COST Action
TU 1402

Quantifying the Value of Structural Health Monitoring

WG 4 – Case Study Portfolio

Jochen Köhler and Helmut Wenzel

TU1402 Final Conference, Berlin, February 2019

WG 4 - objective

- Identify relevant application cases where the benefits and challenges of VoI analysis are demonstrated.
- Pick up the insights obtained in WG 1 – 3.
- Use the case studies to engage infrastructure stakeholders and disseminate action results.

WG 4 - onset

- Call for case studies had been issued early 2016.
- > 10 Teams responded and initiated work on the case studies.
- The topics covered VoI analysis for the design and operation phase of different kind of structures.
- Information is considered not only from SHM but also from discrete inspection and measurement.

WG 4 - realization

- The case studies have been developed by the individual teams.
- Factsheets that follow a standard workflow and a common nomenclature have been drafted.
- The case study development has been supported by the action workshops but in particular during two training schools.

WG 4 - output

- Four case studies have not been followed further after first proposal.
- The remaining 13 case studies have been further developed and reach fact to the following output so far:
  - 10 Factsheets that follow the TU1402 fact sheet template
  - 16 Conference contributions
  - 9 Journal publications
  - (more to come, e.g. special issue in Engineering Structures is in planning)
- A summarizing paper about the case study portfolio and the lessons learned will be also presented in Guimarães 2019 at the IABSE conference.

WG 4 - output

Examples

Optimizing Monitoring: application to assessment of roof snow load risk

Miroslav Sykora, Czech Technical University in Prague, Czech Republic
Dimitris Diamantidis, OTH Regensburg, Germany

- Problem: How to decide on a monitoring strategy and a cost optimal intervention plan in case of roof snow load on a stadium roof
- Consequence: structural roof collapse with possible considerable number of fatalities (CC3 structure)

Optimizing monitoring: application to assessment of roof snow load risk

Miroslav Sykora, Czech Technical University in Prague, Czech Republic
Dimitris Diamantidis, OTH Regensburg, Germany

- Minimization of total costs
- Analysis of costs and impact of monitoring alternatives M1, M2, M3
  C_I initial costs, C_O operation costs
- analysis of total costs:

costs of cleaning of the roof

temporary closure of the stadium

failure costs (human, economic)

Alternative	Cost	Uncertainty
M1: meteorological station snow depth on ground	negligible	very high
M2: snow depth on the roof	C_I= 7000 Euro C_O = 800 Euro /year	high (snow density)
M3: snow load on the roof	C_I= 14000 Euro C_O = 800 Euro /year	reduced (direct measurement)

Optimizing Monitoring: application to assessment of roof snow load risk

Miroslav Sykora, Czech Technical University in Prague, Czech Republic
Dimitris Diamantidis, OTH Regensburg, Germany

Output

a) Presentations and fact sheet (COST TU 1402 output)

b) Publications:

Diamantidis, D., Sykora, M. Lenzi, D., 2018, "Optimizing Monitoring: Standards, Reliability Basis and Application to Assessment of Roof Snow Load Risks" In: Structural Engineering International SEI - Journal of IABSE, ISSN 1016-8664, DOI: 10.1080/10168664.2018.14621.

Diamantidis, D., Sykora, M., 2018, "Optimizing monitoring – implementation of draft guideline and case study of roof exposed to snow loads" IABSE Symposium, September 19-21, 2018, Nantes, France. Zürich: IABSE, p. S27-27-S27-34, 2018, ISBN: 978-3-85748-153-6; ISBN: 978-3-85748-161-1.

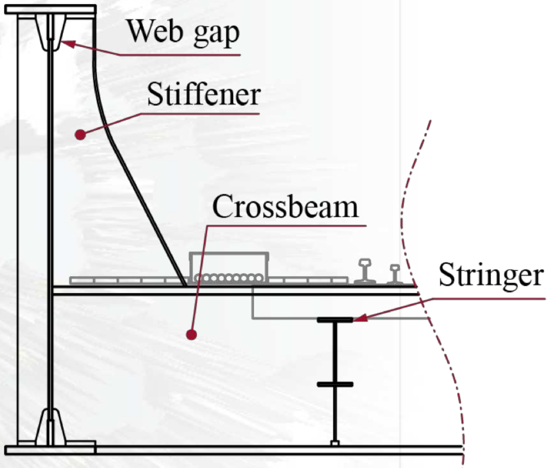
Diamantidis, D. and M. Sykora, 2019, "Implementing Information Gained through Structural Health Monitoring - Proposal for Standards", 13th International Conference on Applications of Statistics and Probability in Civil Engineering, May 2019, Seoul, Korea.

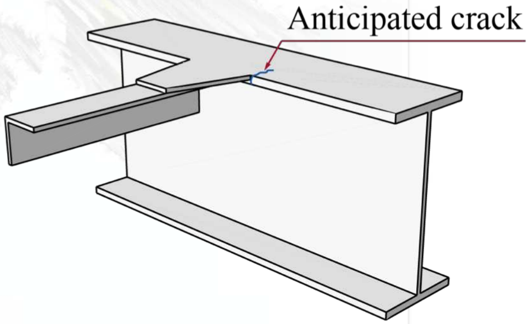
The case study did take benefit in the TU1402 Training Schools and workshops.

The Söderström Bridge

by John Leander, KTH, Dániel Honfi, RISE,
Ìvar Björnsson & Oskar Larsson Ivanov, LTH, Sweden

- Problem: previous assessments have shown an exhausted fatigue life of the studied detail of the steel bridge but no cracks observed.
- Consequence: undiscovered damage leading to reduced fatigue life.

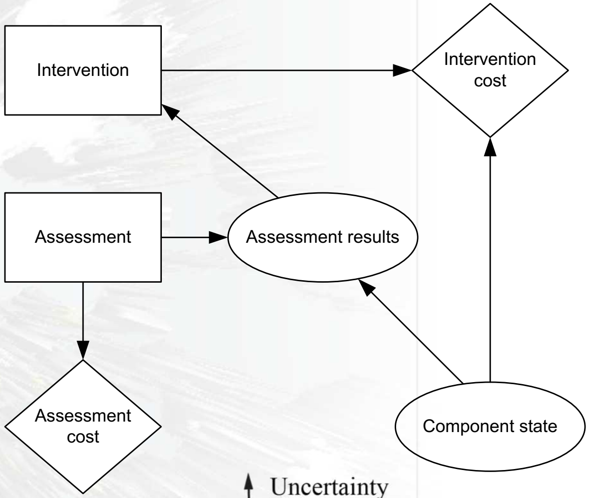


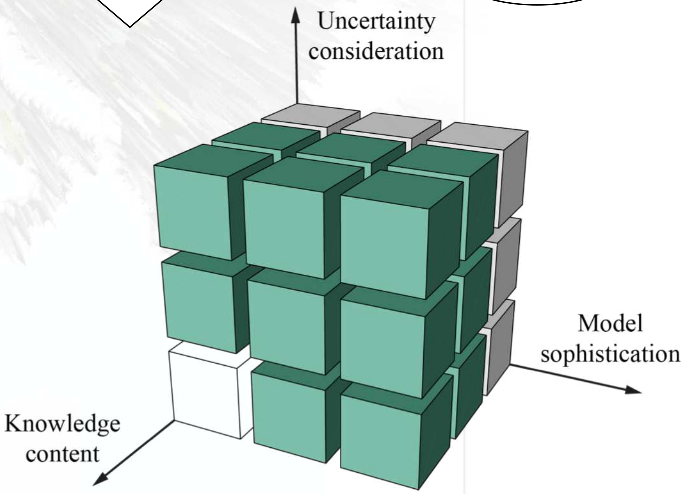


The Söderström Bridge

by John Leander, KTH, Dániel Honfi, RISE,
Ìvar Björnsson & Oskar Larsson Ivanov, LTH, Sweden

- The VoI of various assessment methods is addressed in the case study.
- The information utilized in condition assessment an follow-up maintenance actions.
- The results indicate an improved reliability / useful service life with the application of more advanced assessment methods.
- Critical assumptions: PoD curves, cost of assessments and actions.





The Söderström Bridge

by John Leander, KTH, Dániel Honfi, RISE,
Ìvar Björnsson & Oskar Larsson Ivanov, LTH, Sweden

- The case study is documented in a corresponding TU1402 fact sheet.

- Additionally the results are presented in:
  - Honfi D., Leander J. & Björnsson I. (2017) Decision support for bridge condition assessment. 4th International Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures (SMAR 2017), Zürich, Switzerland, 13-15 September, 2017.
  - Leander J., Honfi D., & Björnsson I. (2017) Risk-based planning of assessment actions for fatigue life prediction. Procedia Structural Integrity, Vol. 5, pp. 1221-1228.
  - Leander J., Honfi D., Larsson Ivanov O., & Björnsson I. (2018) A decision support framework for fatigue assessment of steel bridges. Engineering Failure Analysis, 91, 306–314.
  - Björnsson I., Honfi D., Larsson Ivanov O., & Leander J. (2019) Decision support framework for bridge condition assessments, under review.

