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ASSESSMENT OF FATIGUE OF RAILWAY BRIDGE

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Abstract: *The aim of this paper is to investigate the change of stiffness of concrete railway bridge subjected to cyclic loading since cyclic loading affects several types of concrete structures during their service life. Its greatest impact can be seen on bridges, which are subjected to enormous loads from passenger of freight traffic in terms of weight as well as frequency. A railway bridge was chosen for application in order to simplify the task, as the trains are represented by uniformly distributed load at a specific location defined by the track. In this analysis, only the changes in concrete were considered. The reduced stiffness values were placed in to the calculation model following the standard staggered algorithm scheme. This application provided a base for drawing conclusions regarding the used cross-section of the bridge deck.*

Keywords: ***Cyclic loading, dynamic analysis, fatigue of concrete, stiffness of structures.***

1. Introduction

The civil engineering structures suffer from enormous static and cyclic loads and dynamics effects. For investigation of the effect of cyclic loading, the best example is a railway bridge. This structure has to sustain millions of loading cycles. With proper observation and scanning of the bridge, it is possible to recognize and study the fatigue development.

Fatigue is a permanent process, which is occurring under cycling loading. In concrete the change is connected with grow of the internal micro cracks. This effect is very progressive and may lead to increasing of the strain level. It is displayed as a change in material mechanical properties (Sýkorová, 2008; Stachová, 2010).

The change is unnoticeable at the beginning of cyclic loading. The cracks are appearing on the both sides in tensile reinforcement and in compressed concrete. The cracks developed at the present cycle do not have time to close before a new cycle. That leads to increasing of the crack grow until whole element fails.

Fig. 1: Örnsköldsvik Bridge (Elfgren et. al., 2007)

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2. Model of bridge

Before the calculation could take place, it was necessary to pick a structure in question. The model was inspired by a real structure in Sweden. This bridge stood in Örnsköldsvik (Fig. 1) and it was used for a fatigue field test. It was a two-span concrete railway bridge with a ballast bed.

The bridge has two spans of the length of 11.92 meters and 12.18 meters. The bridge deck is supported by a pier in the middle and two abutments on each side. The railway deck is 4.5 meters above the road level and has a width of 2.9 meters (filled with ballast to the level of the side beam of the deck). The total width of the bridge is 6.15 meters. The structure goes in horizontal curve with a very wide radius and with a slope of 1.75 %. The foundations consist of footing in the basis of the pier and two abutments. They are connected by two underground beams with width of 0.7 meters.

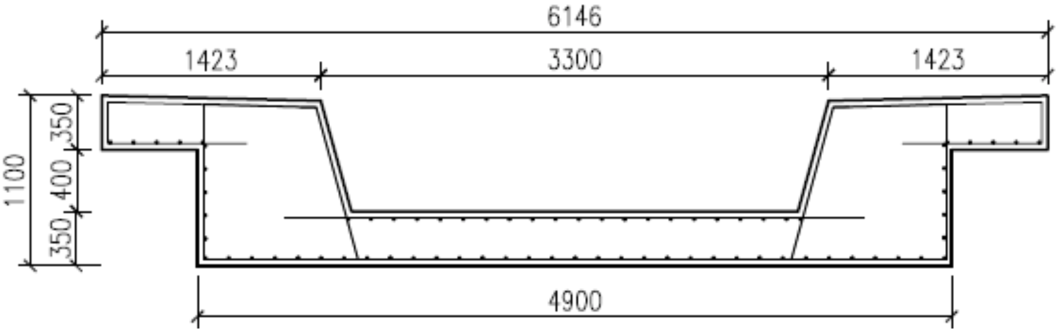

Fig. 2: Cross-section of the bridge deck (Elfgren et. al., 2007)

For further calculation, concrete class C 55/67 was used. This should correspond with the original design of the bridge. Of course the structure would be brand new without any defects from weather or chemical attacks. The original bridge, which had to be torn down, suffered damage from heavy traffic. There were minor cracking, spalling of concrete and wetting. The bottom of the south span had several damages from track collisions. The same was found on the bottom of the north span with addition of visible reinforcement with corrosion. The western and eastern faces have exhibiting a low concrete cover. The reinforcement bars were visible.

