TU1406

COST ACTION

QUALITY SPECIFICATIONS FOR ROADWAY BRIDGES,
STANDARDIZATION AT A EUROPEAN LEVEL

Scientific Report on Short Term Scientific Mission

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CONTENTS

1. AIMS AND OBJECTIVES

Critical infrastructures (CIs) provide crucial services to community and support economic growth. In well-functioning systems, the failure of one CI may result in partial or total failure of the entire system. Transportation infrastructures such as roadway bridges and highways play an essential role for societal developments, i.e. economy, welfare and sustainability. In case of an infrastructure failure, such as collapse of a bridge, the associated consequences may include a significant number of lost lives, severe transportation disruptions but also lead to stakeholder dissatisfaction with organisational turmoil and political repercussions as consequences.

The decision to replace or repair, when and how to repair each individual structure, is a common and difficult issue for asset managers. Due to budget limitations, it is in general necessary to prioritize interventions, based on the available knowledge concerning the actual and projected conditions and performances of structures. In order to describe the current and expected state of the system diagnostic and/or prognostic performance indicators can be used (Limongelli, et al., 2018). Many indicators are currently used in management of bridge maintenance, but disparity exists among different European countries regarding both their definition and their use for condition control. Some of these indicators, such as resilience, even still lack a consensual definition.

The present Short-Term-Scientific-Mission (STSM) aims to identify resilience indicators to support decision making on the management of bridges in their current conditions, in case of a disruptive event and future performances.

2. WORK CARRIED OUT

2.1. BACKGROUND INFORMATION

In decision making process for systems subject to disturbance events such as caused by natural hazards, excessive degradation and failure and accidents, it is instructive to address three different phases, i.e. before, during and after the disturbance event (Faber, 2008). In the before event phase strategic decision making with respect to prevention, preparedness and contingency planning is in the foreground. In the during event phase decision making has tactical characteristics and here the focus is directed on loss reduction. The time extent of the during event phase may be defined in different manners depending on the context. For example, in an incident of bridge collapse, it this phase may be considered to start from the time of the traffic disruption and end when an alternative route is identified and implemented. Alternatively it may be associated with the time of initiation of failure till the end of the process of physical damage (or when the rescue teams arrive). Here in all cases, the type of the disruption and its consequences are same, however the time interval varies from days to hours. Finally, decision making in the post event phase concerns recovery of losses and functionalities as well as adaptation of strategic measures (from the before event phase) including organisational reorganization. For all phases it is crucial that protocols for communication among all stakeholders with respect to the various aspects of the decision making are in place and followed and executed adequately.

There may be various decision alternatives which can result in different consequences as benefits and losses, and the decision maker is obliged to select one of these alternatives (Faber, 2008). Nielsen and colleagues state that the preferences and freedom of the decision maker comprise and rely on the perception of stakeholders. This is why there are crucial dependencies among stakeholder, decision makers and information in the decision making (Nielsen, et al., 2018).

Building a robust and resilient system is only possible with knowledge, awareness, preparedness, effective communication as well resourcefulness. The significance of awareness and preparedness of stakeholders has been seen in the event of the 2009 L'Aquila earthquake. The event of the earthquake itself might be characterized from seismological point of view to be moderate, however, it lead to severe losses of lives, organisational failures and even at the present day many of the functionalities lost during the event have not been recovered yet. Hurricane Katrina can be seen as another important example of failure in communication between infrastructure managers, local and federal authorities. Thus, an adequate risk communication should be provided before, during and after a disruption among all bodies.

The bridge collapse in Genoa, Italy, in August 2018, is another instance of possible consequences associated with a less than perfect appreciation of the known structural vulnerabilities and the significance of full preparedness. The architect of the structure warned authorities in 1979 (News Corp Australia Network, 2018), after 12 years after the opening of the bridge, about the adverse effects of corrosion due to sea salt and pollution coming from a nearby steel plant. He also added that in few years repair measures should be taken to remove the rust (News Corp Australia Network, 2018).