- The case study did take benefit in the TU1402 Training Schools and workshops.

BRIDGE MAINTENANCE STRATEGY USING SHM DATA

Dominik Skokandić, Ana Mandić Ivanković, University of Zagreb, Croatia
Aleš Žnidarič, ZAG, Slovenia
Sebastian Thöns, DTU, Denmark

- Problem: Majority of existing road and highway bridges are designed according to old traffic design codes, and they need to be reassessed for their safe continuous use.
- Consequence: Current design codes are very conservative in terms of traffic load modelling and their application in the assessment results in reduction of estimated service life of those bridges, along with need for their strengthening and additional investments

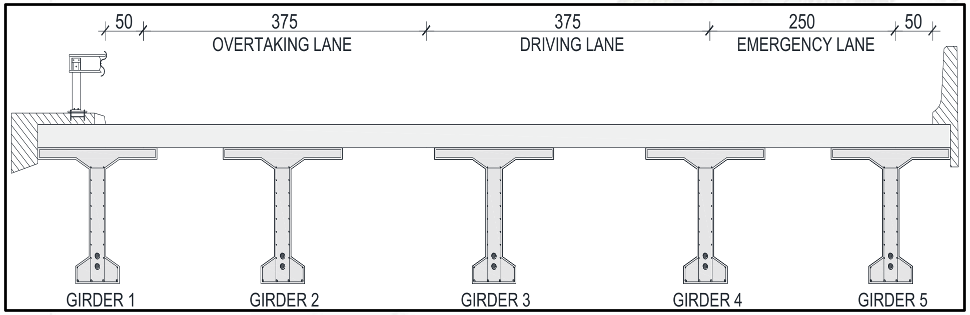


Figure 1: *Cross section of Case Study Bridge*

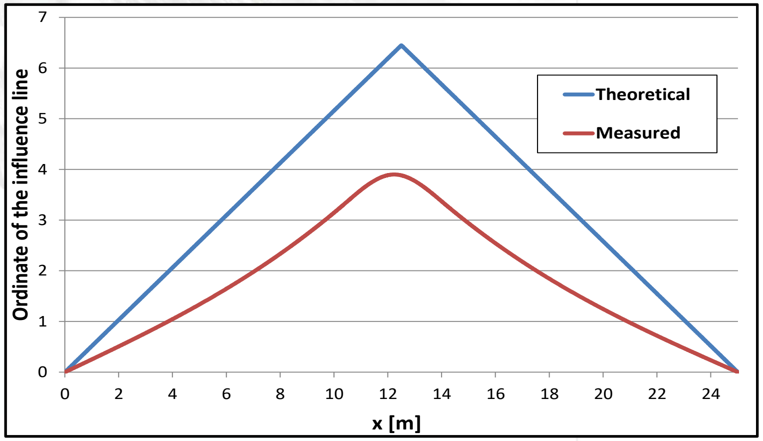


Figure 2: *Difference between theoretical and SHM measured influence line*

BRIDGE MAINTENANCE STRATEGY USING SHM DATA

Dominik Skokandić, Ana Mandić Ivanković, University of Zagreb, Croatia
Aleš Žnidarič, ZAG, Slovenia
Sebastian Thöns, DTU, Denmark

- The VoI analysis of additional traffic and structural data obtained with Bridge Weigh-in-Motion measurements is assessed
- The additional information is utilized trough different assessment and maintenance strategies trough bridge service life
- Preliminary results clearly quantify the value of B-WIM data as a reduction of overall costs and prolonged estimated service life
- Most critical assumptions are the estimation of total costs.

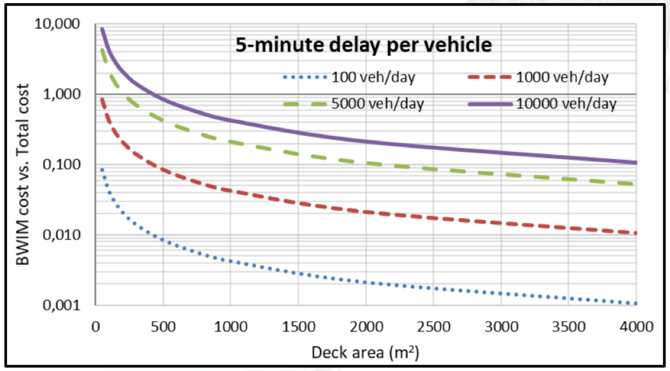


Figure 3: *SHM costs compared to non-availability costs*

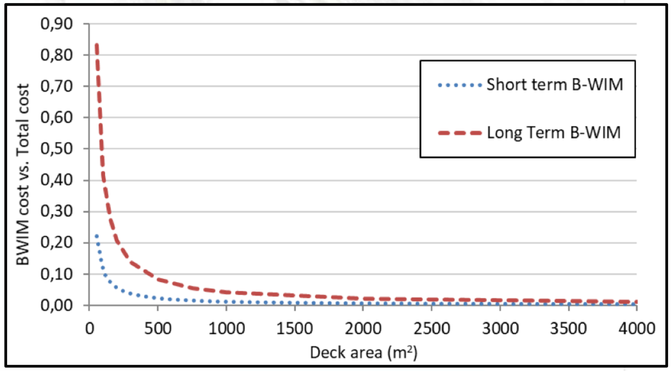


Figure 4: *SHM costs compared to value of the bridge*

BRIDGE MAINTENANCE STRATEGY USING SHM DATA

Dominik Skokandić, Ana Mandić Ivanković, University of Zagreb, Croatia
Aleš Žnidarič, ZAG, Slovenia
Sebastian Thöns, DTU, Denmark

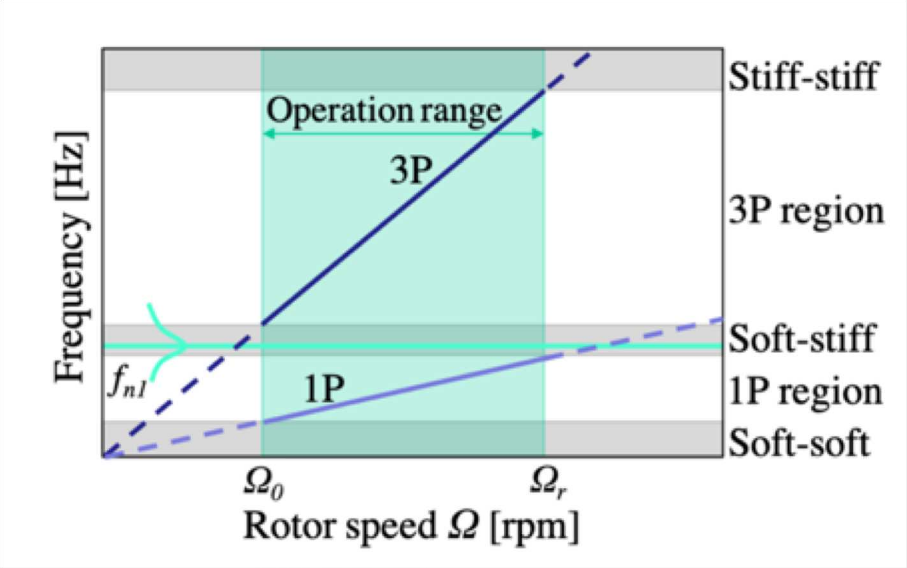
- COST TU1402 Factsheet regarding the Case Study is produced and updated.
- Case Study results were additionally presented in following papers:
  - Ana Mandić Ivanković, Dominik Skokandić, Aleš Žnidarič, Maja Kreslin: ***Bridge performance indicators based on traffic load monitoring***. Structure and Infrastructure Engineering 12/2017
  - Dominik Skokandić, Aleš Žnidarič, Ana Mandić Ivanković, Maja Kreslin: ***Application of Bridge Weigh-in-Motion measurements in assessment of existing road bridges***. JOINT COST - IABSE Workshop, Zagreb, Croatia; 03/2017
  - Skokandić Dominik, Mandić Ivanković Ana, Žnidarič Aleš, Thöns Sebastian: ***Quantifying the value of B-WIM: Assessing costs and benefits for Value of Information Analysis*** , upcoming IABSE Symposium in Guimaraes, March 2019.
- The idea for Case Study was developed on first STSM in 2016, and was further researched on following STSM in 2018, along with the several other COST workshops.

