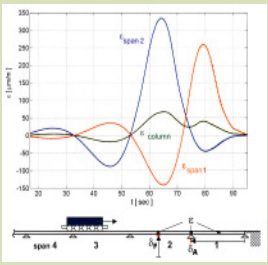
Examples of outcomes:

It could be affirmed that the dynamic loads, as assumed for the static calculations can be neglected.

Within the time of observation no exceeding of the limit state could be noted. The global condition state of the bridge is not yet affected



Strain distribution at a main girder during the crossing of a heavy load vehicle measured by SHM

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Motivation: Condition Assessment Observation Concept: permanent (since 2000)

Zittau Viaduct - Germany

The railway viaduct, with its totally length of 750m was built in 1859 and crosses the Polish-German border. A spacious lowering of the groundwater level led to a pier foundation settling and that caused in wide cracks, appearing at the superstructure above the piers.

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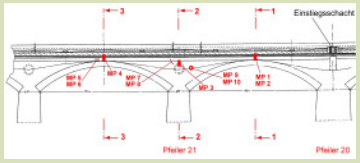
Purpose of Inspection:

It was observed by visual inspection, that the existing cracks still opened. Through structural health monitoring the cause for the additional crack movement ought to be found out and it was also intended to assess, in which degree the bearing capacity of the structure was affected.



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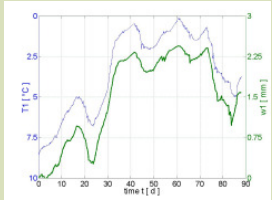
Examples of outcomes:

The long-term monitoring of the crack width together with other monitored parameters showed that the whole cross section of the superstructure was cracked. The crack widths change with the temperature course of structure (see results). The progressive foundation settlings as much as the traffic has obviously no irreversible influence on the crack evolution.



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Submitted by: Federal Institute for Materials Research and Testing (BAM)

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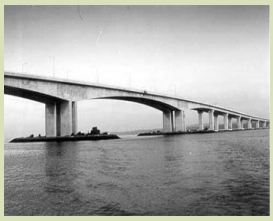
Motivation: **Responsibility** Observation Concept: **permanent** (since 1997)

Tuas Second Link - Singapore

This bridge bears the second road access between Singapore and Peninsular Malaysia. All but 170m of the 1.9km bridge are in Malaysian territory.



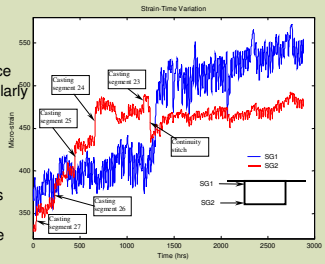
SAMCO Educational Module 02

Submitted by: University of Plymouth

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Monitoring:
Arrays of thermocouples were installed, also stress cells.
The aim was to track performance and earn about behavior, particularly thermal Effects.

Examples of outcomes:
Monitoring during construction provided training for 'pattern recognition' systems for SHM, as well as providing basic data on structural performance and some calibration of thermal loading design codes.



SAMCO Educational Module 02

Submitted by: University of Plymouth

SAMCO Association
Structural Assessment Monitoring and Control

Motivation: **Evaluation** Observation Concept: **Long-term Monitoring** (since 2003)

Pasir Panjang Semi Expressway - Singapore

The expressway was built to carry heavy goods vehicles, principally containers in transit between two container terminals.

SAMCO Educational Module 02

Submitted by: University of Plymouth

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Monitoring:

- Instrument span segments in one span of each bridge, the aim was to capture the performance and interaction of a large stretch of the viaduct.
- Modal testing has been used to validate FEM of substructures during construction for extrapolating to a complete bridge.
- Via a validated FEM the aim is to interpret the static response data in terms of structural events that can be simulated and characterized by FEM.
- A further aim was to evaluate the performance of FBG systems for SHM of such bridges.

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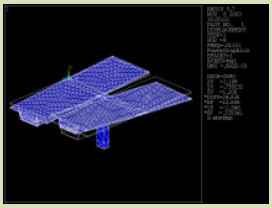
Structural Assessment Monitoring and Control

Examples of outcomes:

It has been possible to create and validate FEM (see below) that will be used to simulate load and structural anomalies as training for diagnosis via performance monitoring.

The exercise so far has shown the utility of remote data collection via wireless modem, from these data, traditional temperature-induced trends and stress-strain correlations have been observed.



SAMCO Educational Module 02

Submitted by: University of Plymouth

SAMCO Association
Structural Assessment Monitoring and Control

Motivation: **Responsibility** Observation Concept: **periodic** (start 2002)

Pioneer Bridge - Singapore

It carries heavy industrial traffic to and from Jurong Port and is rated to carry vehicles of 44 tons. Modal testing and short term strain/vibration monitoring was conducted before and after the upgrade to test the need for and effect of the upgrade.

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Submitted by: University of Plymouth

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Structural Assessment Monitoring and Control

The bridge was upgraded in line with LTA island wide program and carries occasional extra heavy loads:

Purpose of Monitoring:
The program of two modal tests and two short term live response monitoring exercises was aimed at validating analytical models (via modal testing and FE model updating) then using the validated models together with live strain statistical properties to identify the load capacity before and after the upgrade. The exercise was also aimed at evaluating the procedures for doing this.

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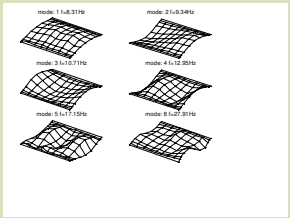
Examples of outcomes:

The mode shapes shows, identified from post-upgrade forced vibration testing, prove the effectiveness of the upgrade through finite element model (FEM) updating, showing clearly the rotational stiffness imposed at the bearings. The FEM has been used to estimate road carrying capacity.



SAMCO Educational Module 02

Submitted by: University of Plymouth

SAMCO Association
Structural Assessment Monitoring and Control

Motivation: Safety Observation Concept: periodic (start 2000)

Saint-Jean Bridge – Bordeaux, France

Like most prestressed concrete bridges built at that time when thermo mechanical behaviors were not taken into account, it is not sufficiently prestressed. To determine whether prestress reinforcement works have to be carried out or not and to validate calculations, Bordeaux Urban Community ordered experimental investigations including SHM.

