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Calibração de Modelo de Método dos Elementos Finitos por Comparação com o Método Experimental: Caso de Chapa com Furo no Centro

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Resumo: No contexto do método dos elementos finitos (MEF), uma tarefa fundamental é a sua validação pelo método experimental. Esse tipo de validação é realizado para evitar outros experimentos análogos para situações semelhantes, o que pode reduzir o custo com protótipos. Neste artigo, é realizada uma análise paramétrica de 15 modelos diferentes de placas com furos no ANSYS®, cujos valores são comparados a uma equação gerada por uma série de experimentos. O diâmetro do furo é a variável parametrizada, mantendo os demais parâmetros constantes. Diante dos resultados, é possível evitar a realização de novos experimentos para uma determinada faixa de valores, bastando obter os fatores de concentração de tensões via cálculo parametrizado na faixa de validação dos modelos.

Palavras-chave: Método dos elementos finitos; Calibração de modelo; Chapa com furo.

Calibration of a Finite Element Method Model by Comparison with the Experimental Method: Case of Plate with Hole in the Center

Abstract: In the context of the finite element method (FEM), one fundamental task is its validation through the experimental method. This type of validation is performed to avoid another analogous experiments for similar situations, which can reduce the cost with prototypes. In this paper, a parametric analysis is conducted over 15 different plate with hole models in ANSYS®, which values are compared to an equation generated by a series of experiments. The hole diameter is the parameterized variable, keeping the other parameters constant. In view of the results, it is possible to avoid the execution of new experiments for a certain range of values, being enough to obtain the stress concentration factors via parameterized calculation in the range covered by the models.

Keywords: Finite element method; Model calibration; Plate with hole.

Introduction

Finite element modelling is relevant in product development process, allowing the reduction of necessity for physical testing and shortening the product development cycle. However, to extract the most accurate predictions, the model parameters have to be determined to obtain a good agreement between the reality and the model. Initial finite element models are often corrupted by uncertainties in boundary conditions, material properties, geometry, etc., which may imply in significant deviations from the reality [1]. In order to make accurate predictions, the process of calibrating the finite element model, also

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known as finite element model updating, is frequently required. One of the most common manners to calibrate the model is by comparing with the available experimental data [2].

The calibration process commonly comprises static and/or dynamic conditions. This process encompasses the adequate selection of calibrating parameters, optimization, and/or trial and error approach [3]. The optimization refers to minimizing the error between testing data and those from calculation of a given material model. The output of calibration process is the determination of the parameter values in the model that establishes the best agreement between experimental and calculation.

The stress level at some point, line, or surface of the discontinuity achieves its highest stress level, $\sigma_{\max}$, and, when compared to the nominal stress, σ_{nom}, introduces the stress concentration factor (SCF) quantity, mathematically expressed by k in Equation 1. Therefore, the absolute value of the percent relative error between $k_{\exp}$ (obtained via experiment) and k_{mod} (obtained via finite element model) is given by Equation 2 [4].

$$k = 2 + 0.284\left(1 - \frac{d}{H}\right) - 0.600\left(1 - \frac{d}{H}\right)^2 + 1.32\left(1 - \frac{d}{H}\right)^3 \quad (1)$$

$$\varepsilon(\%) = \frac{\left|k_{\mathrm{mod}} - k_{\exp}\right|}{k_{\exp}} 100 \quad (2)$$

Therefore, in this paper a calibration of a parameterized finite element method model (case of plate with hole in the center) is performed by comparison with the experimental result. The calibration parameter dealt herein is the medium element size of the mesh in the proximities of the stress concentrator, thus checking the agreement of the SCF obtained via mathematical expression derived from experiments, and the one obtained via MEF.

Objective

The main objective of this paper is to calibrate the finite element models in ANSYS® in order to have the lowest possible disagreement between the experimental results and those obtained from finite element calculation.

Material and Methods

In order to simplify the model to speed up simulations, just one fourth of the plate with hole is shown in Figure 1, which includes its dimensions and the imposed conditions.