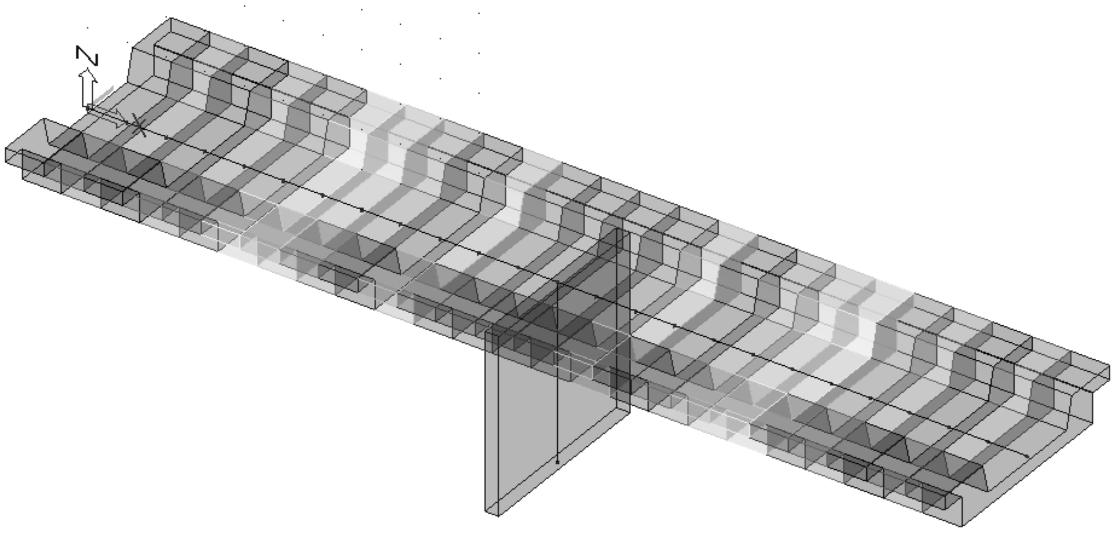

Fig. 3: Static scheme of bridge (SCIA Engineer)

The static system is with two simple beams connected above the swinging rod. The whole model is cut into 24 even pieces and created in SCIA Engineer. Each piece is 1 meter long and its characteristics could be changed accordingly to the calculation.

3. Analysis of bridge

For fatigue testing it is necessary to use a train loading scheme, in this case it was taken from Eurocode. The heaviest condition was considered by using a freight train shown in Fig. 4. The dynamic effect of the train moving across the bridge is represented by the dynamic ratio provided in Eurocode.

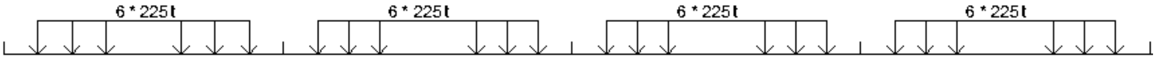

Fig. 4: Heavy train loading scheme.

For exact calculation of fatigue behavior, the structure is divided to smaller elements (see Fig. 3). These elements are 1 meter long and the values from the start and end is interpolated to get the approximate value from the middle. Every element is calculated separately. The bridge has two spans, but the results are the same on each span. Further in calculation it is assumed that both spans are behaving the same.

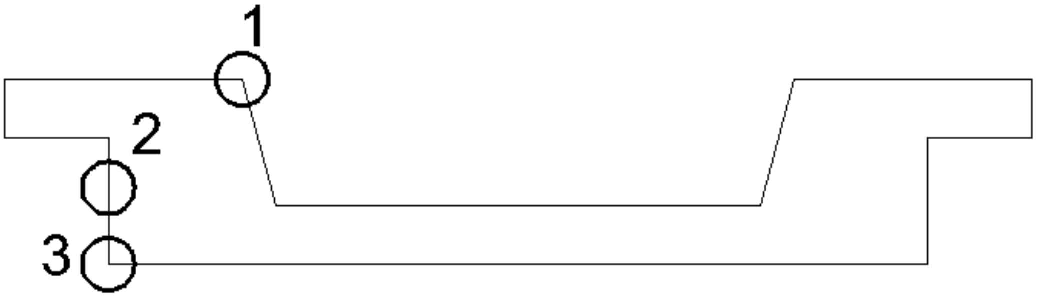

Fig. 5: Heavy train loading scheme.

For the calculation it is necessary to determine stresses acting on the structure. It can be seemed well in Fig. 5, where the checking points are indication in the cross section. One is on the top of the cross section right next to the ballast bed. The second one is in the middle of the cross section and the third is in the bottom of the bridge deck. These stresses have to be calculated for dead load of the structure and dead load and traffic load.

