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FE-MODELING OF STIFFNESS EQUIVALENT RIVETED JOINTS

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Abstract: *This paper deals with the FE-modeling of the riveted joints usable on the structures with a large number of rivets. The quick built capacity and the load-carrying characteristic close to reality are preferred. The 1D connecting element is used and determination of the stiffness characteristic is presented.*

Keywords: ***Rivet, riveted joint, FEM, stiffness equivalent joint.***

1. Introduction

The sheet stiffening of the structure is one of basic parameters determining the stress and strain state in the vicinity of a crack in the stiffened structure. Stiffening is important when connecting sheets to the structural parts like beams, stringers and ribs and it can affect the fatigue crack growth rates. The influence of the structure stiffening has to be included in the analysis of the fatigue crack characteristics in order to determine the life prediction in accordance with the damage tolerance philosophy.

Current airframes are mostly riveted and bolted. The structural joint fatigue life depends on many factors such as a type of joint, characteristics of the local stress state, stiffening, loading, quality of material and assembly, etc. The stiffness of joint elements affects the load transfer between the sheet and stiffeners. The joint is the critical point of the structure with respect to the fatigue and a crack is initialized right here.

The most of the finite element models of the aircraft structures are built by means of the 1D and 2D elements. However, principal structure elements with complicated geometry should be analysed by 3D elements to ensure the correct local stress state representation. So there is an effort to get a suitable model of riveted joints to ensure the quick built capacity and the load-carrying characteristic close to reality.

2. Riveted joint stiffness determination

The riveted joints stiffness influence to the assembly stiffness may be significant. There are applied completive adjustments in order not to neglect the stiffness variations.

Basic analyses of the riveted joint applicable to the large assemblies deal with the model of equivalent cross-sections of the rivet and the modeled part of the substitutive structure scheme and with the model of the stiffness equivalent joint. Comparison of both approaches in Běhal (1985) shows the ability of the second model to give better representation of the real properties of the joint.

Characteristics of the joint stiffness and the joint deformation are available from experimental measurements on geometrically, mechanically and technologically analogical specimens of the real joint or from the FEM analysis. Analytical equations to specify the joint stiffness characteristics were determined by the experimental measurements by Swift (1974) and Vogt (1947) and by the derivation on the basis of differential equations of the deflection curve by Barrois (1978).

Analytical models formulated generally by the term (1) enable analysis of the aircraft structure joints with a wide thickness range. There are different abilities regarding the usage of the joint material

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(Young's modulus E_s), jointed materials (Young's modulus E_1 and E_2) and the joint geometry (rivet diameter d and thicknesses t_1 and t_2).

$$\delta_R = \delta_R\,(F, d, t_1, t_2, E_1, E_2, E_s) \tag{1}$$

Models were verified by the experimental stiffness measurements of the specimens representing the typical riveted joint in the aircraft structure (Doubrava & Beránková, 1998). The experimental data comparing to the analytical models of Swift and Barrois shows the adequate specimen stiffness at the unloaded area (see Fig. 1). The riveted joint stiffness depends on the loading history, therefore the nonlinear behaviour should be taken into account.