2.2. RESILIENCE

Resilience is the capability of a system to anticipate a possible disruption to reduce failure probabilities; to resist, absorb and respond in an effective way to decrease the consequences of an incident; to perform recovery activities in order to mitigate the future disruptions (Bruneau, et al., 2003) (Cutter, et al., 2008) (Faber, et al., 2017). An important consideration to analyse a resilient infrastructure system after a hazardous event is treating the system in three event phases i.e. before, during and after (Faber, 2008). It can be also thought that these three event phases are present in an infinite time period and each event follow another continuously. This is why, the recovery of an event, lessons learnt and subsequent adaptation may significantly improve preparedness for future disruptions. Resilience failure may be associated with the event of exhaustion of one or more of the systems capacities e.g. with respect to economy, culture, organization, environment and social services.

Generally, the system characteristics robustness, redundancy, resourcefulness and rapidity are associated with resilience. Robustness may be associated with the systems ability to endure an unexpected disruption without severe loss of function/service. Redundancy is the ability to fulfil functional requirements in the disruptive event. Resourcefulness is the capacity to determine priorities as well as to be able to mobilize required material and human resources. Rapidity is the capacity to meet priorities in a timely manner (Bruneau, et al., 2003) (Giuliani , et al., 2016). These properties can be designated to event phases, e.g. robustness may be seen to be effective in the during event phase, rapidity is important in the after event phase and resourcefulness is essential both in the before and after event phases, see Figure 1.

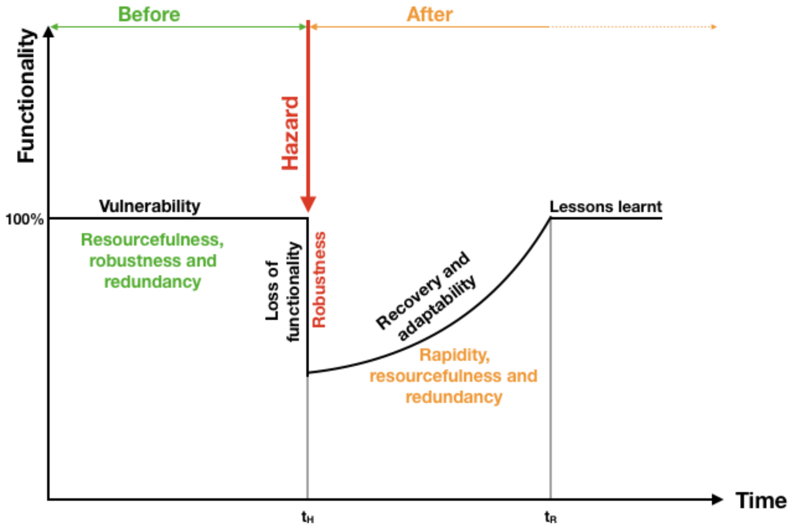

Figure 1 Functionality changes of an infrastructure system before, during and after a disturbance event together with associated changes in resiliency properties.

2.3. INDICATOR BASED ASSESSMENT

Following the framework for the probabilistic modelling of systems by the JCSS (Faber (2008), the exposure of a bridge might be associated with damages and failures caused to aging, earthquake loads and any operational or environmental loads acting on the structure. The indicators related to the exposure (Faber, 2008) might include use/functionality, location, environment, design life and societal importance. There are two types of consequences of exposure, namely direct and indirect consequences. Direct consequences are associated with the damages on the system which are induced by failures of the elements of the system. While indirect consequences are related with the functionality losses. The vulnerability and lack of robustness are associated with direct and indirect consequences respectively.
Indicators are the instruments providing specific information on the state or condition of the constituents of systems. As seen in Figure 2, indicators are used to provide information on direct and indirect consequences of hazardous events which may damage both environment and negatively affect safety. The knowledge and information gathered through indicators are also essential in decision making for built and organizational system.

