The Railway Concrete Arch Bridge over Kalix River - Dynamic Properties and Load Carrying Capacity

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ABSTRACT
The concrete bridge over Kalix river at Långforsen was built in 1960 and has a span of 90 m and a height of 13,7 m. The bridge owner, Trafikverket, now wants to increase its allowable axle load from 225 to 300 kN. Field tests were carried out under service condition and with ambient vibrations. The test results were used to update and validate Finite Element Models. At last, the refined models are used to check the possibility to increase the axle load.

Key words: Codes application, life-cycle assessment, modelling, methods and behaviour, monitoring, assessment and maintenance, numerical methods, sustainable structures.

1. INTRODUCTION

1.1 General

The Swedish Railways have a history of about 150 years and several of the bridges along the lines have been in service for more than 50 years, some even more than 100 years. The owner, Trafikverket, now wants to increase the maximum allowed axle load from 225 kN to 250 kN or more along the main lines in northern Sweden and this calls for an appraisal of the bridges.

Before higher axle load can be allowed it is necessary to check the maximum deflection and the general dynamic behaviour of the bridges. The concrete was designed to have a compressive strength of 40 MPa. Test on drilled out cores now show that the strength has increased to a mean strength of 56 MPa. In this paper, several finite element models of the Långforsen Bridge are discussed. Field tests are carried out under service condition and with ambient vibrations. The test results were used to update and validate finite element models. At last, the refined models are used to check the possibility to increase the axle load, Sabourova et al (2012).

1.2 Design and Construction

The bridge at Långforsen has a total length of 177.3 m with a central arch of 89.5 m and two side spans of 42 m, see Figure 1. It was built in 1960 and consists of an arch which carries a reinforced concrete slab via underlying longitudinal and transversal concrete beams, connected through fixed columns. The arch is a reinforced concrete box girder with two hollow spaces. The cross section is lowest at the crown and highest at the connection to the arch abutment. The original train load corresponds to an axle load of 250 kN for the locomotive and a distributed load of 72 kN/m.