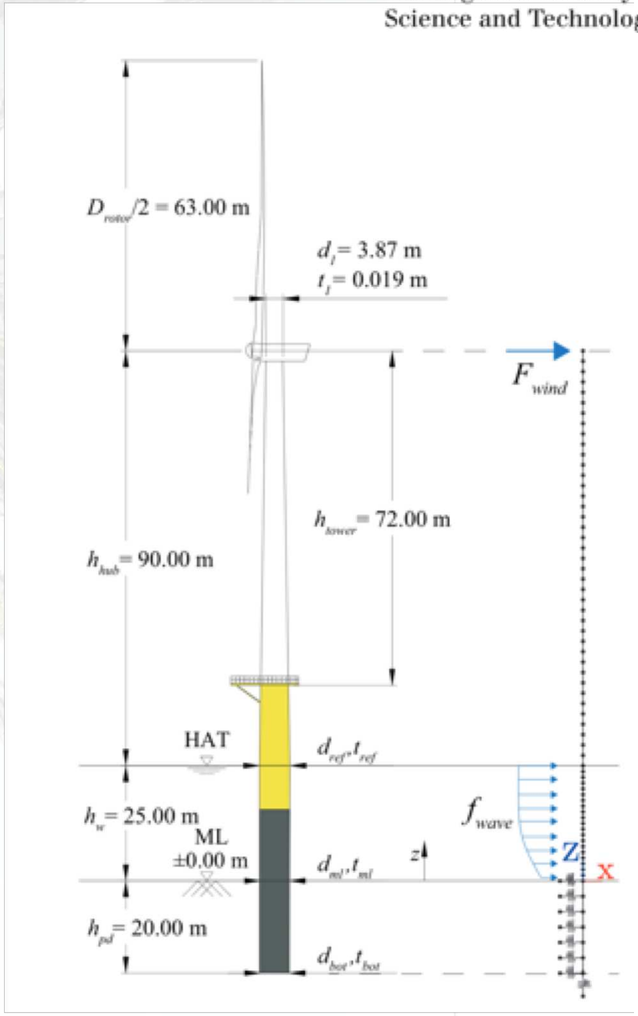
Case Study on Offshore Wind Farm Foundation

by Jorge Mendoza Espinosa and Jochen Köhler, NTNU Norway

NTNU
Norwegian University of Science and Technology

- Problem: Wind energy converters are designed such that they most likely operate in the "soft-stiff" region.
- Consequence: A deviation of that causes a reduction of the fatigue life.

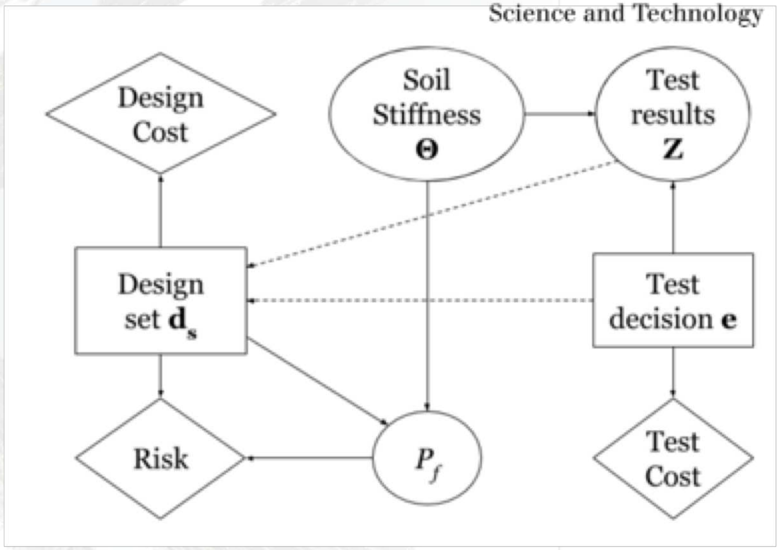




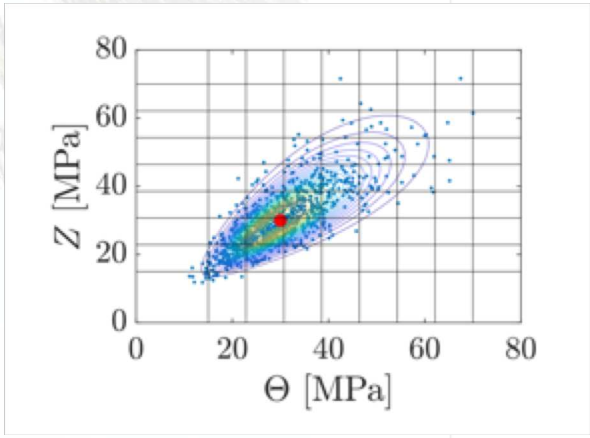
Case Study on Offshore Wind Farm Foundation

by Jorge Mendoza Espinosa and Jochen Köhler, NTNU Norway

NTNU
Norwegian University of Science and Technology



- The VoI of additional soil tests is assessed.
- The Information is potentially utilised for the design decision of the monopile.
- Results indicate a relative low VoI considering one converter.
- Critical assumptions in regard to the test likelihood.



Case Study on Offshore Wind Farm Foundation

by Jorge Mendoza Espinosa and Jochen Köhler, NTNU Norway

NTNU
Norwegian University of Science and Technology

- The case study is documented in a corresponding TU1402 fact sheet.

- Additionally the results will be disseminated at upcoming conferences:

  - IABSE Symposium 2019 Guimarães, Portugal, March 27-29, 2019
    «Value of site-specific information for the design of offshore wind farms»

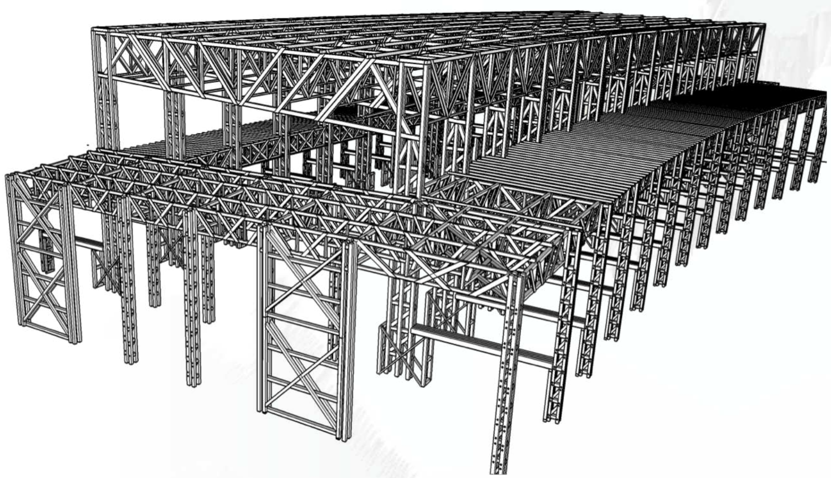
  - ICASP13, Seoul, South Korea, May 26-30, 2019
    «Risk-based Design of an Offshore Wind Turbine using VoI Analysis»

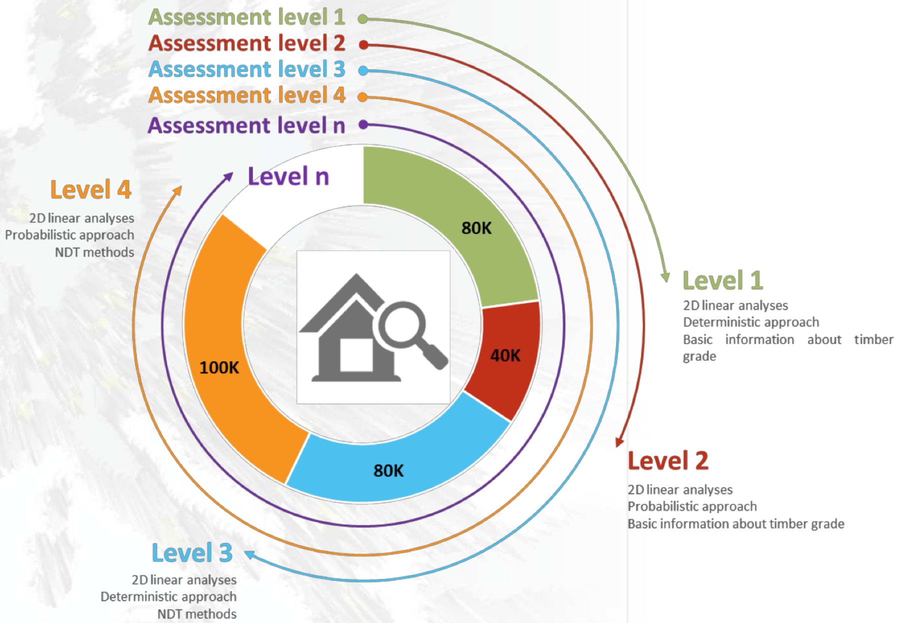
- The case study did take benefit in the TU1402 Training Schools and workshops.

Condition assessment of timber structures – quantifying the value of information

by Mislav Stepinac, Vlatka Rajčić and Daniel Honfi

- Problem: various levels of condition assessments of existing timber structures give results of different quality and quantity
- Consequence: decisions based on the assessments lead to various costs of repair, strengthening or structural failure.

