Direct Route Analysis in Preliminary European Standard using Elasto-Plastic FEA

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1. Introduction

Recently, inelastic analyses are increasingly used to optimize passive components for safety and for an economic service operation. The performed direct route analysis is the example case for the application of the check against progressive plastic deformation as stated in the new European standard, Annex 5.B: "Direct route for design by analysis"[1]. To calculate the shakedown limits, Melan's lower bound shakedown theorem was used.

2. Methods and Results

Two different ways of performing calculations to check plastic deformation(PD) are possible: First, if the action cycles for a given structure are specified, a real check can be performed, showing that the actions are admissible or not. The second way is to calculate the limit actions for a given structure, and afterwards using these limit actions to determine the maximum admissible actions. Inthis study, the latter procedure was used[2].

2.1 Procedure for PD check

In the following procedure, it is assumed that the only action acting at the structure under consideration is internal pressure, and that it varies between 0 and the maximum admissible pressure for shakedown $PS_{\max\ SD}$.

The problem in using Melan's theorem is to find an optimal self-equilibrating stress field. Often, the optimal, or a near optimal, stress field can be found from the stress fields at the limit load:

The difference of the linear-elastic stress field at the limit pressure of the structure $(\sigma_{ij})_{le,l}$ and the elasto-plastic stress field at the limit pressure $(\sigma_{ij})_{ep,l}$ is a self-equilibrating field $(\sigma_{ij})_{res}$:

$$(\sigma_{ij})_{res} = (\sigma_{ij})_{ep,l} - (\sigma_{ij})_{le,l}$$

Since one endpoint of the considered linear-elastic load cycle is the point PS=0, the self-equilibrating stress field used in Melan's theorem must not violate the yield condition itself. Therefore, the self-equilibrating stress field $(\sigma_{ij})_{res}$ has to be scaled with a factor such that it does not violate the yield condition:

$$(\sigma_{ij})_{res,co} = \beta(\sigma_{ij})_{res}$$

If the uncorrected self-equilibrating field according to the limit loads $(\sigma_{ij})_{res}$ does not violate the yield condition, the shakedown load is not smaller than the limit load.

After this correction of the self- equilibrating stress field, the linear-elastic stress field with the possible greatest value of internal pressure has to be determined, such that the superposition with the corrected self-equilibrating stress field does not violate the yield condition. The stress field at a lower bound shakedown limit $(\sigma_{ij})_{SD}$ is found as

$$(\sigma_{ij})_{SD} = (\sigma_{ij})_{res,co} + \alpha\,(\sigma_{ij})_{le,l}$$

The scaling factor α and β can be determined easily using the equivalent stress plots[3].

2.2 Analysis Model

The geometry of the considered welded-in flat end is shown in Fig. 1. The material of the structure is P265GH according to EN 10028-2, and the service temperature is specified with 20°C. In the finite element model, a total number of used element is 2690 and the element type in ANSYS program is 4-node axisymmetric solid elements PLANE42. The boundary conditions applied in the model are symmetry ones in the nodes in the center of the plate and constraining the vertical degree of freedom in the nodes at the undisturbed end of the cylindrical shell to zero.

2.3 Analysis Results

The elasto-plastic FE analysis as shown in Fig. 2- Fig. 5 was carried out using Mises' yield condition and associated flow rule, a linear-elastic ideal-plastic constitutive law with design material strength parameters of 255 MPa for the shell and 245 MPa for the plate, and first order theory. Also, the analysis in the stress categorization route as shown in Fig. 6 was performed for the example case and the analysis results were compared to the results by the direct route analysis as shown in Table1.

3. Conclusion

The direct route method in PD check provides a simple and robust method for calculating lower bound elastic shakedown loads using conventional finite element software. The calculated limit pressure according to PD check procedure have been verified by the comparison with the analysis results in the stress categorization route[4,5]. This example indicate that the proposed method yields accurate lower bound shakedown loads with minimal analysis.

Acknowledgements

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REFERENCES

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[5] European commission, The Design by Analysis Manual, 1999

Table1 Analysis results for welded-in flat end

Design check	Limit Pressure		Remarks
	Direct route in PD check	Stress Categorization route	
Units (MPa)	13.3	12.5	

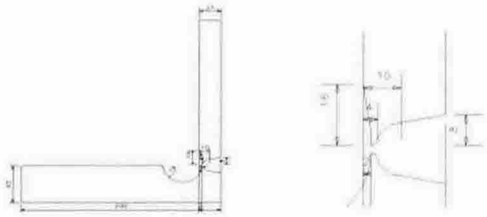

Fig. 1 Configuration of the welded-in flat end

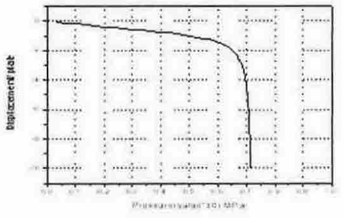

Fig. 2 Vertical displacement of the plate versus the internal pressure

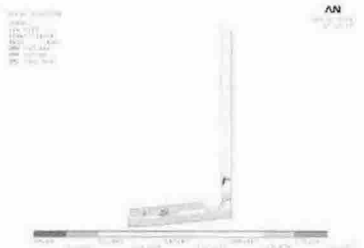

Fig. 3 Elasto-plastic Mises equivalent stress distribution at limit pressure

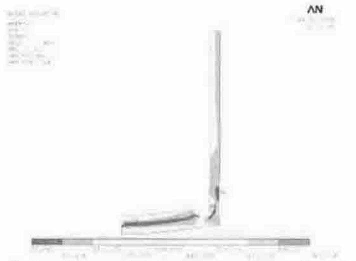

Fig. 4 Linear elastic Mises equivalent stress distribution at limit pressure

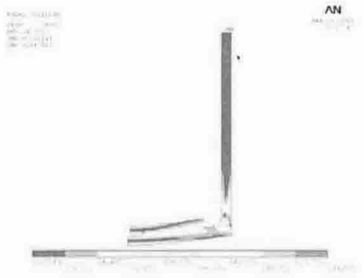

Fig. 5 Mises equivalent stress of corrected residual stress field

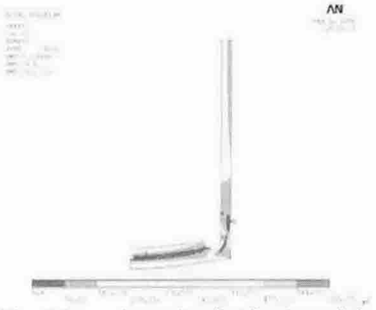

Fig. 6 Stress intensity distribution of elastic analysis