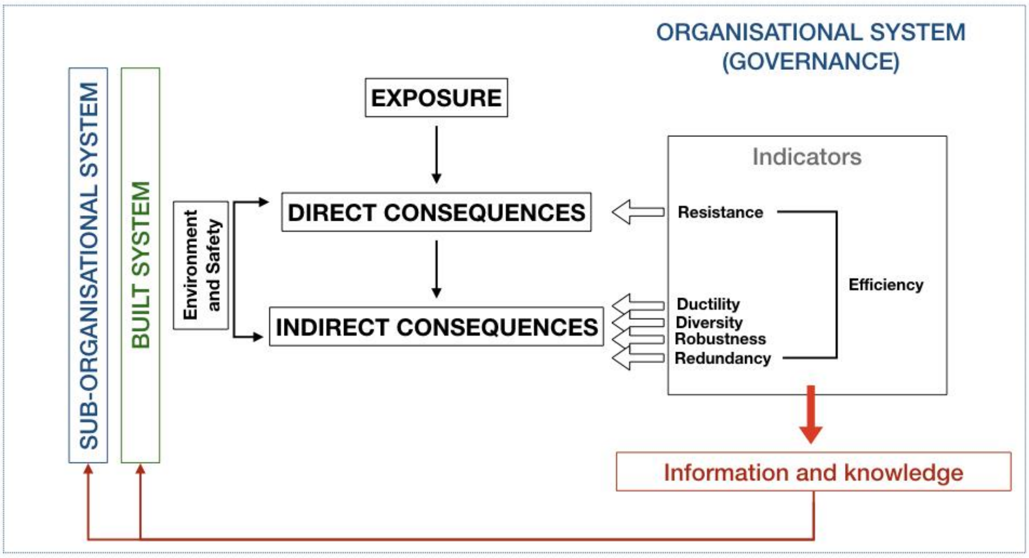

Figure 2 Representation of Resilient Organisational System at different levels of hazard scenario, adapted from (Faber, 2008).

3. MAIN RESULTS

3.1. RESILIENCE INDICATORS

Any observable and measurable property of the system or its constituents which contain information about the risk may be associated with the term risk indicators (Faber, 2008). In the following, such indicators are identified with the objective to support decision making on how to improve and ensure adequate resilience performances of systems – with specific address of the three different phases, before, during and after disturbance events, see Figure 3. Resilience indicators have been set as ductility, resistance, redundancy, efficiency and diversity which differ for Structure and Organization in each event phase. Moreover, the information flow which provide information, data and knowledge to decision makers is demonstrated between structure and organization. Herein, Organization includes both the operational management of bridge structures and their governance.

	Structure	Information flow	Organization

Before	• Ductility
	• Resistance
	  • Design codes&standards
	  • Design target reliability
	  • Protective measures
	• Redundancy
	• Efficiency
	• Diversity (variety)
	  • Use/functionality
	  • Location - environment
	  • Age
	  • Materials
	  • Quality of workmanship
		• Efficiency
		  • True information & knowledge
		  • Data collection on structural state - knowledge accumulation
		  • Models & databases
		• Diversity (variety)
		  • Quality and availability of data
		  • Communication technologies
		  • Monitoring, inspections, etc. on structure
		  • Scenarios
		• Experience
		  • Maintenance history
		  • Architectural & engineering style
		  • Available design plans
		  • History of extreme events
			• Ductility
			  • Load
			• Resistance
			  • Ultimate capacity
			• Redundancy
			  • Stakeholders
			  • Teams
			• Efficiency
			  • Coordination
			  • Communication plans
			  • Emergency plans
			• Diversity (variety)
			  • Quality management
			  • Resourcefulness

During	• Ductility
	• Resistance
	• Redundancy (immediate failure or redundant elements)
	• Efficiency
	• Diversity (variety)
	  • damages
		• Efficiency
		  • Use of existing data
		  • Using models
		  • Scenarios
		  • Linked with 'before'
		  • Communication plans
		• Diversity (variety)
		  • quality and availability
		  • communication technologies
		  • monitoring, inspections, etc.
		• Life safety risks
			• Ductility
			• Resistance
			  • Ultimate capacity
			• Redundancy
			  • Stakeholders
			  • Teams
			• Efficiency
			  • First responders - response time
			• Diversity (variety)
			  • Quality management
			  • Resourcefulness
			  • Decisions