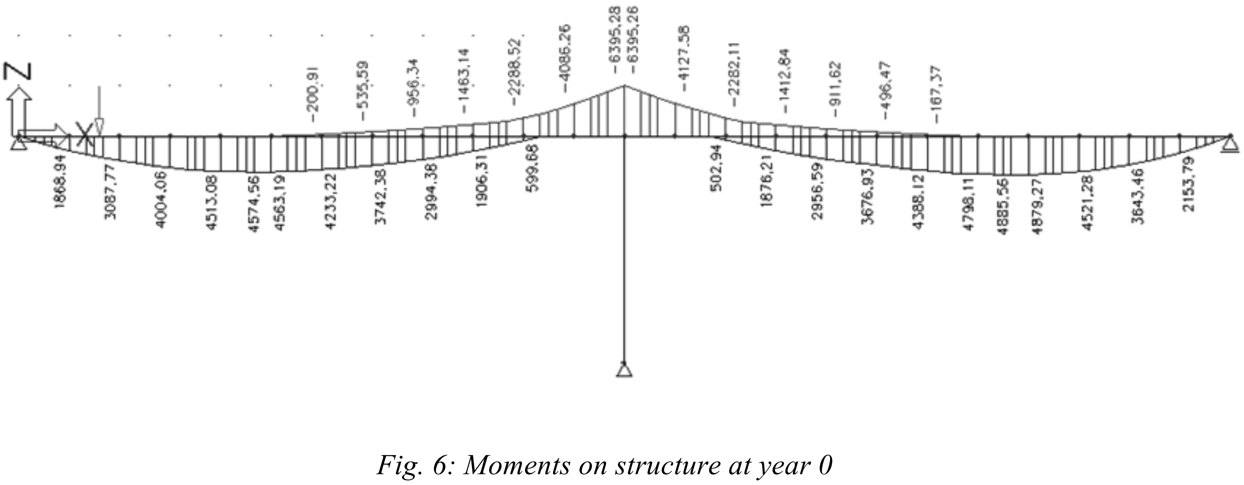

Fig. 6: Moments on structure at year 0

The calculation is run by static program and results from those points are placed into excel spread sheet. The minimum stress is from the period were there is just a dead load acting on the structure. If this value is in fact tensile stress, the calculation value is 0. The same point exhibits also different value such as the maximum stress, which is obtained from the train traffic and dead load of the bridge.

From Figs. 6 and 7 it possible to see that the bending moments are changing, but very slowly, over the 100 years of cyclic loading. The values in the mid-span are slowly decreasing. On the other hand, the values above the support increased gradually. It is explainable that in the mid-span a loss of stiffness started the process of softening. This change of concrete resulted in creation of a hinge while the rest of the beam is acting more as a cantilever.

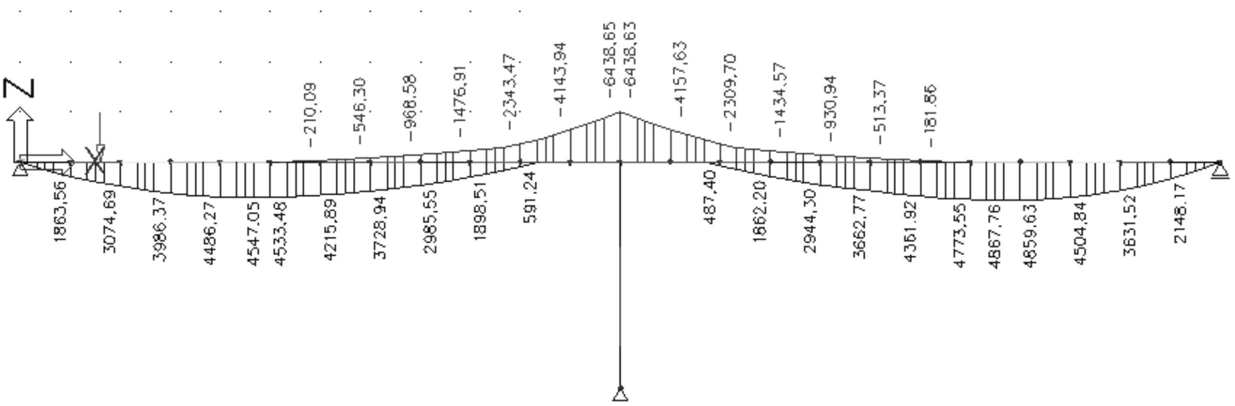

Fig. 7: Moments on a structure at year 100

From the previous calculations it was learned that the compressive stresses were very small along the structure. Then, S_{max} resulted in a small percentage. It is known that smaller stresses lead to faster reduction of stiffness in first interval (see Fig. 8). In this interval, the stiffness changed noticeably. In the second interval, the shape is almost flat with the almost same values of E_c after the first interval, see Tab. 1.

