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Aspects of the Analysis "In Situ" of the Remaining Mechanical Stresses with "Blind Hole" Method for a Technological Equipment

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Abstract

The publication highlights the tensions are remaining in the mantle of vertical cylindrical tank under rolled on construction generated by the technological process of manufacturing and assembly. Experimental testing is applied "in situ" on a "new" tank, type standard 2000 m^3 with a fixed cover, located on an industrial transport petroleum product. It applies the resistive electric tensometric method, experimental-numeric hybrid semi-destructible proceeding of "blind hole". To determine the specific dimensional parameters geometric characteristics of the special transducers used in the paper apply to a genuine process of calibration by FEM numerical simulation, for different values of simplexes appeals D_0/D, h_i/D.

Key words: *blind hole, remaining, transducers, tensometric method, numerical simulation.*

Introduction

To put the record the remaining tensions in vertical cylindrical mantle tanks into rolled construction, generated by the technological process of implementation, the experimental tests are applied "in situ" on a "new" reservoir type standard RCV 2000 with a fixed cover, before calibration phase, located on a platform of industrial transport petroleum products. It applies the electrical resistive tensometric method (ERTM), the experimental-numerical hybrid semi destructive proceeding of "blind hole" [1, 2, 3], respective numerical and operating with finite element method (FEM) [2, 4].

Blind Hole Principle

The effectuation of a hole - just with a very small diameter - in a geometrical solid with residual mechanical stresses, relaxes the tensions in the location zone of the respective hole. The elimination of tensions by the surface of hole conducts to the change of tensions status in the adjacent area of respective hole, which causes that local deformations of the area it to be change corresponding. This principle is the basis of the measuring residual stresses method, it is called the *"hole - drilling"* principle. To determine the residual tensions in the particular case of a thin shell in the flat and uniform state of tensions it applies *through - hole* method, agency the practice of a small diameter hole, D_0, which crosses the entire thickness h of wall. The theoretical foundation of method is based on Kirsch problem in elasticity theory concerning on the variation of tensions in the vicinity of through hole.

In most practical cases the as shells with thick wall, various organs of machines, the bodies, carcasses and frames of machines, the punching of a structural component is practically impossible to achieve technically and also nonconforming with the requirements of the *through - hole* method; also in the case of apparatuses, tanks, technological equipments a.s.o., the punching *"in situ"* of the mantle endangers the structural integrity and functionality of respective equipment. For these cases, in the electrical resistive tensometric method it operates with technique of the "non-through" hole practice generic called *blind hole method* (in the literature of Anglo-Saxon language being called *blind - hole* method of analysis) [1]. The problem was solved by U.S. researchers Rendler and Vigness which put the foundation of a technique for analysis in *blind - hole* method by extending the constitutive laws of response from the *through - hole* method, provided the requirements of this method are fulfilled [5].

In the *blind hole* method, the calculation coefficients A and B, can not be analytically determined by direct theoretical approach (based on Kirsch formulas), these are being evaluated through experimental calibrations on models [1] or numerical techniques operating with the finite element method [1, 4, 6].

Compared with the method *through hole*, in the *blind hole* method the calculation coefficients A and B depend on additionally an independent variable which is represented by the depth hole, grade h. This variable is entered into calculus by dimensionless geometrical simplex h/D shown in figure 1, so it results from the generalized formulation (1),

$$A=f_A(E, \mu, h/D), \quad B=f_B(E, \mu, h/D). \tag{1}$$

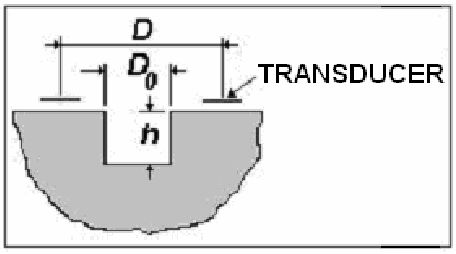


Fig. 1 The dimensionless geometrical parameter *h/D*

The experimental tests carried out on papers [5, 7], showed that for the same material, a level of residual tensions default (σ_{tank} = constant), a fixed diameter D_0 and for the same type of tensometric rosette specific *blind hole* method (D = constant, respective D_0/D = constant), the specific strains of relaxation increase from step i to step $i+1$ as the depth of drilling hole h_i is growing, as result from the dependence curve between dimensionless geometrical simplex h_i/D and specific relaxation normalized strains value of 100% for h_i/D = 0,4, shown in figure 2, it is noted dimensional threshold $h_i = 0,4 \cdot D$ from which the dependency curves have a stabilized monotone variation, they accept an parallel asymptote to the horizontal axis.