After	• Ductility
	• Resistance
	  • New design codes&standards
	  • Design target reliability
	  • Protective measures
	• Redundancy (redundant elements)
	• Efficiency
	• Diversity (variety)
	  • Use/functionality
	  • New materials
	  • Quality of workmanship
		• Efficiency
		  • renewal activities
		  • updated data
		• Diversity (variety)
		  • Life time learning
		  • Dissemination of knowledge
		• Life safety risks
			• Ductility
			• Resistance
			• Redundancy
			  • Lessons learnt
			  • Restructure
			• Efficiency
			  • Number of rescued people
			  • Number of fatalities
			• Diversity (variety)
			  • Quality management
			  • Resourcefulness

Figure 3 Resilience indicators.

Before defining the sub-indicators, major indicators for mechanical, organizational, ecological and information systems are emphasized;

1) **Resistance** is a system characteristic indicating a system's ability to meet ultimate demands with respect to service provision. The resistance of a system might be limited by physical and organizational constraints. Typically, a system's resistance is associated with the ultimate level of demands the system can meet. A system can be designed to fulfil criteria with respect to its resistance, e.g. in accordance with design codes.

- The resistance of a mechanical system might be characterized by its ultimate load carrying capacity.
- The resistance of an organizational system might be characterized by its maximum level of provision of intended services.
- The resistance of ecological systems might be characterized by maximum stress (i.e. climate change impacts) that environment and its assets can bear.
- The resistance of knowledge/information systems might be characterized by ultimate amount of data which can be transmitted between systems.

2) **Redundancy** is a system characteristic indicating a system's ability to meet demands by internal distribution and sharing of functions. The redundancy of a system might be limited by physical and organizational constraints. A system can be designed to meet criteria with respect to redundancy.
   - The redundancy of a mechanical system might be characterized by its degree of static indeterminateness.
   - The redundancy of an organizational system might be characterized by the number of organizational units which can provide the same functionalities and services.
   - The redundancy of knowledge/information systems might be characterized by the availability of same data that can be provided with different techniques.

3) **Ductility** is a system characteristic, which indicates the system's ability to continue service provision after its ability to meet demands has been exhausted. A systems ductility might be limited by physical and/organizational constraints. A system can be designed to meet criteria for ductility.

- The ductility of a mechanical system might be characterized by its ability to carry load after reaching its ultimate load bearing capacity (resistance). If the loading at this stage is maintained or increased on the mechanical system this will cause increasing strains. The ductility of a mechanical systems might be limited by strain. A mechanical system which has infinite strain capacity is often referred to as perfect plastic or perfectly ductile. A mechanical system which has no strain capacity after reaching its ultimate load bearing capacity is referred to as perfect brittle and has no ductility.
- The ductility of an organizational systems might be characterized by its ability to maintain its operations and provide its intended services after the point where demands have reached or exceeded its capacity. The ductility of organizational systems might be limited by stress which in turn might depend on the time duration and level of exceedance of its capacity.
- The ductility of ecological systems might be characterized by the ability to carry stress after reaching the maximum capacity of assets (living creatures). The ductility of ecological systems might be limited by e.g. insufficient diversity (caused by extinction of species).
- The ductility of knowledge/information systems might be characterized by the ability to provide data/information after reaching to ultimate level of demands. The ductility of information systems can be limited with the available and accessible data against demands in timely manner.

4) **Diversity** is a system characteristic indicating the ability of a system to meet different demands and to meet demands by different means. The diversity of a system might be limited due to physical and organizational constraints. The diversity of a system can be designed to meet requirements to diversity.
   - The diversity of a mechanical system might be characterized by its ability to carry loads of different sources, multiple natural hazards, etc. or to provide multiple alternatives for the distribution of internal demands.
   - The diversity of organizational systems might be characterized by the number of different services provided and the number of provided alternative ways to which these services may be provided.
   - The diversity of knowledge/information systems might be characterized by the numerous ways of gathering data and using this data in different scenarios.