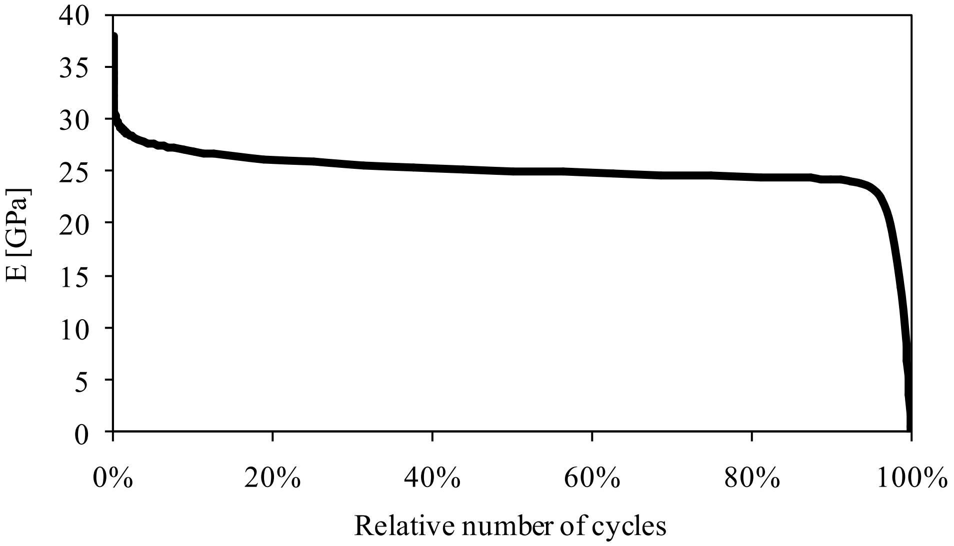

Fig. 8: Decrease of modulus of elasticity

The greatest value of S_{max} was 0.11. The total number of cycles lead to 10^{13}. The minimum number of cycles is 10^6 so this condition is fulfilled with sufficient margin. The initial modulus of elasticity E_c is 38 GPa, as can be seen in Fig. 8.

After this analysis it was concluded that the bridge cross section is very stiff even in extreme conditions when only fatigue of concrete is considered and that the fatigue of concrete does not influence the structure so much since the stresses on the structure are small. It is due to type of the cross section of the bridge. It is shown in Tab. 1 that the structure will not collapse from fatigue of concrete.

Tab. 1: Decrease of modulus of elasticity.

Cyclic loading (year)	E_c (MPa)
1	32.70
25	32.67
50	32.66
75	32.66
100	32.66
200	32.65
300	32.65
400	32.64
500	32.64
600	32.64
700	32.64
800	32.64
900	32.64
1000	32.63

4. Conclusions

A method for evaluation of stiffness decrease of concrete railway bridges due to cyclic loading was developed. The method combines the concept of the fatigue damage function and the commonly available finite element tools for structural dynamics analyses. The computation method represents a staggered algorithm when the actual stiffness of concrete at a given point is updated after a sufficiently small number of load cycles. Then the updated stiffness is used for the dynamic analysis at the following time step. It is believed that the proposed method can help to assess the residual service life of existing concrete structures subjected to cyclic loading or it can support design of new concrete structures and improve their long-term resistance to fatigue effects of concrete.

To prove the applicability of the proposed method, it was applied to an existing reinforced concrete railway bridge, which in turn helped the author to understand some of the dynamic aspects of bridge engineering. The data used in this application were taken from the relevant design documentation and from literature. The tested bridge responded to the cyclic loading by gradual redistribution of the bending moments and deflections. However, the magnitude of the tensile and compressive stresses remained almost constant during the entire tested period, even though an extreme load scenario in terms of the frequency of heavy trains was considered. Therefore, based on the obtained result, it can be concluded that the relatively stiffer bridges with U-shaped cross section decks do not tend to fail due to poor fatigue performance. Then, the actual failure is likely to happen due to exposure to weather and chemicals, which may accelerate the process of loss of stiffness.

Acknowledgement

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