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Symmetry conditions about x- and y-axis were applied. The pressure of 200 MPa is applied at "A" and two displacement restrictions were also applied. A restriction of zero displacement in x-axis is imposed at "B", and a restriction of null displacement is set up in y-axis at "C". The material and geometrical input data are described in Table 1. After a convergence study, the medium triangular element size of 0.05 mm was selected.

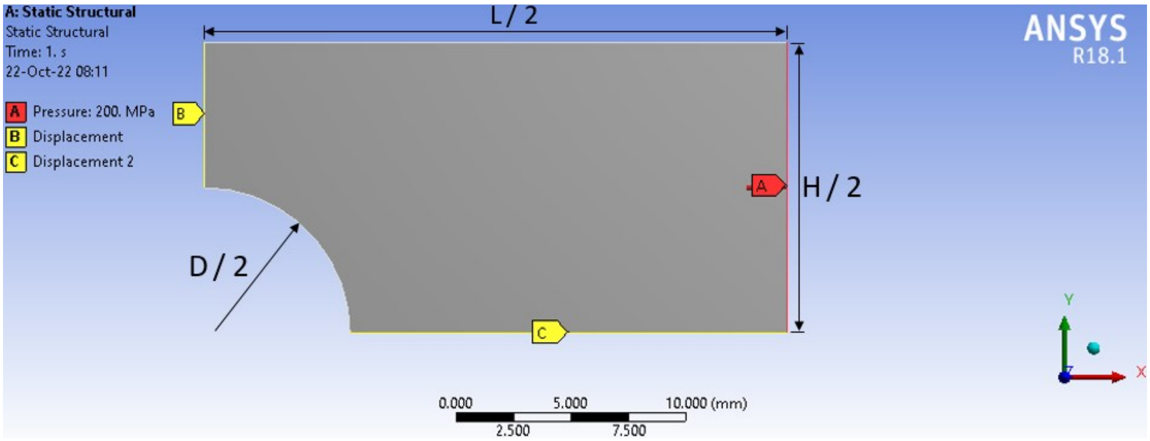

Figure 1. Plate with hole with the imposed loading conditions, support definitions, and geometrical parameters. Source: own authorship (2022).

Table 1. Material and geometrical input data. Source: own authorship (2022).

Geometrical data	Value	Material data	Value
Plate thickness, t, (mm)	12.700	Yield strength, S_y, (MPa)	931.000
Plate width, H, (mm)	25.400	Poisson's ratio, ν	0.290
Plate length, L, (mm)	50.800	Elasticity modulus, E, (GPa)	205.000

Results

Table 2 shows the results obtained throughout FEM calculation. For each D/H ratio, an experimental SCF and a FEM SCF are obtained to be compared.

Table 2. Comparison between SCFs from experimental (Equation 1) and FEM (ANSYS®). Source: own authorship (2022).

D/H	Experimental SCF	FEM SCF	D/H	Experimental SCF	FEM SCF
0.050	2.860	2.858	0.450	2.194	2.217
0.100	2.732	2.733	0.500	2.157	2.186
0.150	2.619	2.622	0.550	2.127	2.163
0.200	2.519	2.525	0.600	2.102	2.145
0.250	2.432	2.440	0.650	2.082	2.130
0.300	2.538	2.367	0.700	2.067	2.118
0.350	2.294	2.307	0.750	2.054	2.105
0.400	2.240	2.624	-	-	-

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Discussion

A more complex model (dotted with more information) commonly has a higher potential to better correlate the experimental with the computational. The ability of a model to reliably reproduce the experimental results depends on the complexity of the model, but there is a limit bounded by cost and feasibility. Therefore, there is a natural interest in investigating how complex a model has to be to fulfill the requirement of strong correlation between experimental and model data.

In terms of the response, Figure 2 presents von Mises stress plot for the case with $D/H = 0.500$. The maximum equivalent stress occurs at the point indicated by the red flag "Max", as expected, while the minimum levels of stresses were expected to occur in the blue regions of the part.