5) **Robustness** is a system characteristic indicating a system's ability to provide of maintain service provision in situations of unintended or unexpected demands. The robustness of a system might be limited by physical and organizational constraints and a generally functions of capacity, redundancy, ductility and diversity. The robustness of a system can be designed to meet requirements.
   - The robustness of mechanical systems might be characterized by its ability to reduce losses in case of accidents or provide services under unintended/unexpected demands.
   - The robustness of organizational systems might be characterized by their ability to reduce

loss of services in cases where parts of the systems have exceeded their capacities or provide services meeting unintended/unexpected demands.

6) **Efficiency** is a system characteristic indicating a systems ability to meet demands relative to the resources required by the system to do this. The efficiency of a system might be limited by physical and organizational constraint – and what is often referred to as best practices. A system can be designed to optimize efficiency.
   - The efficiency of a mechanical system might be characterized by the costs and consumption of natural resources it implies to meet demands.
   - The efficiency of organizational systems might be characterized by costs and time it requires to meet demands.
   - The efficiency of an information system might be characterized by the costs and availability of data flow it implies to meet demands.

3.2. SUB-INDICATORS

3.2.1. BEFORE EVENT

Resilience indicators for Structures include ductility owing to materials and age; resistance which depends on design codes and standards, design target reliability and protective measures; efficiency; redundancy arising from structural elements; as well diversity which may differ for each structure regarding use and functionality, location, environmental conditions, age, materials and quality of workmanship. With respect to the Organization, ductility is the maximum load that stakeholders can withstand; resistance is the ultimate bearing capacity; redundancy defines if a part of organization (one stakeholder or a team) fails can other units take over the functionalities of failed part, or not; efficiency of organization is coordination between stakeholders and availability of communications plans and emergency plans; diversity is quality management which consults more than one expert for crisis management and resourcefulness that can be physical and financial. Presence of knowledge is resourcefulness of a resilient system. Information flow is running between Structure and Organization in support of decision making and management activities. Efficiency involves true information and knowledge, data collection on structural state which develop knowledge accumulation and generating models and databases based on available data. Diversity concerns quality and availability of data explained in detail by (Nielsen, et al., 2018); existing communication technologies that can be used during emergencies; variety of data gathered by monitoring, inspections and other tests on structure; and wide variety of scenarios. Models and scenario representations support preparedness in a resilient system. Experience includes the maintenance history of structures; architectural and engineering style; available design plans and history of extreme events that structures have endured. By using information flow, emergency and communication plans can be developed which will contribute to a resilient system.

3.2.2. DURING EVENT

Resilience indicators for structure during a contingency include ductility, efficiency, resistance, redundancy related with redundant elements which are not leading to total collapse of structure and diversity involving different type of damages on each structural element. In the during event phase the information is passing through Structure to Organization which increases the preparedness and resourcefulness of the system. This information includes efficiency of information as; use of existing data collected before; utilizing models and scenarios built previously; processing and coupling data aggregated during event phase with models and scenarios. Another measure for efficiency are the communication plans facilitating information between all stakeholders. In case of an interruption on information flow during the event leads to low efficiency thus, losing time in decision making and it results in low resilience. Diversity of information flow regards the quality and availability of data; communication technologies which can support emergency communication in case of any disruption in telecommunication infrastructures; and variety of data that is being collected by monitoring, inspections and tests on structure during the event. Lastly, the information flow supports first responders in understanding the actual state of the event and thereby reduces life safety risks. Emergency communication protocols should be available and implemented in communication plans. During any disruptive event it is expected from any stakeholder to have knowledge on where to seek information rather that awaiting information from authorities.

Furthermore, both stakeholders and people should understand the warnings, and use knowledge to act effectively in time manner. In this way, they can reduce losses during the event.

3.2.3. AFTER EVENT

In the recovery phase, i.e. the after event phase, the resilience indicators for bridge structure are selected as;

1) ductility of the new structure;
2) resistance providing with updated and improved design standards and codes, design target reliability considering the vulnerabilities of previous structure and protective measures co-ordinately. For repairing (or replacing) works, standards and design codes should be reviewed with consultants. In this action, leaders may identify new capable partners inside public and private domains for reconstruction (Boin & McConnell, 2007);
3) redundancy of designed structure with redundant elements,
4) efficiency, impeccable workmanship in accordance with structural design
5) diversity of structural use or functionality, new technology materials for reconstruction and quality of workmanship.