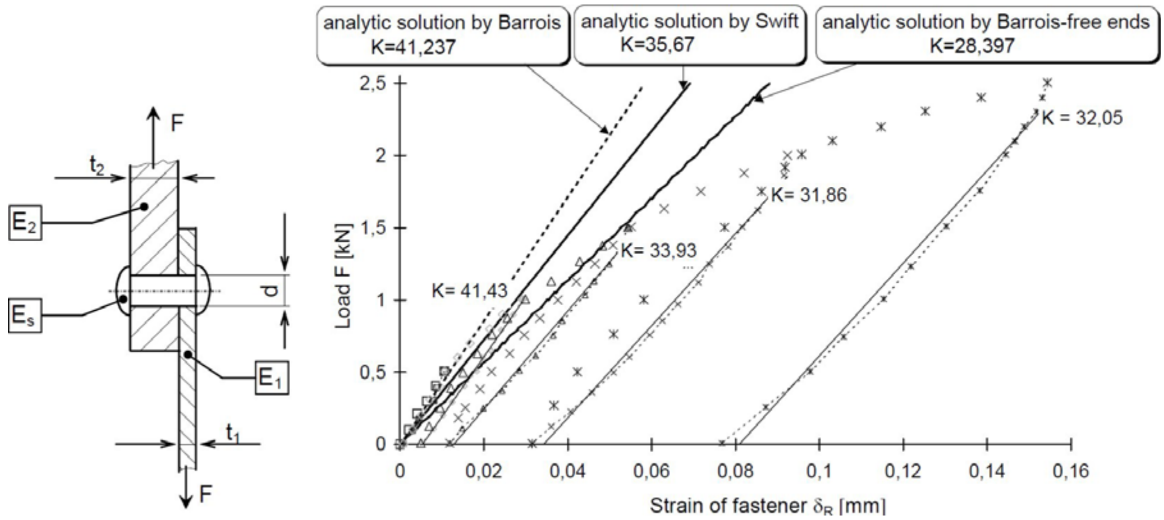

Fig. 1: Experimental data comparison to analytical solutions (lines) – single-shear rivet joint (Doubrava, 1998).

The finite element method (FEM) is possible approach to obtain the stiffness characteristics of joints. The detailed nonlinear 3D analysis including the simulation of the riveting process can be carried out. A sufficient correlation between the experimental data and data from the simulation was reached using elastic-plastic behavior derived from a simple uniaxial experiment (Kaniowski, 2009). However, there was found a high dependency on the friction between jointed materials (Fárek, 2010).

3. Simple rivet replacement for more complex FE-analyses

In practice, it is impossible to perform the FE-analyses of the above mentioned solid model on the structure with a large number of rivets. Models are usually built from the shell elements, also the usage of the 1D elements with a tuned stiffness characteristic in order to simulate the joint stiffness adequately is applicable.

3.1. FE-model of the joint

FE-models of the tested specimens were created to study the joint model properties. The ABAQUS 6.10–2 software was used. The 1D element connects 3D part mesh with 2D sheet mesh through single nodes (see Fig. 2).

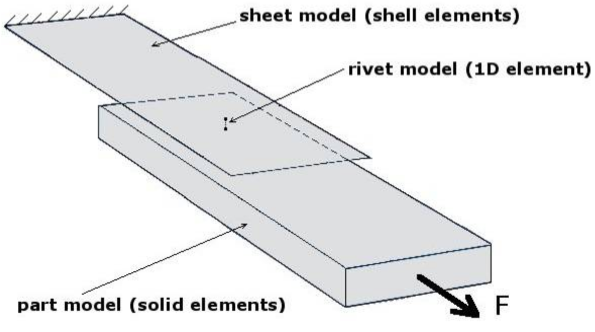

Fig. 2: Schematic model of the specimen.

Firstly, the study of the mesh influence was made using the 3D part with an aluminum material. The analysis was focused on the deformation change in the cylindrical mesh section (see Fig. 3). The mesh around the virtual rivet axis consists of 2nd order hexahedral elements round distribution and 2nd order wedge elements (collapsed hexahedrons) in the centre. The rest of the part is meshed with hexahedral or tetrahedral elements with the size of about 2 mm. The element density increases at the cylindrical section boundary. The number of elements in the direction of the radius varies from 2 to 10. The unit load representing the rivet shear loading is applied to the single outer node on the virtual rivet axis.

