The Influence of corrosion on the stresses in members of open deck railway bridges

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Abstract. Nowadays, many old riveted railway bridges, mainly their members of the open deck, are corroded. The paper demonstrates the influence of corrosion on a stringer beam and on a cross-girder beam of a particular steel truss railway bridge in Slovakia. This is an important step in the assessment of the loading capacity and the residual lifetime of this bridge. A simple beam FEM model was refined by modelling the investigated members as plate elements. In such a way the real boundary conditions of the members were modelled most realistically by keeping the model as simple as possible at the same time. The stresses in the members were first calculated with the original cross-sectional dimensions and the results were compared with the real measured corroded cross-sections. A future corrosion rate was estimated and calculation of this case was also performed. The influence of stringer to cross-beam rigidity, the size of 2D FEM elements, and the steel material model (linear, bilinear with 1% hardening) were investigated too.

1. Introduction
Many bridges in Slovakia are in poor conditions. Their complete diagnostics is therefore required. Instead of designing new bridges, it is useful to verify the load-carrying capacity and the residual life of the old ones. The exact procedures are difficult. The software model of the bridge has to agree with reality to a high degree so that realistic internal forces and stresses in the members can be assessed.

A finite element method (FEM) beam model is frequently used for an analysis. Such a beam model can assess only internal forces and moments in the members. The stresses can then be calculated by means of an engineering theory. Stresses in the elements of the cross-section are different. That is the reason, why a beam model is often insufficient. A FEM model using plate or solid elements can solve this problem. With a plate FEM model it is possible to detect stresses in every structural detail.

2. Finite element method
With FEM it is possible to divide members into many elements. The mesh density can be defined by the user (Figure 1). The mesh of elements can be shaped in various ways. Triangles, rectangles, squares, trapezoids etc. It is necessary to use the right shape of elements for the mesh. Usually a rectangular (square) shape is the most appropriate. In the case of corrosion hole (or gap) modelling, triangles or trapezoids are needed. Generally, the program can define the type of mesh automatically, but the user is advised to control it manually.
Figure 1. Effect of mesh density on results.

The mesh density of elements is also very important in obtaining proper data. Insufficient division can lead to incorrect results. This is caused by low approximation of elements. The more dense the mesh is, the more precise the results will be.

It is very demanding to analyse bridge structures with FEM plate model. For each plate element a proper mesh density has to be defined. Creation of such a model can take several weeks. In practice there is usually not enough time to make this type of calculation. Common engineers could find these calculations very demanding.

3. Modelling and the results
Calculations are much easier with a beam model. Instead of many hours of calculation time, it only takes several minutes. This model is appropriate for calculation of internal forces, moments and deformations. It is not possible to find out stresses in details. The best solution is a combination of both types of models. A beam model combined with a plate FEM model. The critical investigated member can be modelled as a plate member and incorporated into a beam model. However, the connection of these two members is the most problematic issue. With improper connection the results could become inaccurate or even wrong. In this case, it is very important to choose the right mesh density.

Figure 2. Combined model.

A riveted railway steel bridge in Eastern Slovakia was assessed. It is a 129-year old bridge. The bridge was reconstructed in the 60’s. Corrosion is one of the biggest problem of all old bridges, this particular one was no exception. The current state of the members is quite different in comparison with their original condition. A large part of the steel plates were corroded. A thorough check of all members was necessary. The loss of material in some places was almost half of the thickness of the plates. All elements of the bridge were measured and compared with the drawing documentation. Actual condition of all elements was classified. The first class was in perfect condition without corrosion, the second one with a corrosion of approximately 2 mm of the horizontal surfaces of the plates and the third class with
corrosion of about 4 mm. There were not many elements in the third class, but these elements, without strengthening, will develop corrosion gaps in the near future. Complete repair or exchange of this elements will be needed. A complete review was therefore necessary to be done, in order to be aware of the effects of such unpleasant features to the construction.

Program Dlubal RFEM was used for all calculations. This program could calculate a beam model and a 3D FEM model. A space beam model of the structure was made first to properly model the structure, because the bridge is a skew one. The loads were then modelled. Effect of permanent loads, traffic loads (standard load model UIC 71, braking forces, nosing force, etc.) and wind were taken into account. Then load combinations were made with the rules of Eurocode. Later the cross-beam and the stringer were separately analysed in more detail with FEM plate models. Original dimensions were used first, then with corrosion class 2. Due to actual condition of some stringers also a model with gaps in the web was modelled (Figure 3).

