CONSEIL INTERNATIONAL
DES MACHINES A COMBUSTION

INTERNATIONAL COUNCIL
ON COMBUSTION ENGINES

CO-ORDINATING WORKING GROUP

"CLASSIFICATION SOCIETIES – DIESEL"

(WG2)

Proposal by CIMAC WG4

11th May 2012

IACS UR M53, Appendix VI

"Guidance for calculation of

Stress Concentration Factors

in the oil bore outlets of crankshafts through utilisation of the Finite Element Method"

Contents

1. General

The objective of the analysis described in this document is to substitute the analytical calculation of the stress concentration factor (SCF) at the oil bore outlet with suitable finite element method (FEM) calculated figures. The former method is based on empirical formulae developed from strain gauge readings or photo-elasticity measurements of various round bars. Because use of these formulae beyond any of the validity ranges can lead to erroneous results in either direction, the FEM-based method is highly recommended.

The SCF calculated according to the rules set forth in this document is defined as the ratio of FEM-calculated stresses to nominal stresses calculated analytically. In use in connection with the present method in UR M53, principal stresses shall be calculated.

The analysis is to be conducted as linear elastic FE analysis, and unit loads of appropriate magnitude are to be applied for all load cases.

It is advisable to check the element accuracy of the FE solver in use, e.g. by modelling a simple geometry and comparing the FEM-obtained stresses with the analytical solution.

A boundary element method (BEM) approach may be used instead of FEM.

2. Model requirements

The basic recommendations and assumptions for building of the FE-model are presented in Subsection 2.1. The final FE-model must meet one of the criteria in Subsection 2.3.

2.1. Element mesh recommendations

For the mesh quality criteria to be met, construction of the FE model for the evaluation of stress concentration factors according to the following recommendations is advised:

- The model consists of one complete crank, from the main bearing centre line to the opposite side‘s main bearing centre line.
- The following element types are used in the vicinity of the outlets:
  - 10-node tetrahedral elements
  - 8-node hexahedral elements
  - 20-node hexahedral elements
- The following mesh properties for the oil bore outlet are used:
  - Maximum element size ***a* = *r* / 4** through the entire outlet fillet as well as in the bore direction (if 8-node hexahedral elements are used, even smaller elements are required for meeting of the quality criterion)
  - Recommended manner for element size in the fillet depth direction
    - First layer’s thickness equal to element size of ***a***
    - Second layer’s thickness equal to element size of **2*a***
    - Third -layer thickness equal to element size of **3*a***

- o In general the rest of the crank should be suitable for numeric stability of the solver.
- o Drillings and holes for weight reduction have to be modelled.

Submodeling may be used as long as the software requirements are fulfilled.

2.2. Material

UR M53 does not consider material properties such as Young's modulus (*E*) and Poisson's ratio (*v*). In the FE analysis these material parameters are required, as primarily strain is calculated and stress is derived from strain through the use of Young's modulus and Poisson's ratio. Reliable values for material parameters have to be used, either as quoted in the literature or measured from representative material samples.

For steel the following is advised: $E = 2.05 \cdot 10^5$ MPa and $v = 0.3$.

2.3. Element mesh quality criteria

If the actual element mesh does not fulfil any of the following criteria in the area examined for SCF evaluation, a second calculation, with a finer mesh is to be performed.

2.3.1. Principal -stresses criterion

The quality of the mesh should be assured through checking of the stress component normal to the surface of the oil bore outlet radius. With principal stresses σ_1, σ_2 and σ_3 the following criterion must be met:

$$\min(|\sigma_1|, |\sigma_2|, |\sigma_3|) < 0.03 \cdot \max(|\sigma_1|, |\sigma_2|, |\sigma_3|)$$

2.3.2. Averaged/unaveraged -stresses criterion

The averaged/unaveraged –stresses criterion is based on observation of the discontinuity of stress results over elements at the fillet for the calculation of the SCF:

- Unaveraged nodal stress results calculated from each element connected to a $node_i$ should differ less than 5 % from the 100 % averaged nodal stress results at this $node_i$ at the location examined.

3. Load cases and assessment of stress

For substitution of the analytically determined SCF in UR M53, calculation shall be performed for the following load cases.

3.1. Torsion

The structure is loaded in pure torsion. The surface warp at the end faces of the model is suppressed.