SAMCO Educational Module 02

Submitted by: Laboratoire Régional des Ponts et Chaussées

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Inspection:

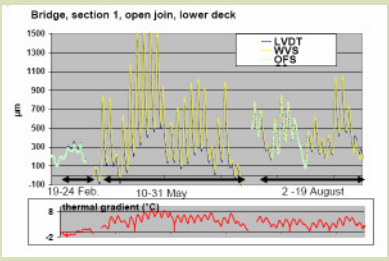
- Monitor the thermo-mechanical behavior of the bridge. Two specific box-girder joints are monitored.
- Evaluate the influence of sensor length over its accuracy and even its relevance. As a result, sensors with length ranging from 10cm to 400cm were installed at different places. Two types of very-long-length-sensors are compared to traditional sensors: optical fiber sensors (OFS) and vibrating wire sensors (VWS).
  Those sensors measure strains due temperature, on a day-night-cycles and also on winter-summer cycles

SAMCO Educational Module 02

Submitted by: Laboratoire Régional des Ponts et Chaussées

SAMCO Association
Structural Assessment Monitoring and Control

Examples of outcomes:



SAMCO Educational Module 02

Submitted by: Laboratoire Régional des Ponts et Chaussées

SAMCO Association
Structural Assessment Monitoring and Control

Motivation: Responsibility Observation Concept: permanent (since 2003)

Széchenyi Bridge – Hungary

The bridge has a total length of 527.2 m and used for heavy loads.

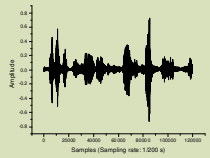
SAMCO Educational Module 02

Submitted by: Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences (GGRI)

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Inspection:
Replacement of the visual inspection and load test by a new, reliable method.

Examples of outcomes:
Only one measurement was carried out and therefore there was not a possible to compare different vibration records made in different times.



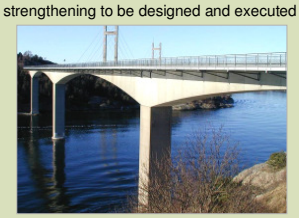
SAMCO Educational Module 02

Submitted by: Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences (GGRI)

SAMCO Association
Structural Assessment Monitoring and Control
Motivation: Safety Observation Concept: periodic (since 2000)

Källösund Bridge – Sweden

When an assessment of the bearing capacity was made in the late 1990´s it was found that the capacity for sagging moment in the superstructure close to the abutments was to low. To maintain the bridge open for full traffic loads while awaiting strengthening to be designed and executed the bridge was Monitored.



SAMCO Educational Module 02

Submitted by: Swedish National Road Administration

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Inspection:

- Static calculations show that the ultimate limit state of the bridge is reached under heavy loads. The bridge was not designed for a sagging moment as creep was not foreseen.
- When the bottom flange cracks under sagging moment there is not enough reinforcement to resist the moment but the bending moment can be redistributed to the support section of the beam.
- The instrumentation was used both for calibration of calculations and for monitoring of those sections.

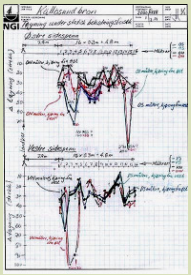
SAMCO Educational Module 02

Submitted by: Swedish National Road Administration

SAMCO Association
Structural Assessment Monitoring and Control

Examples of outcomes:

Strain distribution in the bottom of the main beam during the load test with a heavy vehicle. The test showed a mean strain of 40 micro strain and the calculated value was 50 micro strain. The peak values of up to 280 micro strain are at the cracked joints.



SAMCO Educational Module 02

Submitted by: Swedish National Road Administration

SAMCO Association
Structural Assessment Monitoring and Control
Motivation: Safety Observation Concept: Long-term Monitoring (Start 1996)

Versoix Bridge - Switzerland

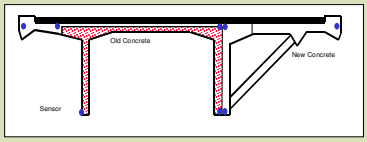
1996 – 1998, the bridge was refurbished and enlarged to accommodate an additional security lane in both directions. Since an important amount of new concrete was added asymmetrically to an existing structure, the issues of differential shrinkage could occur and decrease the structural performance.

SAMCO Educational Module 02

Submitted by: Smartec

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Instrumentation:
The aim of instrumentation of the Versoix Bridge is to monitor long-term performance with particular care to the consequences of interaction between the existing and new part of the structure.
Thus, the following parameters were monitored: average strain in concrete including early and very early age, old-new concrete interaction, average curvature analysis in both horizontal and vertical plan, detection of torsion and distribution of both horizontal and vertical displacements.

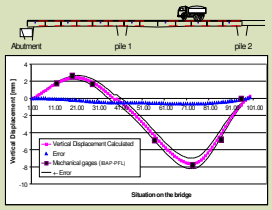


SAMCO Educational Module 02

Submitted by: Smartec

SAMCO Association
Structural Assessment Monitoring and Control

Examples of outcomes:
The early age measurements allowed the prediction of cracking long before it became visible, and the optimization of the concrete mix for successive pours. The sensor pairs at interface confirmed the excellent adherence between the old and new concrete. The vertical displacement was measured during the load test by double integration of the curvatures.



SAMCO Educational Module 02

Submitted by: Smartec

SAMCO Association
Structural Assessment Monitoring and Control

Motivation: **Responsibility** Observation Concept: **periodic** (since 2001)

Talübergang Haag - Austria

In the framework of an Austrian research project focused to noise emission and vibration transmission a work package was related to the global and local vibration behavior of railway bridges. In order to study the dynamic characteristic of the structure accurately a combined approach consisting of forced and ambient vibration testing was designed.

SAMCO Educational Module 02

Submitted by: Arsenal Research GmbH.

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Inspection:

- Main purpose of monitoring in this context was to establish an initial measurement of the structure, which could be the base for future implemented monitoring concepts.
- Moreover the sound emission of a post tensioned concrete bridge should be compared to numerical simulations as well as to other bridge types within the research project.
- In addition a comparison between the results of ambient and forced vibration testing was performed in order to point out the advantages and disadvantages for both systems in practical testing.

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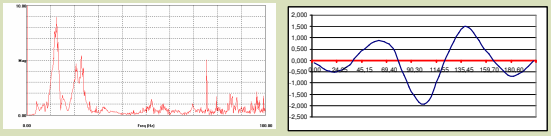
Submitted by: Arsenal Research GmbH.

SAMCO Association
Structural Assessment Monitoring and Control

Examples of outcomes: The corresponding mode shapes are very well developed and do not show any unsuspected shapes. Due to the fact, that almost no excitation was available during testing the Reaction Mass Exciter was required for successful System Identification. It was observed recently, t hat especially for railway bridges with low ambient excitation the identification of the dynamic response is hardly possible.



SAMCO Educational Module 02

Submitted by: Arsenal Research GmbH.

SAMCO Association
Structural Assessment Monitoring and Control

Motivation: **Life-cycle Management** Observation Concept: **current** (since 1999)

Warth Bridge - Austria

In the framework of an European research project SIMCES several bridges were extensively instrumented to setup a long term test for quantifying the degree of variance due to environmental influences and also due to differences induced by the parameter choice of the selected system identification methods.
Moreover the intention was to create a initial measurement of the structure, which might be used for future monitoring and maintenance concepts.

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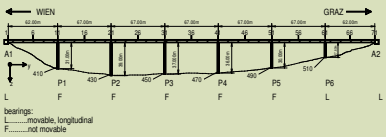
Submitted by: Arsenal Research GmbH.

