DETERMINING LOAD RESISTANCE OF EXISTING CONCRETE BRIDGES

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ABSTRACT : In many countries, the road network include high number of ordinary concrete bridges. In course of time, these have been designed for variable traffic loads, type of concrete and type of reinforcement. As the design traffic loads have a tendency to increase over time, the bridge owners need to estimate the true load resistance of the bridges to avoid weight limitations, unnecessary replacement and strengthening of the structures. Moreover, industry wants to have bigger and bigger special heavy transports on the roads. This paper addresses the problematic on assessing the load resistance of ageing concrete bridges with enhanced assessment methods and using the results on decision making on the viewpoint of the bridge owner. Medium-span prestress concrete bridge is dealt as a case study to highlight a project, where notably heavy transport is planned on to the bridge. Enhanced assessment methods are used including load testing, structural monitoring and Finite-Element simulation.

KEYWORDS: concrete bridges, load resistance, load testing, bridge assessments, heavy transport.

1. INTRODUCTION

Bridges are structures designed and build for extended service life of 100 years and more. During such long time notable changes occur in transport needs, traffic volume and vehicles. As a consequence, the design traffic loads of bridges, as well as maximum weight of permitted vehicle on roads, have a tendency to increase over time. Special heavy transports are also on issue that put the load resistance of older bridges in proof. Although the bridge collapses due to the excessive traffic load are rare events, minor damage may occur that reduce the durability of structures and cause maintenance costs. Bridge owners need to estimate the true load resistance of the bridges to avoid unnecessary weight limits, replacement and strengthening of the structures. Evidently, concepts like load testing, non-destructive testing, structural monitoring and advanced Finite-Element (FE) structural simulations are likely to come more popular in many countries. For example In Finland, the concept of load testing is widely used, non-destructive testing has been found successful applications and the structural monitoring is used in individual research projects [1,2,3].

As far of concrete bridges are concerned the assessment of structures includes some fundamental uncertainties because of the concrete material itself. In sound structures, the strength of concrete and modulus of elasticity tends to increase over time. To approve and fulfil the design strength in statistical sense during construction, the contractors need to put some extra onto the strength. On the other hand, specific aging problems can significantly reduce the strength and the bonding capacity between rebar and concrete. These problems are usually more severe in some problematic locations in the structure.

Thus, the strength parameters and modulus of elasticity of concrete remain widely unknown. One typical solution would be to take bored cylindrical samples to inspect the true material parameters. In concrete bridges, however, the concrete cover is usually contaminated with chloride ingress and

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carbonisation making the material test interpretation difficult. Another issue is the cracking of concrete, which affect the stiffness and may redistribute the forces in different manner than assumed in original assessments. Load testing and structural monitoring would be the tool to inspect this and to calibrate assessment model. To do this for the design traffic load, one actually needs a test vehicle of same order in weight than the design load is. This in turn is difficult to arrange and causes unnecessary cracking to bridge that will reduce the durability.

When using current design guidelines for the bridge assessments, one has not much possibility to show extra load resistance in addition to that, which was already done in the original design assessment. It could be even the case that when old concrete bridges are analysed with modern methods, they do not resists the old design load, because of the tightened limits to crack widths, minimum amount of transverse reinforcement, minimum number of stirrups etc. It is well known fact that when a concrete bridge is test loaded up to the failure, the actual load resistance may be typically two to three times the theoretical one. This originates from various issues like the actual strength of the concrete, various friction effects; and participation of edge beams and asphalt layers to structural resistance. When assuming such extra load resistance over the standard design guidelines, one challenge is what could, and what could not, be considered as proven methods from administrative point of-view to ensure a safe structure.

This paper discusses the above problematic using an actual case study of a medium-span prestress concrete bridge. To study a possibility for a special heavy transport, a load testing for one of the biggest proof-loads ever used in Finland is made. Structural monitoring for static and dynamic actions is conducted together with detailed FE-analysis and material testing.

2. CASE STUDY OF THE SUNDOM BRIDGE

Sundom Bridge (Figure 1) is a 3-span continuous prestress concrete slab-girder bridge situated in the coastline of Finland. Bridge is completed in 1975 and is generally good condition at the time the present study is made (Figure 2). The longitudinal prestress-level in the bridge is relatively high, and the cross-sections remain compressed in service-limit-state loads.