![Figure 3. Stringer with gaps at the supports.](image)

The FEM model was created by plate surfaces. The cross-sections are riveted. Connections between each surface were made using rigid surfaces, because a line of rivets is rigid enough (up to a very high level of corrosion). The rigid surface was located at the line where the actual rivets are placed. Connection of web with the angles was simplified. A plate with a thickness of both angles and web was used. Due to a better transfer of forces a rigid surface was placed also into the middle of the cross-section above the member web (Figure 4). Steel S235 with a yield stress 235 MPa was used for calculation.

![Figure 4. Connection between components.](image)

It was necessary to properly model the boundary conditions and the loading of the separately investigated member. The internal forces and moments from the beam model were used. These forces and moments were used to calculate the imposed line support displacements and rotations. In combination with the loading we arrived to the same internal force and moment distribution as in the beam model.

The loading of the stringer was modelled by a surface load to the top of the member. The cross-beam has a different distribution of bending moment. This was slightly varied to make it easier for modelling. This is shown in Figure 5.

The load was divided between the elements. One third of the load was acting on the flange. The rest of the load was acting on the web. Calculation was without any problem with this division.
The members had pinned supports. In cross-beam there was a nodal support inserted in the place of the stringers. These supports were free in the direction of axis y and z. They were prevented to move in the direction of axis x, that means out of the web of the cross-beam. Two models were created. The first one, the original, the second one with corrosion. The member was classified as class 2.

![Bending moment of cross-beam](image)

**Figure 5.** Bending moment of cross-beam.

The results show that the effect of corrosion is significant. Stresses in the bottom of web reached 235 MPa and plastification occurs. Stresses at the supports got higher too. The original state beam performed in an acceptable way, but the actual condition of the member can be dangerous. Some members of the bridge were even in a worse condition. Different results have been achieved by different mesh density.

![Stresses in cross-beam](image)

**Figure 6.** Stresses in cross-beam.
Final mesh density was 10 mm. Diagram 1 is provided for the comparison. It shows time dependence of mesh density.

![Time dependence of mesh density](image)

**Figure 7.** Time dependence of mesh density.

The stringer was created the same way. Nodal supports were used, however, without any stiffening along the length of element. There were three models. The original one, the corroded one in class 2 and the corroded one with gaps. Results were the same as for the cross-beam, but gaps caused a much more change in stresses.

![Stresses in stringer](image)

**Figure 8.** Stresses in stringer.

As it is shown in Figure 7, element with gaps has high stresses not only at the supports, but across the entire cross-section as well. This was only an experimental model, but the current state of some stringers approach already this condition.

The combined model was created on the basis of the beam model. The cross-beam plate model was embedded into the beam model. Connection between both model types was made by means of a rigid area. Triangle shape of area was used to provide connection between members. This type of connection ensured the right transfer of forces. A problematic detail was the connection between cross-beam and
stringer. Local peaks of stresses appeared there. Deformations of the plate model were similar as of the beam model.

The results depend on many factors. First one is a problematic connection between the beam and plate model. As shown in Figure 8, local stresses exceed the limit in these places. With a mesh density of about 10 mm we obtained lower stresses than with the one with 20 mm density. Problem was calculation time.

Figure 9. Local areas of stress peaks.

In addition, calculation with linear and bilinear diagram of steel was compared. It is considered with hardening of steel in bilinear diagram. For this time hardening about value of 1 % was used. It has no effect to the results. Stresses in cross-beam were the same.

Figure 10. Diagrams of steel [3].

4. Conclusion
Assessment and design of steel bridges and other more complicated structures is not easy. The best way is to use a combined model, but it is not always possible. The biggest problem is the necessity of very sophisticated information technology. For the beginning the best way for exact computing is to make a beam model. With this model it is possible to detect internal forces, moments and deformations. Then to select members for the plate FEM model. With the internal forces and moments from the previous model it is possible to assess the stresses. The best way to get the right stresses is to input internal forces by imposed deformations into the member.

5. References
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