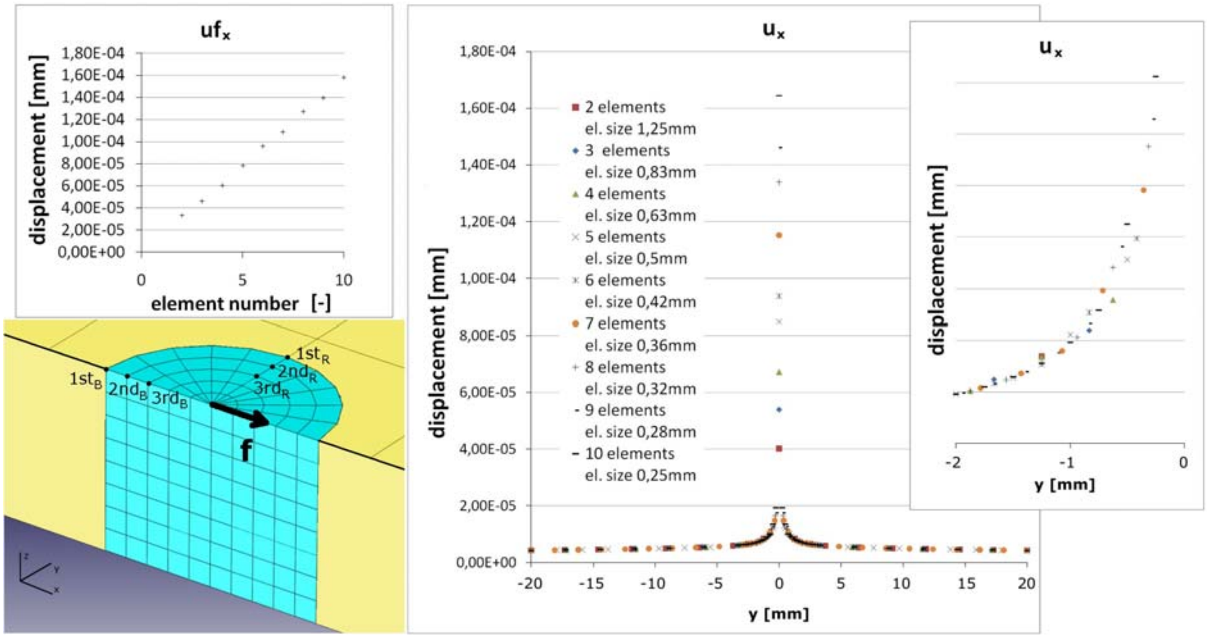

Fig. 3: Mesh type and nodal displacements on the line perpendicular to the load direction in the direction of diameter.

Nodal displacements in the section perpendicular to the load direction rapidly increase about 3 mm around the center (see Fig. 3). The displacement of the loaded outer center node linearly increases in the range of 10 elements along the radius and it is not possible to obtain the higher stiffness by refining the mesh. Reducing the element size doesn't affect the displacement accuracy out of the 1mm radius zone significantly (see the detail in Fig. 3).

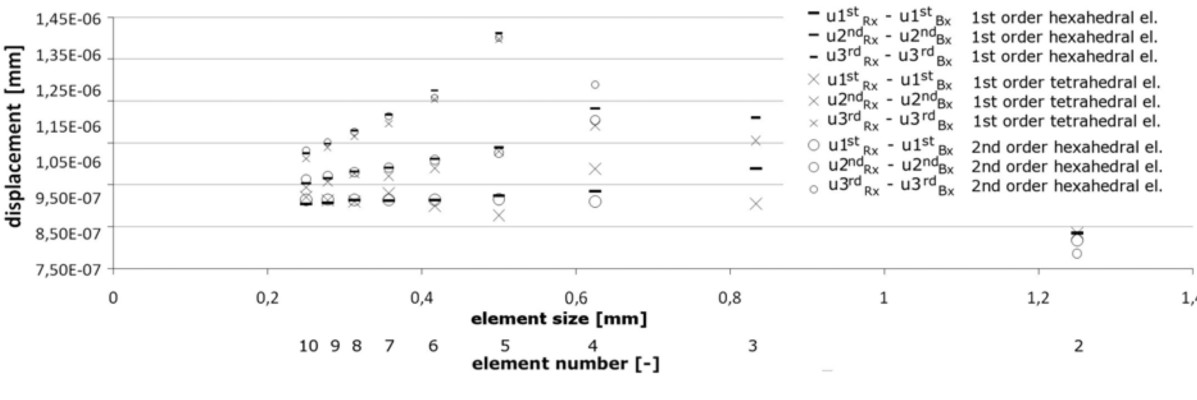

Fig. 4: Displacement differences of 1st, 2nd and 3rd surface nodes in the x-axis direction (signed by Fig.3).