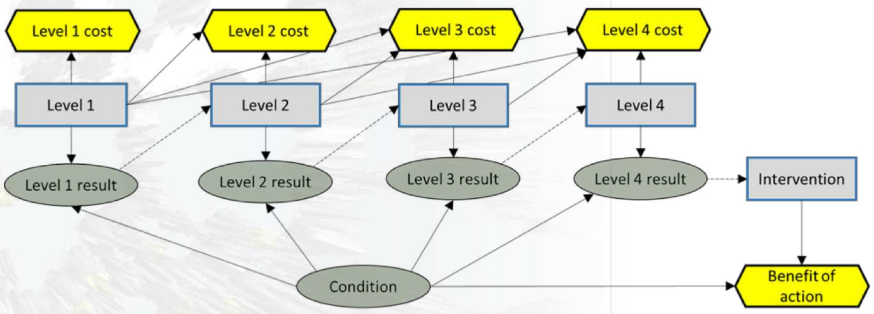


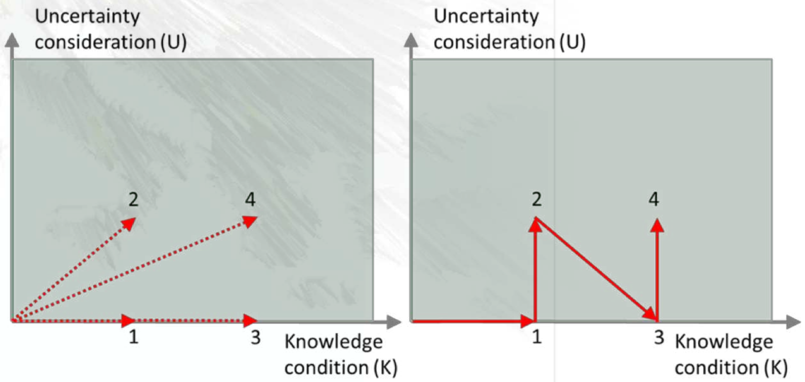


Condition assessment of timber structures – quantifying the value of information

by Mislav Stepinac, Vlatka Rajčić and Daniel Honfi

- The expected costs of different assessment strategies were compared (successive vs non-successive, damaged member vs all members).
- The information is utilized to determine the best assessment strategy.
- The results indicate that:
  a) With a successive assessment strategy the expected costs can be decreased.
  b) Depending on the case an extensive and costly assessment may result in lower overall costs.
- The most critical assumptions were regarding the sample likelihoods and the prior probabilities.





Condition assessment of timber structures – quantifying the value of information

by Mislav Stepinac, Vlatka Rajčić and Daniel Honfi

- The case study is documented in a corresponding TU1402 fact sheet.

- Dissemination at conferences:
    - ✓ IABSE Symposium 2019 Guimarães, Portugal, March 27-29, 2019 «Decision analysis and scenarios for the assessment of existing timber structures»
    - ✓ IABSE Symposium 2018 Nantes, France, September 19-21, 2018 «Condition assessment of timber structures – quantifying the value of information»

- Case Study did take benefit from STSM (Zagreb > Gothenburg), Training Schools & Workshops

WG 4 – lessons learned

- The 1:1 implementation of the VoI concept into practical contexts is demanding. Challenges are associated with a reasonable system representation in order to capture:
    - The events that lead to direct and indirect consequences (i.e. «Failure» can be manifold / cascading over space and time)
    - How to relate the information acquired to the properties / variables of interest (i.e. by likelihoods).
- In practical structural engineering contexts VoI is relevant not only in relation to SHM but also regarding discrete inspections and enhancement of engineering modelling.

WG 4 – further activity

- Documenting the case study on the Action web page.
- Special issue planned with approx. 12 contributions.
- Industry innovation events, presenting case studies to relevant industry.

Thanks to all WG 4 participants !!

And thank you for your attention !!

Value of Information of a pro-active SHM tool devoted to early damage detection on bridges

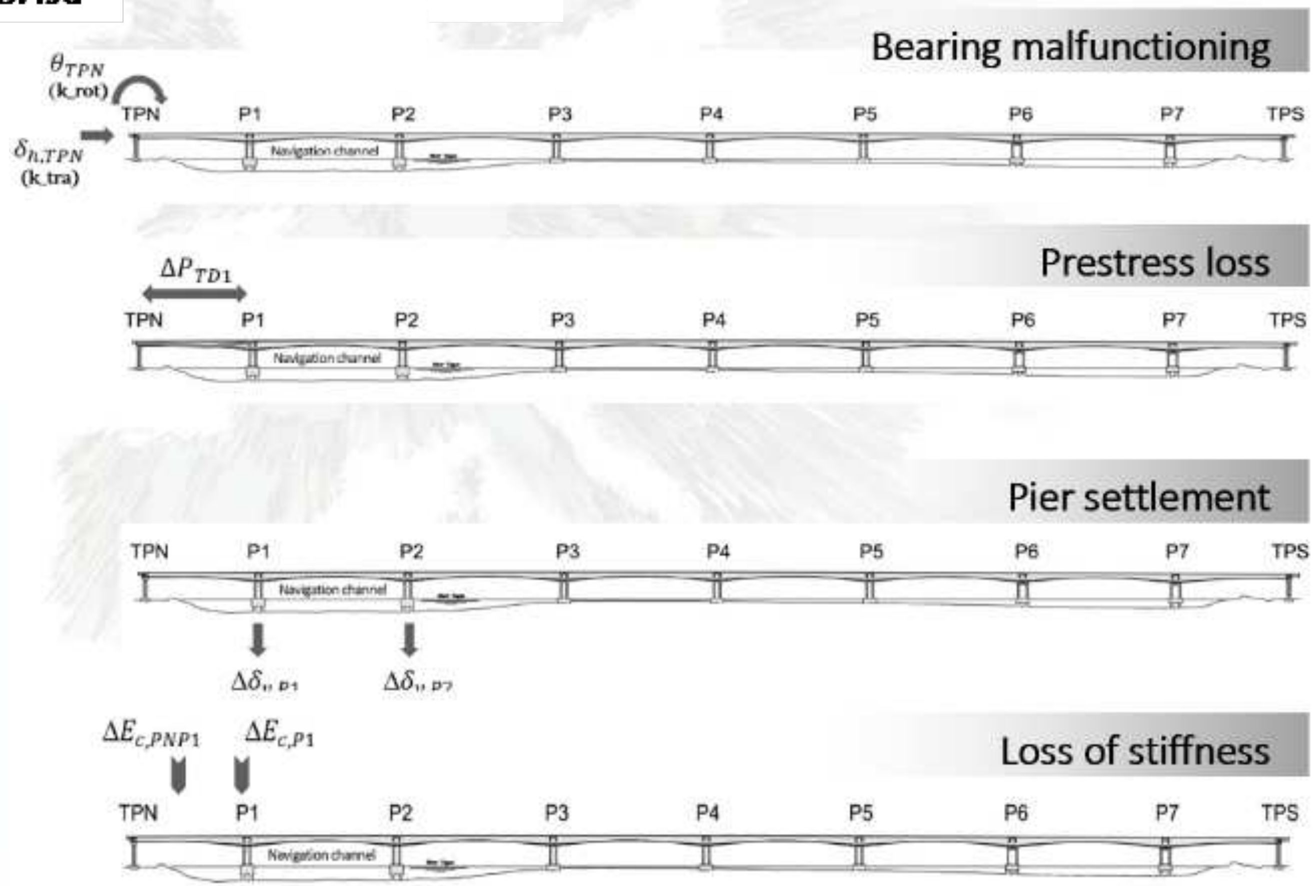
By: Helder Sousa HS Brisa Wim Courage TNO

- Problem:

  Detect damages on bridges, as early as possible, taking into account the importance of this type of structures.

- Consequence:

  Absence of an early detection of damage will lead to higher costs (both direct and indirect).

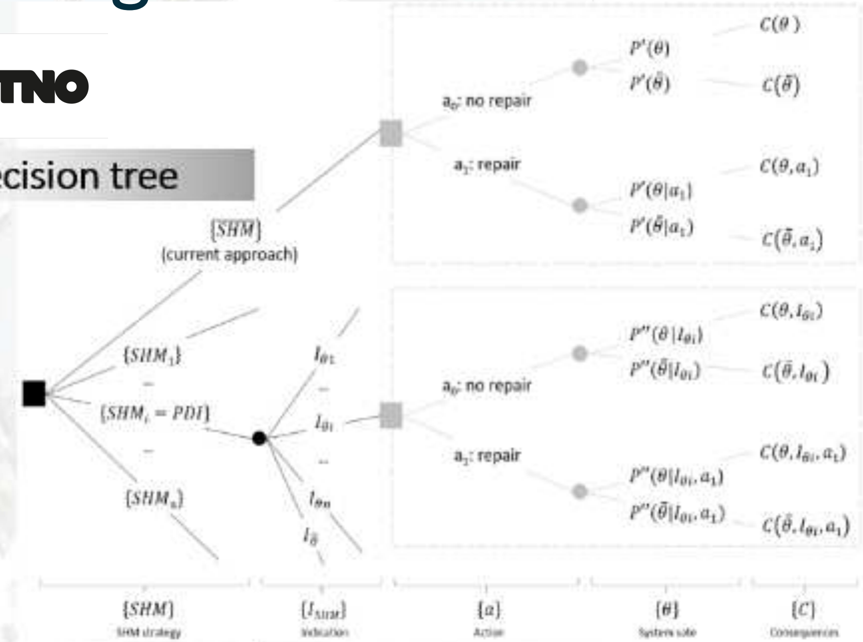


Value of Information of a pro-active SHM tool devoted to early damage detection on bridges

