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Christensen, Christian Overgaard

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Monitoring Thresholds in In-situ Full-scale Concrete Bridge Testing

Christian Overgaard Christensen, Ph.D. student

Advanced monitoring in full-scale in-situ testing could hold the key to optimized response- and threshold evaluation when performing proof- and diagnostic loading. Consequently, making full-scale testing a more efficient and commonly used tool in response evaluation of existing bridges.

Full-scale testing of concrete bridges

A growing challenge in many countries is that aging traffic infrastructure, such as concrete bridges, are slowly worn down and approaching its expected life span. However, the bridges have to meet today's demands to increasing traffic and high load magnitude, which often yields a need for an expensive replacement or capacity upgrading.

The real capacity of these aging bridges can be an open discussion since the input parameters related to the theoretical capacity evaluations can have a significant effect on the result precision. Questionable input parameters are often related to available knowledge about the structure, such as: Actual boundary conditions, real material parameters, in-situ geometry, re-arrangement of load etc. Precise theoretical capacity estimation can therefore be difficult and vary compared to the true capacity.

Full-scale testing is deemed to be a good support to the identification of the capacity of the tested bridge. It is often seen that such tests provide higher capacity than expected and thus holds major possible economic benefit for the society . However, the scopes, final outputs, theoretical approaches, and the test procedure related to the full-scale test schemes often vary significantly in published work and can therefore be difficult to compare.

In-situ full-scale testing of bridges can typically be separated into three categories: i) Proof loading, to verify a given response and/or capacity, where loading of an existing structure is applied until a pre-defined stop criterion (or target load) is observed, ii) Diagnostic load tests, to verify the response of newly build- and existing bridges for specific load setups, iii) Collapse testing, to determine the behaviour and capacity of the bridge up to failure, which include loading until irreversible damage or collapse occurs.

Recently developed method for high magnitude loading

Only limited testing of bridges to failure or high magnitude loading have been done in Denmark. An ambitious research project was therefore initiated in 2016 concerning full-scale testing of one span concrete bridges with a maximum span of 12 m (39.4 feet). The project can be divided into three main research topics: i) Development of a reliable full-scale test method for high magnitude loading, ii) Application of advanced monitoring, where measurements are performed in an advanced, fast- but simplified way, iii) Calibration of theoretical models by using input from in-situ and laboratory testing. A test rig has since then been developed and successfully verified and developments for monitoring and theoretical modelling is now ongoing [1].

The novel test rig was constructed as a cradle system, where load can be applied using weights and hydraulic jacks combined, which makes it capable of applying semi-deformation controlled loading. The test rig is capable of applying a high magnitude load level in a short test period and provides precise load placing with a loading scheme identical to the one used in the Danish bridge classification system based on "standard vehicles".

The test rig is constructed for high magnitude loading (potentially collapse testing), but in in-situ proof loading tests additional demands become present. One of the main challenges is to apply monitoring methods, which can reveal the stop criterion, response, and target load to an extend, which enables prevention of irreversible damage. In addition, Since the testing time is very limited due to required traffic regulations, such methods have to be developed so the equipment is quickly prepared and is reliable and fast to use on-site. Two promising monitoring methods for such an application are 2D Digital Image Correlation (DIC) and Acoustic Emission (AE).

Digital Image Correlation (DIC) – Exterior measurements

DIC is an advanced method for evaluation of photographs taken of a surface before and during deformation to evaluate surface displacement- and strain magnitudes. The photographs are divided into subsets of a certain size (e.g. 80x80 pixels), which are then tracked continuously throughout the test. DIC has proven a promising method for crack detection, where cracks can be detected prior to detection from visual inspection. 3D DIC is known to account for out-of-plane movement, but the mounting and calibration procedure can be difficult to handle in the field, which is why 2D DIC is researched more thoroughly in the project.