Torque is applied to the central node, on the crankshaft axis. This node acts as the master node with six degrees of freedom, and is connected rigidly to all nodes of the end face.

The boundary and load conditions are valid for both in-line- and V- type engines.

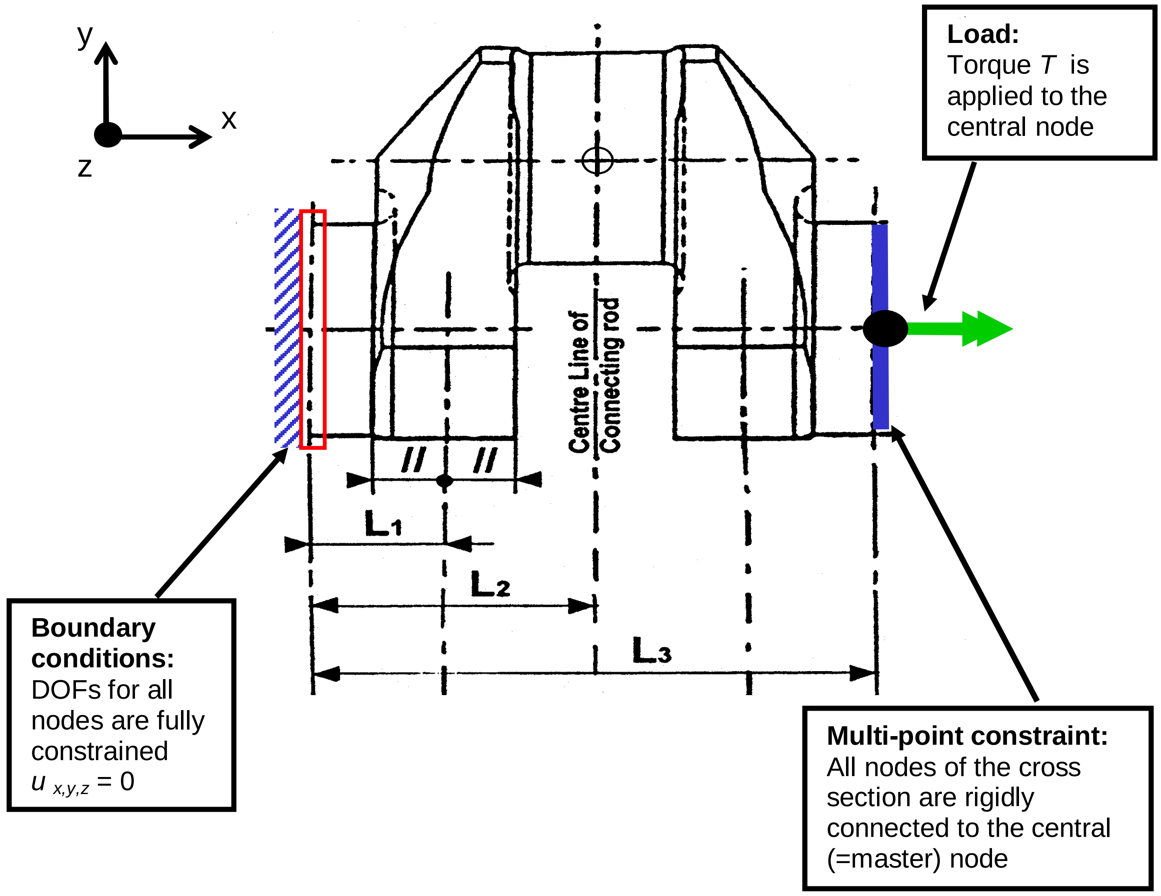

Figure 3.1 Boundary and load conditions for the torsion load case.

For all nodes in an oil bore outlet, the principal stresses are obtained and the maximum value is taken for subsequent calculation of the SCF:

$$\gamma_T = \frac{\max(|\sigma_1|,|\sigma_2|,|\sigma_3|)}{\tau_N}$$

where the nominal torsion stress τ_N referred to the crankpin is evaluated per UR M53's item 2.2.2 with torque T:

$$\tau_N = \frac{T}{W_P}$$

3.2. Bending

The structure is loaded in pure bending. The surface warp at the end faces of the model is suppressed.

The bending moment is applied to the central node on the crankshaft axis. This node acts as the master node, with six degrees of freedom, and is connected rigidly to all nodes of the end face.

The boundary and load conditions are valid for both in-line- and V- type engines.