The most of the fatigue crack analyses using the FEM need 1st order elements. The out-of-cylinder mesh quality takes more effect to the inner nodal displacements using the 1st order elements than the 2nd order elements. The bias of the out-of-cylinder mesh decreases with the distance from the cylinder edge. In Fig. 4 there are shown the x-axis displacement differences of signed surface nodes. The 3rd node displacement seems not to alternate a lot anymore and could be suitable for the stiffness determination. The similar analysis was made on the sheet represented by the shell elements as well.

3.2. Methodology for modeling

Since the FE-assembly stiffness must be higher than the experimental in order to keep the ability to tune the connector stiffness, it is necessary to expand the center elements and to include the finer elements around them to reduce the out-of-cylinder mesh bias. The evaluation of the proposed procedure was made by using the experimental test results. The stiffness characteristic of the connecting BUSH type element was set by the part and sheet computed stiffnesses and the experimental stiffness in several steps in order to respect the nonlinearity of the experimental deformation curve. The procedure of the joint stiffness FE-model determination is following:

- Joint geometry determination from the assembly model;
- Joint stiffness determination on the experimental, analytical or numerical basis;
- Joint area mesh design and the FEM stiffness computation of the jointed parts;
- Stiffness characteristic setting of the 1D connecting element.

The formation and application of the stiffness equivalent riveted joints are shown in Fig. 5.

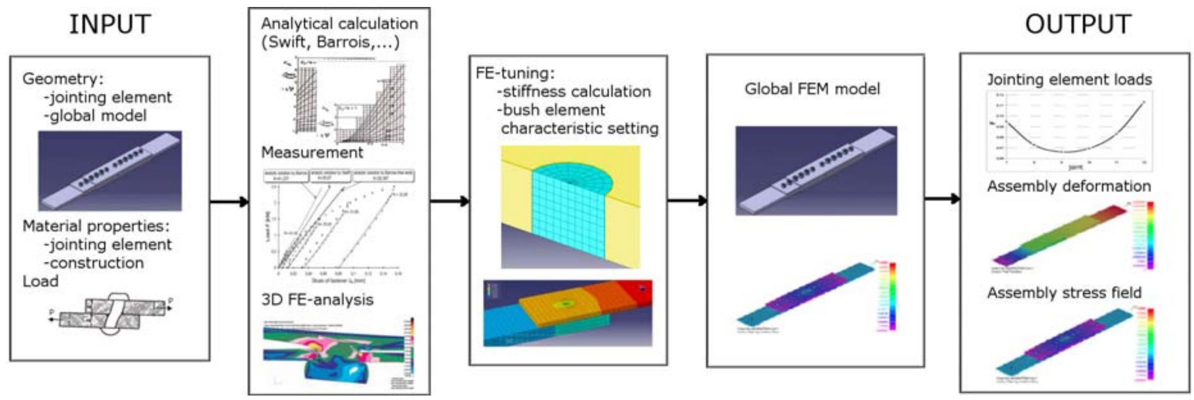

Fig. 5: Formation and application diagram of the stiffness equivalent riveted joints.

4. Conclusions

Crack analyses are affected by the stiffening of the structure due to the connected parts. It is necessary to use simple method to reflect real loading characteristics of the joints in FE-analyses of structures with a large number of rivets. Usage of the 1D element connected to single nodes enables easy preprocessing and gives the possibility to choose the element type and the properties. On the other side it requires the more detailed analysis of the mesh stiffness influence.

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