SAMCO Association
Structural Assessment Monitoring and Control



Purpose of Inspection:

- The first goal was to demonstrate the high capability of measurements using swept sinusoidal force excitation. The experiments have been carried out under operational conditions.
- The second goal for the measurement campaign was to compare the results obtained by forced vibration and by ambient vibration testing.

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Submitted by: Arsenal Research GmbH.

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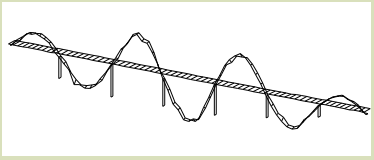
Structural Assessment Monitoring and Control

Examples of outcomes:
The modal properties can be identified by forced vibration under traffic disturbance quite well. Due to the large number of sweeps, the traffic disturbances can be filtered out at least to a great extent.
Also the transverse modes could be identified quite well. In general comparable results have been obtained by ambient and forced vibration testing.



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Submitted by: Arsenal Research GmbH.

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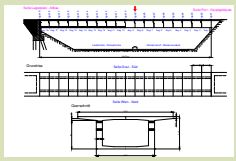
Structural Assessment Monitoring and Control

Motivation: Curiosity Observation Concept: Event

PORR Bridge - Austria
In the framework of a research project it was possible to introduce artificial damages and study the changes of the dynamic behavior of the structure.



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Submitted by: Arsenal Research GmbH.

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Structural Assessment Monitoring and Control

Purpose of Inspection:

- The main target of the investigation was to evaluate and determine the changes of the dynamic properties of the structure caused by artificial damages. These damages have been applied to the concrete itself as well as to selected prestressing tendons.
- In particular it was from main interest, how the dynamic properties (frequencies, modes and damping coefficients) are changing due to loss in prestressing forces.
- An other question was to assess, if vibration testing technologies may be used as early diagnosis tool for failure of single tendons.

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Submitted by: Arsenal Research GmbH.

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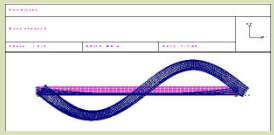
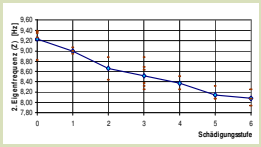
Structural Assessment Monitoring and Control

Examples of outcomes:
The first two modes have been identified reliable by the ambient vibration method. Both frequencies were reduced with increasing damage stage in the loaded condition.
An important damage indicator is the mode shape, which is in particular sensitive for smaller damages. In addition the higher order modes are relevant if local damages should be reliable detected.





SAMCO Educational Module 02

Submitted by: Arsenal Research GmbH.

SAMCO Association
Structural Assessment Monitoring and Control

Motivation: Serviceability Assessment Observation Concept: Event

Railway Bridge Heugasse - Austria
In particular the eigenfrequencies and modes in ambient and loaded condition are desired, moreover estimates for the deflection caused by the traffic-load as well as damping coefficients should be derived. This measurements are contributing to a pilot project for future monitoring concepts. Therefore several measurement points and different sensing technologies have been used in order to identify the equipment which is suited best for fast and reliable testing under operational conditions.

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Submitted by: Arsenal Research GmbH.

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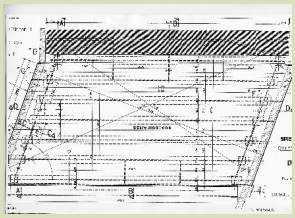
Structural Assessment Monitoring and Control

Purpose of Inspection:

The assessment of the serviceability of railway structures is done under operational conditions and no Interruption of the track is required compared to static load tests.
Moreover the results are Representing the real behavior of the structure in operation.
Therefore a Pilot project was performed, presenting the powerful approach of dynamic testing of structures.



Geometry of the structure

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Submitted by: Arsenal Research GmbH.

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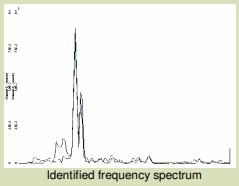
Structural Assessment Monitoring and Control

Examples of outcomes:

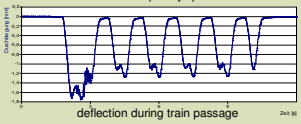
Some results are available on-site:

- the eigenfrequency,
- the maximum vertical deflection
- and the maximum acceleration level induced by the train passage.

The free decay of the structure after train passage results in a damping of 2,4 %. A maximum acceleration level of 9,2 m/s² has been identified, the maximum vertical deflection of the structure in mid span equals 1,2mm.



Identified frequency spectrum



deflection during train passage

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Submitted by: Arsenal Research GmbH.

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Structural Assessment Monitoring and Control

Motivation: Noise Assessment Observation Concept: periodic (Start 2001)

Melkbridge M6 – Austria

In the framework of an Austrian research project focused to noise emission and vibration transmission a work package was related to the global and local vibration behavior of railway bridges to study the sound emission radiated by steel structures. A detailed monitoring concept was implemented, consisting of ambient and forced vibration testing of the global structure, testing of the steel webs and measurement of the related noise emission.

Using this data, an extensive comparison between the noise radiation of steel and concrete bridges was performed.

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Submitted by: Arsenal Research GmbH.

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Inspection:

- Main purpose of the investigation performed in this case was the check and further development of the technology to assess the noise emission. Therefore the noise emission was measured during a train passage.
- This measurement was compared to the frequency response of the girder webs.
  → From the investigation it was shown, that **the vibration** of the web is mainly **responsible for the noise emission** (sound speaker effect).
- Moreover an initial dynamic investigation was performed to assess the global response of the structure.

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Submitted by: Arsenal Research GmbH.

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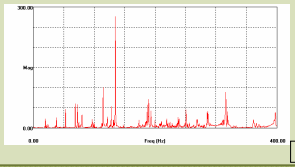
Structural Assessment Monitoring and Control

Examples of outcomes:

The comparison between ambient and forced vibration testing has shown very good correspondence. Due to the curved shape of the structure, all modes have a major transversal and torsion component.
Main energy is represented by the first mode of the web. The modes of the web elements have been identified by a detailed finite element model.



SAMCO Educational Module 02

Submitted by: Arsenal Research GmbH.

SAMCO Association
Structural Assessment Monitoring and Control

Motivation: Safety Observation Concept: periodic (29.8.-4.9.2002; 13.1.-15.1.2003)

Bridge BE 109/21- Switzerland

In order to collect data about the behavior of the bearings dependent on temperature influences, two monitoring periods measuring the deformations of the bearings and the temperature of the superstructure during the summer- and winter time were performed.

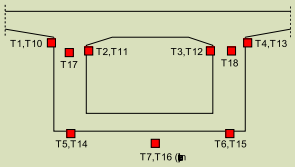
SAMCO Educational Module 02

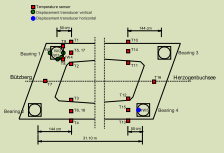
Submitted by: EMPA, Swiss Federal Laboratories for Materials Testing and Research

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Inspection:

After demolishing the bridge BE 109 the bearings will be dismantled and tested within labor experiments by fatigue loads and in a later state up to failure loads. The temperature influences and the deformations caused by traffic have been observed within two monitoring periods.