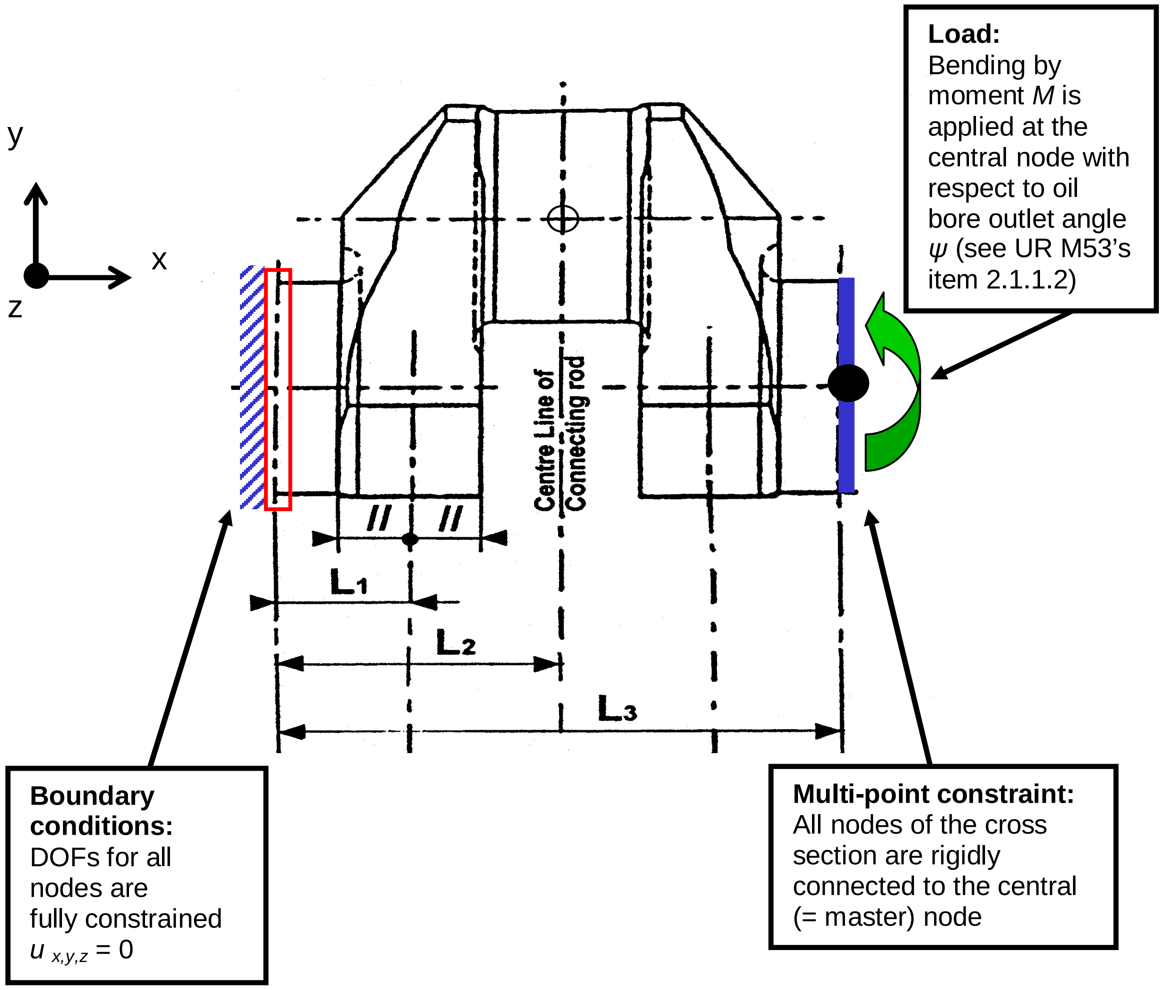

Figure 3.2. Boundary and load conditions for the pure bending load case.

For all nodes in the oil bore outlet, principal stresses are obtained and the maximum value is taken for subsequent calculation of the SCF:

$$\gamma_B = \frac{\max(|\sigma_1|, |\sigma_2|, |\sigma_3|)}{\sigma_N}$$

where the nominal bending stress σ_N referred to the crankpin is calculated per UR M53's item 2.1.2.2 with bending moment *M*:

$$\sigma_N = \frac{M}{W_e}$$