Experimental results further developed in accordance with standard ASTM E 837 - 2001 under a research program supported by Residual Stress Technical Division of the Society for Experimental Mechanics and ASTM Subcommittee E 28.13, showed the influence of the hole diameter D_0 on a wide range of variation of the dimensionless geometric parameter D_0/D I accordance with tensometric rosettes manufactured today.

Thus, figure 3 it shows the curve of dependence between dimensionless geometrical simplex h_i/D_0 and specific strains of normalized relaxation value of 100% for $h_i/D_0 = 1,2$, in the field $D_0/D = 0,3 \ldots 0,4$, it is noted the value of the drilling depth $h_i = 1,2 \cdot D_0$ from which dependence curves are stabilized, specific strains relaxed reaching the maximum value.

Rendler and Vigness notes that the parameters of calculation *A* and *B* - the same material characterized by elasticity module longitudinal Young and Poisson's coefficient, *E*, respectively

μ - depends only of the typical geometrical dimensions of the tensometric rosettes and the blind hole depth h_i.

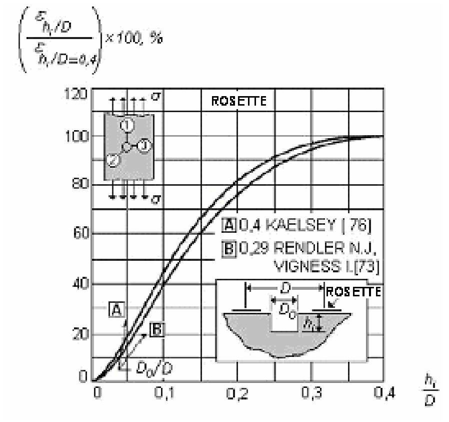


Fig. 2. Variation curve dimensionless geometrical simplex h_i/D depending on the specific strains of relative relaxation, normalized value of 100% for *h_i/D = 0,4.*

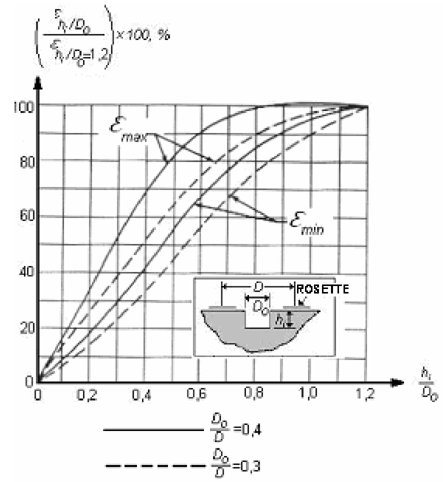


Fig. 3. Variation curve dimensionless geometrical simplex h_i/D depending on the specific strains of relative relaxation, normalized value of 100% for *h_i/D = 1,2.*

Thus, Schajer [4] reiterates the parameters of calculation A and B, introducing a and b coefficients,

$$a = \frac{2EA}{1+\mu}, \quad b = -2EB, \tag{2}$$

whose values are dependent only by geometrical simplex $r = D/D_0$, independent of material. In the paper [6], Schajer, determines the calculation coefficients a_i and bi according to the dimensional parameters h_i/D, D_0/D for a wide range of types of rosettes using the finite element method.