SAMCO Educational Module 02

Submitted by: EMPA, Swiss Federal Laboratories for Materials Testing and Research

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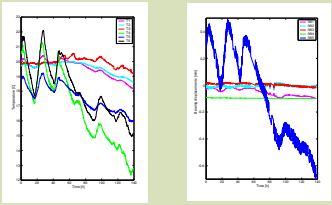
Structural Assessment Monitoring and Control

Examples of outcomes:
The deformations of the bearings according to temperature influence and traffic loads were observed. No particular deformation scenario was found. The bearings were working well and were in good general condition.



SAMCO Educational Module 02

Submitted by: EMPA, Swiss Federal Laboratories for Materials Testing and Research

SAMCO Association
Structural Assessment Monitoring and Control

Motivation: Safety Observation Concept: periodic (Start 2003)

The New Årsta Railway Bridge - Sweden

The structure is a very slender and complex prestressed concrete bridge without any ballast. Therefore, the Swedish National Railway Administration (Banverket) has initiated a measuring program to follow up and evaluate/verify stresses and deformations during construction and operation. Static and dynamic measurements/analyses are being conducted

SAMCO Educational Module 02

Submitted by: Royal Institute of Technology (KTH)

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Inspection:

Static measuring:

- Verify that maximum strains and stresses are kept within permissible limits.
- Check that no cracking occurs in critical sections, according to design.
- Study changes in strain, both during construction and in service.
- Compare results from fibre optic sensors with results from strain gauges.

Dynamic measuring:

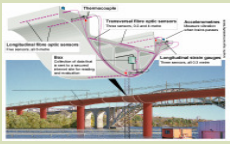
- Evaluate fundamental frequencies, mode shapes and damping ratios.
- Evaluate dynamic effects of trains crossing the bridge, especially train/bridge interaction and effects of track irregularities.
- Evaluate long-term changes in the bridge's dynamic properties.

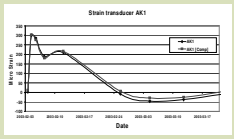
SAMCO Educational Module 02

Submitted by: Royal Institute of Technology (KTH)

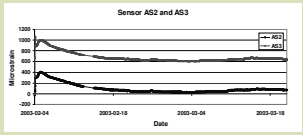
SAMCO Association
Structural Assessment Monitoring and Control

Examples of outcomes:
Only some early results are presented here and much more will be presented in a short time since more data acquisition and analysis work in the office has to be Carried out before any further conclusions can be drawn.





Typical results from strain transducers during construction. One of the curves is temperature compensated.



Results from two different fibre optic sensors in a very early stage.

SAMCO Educational Module 02

Submitted by: Royal Institute of Technology (KTH)

SAMCO Association
Structural Assessment Monitoring and Control

Motivation: Life-cycle Assessment Observation Concept: current (since 2003)

Highway Bridge BW 91, Germany

The highway-bridge BW91 is part of the highway A2 between Hannover and Berlin, Germany. The bridge crosses the Mittellandkanal near Braunschweig. It was opened in 2003 as a three-lane-bridge.

SAMCO Educational Module 02

Submitted by: University of Technology at Braunschweig

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Inspection:
Due to the central position of the bridge BW91 the validity area of the measured weights of the vehicles and their distribution in the flow of traffic covers a large number of other bridges of the Highway A2. Beside this, the measurements are carried out to obtain the strains at critical details. The measurements are carried out within the collaborative research center SFB 477 ´Life Cycle Assessment of Structures via Innovative Monitoring´

Example of Outcome:
The calibration of the sensors was carried out by use of a 30 to truck. According to the specification of the COST 323 - Project the measuring system has an accuracy class of D+(20).

SAMCO Educational Module 02

Submitted by: University of Technology at Braunschweig

SAMCO Association
Structural Assessment Monitoring and Control

Motivation: **Life-cycle Assessment** Observation Concept: **permanent**
(up to the Year 2006)

Herrenbrücke Bridge Lübeck – Germany

The Herrenbrücke was built between 1962 and 1964. The highways department of the city Lübeck assigned a consultant engineer for a statement, which has to assess the life cycle of the bridge up to the year 2006.

The bridge shows signs of corrosion damage, which is attributed to poor working quality in grouting the tendons. Tendon failure is assumed to account for up to 45%. Repair measures were executed thereupon.

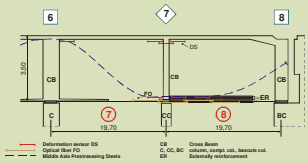
SAMCO Educational Module 02

Submitted by: University of Technology at Braunschweig

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Inspection:
From the point of view of the consultant engineer, a life cycle assessment of this bridge is not yet possible on the basis of today's level of knowledge regarding its state of condition only. Therefore SHM systems had to be installed to monitor displacements and deformations of the bridge.

Instrumentation plan



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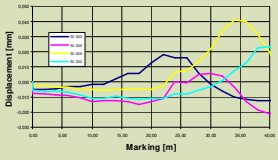
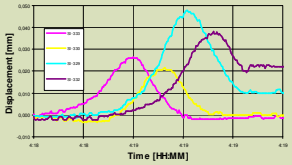
Examples of outcomes:
Static as well as dynamic measurements are possible.



static measurement



dynamic measurement

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Structural Assessment Monitoring and Control

Motivation: **Serviceability Assessment** Observation Concept: **permanent**
(since 1998)

St. Marx Bridge - Vienna

The total traffic volume averages about 240,000 motor vehicles per day, whereas an increase of the ratio of heavy loads is detected as well. As a consequence thereof the serviceability of the expansion joints and the bridge bearings is affected.
Thus, in order to detect the passing heavy loads, which cause damage, a structural health-monitoring system in combination with a video control system

SAMCO Educational Module 02

Submitted by: Vienna Consulting Engineers (VCE)

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Inspection:
On the basis of a permanent analysis of the dynamic structural behavior possible issues to be considered are as follows:

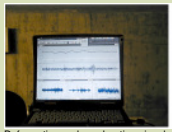
- Determination of passing heavy loads causing structural damage;
- Verification respectively update of the existing numerical load models;
- Determination of the overall load configurations and vibration coefficients, whereas wind and temperature effects are considered optionally;
- Consideration of long-term trends with respect to the life loads by means of statistics;
- Monitoring of the structural loading capacity and serviceability by means of structural identification.

SAMCO Educational Module 02

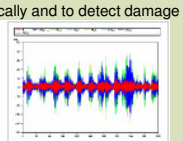
Submitted by: Vienna Consulting Engineers (VCE)

SAMCO Association
Structural Assessment Monitoring and Control

Examples of Outcomes:
In general the observed bridge structure is characterized by a distinct dynamic behavior. Therefore a long-term **S**tructural **H**ealth **M**onitoring is very well applicable. The implemented statistic analysis showed a relevant influence of the heavy loads. Environmental effects, e.g. wind induced vibrations and temperature influence, are recognized as well. Additionally, in order to simulate the structure numerically and to detect damage Finite Element Model Update is applied.