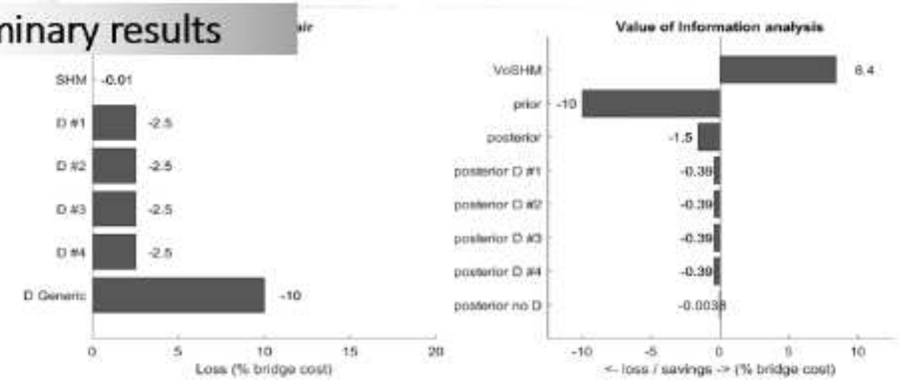
By: Helder Sousa HS Brisa Wim Courage TNO

- The VoI of monitoring on the bridge is assessed.
- The Information obtained might potentially lead to improved asset management.
- Preliminary results indicate a benefit in using SHM for early damage detection.
- Prior distributions are assumed uniform, which might not be representative of all scenarios in the asset management context

Decision tree



Preliminary results



Value of Information of a pro-active SHM tool devoted to early damage detection on bridges

By: Helder Sousa HS Brisa Wim Courage TNO

- The case study is documented in 1 TU1402 fact sheet.
- The results will be disseminated on 1 conference paper:
  - «A pro-active concept in asset management supported by the quantified Value of Structural Health Monitoring», Sepcial Session: Why Invest on SHM?, IABSE Symposium 2019 Guimarães, Portugal, March 27-29, 2019
- Additionally, 2 journal papers in process for publication:
  - «A novel pro-active SHM approach devoted to bridge management based on FE analysis and Bayesian methods» - submitted 05.12.2018
  - «Value of Information of a pro-active SHM tool devoted to early damage detection on bridges» - planned submission for a special issue on the case studies
- The setup on the case study did take benefit in the TU1402 Training School (Villa La Collina, 09-11.11.2017), STSM scheme and workshops in general.

Optimizing in-situ testing for historic masonry structures

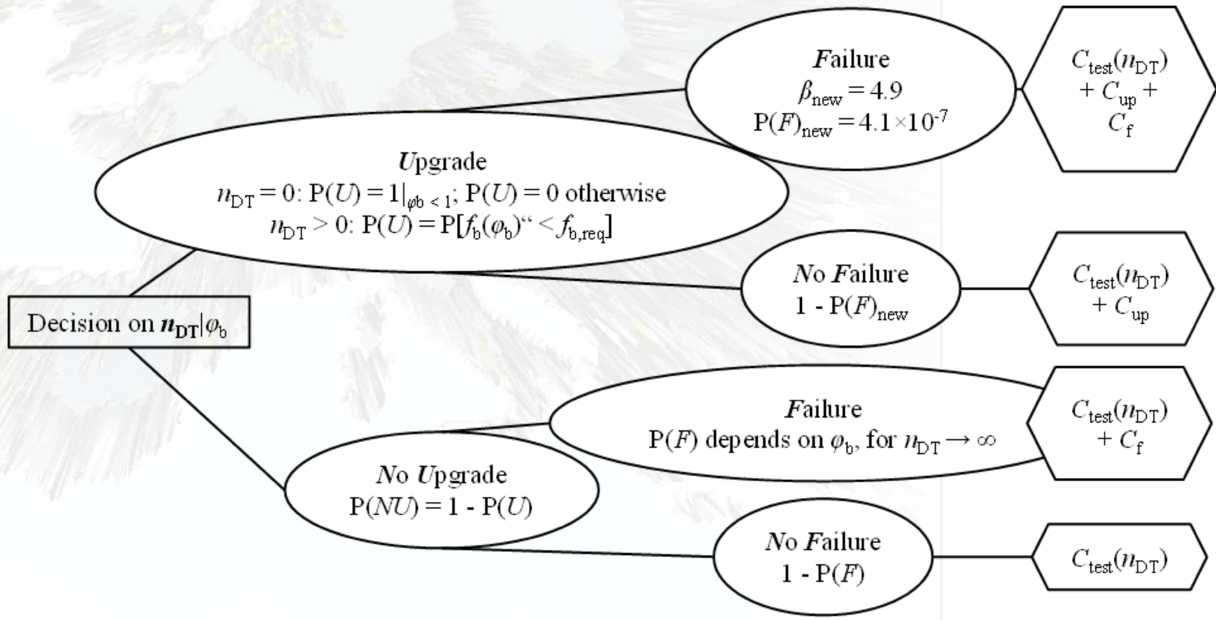
Miroslav Sykora and Jana Markova, Czech Technical University in Prague, Czech Republic
Dimitris Diamantidis, OTH Regensburg, Germany
Maria Giovanna Masciotta, University of Minho, Guimaraes, Portugal

- Problem: How to obtain case specific information of compressive strength of historic masonry (masonry unit strength f_b)
- Consequence: structural compressive failure of parts of historic structures with heritage value

Optimizing in-situ testing for historic masonry structures

Miroslav Sykora and Jana Markova, Czech Technical University in Prague, Czech Republic
Dimitris Diamantidis, OTH Regensburg, Germany
Maria Giovanna Masciotta, University of Minho, Guimaraes, Portugal

- Reliability analysis for compressive failure
- Decision based on expected total costs
- Analysis of costs of tests, costs of upgrade and failure costs
- Optimal number of DTs given sufficient number (>25) of NDTs



Optimizing in-situ testing for historic masonry structures

Miroslav Sykora and Jana Markova, Czech Technical University in Prague, Czech Republic
Dimitris Diamantidis, OTH Regensburg, Germany
Maria Giovanna Masciotta, University of Minho, Guimaraes, Portugal

Output

a) Presentations and fact sheet (COST TU 1402 output)

b) Publications:

Sykora, M., Diamantidis, D., Holicky, M., Markova, J. and Rozsas, A., 2018, "Assessment of compressive strength of historic masonry using non-destructive and destructive techniques", *Construction and Building Materials*, Volume 193, 30 December 2018, pp. 196-210.

Sykora, M., Diamantidis, D., Markova, J. and M. G. Masciotta, 2019, "Optimizing in-situ testing for historic masonry structures: a case study", *2nd RILEM Spring Convention* & International Conference on Sustainable Materials, Systems and Structures, March 2019, Rovinj, Croatia.

Diamantidis, D. and M. Sykora, 2019, "Implementing Information Gained through Structural Health Monitoring - Proposal for Standards", 13th International Conference on Applications of Statistics and Probability in Civil Engineering, May 2019, Seoul, Korea.

The case study did take benefit in the TU1402 Training Schools and workshops.

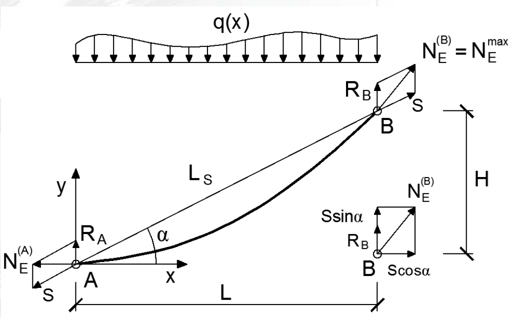
Case study on the maintenance of a tendon supported large span roof

by Mariusz Maślak, Michał Pazdanowski, Tomasz Howiacki
Cracow University of Technology, Cracow, Poland

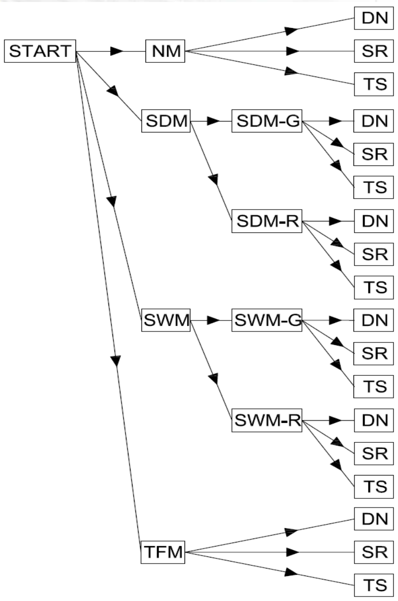
- **Problem:** Magnitude of the force induced in tendons is strongly dependent on the deformation of the whole structure, and this changes during the service due to the stochastic nature of the loading process, but also due to the long term yearly and short term daily fluctuations of the external temperature.
- **Consequence:** Collapse of the whole supported roof structure should only a local set of bearing tendons be incapable of resisting tension.