The "in situ" Determination of the Remaining Mechanical Stresses for the Standard Tank Type RCV 2000 with Fixed Cover into Rolled Construction

For this purpose, for each point of measurement are used rosettes with three special transducers type Hottinger *RY 21 3/120* code. Experimental tests are carried out in accordance with standard *ASTM E 837 - 01 "Standard Test Method for Determining Residual Stresses by the Hole-Drilling Strain-gauge Method"* [1].

For determining the dimensional parameters *a*, *b*, specific to the geometric characteristics of the transducers type Hottinger *1-RY 21 3/120* code, the paper applies an original calibration process by numerical simulation MEF, for different values of simplex attacks D_0/D, h_i/D, based on the methodology described in the preceding paragraph. This numerical approach was necessary because the dimensional parameters *a*, *b*, are not found in standard *ASTM E 837 - 01* for simplex attacks D_0/D, h_i/D specific to the geometrical features of the transducers HBM *1-RY 21 3/120* type. The calibration plate - test dimensions 650x650x7 mm is modeled through 6720 finite elements with eight knots on the element called *SOLID*, interconnected in 7688 meshing nodes. The model calibration process in figure 4 is applied to simple compression after *OZ* general axis. Controlled mechanical tension, representing calibration tension σ_{cal} is provided by the condition $\sigma_{cal} = \frac{N}{sB} \leq \frac{1}{3} R_{P0,2} = 80MPa$, the technical flow limit for steel used S235JR (OL37.2k) is $R_{p0,2} = 240MPa$. In figure 5 is presented in detail meshing area in the blind hole. To increase the sensitivity of the model additional with the selection of the response points with concentrated tensions, after practice the hole, finite elements in contact with tensometrice transducer have the height of 0,082 mm (see figure 5. b).

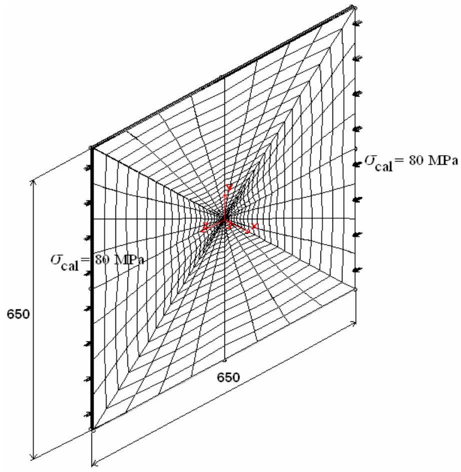
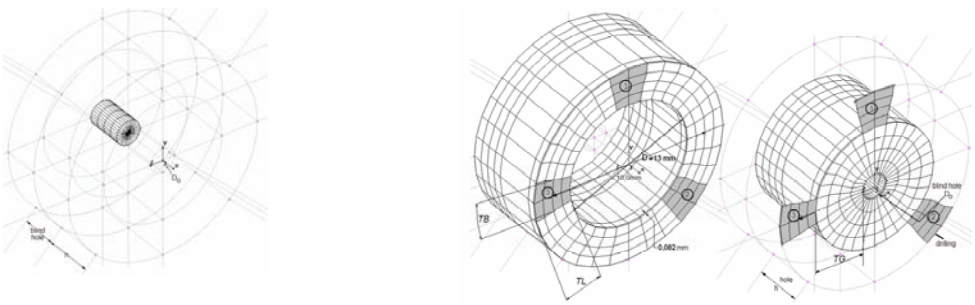


Fig. 4. General model for analysis and the type of solicitation for the shell used