Deformation and acceleration signals during test phase



Vertical acceleration signal: all sensors

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Submitted by: Vienna Consulting Engineers (VCE)

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Structural Assessment Monitoring and Control

Motivation: **Responsibility** Observation Concept: **permanent** (since 2003)

Taichung Bridge - Taiwan

Due to the requirement to assess the cable forces, the global state of the structure and the dynamic behavior of the pylon base a Permanent Monitoring System have been installed in 2003.

Wind Sensor at
Taichung Bridge, Taiwan

SAMCO Educational Module 02

Submitted by: Vienna Consulting Engineers (VCE)

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Inspection:

The Permanent Monitoring System gives an overview about the global behavior of the bridge structure and supplies the actual cable forces. The system consists of following parts, which are monitored:

- Dynamic determination of the cable forces of 8 selected cables.
- Measuring of temperature, wind speed and wind direction.
- Dynamic measurement of the main girders and the pylon top.
- 3-dimensional measurement of the pylon base.

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Submitted by: Vienna Consulting Engineers (VCE)

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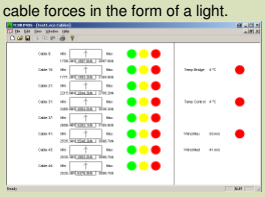
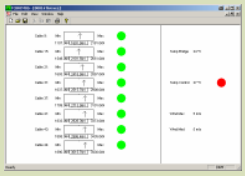
Examples of outcomes:

The Permanent Monitoring System at Taichung Bridge measures vibration, temperature and wind. The self-made software supplies the cable forces of 8 selected cables in the way that the client can easily check the status of the cable forces in the form of a light.



Theoretical output of the Monitoring System



Real Output of the Permanent Monitoring System

SAMCO Educational Module 02

Submitted by: Vienna Consulting Engineers (VCE)

SAMCO Association
Structural Assessment Monitoring and Control

Motivation: **Safety** Observation Concept: **periodic** (Start 1998)

A14 Huntingdon Railway Viaduct

The structure has been the subject of a Special Inspection that indicated the presence of voids, water and chlorides in the tendon ducts, but no significant corrosion of the strands. A SoundPrint® acoustic monitoring system, was installed to monitor tendon wire break activity in one of the cantilevers.

SAMCO Educational Module 02

Submitted by: TRL Limited

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Inspection:

The structure possessed features that made it a good candidate for acoustic monitoring:

- Additional structural investigations were in progress. This would be enhanced by a clear indication of the presence or absence of actively fracturing wires.
- The structure contained features that lent themselves to monitoring, such as difficult to inspect half joints.
- The structure occupies a strategic position on the network and carried a high volume of HGV traffic.

SAMCO Educational Module 02

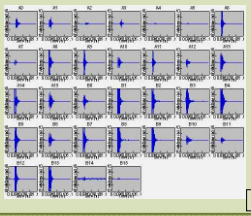
Submitted by: TRL Limited

SAMCO Association
Structural Assessment Monitoring and Control

Examples of outcomes:

The probability of a tendon wire break occurring in the structure is very low so an external wire break device was installed on the structure to check the operation of the monitoring system.

Typical acoustic response from externally mounted wire break device



SAMCO Educational Module 02

Submitted by: TRL Limited

SAMCO Association
Structural Assessment Monitoring and Control

Motivation: **Condition Control** Observation Concept: **current** (Start 1996 / 1999)

ESK551 Bridge – Bad Bevensen/Germany

Sie ist eine dreifeldrige Spannbetonbrücke mit den Spannweiten 32,05 – 66,40 – 32,05 m und weist als Folge von Herstellungsfehlern relativ starke Durchbiegungen auf. Bereits für den Lastfall Eigengewicht lässt das Bauwerk in Feldmitte Biegerisse erkennen.

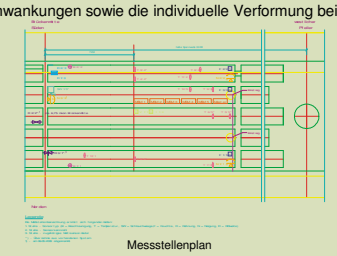
SAMCO Educational Module 02

Submitted by: Infokom GmbH

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Inspection:

Überwachung der Bauwerksverformungen infolge der allgemeinen Klimaschwankungen sowie die individuelle Verformung bei Überfahrten



Messstellenplan

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Submitted by: Infokom GmbH

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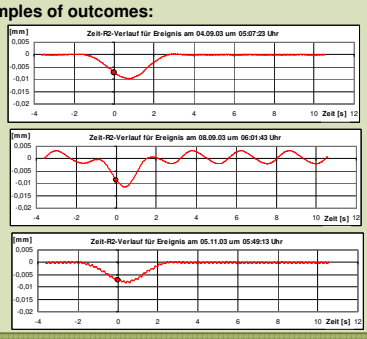
Structural Assessment Monitoring and Control

Examples of outcomes:



Dynamische Ereignisse
an demselben Wegaufnehmer

SAMCO Educational Module 02

Submitted by: Infokom GmbH

SAMCO Association
Structural Assessment Monitoring and Control

Motivation: **Special Case** Observation Concept: **periodic** (Start 2001)

I40-Bridge, New Mexico, USA

These bridges were built without structural redundancy and typically had only two plate girders carrying the loads. Failure of either girder was assumed to produce catastrophic failure of the bridge, hence these bridges were referred to as fracture critical bridges.

SAMCO Educational Module 02

Submitted by: University of Siegen

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Inspection:

After a modal analysis of the undamaged bridge, it has been damaged artificially in different states where all scenarios have been chosen to reproduce observed damage in the field.
The test data has been made available for the scientific community and so the bridge tests could be used as benchmark for testing structural damage assessment methods at a full scale structure.

→The purpose of the measurement was to detect the applied damage based on measured modal data and model based damage detection algorithms.

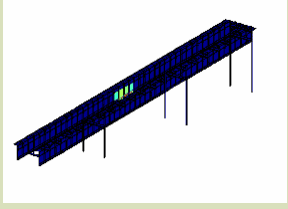
SAMCO Educational Module 02

Submitted by: University of Siegen

SAMCO Association
Structural Assessment Monitoring and Control

Examples of outcomes:

The damage could be detected, localized and quantified by means of an inverse eigensensitivity approach and Frequency Response Function (FRF) approach (alternatively) combined with parameter selection and regularization techniques.