Case study on the maintenance of a tendon supported large span roof

by Mariusz Maślak, Michał Pazdanowski, Tomasz Howiacki
Cracow University of Technology, Cracow, Poland



- Decision tree analysis was applied to select the optimum strategy of structural health monitoring for measurements of tensile force in the tendons,
- Value of information was a strategy selection measure,
- Relation of monitoring gains versus costs incurred during installation and setup was evaluated for each considered scenario,
- Qualitative and quantitative specification of the formal limits for the threshold values.



Case study on the maintenance of a tendon supported large span roof

by Mariusz Maślak, Michał Pazdanowski, Tomasz Howiacki
Cracow University of Technology, Cracow, Poland

- This case study is not documented in a corresponding TU1402 fact sheet,

- The obtained results were published in the following paper:

Maślak M., Pazdanowski M., Howiacki T. – Value of information in the maintenance of a tendon supported large span roof, Proceedings of the 40th IABSE Symposium "Tomorrow's Megastructures", September 19-21, 2018, Nantes, France, pp. S27-19 – S27-26,

- This case study did benefit from the TU1402 Training Schools and workshops.

Value of structural health information for the operation of wind parks

Sebastian Thöns[a], Michael H. Faber[b], Dimitri V. Val[c]

[a] Department of Civil Engineering, Technical University of Denmark, Denmark

[b] Department of Civil Engineering, Aalborg University, Denmark

[c] Institute for Infrastructure and Environment, Heriot-Watt University, UK

A service life extension of wind parks allows for more power production and a significant higher return over investment.

- How does Structural Health Monitoring (SHM) Information contribute to a service life extension of wind parks?
- What SHM characteristics are important to facilitate a high Value of Information?

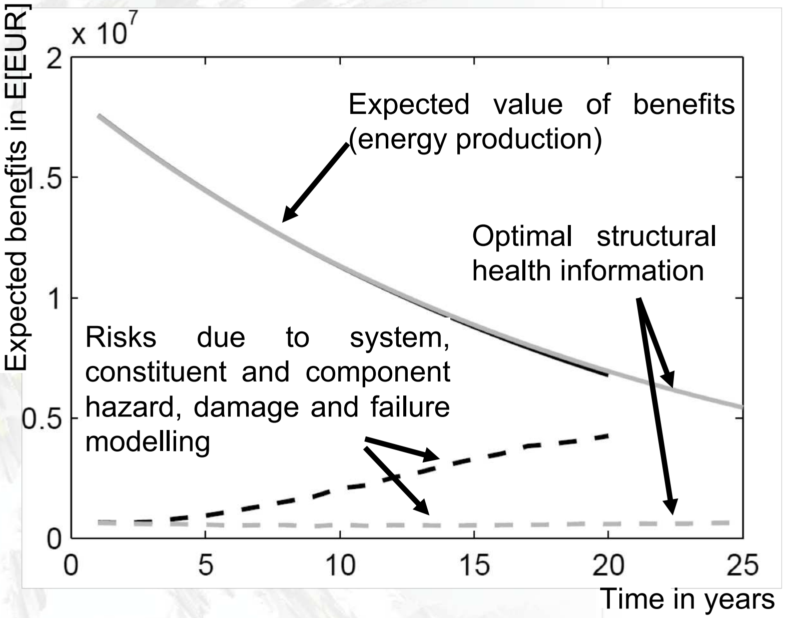
Value of structural health information for the operation of wind parks

Decision scenario

- Decision maker: Wind park operator in commissioning phase with the objective of maximising the value of information
- Decision variables: 3 SHM strategies
- Performance: Structural reliability on component, wind turbine and system level with respect to extreme events and fatigue throughout operation phase

Result

- Wind park service life extension is only optimal with structural health information of high precision.



Value of structural health information for the operation of wind parks

Dissemination

- Two factsheets for preparation: test case for offshore wind park operation (WG1-6) and on wind park production modelling

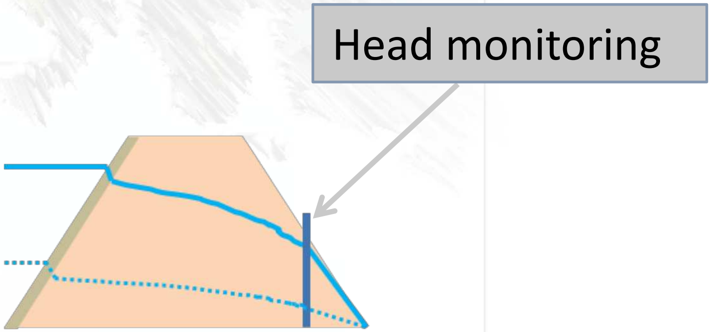
- Thöns, S., M. H. Faber and D. Val (2017). On the Value of Structural Health Monitoring Information for the Operation of Wind Parks. ICOSSAR 2017, Vienna, Austria

- Journal paper in preparation.

Head monitoring for flood defences

Wouter Jan Klerk, TU Delft, the Netherlands

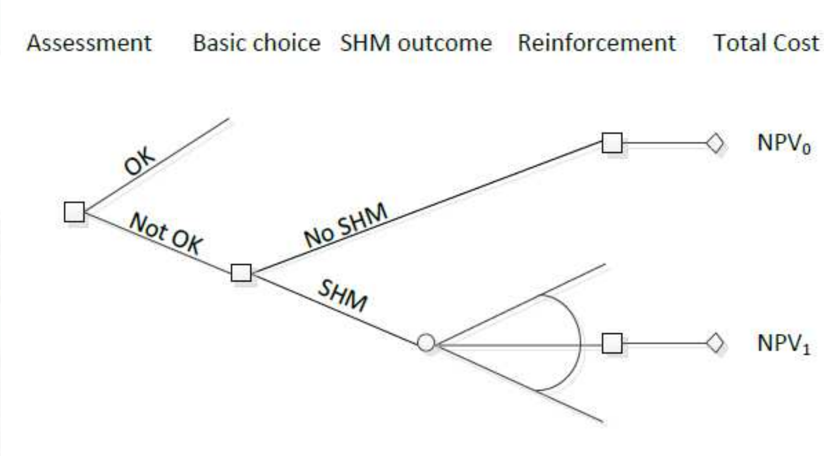
- Problem: Large uncertainties in behaviour of hydraulic head inside dike body
- Consequence: very large epistemic strength uncertainties dominate reliability assessment
- Solution: Head monitoring can reduce this uncertainty

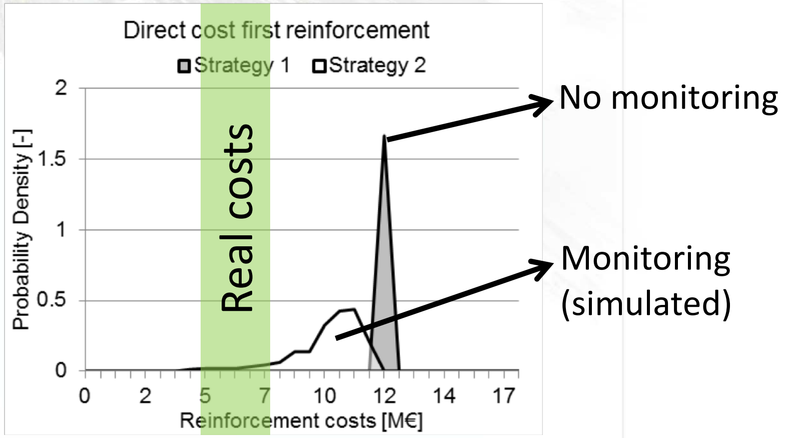


Head monitoring for flood defences

Wouter Jan Klerk, TU Delft, The Netherlands

- Posterior and pre-posterior analysis of effects of monitoring have been done
- Posterior estimate shows large benefits, mainly due to extreme storm during monitoring
- Information has been used to drastically reduce the required renovation (≈40% cost reduction)
- Pre-posterior has less benefits due to very bad a priori strength estimate (= high risk costs)





Head monitoring for flood defences

Wouter Jan Klerk, TU Delft, The Netherlands

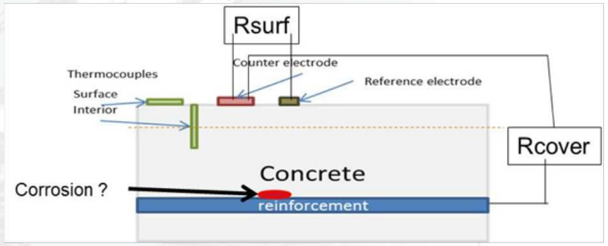
- Did you produce a TU1402 fact sheet?
  - No

- Did you publish papers?
  - Klerk, W.J.; Kanning, W.; van der Meer, M.T.; Nieuwenhuis, J.W. Structural health monitoring in life-cycle management of dikes: a case study in the north of the Netherlands. *Life-Cycle Eng. Syst. Emphas. Sustain. Civ. Infrastruct. Proc. Fifth Int. Symp. Life-Cycle Civ. Eng. (IALCCE 2016)* **2016**.
- Did the Case Study benefit from STSM, Training School, Workshops?
  - Discussions within TU1402 helped sharpen definitions and conclusions