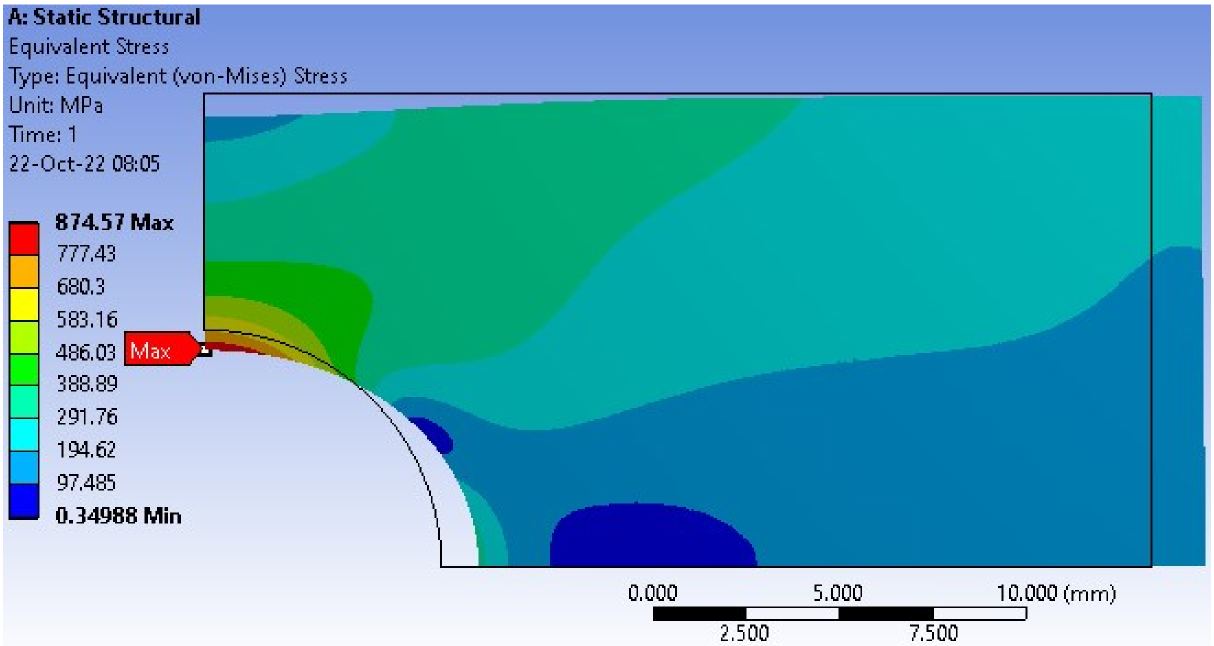

Figure 2. Von Mises stress plot for $D/H = 0.500$. Source: own authorship (2022).

Table 3 presents the relative error between experimental and FEM SCFs. For lower values of D/H ratio, the relative error corresponds to values lower than 1%. For higher values of D/H ratio, the relative error shows an upward trend. The specific ratios $D/H = 0.300$, and $D/H = 0.400$ differ from the other values.

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Table 3. Relative error related to SCFs from experimental (Equation 1) and FEM (ANSYS®). Source: own authorship (2022).

D/H	**Relative error (%)**	D/H	**Relative error (%)**
0.050	0.072	0.450	1.048
0.100	0.039	0.500	1.346
0.150	0.122	0.550	1.658
0.200	0.225	0.600	1.996
0.250	0.324	0.650	2.266
0.300	7.201	0.700	2.394
0.350	0.546	0.750	2.440
0.400	14.625	-	-

If, for example, a criterion of 3% is imposed for the relative error between the experimental and the FEM SCFs, then the only two ratios to be improved are $D/H = 0.300$, and $D/H = 0.400$. Their corresponding percentages, 7.201%, and 14.625%, respectively, are comparatively higher than the others, which are inacceptable in a more accurate analysis. However, if a criterion of 1% in relative error was imposed, most of the ratios would be non-compliant, emphasizing the need to recalibrate the FEM model.

Conclusions

This paper presented the comparison between experimental and finite element model results for the stress concentration factor of a plate with hole under tension. This comparison was made in order to calibrate the finite element model by its element size, possibly avoiding the execution of new experiments, being enough to obtain the stress concentration factors via parameterized finite element calculation in the range covered by the models.

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