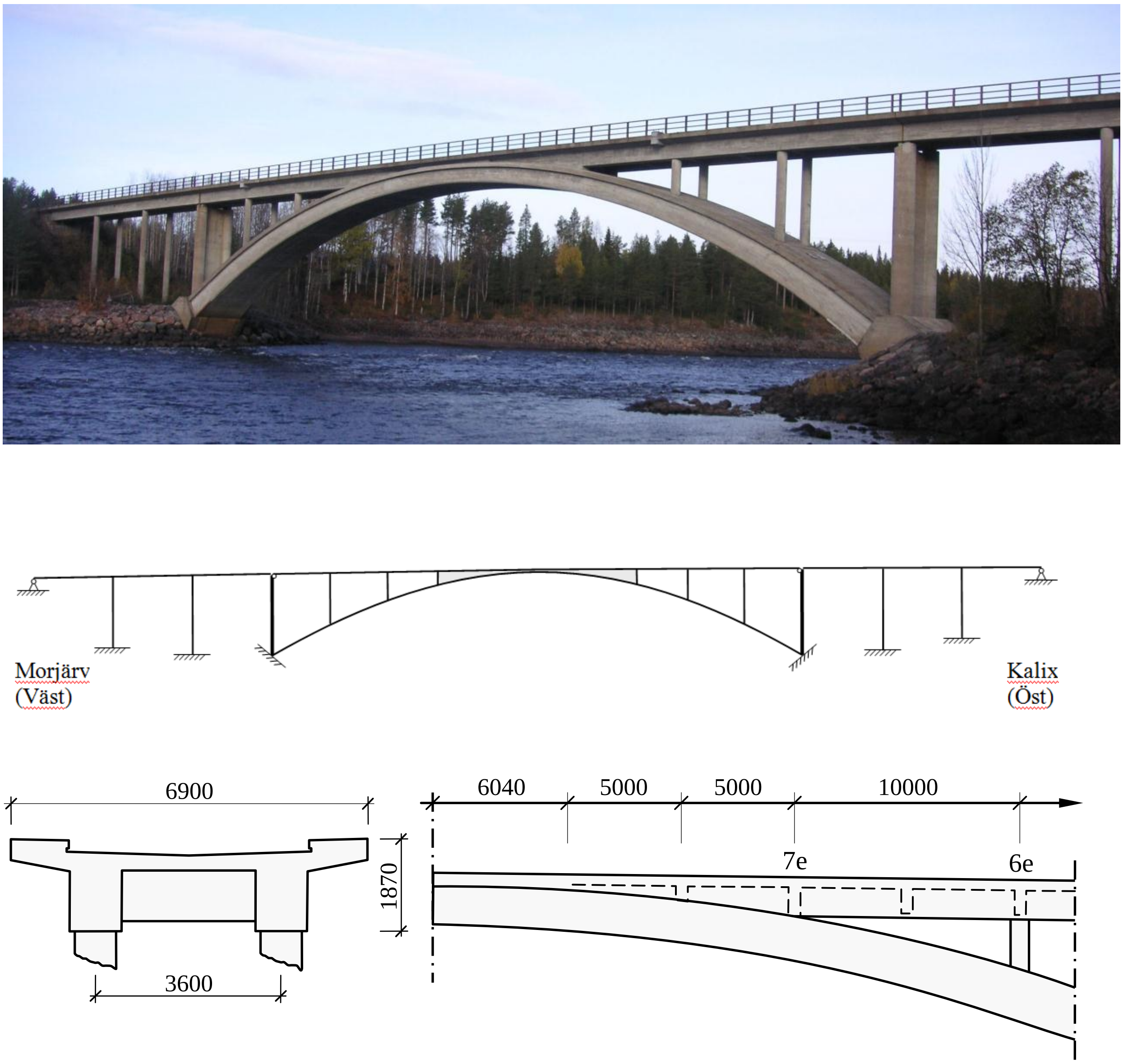

Figure 1. The Railway Concrete Arch Bridge over Kalix River at Långforsen.

2. GEOMETRY AND MATERIAL PROPERTIES

The bridge was built with concrete Btg K 400 with nominal characteristic compressive and tensile strengths of f_{cck} = 30.775 MPa and f_{ctk} = 1.95 MPa and with a modulus of elasticity of E_c = 32 GPa. The foundations were cast with a slightly lower concrete quality, Btg K 300. The reinforcement was ribbed bars Ks 40 and high strength steel Ss70 with yield strengths of f_{yk} = 390 and 720 MPa respectively.

In 2009 six cylinders with a diameter of 95 mm were drilled out of the lower part of the arch. Three were tested in compression giving compressive strengths of 76.7; 79. 8 and 65.2 MPa with a mean value of 73.9 MPa; three were splitted with splitting strengths of 1.85; 4.17 and 3.77 MPa. This corresponds to concrete quality K80 according to the Swedish Code BBK 94 with a characteristic compressive strength of f_{cck} = 56.5 MPa and a modulus of elasticity E_{ck} = 38.5 GPa.

3. FINITE ELEMENT MODELS

A lot of work has been invested in different FEM models over the years, Sabourova et al (2012). During 2011 two types of bridge models have been developed by Yongming Tu with Abaqus/Brigade: A comprehensive model with foundations (Type I) and a simplified model where the foundations have been exchanged by springs (Type II). The advantage of the former model is that it is closer to the real bridge structure, and the predicted results from it should be more reliable and closer to the 'real results', but the disadvantage is that the problem size is rather high. The number of elements is 93 910 in type I and decreases to 47 438 in type II and the number of variables decreases from 438 800 to 282 808. Both models give very close predictions of eigenfrequencies and deflections.