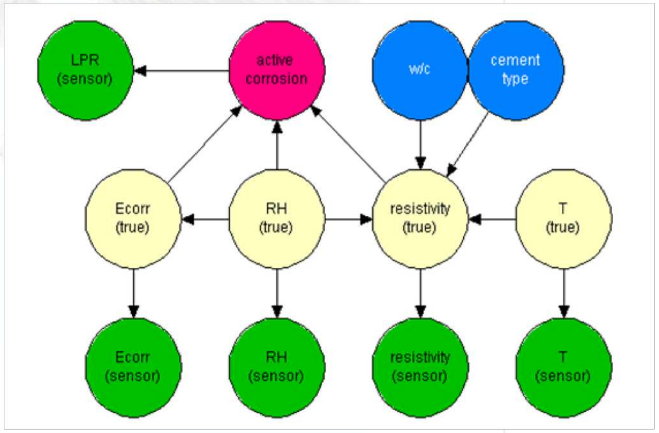
Case Study on Reinforcement Corrosion Sensor Alternatives

By Wim Courage, Nadieh Meinen, Liesette de la Gasse, TNO, the Netherlands

- Problem: corrosion of reinforcement decreases the load bearing capacity of structures and early detection methods often show large uncertainties.
- Consequence: when not detected in time and dealt with appropriately, it can ultimately lead to structural collapse or component failure.



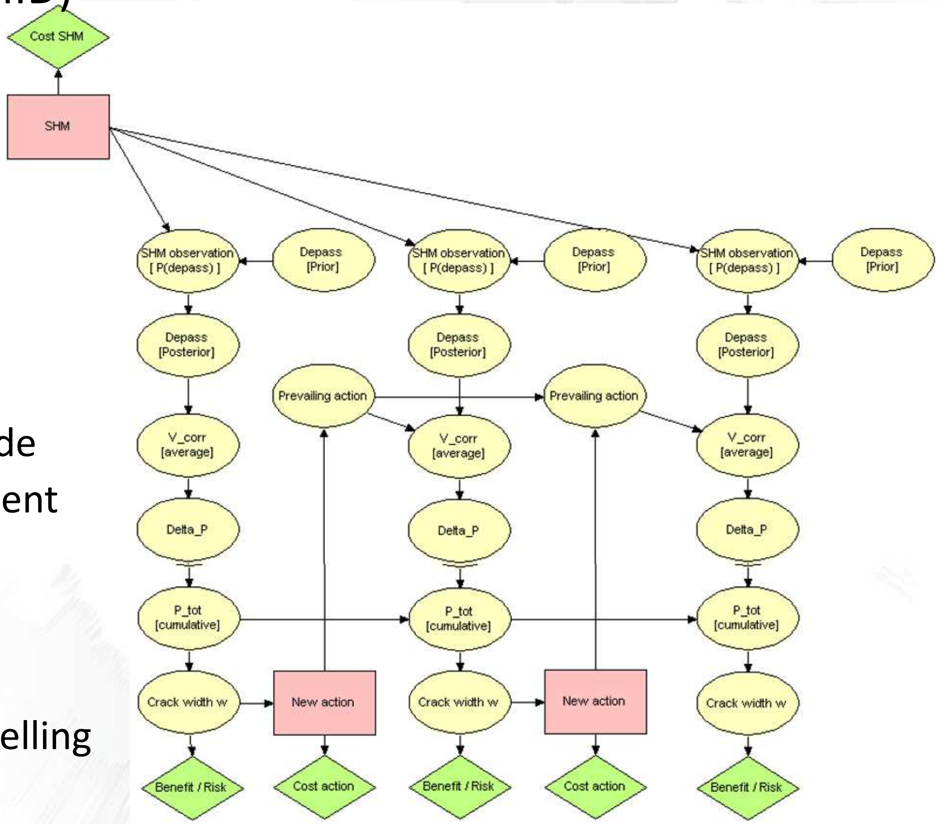
Measured parameters
Corrosion potential - Ecor
Corrosion rate – icor – LPR
Corrosion rate – icor – EN
Concrete cover resistivity – Rho_co
Concrete surface resisitivity – Rho_s
Air humidity – RH
Air Temperature – T_air
Concrete cover temperature T_cover



Case Study on Reinforcement Corrosion Sensor Alternatives

By Wim Courage, Nadieh Meinen, Liesette de la Gasse, TNO, the Netherlands

- The VoI of a new multi-sensor corrosion node is assessed by means of a BN (LIMID) approach.
- The Information is potentially used for optimal maintenance policy
- Final results were not obtained, due to
  - Early research development of sensor node
  - Organisational decision to stop development
- Most critical assumptions
  - Large data set with ground truth
  - Simplified Dynamic BN for corrosion modelling



Case Study on Reinforcement Corrosion Sensor Alternatives

By Wim Courage, Nadieh Meinen, Liesette de la Gasse, TNO, the Netherlands

- The TU1402 fact sheet was not completed due to premature ending of developments

- As a result no case study related papers are published

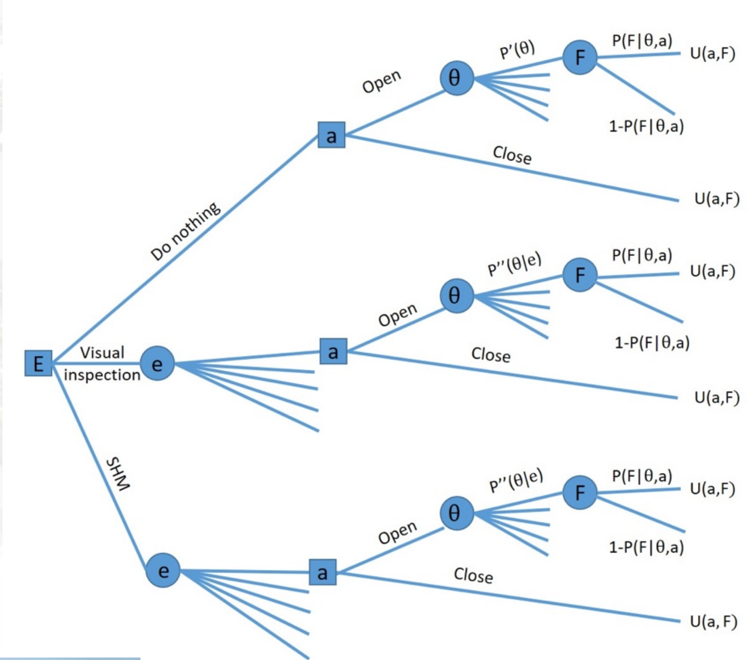
- The case study did take great benefit in the TU1402 Training Schools and workshops

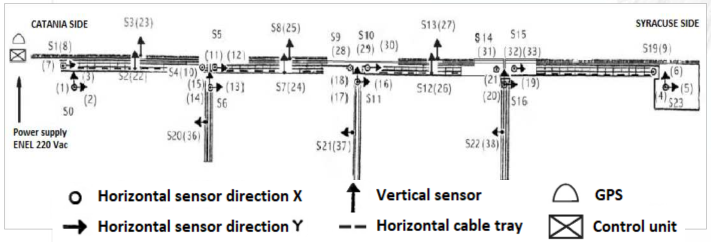
Emergency Management of Highway Bridges

by P. F. Giordano and M. P. Limongelli, Politecnico di Milano, Italy
S. Miraglia, Aalborg University, Denmark

- Problem: Decision over using the bridge in post-earthquake scenario has to be taken (bridge closed, open).

- Consequence: damage could lead to structural collapse and fatalities during emergency operations. Closing the bridge will delay emergency operations and ordinary traffic.





Acceleration sensors setup

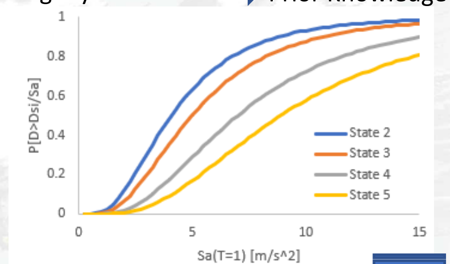
The Cusumano Bridge, SS114, Italy

Emergency Management of Highway Bridges

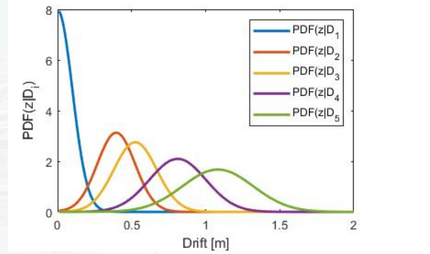
by P. F. Giordano and M. P. Limongelli, Politecnico di Milano, Italy
S. Miraglia, Aalborg University, Denmark

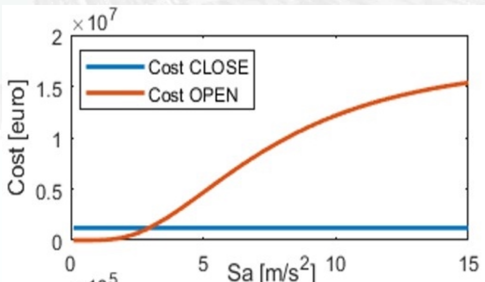
- Permanent vibration-based SHM providing the drift due to the seismic excitation is compared to visual inspections.
- The Information is potentially utilized to infer the damage state, i.e. the residual capacity to traffic load before issuing traffic restrictions on the bridge.
- Results indicate high sensitivity of VoI on data quality and indirect consequences (IC). Max VoI for equal consequences of the two actions (open/close)
- Critical assumptions in regard to the likelihood of the indicator (measure, signal processing, environmental effects).