Acoustic Emission (AE) – Interior measurements

AE is defined as a phenomenon of radiation of elastic acoustic waves generated in the rapid release of energy when a material undergoes irreversible changes in its internal structure, for example as a
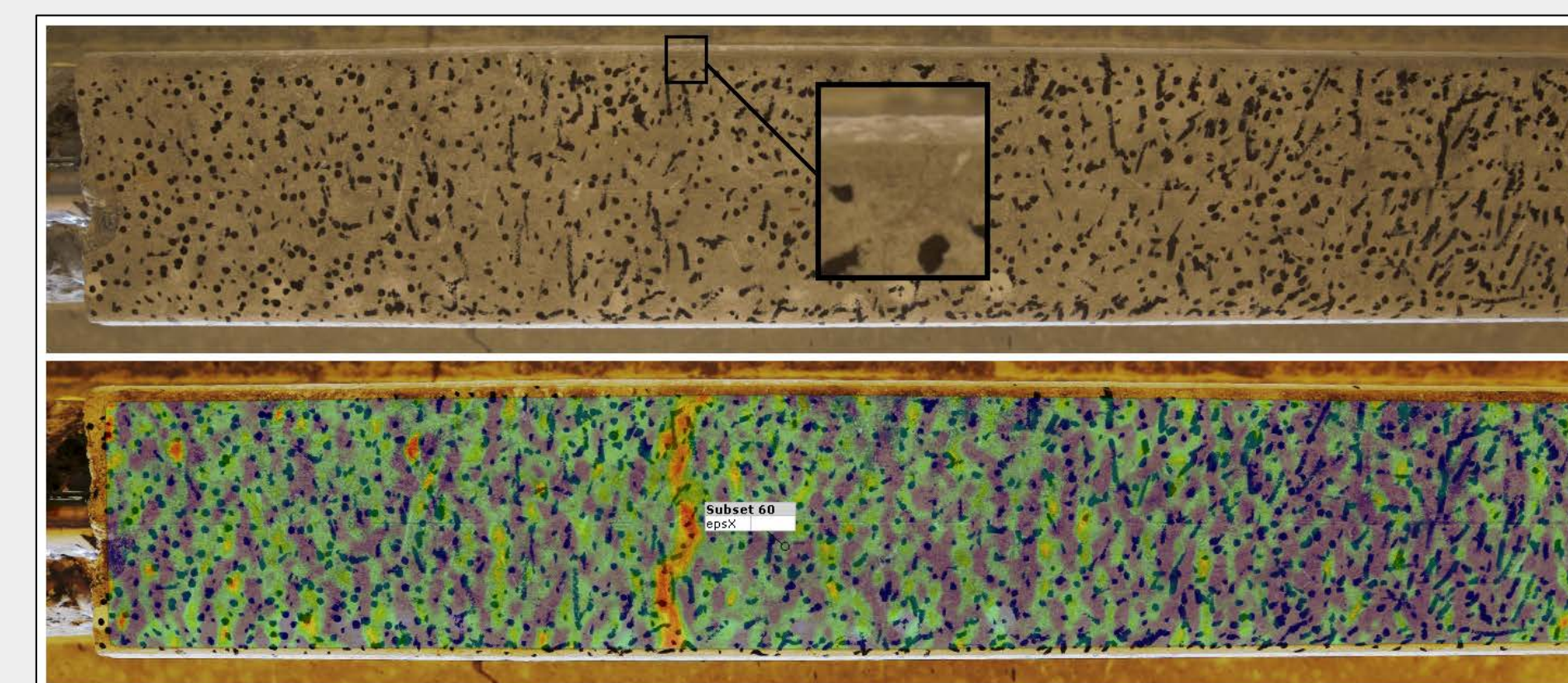

Figure 2 - Crack detection by DIC, visual detection (top), 19 kN, DIC detection (bottom), 13 kN.

result of crack formation. The released energy propagates with the speed of sound and can be detected by a sensor on the structure surface. This makes it possible in a non-destructive way to detect internal crack formation.

Combined DIC and AE as part of a threshold evaluation

The combination of DIC and AE is hypothesized to make it possible to simultaneously detect and monitor crack initiation, both internally and externally. This combination of the two measurement methods is deemed to provide a unique identification of relevant stop criterion thresholds. Consequently such information can provide input data for theoretical capacity evaluations as well as probabilistic approaches. In combination with other advanced monitoring methods, the combination of DIC and AE holds the potential to provide monitoring thresholds in In-situ Full-scale Concrete Bridge Testing.