SAMCO Educational Module 02

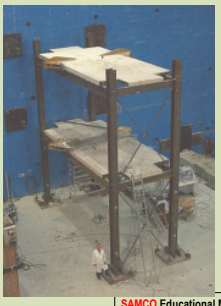
Submitted by: University of Siegen

SAMCO Association
Structural Assessment Monitoring and Control

Motivation: **Simulation** Observation Concept: **periodic** (Start 1998)

Steelquake Structure – JRC, Ispra, Italy

The structure can be interpreted as a module of a high-rise building, which has been loaded via shakers to simulate an earthquake-like loading. During this loading, damage (cracks) occurred at several locations which had to be detected.



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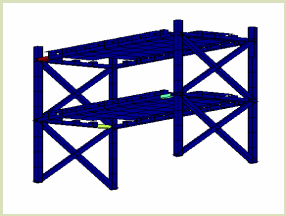
Submitted by: University of Siegen

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Inspection:
The benchmark was performed for testing and further enhancement of damage detection algorithms in the frame of the European COST F3 action.

Examples of outcomes:
The damage could be detected, localized and quantified by means of an inverse eigensensitivity approach combined with parameter preselection and regularization techniques.



Detected damage along the structure (dark locations)

SAMCO Educational Module 02

Submitted by: University of Siegen

SAMCO Association
Structural Assessment Monitoring and Control

Motivation: **Responsibility** Observation Concept: **periodic** (Start 2001)

Roberval Bridge – France

This bridge is submitted to heavy traffic loading which is of interest for bridge design codes.

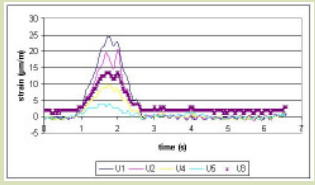
SAMCO Educational Module 02

Submitted by: Laboratoire Central des Ponts et Chaussées (LCPC)

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Inspection:
The aim of the instrumentation is to record the loads and the effects of the heavy traffic. Database (WIM data - peak strain values) for calibration of bridge loading codes.

Examples of outcomes:



SAMCO Educational Module 02

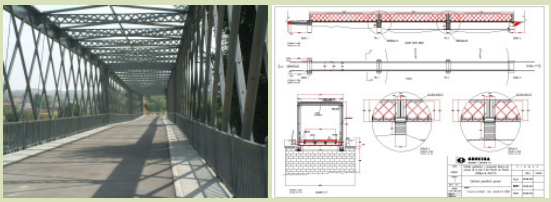
Submitted by: Laboratoire Central des Ponts et Chaussées (LCPC)

SAMCO Association
Structural Assessment Monitoring and Control

Motivation: **Safety** Observation Concept: **periodic** (Start 2003)

Titulcia Steel Bridge – Madrid / Spain

The Titulcia Steel Bridge dates from the XIX century, specifically from the year 1894.



Bridge geometry

SAMCO Educational Module 02

Submitted by: GEOCISA

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Inspection:

This bridge is integrated in a Bridge Management System implemented in the Madrid Community and it is periodically inspected.

- In 1998 a scour problem was detected in a periodical inspection. In 1999 a sub aquatic inspection was carried out, confirming the scour problem.
- From 2000 to 2003 periodical inspections have been carried out. In 2003 it is decided to implement a topographic control on the structure, to monitor the scour movements of pile 2.
- In 2004 a repair work was decided due to the evolution of measured settlements. The topographic measurements were continued during the repair process to control its efectiveness.

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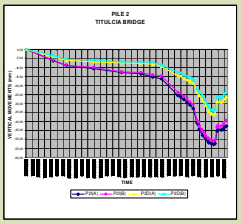
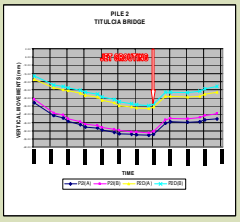
Submitted by: GEOCISA

SAMCO Association
Structural Assessment Monitoring and Control

Examples of outcomes:



Evolution of the pile 2 (4 topographic references)



Evolution of the pile 2: repair works detail

SAMCO Educational Module 02

Submitted by: GEOCISA

SAMCO Association
Structural Assessment Monitoring and Control

Motivation: Safety Observation Concept: periodic (Start 2000, 2003)

Skovdiget Bridge Superstructure – Denmark

The superstructure in the western bridge is severely deteriorated in critical positions, while at the same time facing an increased traffic load. The main girders are therefore under surveillance in order to follow the effect of the replacement of the water protection and drainage, while at the same time following the corrosion rates in the critical parts of the structure. The variations of the strains are at the same time logged, in order to generate a realistic statistic of the load variations and frequencies as well as provide a control of the FEM-modelling.

SAMCO Educational Module 02

Submitted by: RAMBOL

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Inspection:

Initial inspection has shown severe damages in parts of the structure and the ingress of chloride and variations of humidity and corrosion potentials have been followed since 2000.
It has been found necessary to determine the condition of the reinforcement in the most deteriorated parts of the main girder as well as to determine the corrosion rate.

This leads to the conclusion that the traffic loads must be logged in order to generate an overview of the actual variations of the traffic loadings in the bridge.

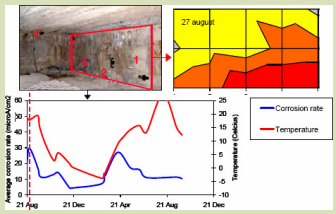
SAMCO Educational Module 02

Submitted by: RAMBOL

SAMCO Association
Structural Assessment Monitoring and Control

Examples of outcomes:

The corrosion rates have been determined several times by means of NDT methods, using the Galvapulse equipment. This verified, that the apparent corrosion rate would limit the service-life of the structure, despite the recent renovation of the water-proofing.



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Submitted by: RAMBOL

SAMCO Association
Structural Assessment Monitoring and Control

Motivation: Safety Observation Concept: periodic (Start 1975, 2000)

Skovdiget Bridge Columns – Denmark

Currently the columns under the western bridge are much deteriorated, just as the foundations used are of the same type, which have previously failed at the Fiskebæk bridge. The columns are therefore under surveillance in order to secure their performance in the future.

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Submitted by: RAMBOL

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Structural Assessment Monitoring and Control

Purpose of Inspection:

It is necessary to verify that the foundations have no unexpected settlements, that the columns remain in position and that the supports work properly.
It is also necessary to check the deterioration of the columns, especially that the corrosion will not lead to an unacceptable decrease of the load-carrying capacity due to corrosion of the reinforcement.

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Submitted by: RAMBOL

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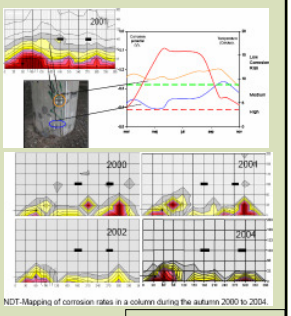
Structural Assessment Monitoring and Control

Examples of outcomes:

It has been shown that the columns and foundations has performed well so far, as very little variations in the positions of the supports on top of the columns have been observed.

The inclinometer measurements over 30 years have also shown that the columns remain vertical.