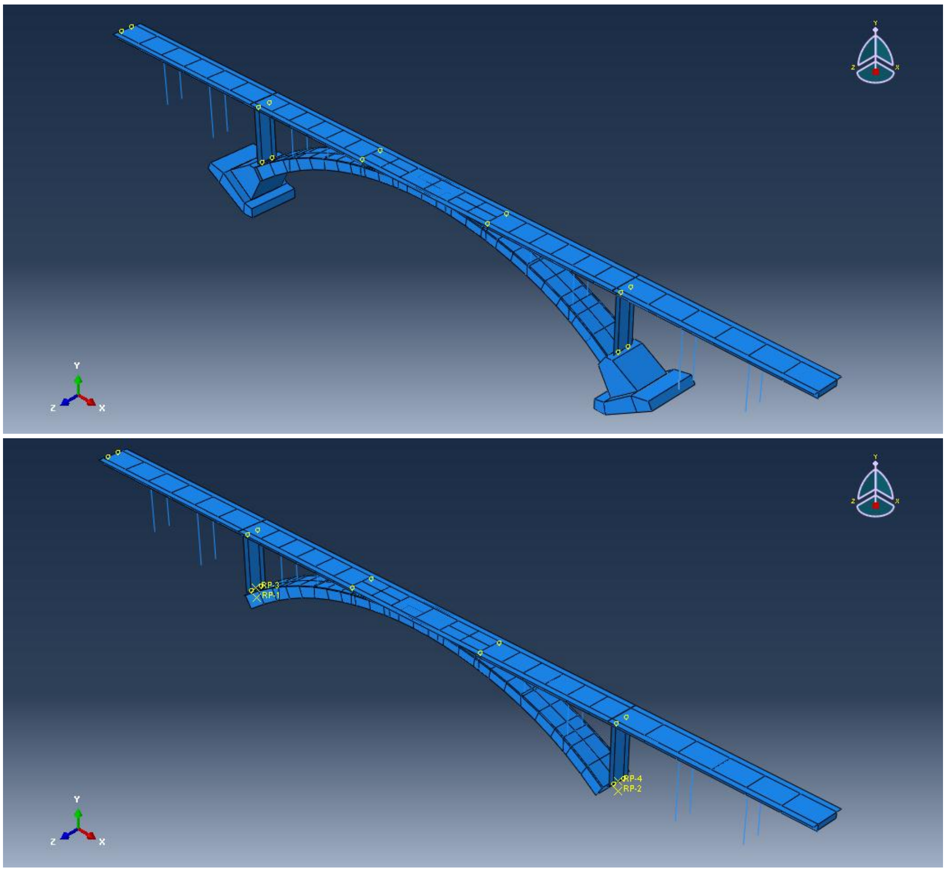

Figure 2. Two FEM models were used: A detailed model, where the foundations are included in the model (top); and a simplified model, where the foundations are simulated with springs (bottom).

4. MEASUREMENTS

Measurements of accelerations, strains and deflections have been carried out during 2009 and 2011. A simple non-iterative method to calibrate the accelerometers has been developed by Grip and Sabourova (2011) and further work is going on. A comparison between some measured and predicted eigenfrequencies with the Type II FEM Model are illustrated in Figure 3.

A comparison was made for some of the measured and predicted strains in a section in the top beams carrying the slab and the rail close to the centre of the arch. These sections had been critical in earlier assessments of the bridge. The maximum measured and predicted strains during the passing of a locomotive with an axle load of 180 kN were rather close and of the order of $\Delta\varepsilon = 20 \cdot 10^{-6}$ corresponding to a stress amplitude of only $\Delta\sigma = 4$ MPa.

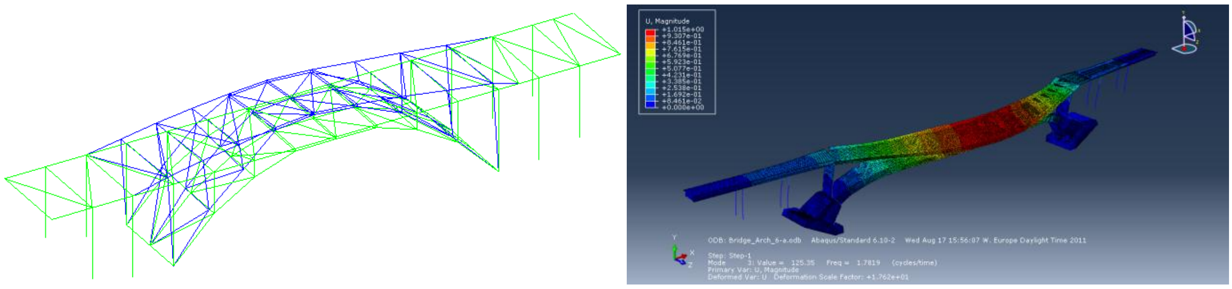

Figure 3. The first transverse bending eigenmode according to measurements gave a frequency 1.79 ±0.002 Hz (left). According to the FEM model we got the corresponding value 1.78 Hz (right). The difference is less than 1%.

5. LOAD CARRYING CAPACITY AND CONCLUSIONS

Methods for assessing the load carrying capacity have been developed in the EC-project Sustainable Bridges (2008), He et al (2008). These methods have been used here.

According to earlier assessments most parts of the bridge is capable of carrying an axle load of 330 kN. The only critical sections are located in the slab on top of the arch: (1) in the section where it is united with the arch, where the longitudinal top reinforcement is highly stressed; and (2) in the transverse direction between the supporting beams, where the bottom reinforcement is highly stressed. We are now studying these sections in the FEM model for different loads and preliminary results show low maximum stress ranges of 10 MPa in the critical sections and vertical deflections of the crown of the arch of the order of only ± 5 mm indicating that the bridge may be able to carry an increased axle load of 330 kN without problems.

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