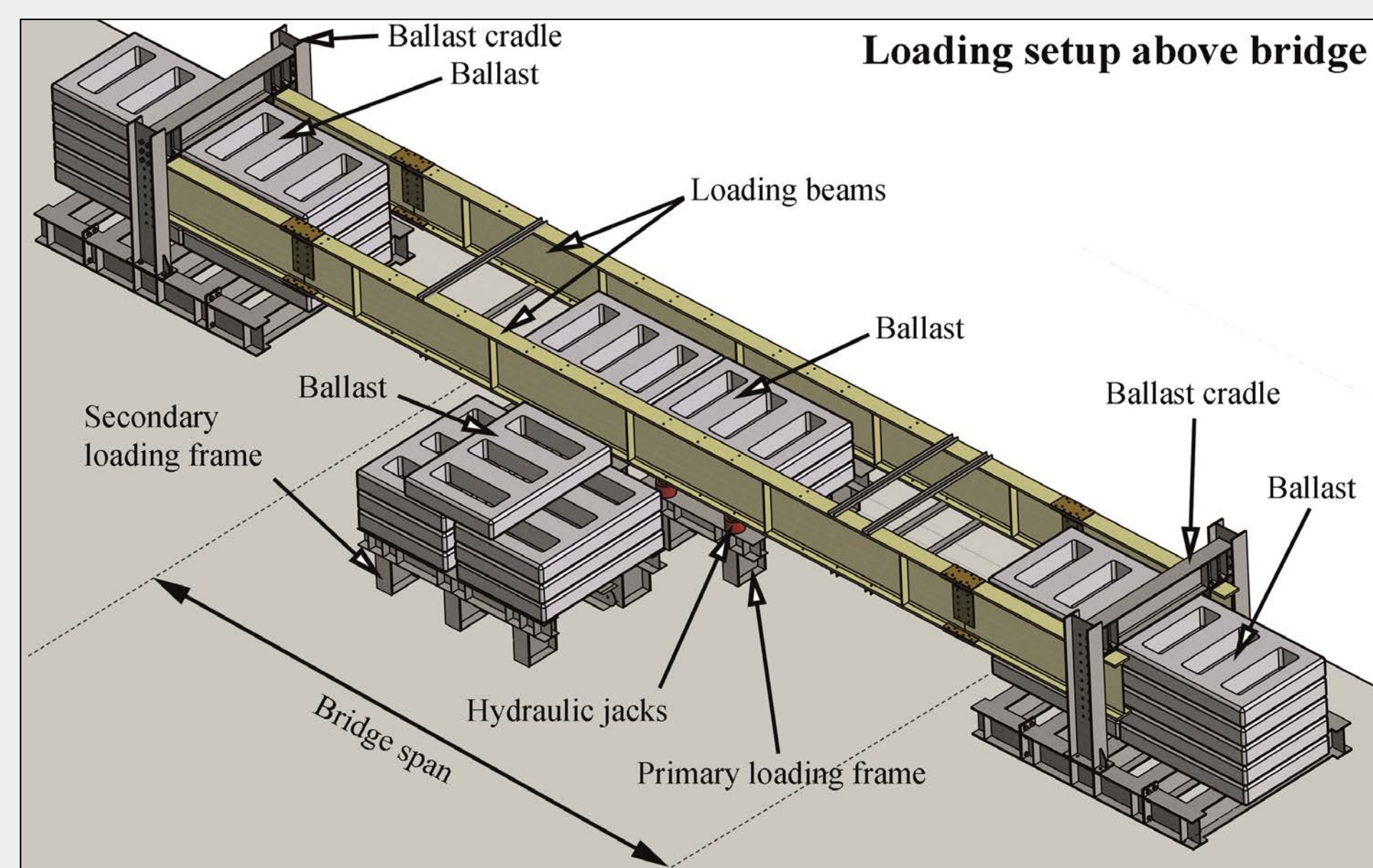Figure 3 - AE sensor mounted on concrete surface [2].

Figure 1 – Cradle loading rig with ballast, loading beams, and hydraulic jacks to apply load [1].

Loading setup above bridge

Ballast cradle
Ballast
Loading beams
Ballast
Ballast cradle
Ballast
Secondary loading frame
Ballast
Hydraulic jacks
Bridge span
Primary loading frame

[1] Schmidt, J. W., Halding, P. S., Jensen, T. W., and Engelund, S. 2018, "High magnitude loading of concrete bridges", [2] Lantsoght, E. O. L., Van Der Veen, C., De Boer, A., and Hordijk, D. A. 2017. "Collapse test and moment capacity of the Ruytenschildt reinforced concrete slab bridge" *Structure and Infrastructure Engineering*, 13, 1130-1145.