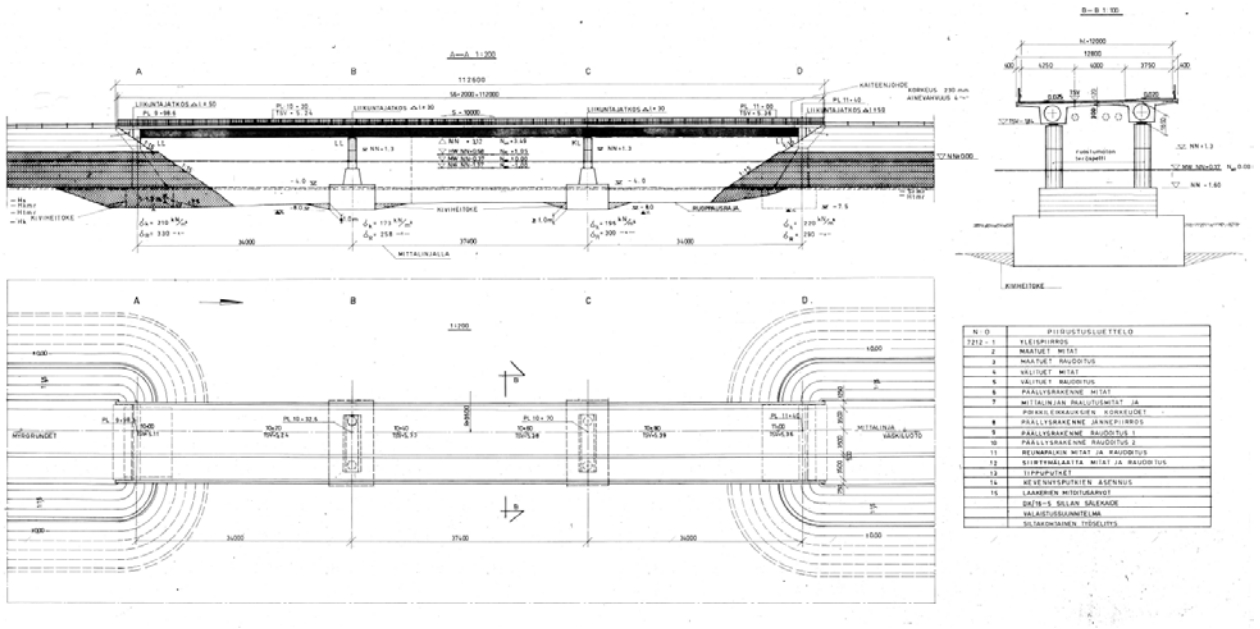

Figure 1. Elevation, plan-view and cross-section of the Sundom Bridge.

Figure 2. Photo of the concrete covers.

In late 2010 a need was invoked to continuously use the bridge for special heavy transports, where the total weight of the transport will be 357…385 t, depending on the final vehicle type. To the authors' knowledge, such heavy transport has been permitted in Finnish roads only once in the history. The Sundom Bridge is designed for 168 t axle load pattern for special heavy transport that has, although much smaller total weight, bigger axle weight.

Initial static assessments, provided by the involved transport company, cope to suggest that the load resistance of the bridge might be adequate. The owner of the bridge, Finnish Transport Agency has, however, concerns about the proper detail of the assessment and that the elementary static models might be unreliable because of the huge magnitude of load.

The bridge owner decided to study the bridge resistance more thoroughly involving the first and the second authors. More advanced FE-modelling with structural dynamic study was made. Load testing was designed and conducted (Figure 3) with a record proof-load in Finland. Structural monitoring was conducted to verify the structural dynamic simulations.

Figure 3. Load testing on the bridge in August 2011.

The basic quantities monitored in the load test have been the strains in some rebar and the deflection of the deck. Two types of tests have been used: static and dynamic, i.e., test vehicle stopped on to the bridge and running over the bridge with varying speed.

Theoretical dynamic simulations indicate that there could be resonance with the bridge superstructure at driving speed approximately 15 km/h. This has only theoretical importance, as the transport in practice needs to across the bridge with walking speed. Dynamic study was, however, more meaningful to confirm the overall stiffness of the structure. I turned out that in dynamic loading the bridge is much stiffer (almost 90%) than conventional static models indicate. This was concluded from various reasons including:

- present strength of concrete (design value = 40 MPa, measured = 71 MPa) and associated effects to modulus of elasticity
- dynamic modulus of concrete is bigger than the static
- concrete edge beams act as part of the working cross-section
- deck surface structures act as part of the working cross-section. Test was conducted in temperature around 10^{o}C; in such temperatures asphalt has notable stiffness.

After calibrating the FE-model with above parameters, it was possible to get good agreement with measured strains in the rebar. The rigorous static analysis indicates that safety against crushing of concrete of main girders at the region of intermediate piers is not adequate. If the measured concrete strength (71 MPa) could be accepted for assessments, however, then the resistance might be adequate. This would be against most of the design guidelines as the general principle is that the strength-increase over time in concrete cannot be utilised.

3. CONCLUSIONS

- Actual load resistance and stiffness of existing concrete bridges is complex to determine. Load testing, structural monitoring and advanced FE-modelling are all useful on modelling the actual static and dynamic response
- the case study demonstrates the more general conclusions that without relevant guidelines for resistance assessments of existing aged bridges and proper background studies, the bridge owner have challenges to accept the use of specific measured design parameters in assessments
- more effort is needed internationally to develop widely accepted design guidelines and practices to use load testing, structural monitoring and material testing data on assessments of existing ageing bridges.

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