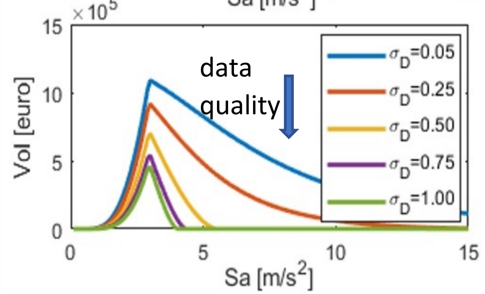
Fragility functions → Prior Knowledge

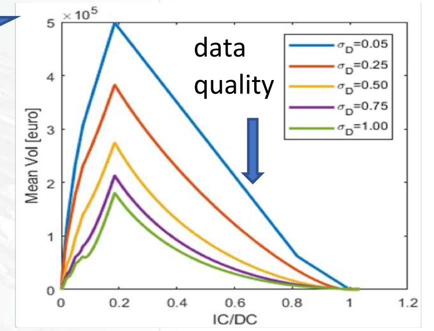


Likelihoods of the indicator (for SHM)

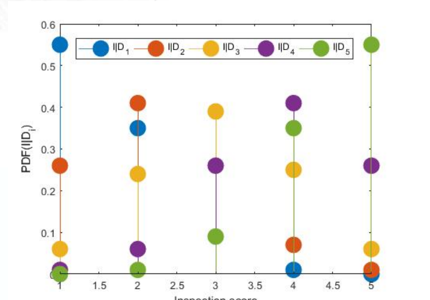








Likelihood functions of inspection score



Emergency Management of Highway Bridges

by P. F. Giordano and M. P. Limongelli, Politecnico di Milano, Italy
S. Miraglia, Aalborg University, Denmark

- The case study is documented in a corresponding TU1402 fact sheet.
- Additionally the results will be disseminated at:
    - SHMII-9 International Conference on Structural Health Monitoring of Intelligent Infrastructure, St. Louis, Missouri (USA), August 4-7, 2019 «The benefit of permanent monitoring for seismic emergency management»
- The case study did take benefit in the TU1402 Training Schools, workshops and STSM at Aalborg University (September-October 2018).
- Future work: expanding the case study to include the VoI for measurement of global dynamic characteristics of the structure to infer damage in comparison to the drift.

Case study „Digital Test Area Autobahn"

bast

by Iris Hindersmann and Peter Haardt, Federal Highway Research Institute, Germany

- new built concrete bridge at the highway A9 in Nuremberg, Germany
- equipped with different sensor systems for the detection of the loads (for example traffic load) and the reaction of the bridge and its individual components (instrumented bearing, movable joint, tendons, superstructure, weather station and video)
- Different aims were followed with the instrumentation of the bridge:
  – testing of newly developed monitoring systems
  – combination of different systems
  – but: redundant information possible

Concrete bridge (source: BASt)

Instrumented bearing (source: BASt)

Source: BASt

Case study „Digital Test Area Autobahn"

by Iris Hindersmann and Peter Haardt, Federal Highway Research Institute, Germany

- since October 2016 data is available (large amount of sensor data)
- until now no VoI analysis has been started
- the set out of the case study is documented in a corresponding TU1402 fact sheet

Case Study Fact Sheet No. WG4-##

"Digital Test area Autobahn"

Hindersmann, Iris Federal Highway Research Institute (BASt), Germany
Haardt, Peter, Federal Highway Research Institute (BASt), Germany
Dabringhaus, Sarah, Federal Highway Research Institute (BASt), Germany

I. Scope of the fact sheet

This fact sheet is presenting the working progress on a case study. It summarizes the character and context of the study and highlights the major steps and challenges for the implementation of a value of information assessment. Furthermore and outlook on the further development of the case study is given.

II. Abstract

The case study "Digital Test area Autobahn" is presented. A new built (September 2016) pre-stressed concrete bridge is equipped with different monitoring systems for the detection of traffic load, climatic influence and the reaction of the bridge. Possibilities for the implementation of a VoI analyses are presented.

III. Description of the case study

In the project cluster "Smart Bridge" an adaptive system for information and holistic evaluation in real time is developed. The adaptive system consists of suitable sensors and sensor networks, suitable data analysis, and evaluation methods. The main benefit of the Smart Bridge are economic and safety improvements.
Within the scope of the research project "Digital Test area Autobahn" "intelligent expansion joints and bearings", a "monitoring of traffic loads" and "sensor networks" are presented at a bridge in the highway interchange Nuremberg A3/A8. The impacts of traffic loads and climatic influences on the bridge are measured. The reactions of the components with regard to the functionality of individual bridge components are detected locally. By using analytical bridge models and evaluation methods the condition and reliability of the bridge construction and its components can be determined.

IV. Implementation of a VoI analysis

a) Decision maker: The decision maker is the Federal Ministry of Transport and Digital Infrastructure and an additional stakeholder is the local read administration.

b) Regulative constrains: Over the whole lifetime the bridge should generate only small life cycle costs (predictive maintenance strategy). But most important are the aspects fulfill functionality and safety (code requirements). During the whole lifetime the structure must be available for the road users. To fulfill the aspects periodically visual inspections and maintenance and repair measures are implemented

c) System temporal and spatial boundaries:
   - Only one driving direction with two lanes is equipped with sensors.
   - The monitoring system should be run on only for five years.

d) Events of interest and the corresponding representation: The bridge was built in 2016 and until now there are no events, which are important for the structural safety or the serviceability of the bridge. In the future heavy-transports can be important events.

e) Events consequences: Until now there are no events and consequences.

f) Indicators (to observe):

The following information is made available through different monitoring systems:

1. Data of the current traffic: The data of the current traffic are recorded by two different systems. The first system is the Roadtraffic Management System (RTMS). The RTMS is a modular system for determining the effects, resistances and the condition as well as the prognosis of the condition of a bridge structure. The following traffic data can be detected by the system: the number of vehicles, vehicle speeds, axle distances, dynamic axle loads per single axle and vehicle gross weight. The data are collected by using strain gauges (Freundt et al. 2014). The second system is the instrumented expansion joint. The following traffic data are detected by the expansion joint: number of vehicles, vehicle speeds, axle distances, dynamic axle loads per single axle and the vehicle gross weight. The vehicle speeds are detected due to the registration of the moving of lamellae by optical displacement sensors. The number of vehicle axle is detected by force sensors. Axle distances are derived from the vehicle speed. The dynamic axle loads are determined by the reaction force between the expansion joint and the frame construction.
2. Climate data: The parameters shadow temperature, wind speed and air moisture are detected at the bridge.
3. Prestressing force curve of the external tendons: The prestressing force curve of the external tendons is determined by accelation sensors.
4. Instrumented expansion joint: For the concrete bridge a modified expansion joint developed by Maurer SE was equipped with strain gauges and force sensors. Herewith the data of the current traffic can be determined as described above. Additionally a self-monitoring of the expansion joint in relation to the natural frequencies and the gap width takes place.
5. Instrumented bearing: The instrumented bearing monitors the range of functionality of the bearing by detecting the load and the sliding gaps. Additionally the distribution of the load, bearing rotation and displacement in dependence of temperature and traffic is determined.
6. Actual object-specific static traffic load and actual object-specific fatigue state: These aspects are detected by the RTMS. For the RTMS the bridge is equipped with strain gauges, inductive displacement transducers, and thermometers. With the measuring results of the sensors and within the framework of data processing, the degree of damage due to fatigue of the reinforced concrete of the bridge can be determined (Freundt et al., 2014).
7. Chronological sequence of the global stiffness: With the sensors of the RTMS and the framework of data processing the time course of the global stiffness of the bridge is determined (Freundt et al., 2014).

g) Decision alternatives – monitoring and or inspection options:

h) Decision alternatives – other measures, repairs, replacement, etc.:

Project ”Economic feasibility studies of monitoring “bast

by Iris Hindersmann and Peter Haardt, Federal Highway Research Institute, Germany

- “Economic feasibility studies of monitoring - Development of a concept for the analysis of benefits and costs of monitoring”
  - new project started in 2017
  - the project is performed by Matrisk, Switzerland
  - the concept based on the VoI analysis
  - aim was the practical applicability of the method for the road administrations in Germany
  - 2 case studies (Schwelmetal bridge und highway bridge in Duisburg-Beeck)

Schwelmetal bridge (Source: A. Jarosch, 2015)

Highway bridge in Duisburg-Beeck (Source: Straßen.NRW 2018)