The continuous monitoring has been combined with the NDT mapping of resistance and corrosion potential



NDT-Mapping of corrosion rates in a column during the autumn 2000 to 2004.

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Submitted by: RAMBOL

SAMCO Association
Structural Assessment Monitoring and Control

Motivation: Safety Observation Concept: periodic (Start 2004)

Cassiopée Car Park, Paris

Monitoring in an underground car park: dynamic assessment of rotations of slabs and cantilevers.

SAMCO Educational Module 02

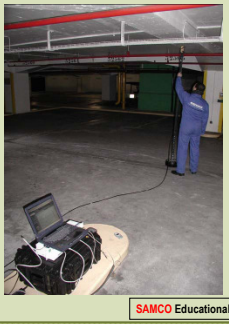
Submitted by: OSMOS

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Inspection:

The Cassiopée Car Park had closed to the public for over a year. This was due to numerous structural problems which had appeared from the beginning of its service life.

Among the problems identified were gaps between beams, sagging slabs and widening of the expansion joints.



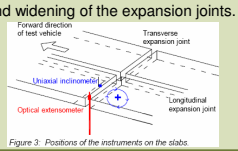


Figure 3: Positions of the instruments on the slabs.

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Submitted by: OSMOS

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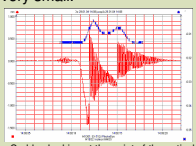
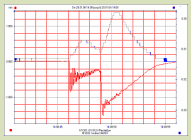
Structural Assessment Monitoring and Control

Examples of Outcomes:

The results of the dynamic tests can be summarized as follows:

- The amplitude of the deformations at the measured points can reach 5 mm. These deformations are reversible. The structure's behavior is completely elastic.
- The repeatability of the sags under equal loads is rather irregular. The typical variance is approximately 15% of the average sag amplitude.
- The presence of microcracks is probable. However, it is likely that they are very small.


Sudden braking at the point of the optical extensometer.


Reverse passing.

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Submitted by: OSMOS

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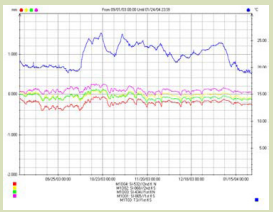
Structural Assessment Monitoring and Control

Examples of Outcomes:

The first six months of monitoring revealed that all levels of the structure exhibit roughly similar deformations. This may mean that the structure behaves like a statical "monolith".


Similar deformations on first and second floors (four lower curves). (Temperature readings indicated in blue.)

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Submitted by: OSMOS

SAMCO Association
Structural Assessment Monitoring and Control

Motivation: Life-time Assessment Observation Concept: periodic (Start 2003)

Manhattan Bridge – New York

The Manhattan Bridge was built between 1901 and 1912 and spans the East River. Its pylons, deck and cables are of steel. It serves both automobile traffic and railroad traffic.

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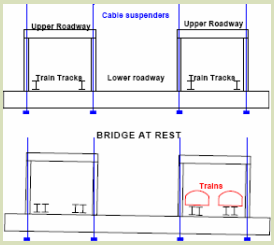
Submitted by: OSMOS

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Inspection:

The loads borne by the structure are quite frequently asymmetrical, due to train passings on one side or the other. The client (New York Department of Transportation) was in need of an extended monitoring scheme with a view to:

a) establishing the structure's reference state;
b) detecting any effects due the stiffening campaign itself;
c) evaluating the campaign's effectiveness following its completion.



Inclination of deck under asymmetrical load.

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Submitted by: OSMOS

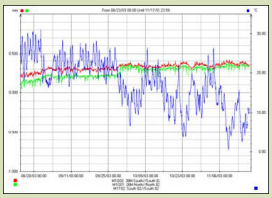
SAMCO Association
Structural Assessment Monitoring and Control

Examples of Outcomes:

Over a three-month period, both of the optical extensometers registered similar deformations. The main cause is apparently thermal variations.

Over the same three-month period, both of the optical inclinometers registered similar movements. This may indicate that the entire width of the deck behaves identically.

To date, all deformations have been reversible.


The optical extensometers have indicated small amplitude deformations.

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Submitted by: OSMOS

SAMCO Association
Structural Assessment Monitoring and Control

Motivation: **Construction** Observation Concept: **Event** (Construction)

Berlin Main Station, Lehrter Bahnhof – Germany

The East-West-superstructure consists of 4 parallel track viaducts, partially covered by a steel glass roof which is sensitive to vertical movement in the level of its bearings, especially during construction work on site.

SAMCO Educational Module 02

Submitted by: Federal Institute for Materials Research and Testing (BAM)

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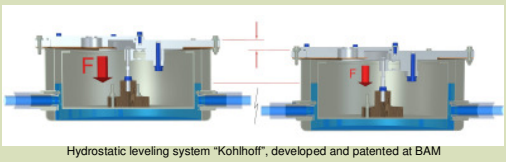
Structural Assessment Monitoring and Control



Hydrostatic leveling system "Kohlhoff", developed and patented at BAM

Purpose of Inspection:

As result of static calculation the vertical movement of the bearings for the steel-glass roof was limited by the railway authorities (EBA). The bearings of the glass roof are located on the top of the outer bridges of the East-West Tracks. The roof is loading the track bridges with a torsional load additional to the symmetrical traffic load.

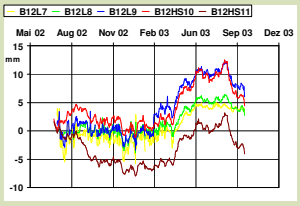
SAMCO Educational Module 02

Submitted by: Federal Institute for Materials Research and Testing (BAM)

SAMCO Association
Structural Assessment Monitoring and Control

Examples of outcomes:

During the building process monitoring showed, that limit values for vertical displacements were not exceeded. The global condition state of the bridge and of the glass roof did not suffer from a critical loading situation.



SAMCO Educational Module 02

Submitted by: Federal Institute for Materials Research and Testing (BAM)

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Structural Assessment Monitoring and Control

Motivation: **Curiosity** Observation Concept: **permanent** (since 1994)

Republic Plaza -Singapore

Republic Plaza is one of the three tallest buildings in Singapore, at 280m. Monitoring, for the purpose of tracking wind and seismic loads has included for example:

- manual readings of stress and strain,
- periodic measurements of natural frequencies during construction,
- addition of wind sensors and basement accelerometers,…

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Submitted by: University of Plymouth

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Purpose of Monitoring:

- Static monitoring was installed to track the load sharing between structural components and to identify creep.
- Dynamic monitoring was installed to monitor the wind loading and effects, and proved highly capable of recording earthquakes originating from hundreds of thousands of km distant.
- A GPS system has been installed to identify the relative contributions of static and dynamic wind-induced response.

→The focus has been more on using the building as a wind and earthquake 'super-sensor'

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Submitted by: University of Plymouth

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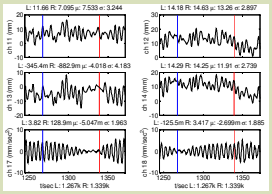
Structural Assessment Monitoring and Control

Examples of outcomes:

Static monitoring over ten years has shown distinct load transfer and creep tendencies in the structural system.