The indicators for information flow in recovery are efficiency of knowledge about renewal activities and updated data gathered by monitoring during and after rehabilitation activities; diversity of information as life time learning and dissemination of this knowledge to relevant stakeholders to support their preparedness based on learnings; and life safety risks rising due to renewal actions to remove debris which may increase the risk of occurring another event due to improper demolishing activities. Stakeholders should be informed about structural state and reduce the possible risks before demolishing the old bridge. Furthermore, communication protocol should be proceeded between authorities and stakeholders by informing all actors about what happened, why happened, what are the consequences and losses (Vrouwenvelder, et al., 2015).

For the Organization, the indicators are ductility, resistance and redundancy of stakeholder which can be improved in recovery phase by taking lessons from the past event and restructuring of management levels. Lessons taken from the past event are knowledge coming with information flow, understood by population thus enhancing community engagement and participation to preparedness activities. Efficiency of the first responders' performance considering number of rescued people and number of fatalities, and of the actions taken on structure; while diversity is comprising quality management and resourcefulness in recovery activities. For the alternative route, opinions of authorities should be taken under quality management and the length of the new route must be considered both in terms of time spent and fuel consumed. Organizational resourcefulness such as availability of medical care centres, hospitals, medicines etc. is essential to foster the recovery of people. The post event rehabilitation of people can be supported by physical and/or psychological help and by medical support to people staying in health care facilities.

3.3. CONSEQUENCES

During the STSM, resilience indicators have been studied. The indicators have been determined at the levels Structure, Organization and Information flow, in three phases of, namely before, during and after the event of disturbances. There was no possibility to apply maturity level for each indicator, as considered in COST ACTION TU 1406, since a resilient system should be considered in a holistic framework.

4. FUTURE COLLABORATION

I have exchanged many ideas and knowledge during my STSM and I believe that I have developed good relationship with Prof Michael Havbro Faber. We have agreed to improve this work and make a publication about it.

5. FORESEEN PUBLICATIONS/ARTICLES

I am planning to submit my paper for the conference of IFED Forum-2019 with collaboration of Prof Faber.

6. ADDITIONAL COMMENTS

I am currently PhD student in Politecnico di Milano and my topic is Resilience of Cultural Heritage. During my STSM I studied bridge structures which can be thought as cultural heritage structures due to their cultural services (i.e. traditional knowledge on construction and management, being local or national symbol, etc.). This mission gave me a chance to consider a different type of built structure than my previous studies and perform the concept of resilience on this. I really appreciate that I worked with the expert of this topic. Undoubtedly, my knowledge has been enriched thanks to Prof Faber.

I would like to thank to COST ACTION TU1406 Management Committee to give me this chance. Additionally, I thank to host institution, University of Aalborg Civil Engineering Department, and my host Prof Michael Havbro Faber.

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8. ANNEXES

8.1. CONFIRMATION BY THE HOST INSTITUTION ON THE SUCCESSFUL EXECUTION OF THE STSM

COST ACTION TU1406: QUALITY SPECIFICATIONS FOR ROADWAY BRIDGES,
STANDARDIZATION AT A EUROPEAN LEVEL

Confirmation of the successful execution of a Short Term Scientific Mission

STSM applicant (first and last name): Zehra Irem TURKSEZER

Home Institution: Politecnico di Milano, Milan, Italy

Host Institution: University of Aalborg, Aalborg, Denmark

I hereby confirm that Zehra Irem Turksezer completed her research within the framework of the TU1406 Short Term Scientific Mission (STSM) program in University of Aalborg from September, 10 to October 26, 2018.

In consideration of the performed activities, this work was a mutual benefit for both the STSM applicant and towards the current needs of the COST TU1406.

It has been a pleasure to host Zehra Irem Turksezer in my group and I look forward to continue collaboration with her in the future.

Yours sincerely,

Aalborg, November 19, 2018.

Michael Havbro Faber

Michael Havbro Faber

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