Effects of distance tremors have been captured and compared with those due to strong winds. It has been shown that seismic load is the dominant effect for medium to tall buildings in Singapore.



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Submitted by: University of Plymouth

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Motivation: **Quality Control** Observation Concept: **Long-term Monitoring** (since 2001)

Punggol EC26, Block 166A - Singapore

The monitoring is to be performed during its whole lifespan of the building, from construction stage to occupancy. Thus, for the first time the sensors are used in large-scale life cycle monitoring of high-rise buildings.

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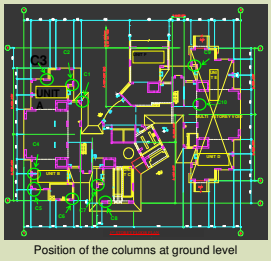
Submitted by: Smartec

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Instrumentation:

This monitoring project is considered as a pilot project with two aims:

- to develop a monitoring strategy for column-supported tall building structures
- and to collect data related to the stress behavior of this building providing rich information concerning their 'health' conditions.



Position of the columns at ground level equipped with sensors.

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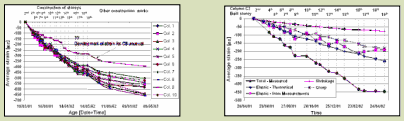
Submitted by: Smartec

SAMCO Association
Structural Assessment Monitoring and Control

Examples of Outcomes:

Measurements were recorded during the construction of the 19-storey residential building. To decrease the costs of monitoring in this phase, only periodical readings were taken. One round of readings was taken for all the sensors after a new storey was completed.



Average strain evolution in columns during construction works.

The elastic strain is obtained from monitoring in an indirect way, subtracting the creep and shrinkage from the total monitored strain. Influence of temperature variations to the strain was neglected.

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Submitted by: Smartec

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Motivation: **Serviceability Assessment** Observation Concept: **current** (Start 2001)

Floridotower Highrise Building - Austria

The Florido high-rise building consists in total of 31 floors with a total floor space of approximately 36.000 m². The height of the building is 113,00 m.

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Submitted by: Arsenal Research GmbH.

SAMCO Association
Structural Assessment Monitoring and Control

Purpose of Inspection:

- In the scope of the comprehensive investigations of the Floridotower in Vienna, the registration and determination of the dynamic characteristic of the structure was major task.
- Moreover an assessment of the vibration response as well as the proneness of vibration in case of seismic events should be performed.
- The investigation was additionally focused to determination of the serviceability stage and user comfort in operation.

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Submitted by: Arsenal Research GmbH.

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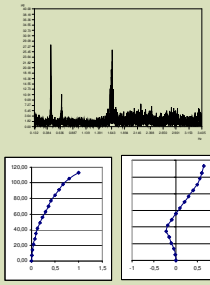
Examples of outcomes:

The modes in transversal and longitudinal direction are clearly separated for the forced and ambient vibration tests. The structure represents a well developed dynamic response in the observed frequency range. Due to the high number of measurement points in each floor the first three modes of vibration could be clearly determined in transverse and longitudinal direction.



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Submitted by: Arsenal Research GmbH.

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Structural Assessment Monitoring and Control

Motivation: Special Cases Observation Concept: periodic (Start 2003)

Seismic Vulnerability of Hospitals - Austria

Main problem in context of seismic events is the effect to existing structures, which are always designed according the current standards. Thus it is clear, that the main part of human and economic losses appear for this old structures, which are not appropriate designed. An assessment and improvement of all existing structures which are subjected to excessive seismic loads is not feasible, but the improvement of major structures which must fulfill their function after a seismic event is an economic approach.

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Submitted by: Arsenal Research GmbH.

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Purpose of Inspection:

→First step of the investigation was related to the measurement of the vibration response of major structures. The determined natural frequencies and mode shapes are representative for the current undamaged condition of the buildings.

→During the next step a numerical analysis was performed for the structures, reaching from simple MDOF systems to advanced finite element models.

→Consequently, these models are fitted to the measured data.

- The capacity of the structures was evaluated in accordance to the Austrian Code B 4015, which was described by the "GPR" index. Secondary risks were also considered (GSR-index). Both indices are contributing to the risk index, which was presented by a risk-mapping technique.
- Main outcome are measures which should be implemented in order to increase seismic safety for identified areas of the structure.

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Submitted by: Arsenal Research GmbH.

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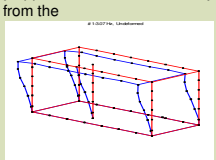
Examples of outcomes:

- The modal parameter of each building were identified by measurements, which have been compared to the results of the finite element analysis.
- The modal parameters were identified by ambient measurement and by forced vibration testing employing the reaction mass exciter VICTORIA.
- the ground response was identified, using the exciter as well

→ A conventional risk study was additionally applied for each structure. By combining all results, a detailed impression from the structures could derived, which is base for seismic upgrading and future monitoring concepts.



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Submitted by: Arsenal Research GmbH.

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Motivation: Special Case Observation Concept: periodic (Start 2003)

Federal Hall - New York

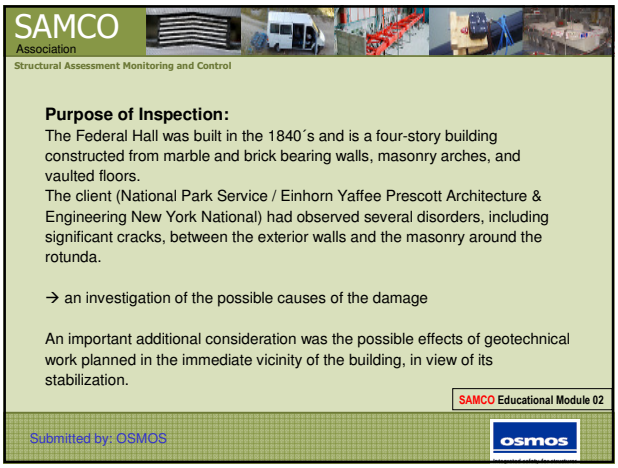
Preventive Monitoring of Effects of Geotechnical Work

Close-up of splice box at one end of optical strand

Crack watcher X-Trigger on the subbasement level

SAMCO Educational Module 02

Submitted by: OSMOS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Purpose of Inspection:
The Federal Hall was built in the 1840´s and is a four-story building constructed from marble and brick bearing walls, masonry arches, and vaulted floors.
The client (National Park Service / Einhorn Yaffee Prescott Architecture & Engineering New York National) had observed several disorders, including significant cracks, between the exterior walls and the masonry around the rotunda.
→ an investigation of the possible causes of the damage
An important additional consideration was the possible effects of geotechnical work planned in the immediate vicinity of the building, in view of its stabilization.
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Submitted by: OSMOS
osmos