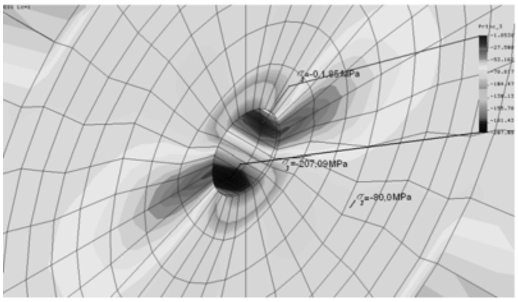


a. **b.** **c.**

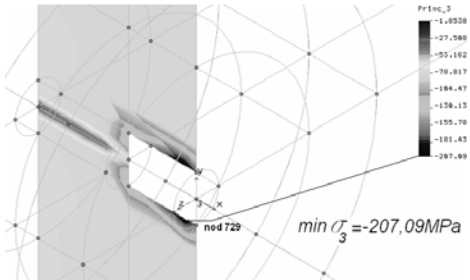
Fig. 5. Meshing model of the blind hole: a blind hole middle with diameter D_0 = *2 mm*; b. shell area related to active integration areas *TLxTB = 3x2, 5* mm of the transducers placed after circle of the geometric centers with a diameter *D = 13 mm*; c. Active area of transfer for relaxed specific strains from the outlines hole diameter D_0 = *2 mm* to tensometrice transducers with *TG = 4 mm*.

Calibration plate - test remain permanently in elastic domain of solicitation after progressively practice hole, as it show from the results presented in the distribution maps of mechanical tensions in areas with tensions concentrators, in figure 6, processed on the outlines of the model and sections in areas with tensions concentrators, for maximum depth $maxh_i = 3,0\ mm$. Thus, in first theory of resistance ($T\sigma$), in the case examined the theory that more severe, $\sigma_{ech}^{T\sigma} = \max\left[|\sigma_1|\,|\sigma_2|\,|\sigma_3|\right] = 207,09 < R_{PO,2} = 240MPa$. For calibration of the parameters a and b, from the set of results obtained by the FEM are extracted the specific strains (ε_y, ε_z and γ_{yz}), corresponding with the finite element related tensometric transducers of the rosettes.

Based on these numerical results are determined the dependency curves of the calculating parameters *a*, *b*, depending on attacks simplex D_0/D, *h/D*, processed in the figures 7.a respectively 7.b.

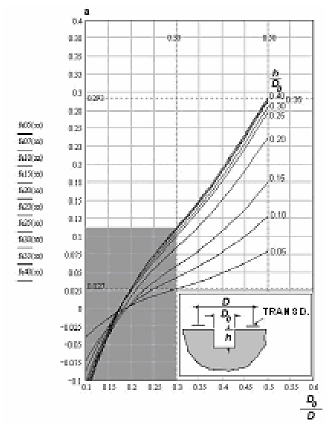


a.

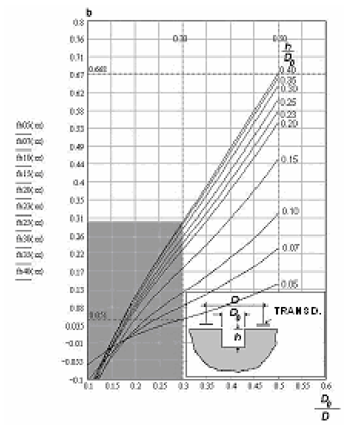


b.

Fig. 6. Distribution map of the principal mechanical stress σ_3 in areas with concentrators tensions after practicing progressively the hole depth for *maxhi = 3.0 mm*: a. the outlines of the model; b. in the section *Z = 0*.



a.



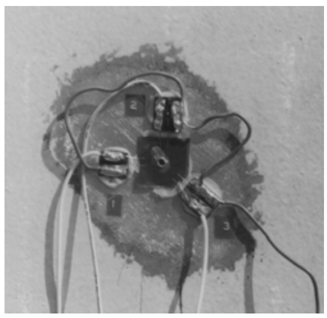
b.

Fig. 7. Dependency curves of the calculating parameters *a* and *b*, depending on attacks simplex D_0/D, *h/D*.

Areas marked in figure 7. a, b are conform with domain $0,1 < D_0/D < 0,.4$ and covers the calculating parameters for the traducers Hottinger type *RY 21 3/120* code and represent the variation domain of the parameters *a*, *b* for transducers VISHAY *A, B, C* type, recommended by the standard *ASTM E 837 - 01*.

In figure 8 are presented tensometric rosettes and cable lay-up according with the two points of measurement P1 and P2 located on the base of the shell.

a.



b.

Fig. 8. Tensometric rosettes mounting in the points of measurement: a. P1, b. P2

Base on the specific strains assessed according to *ASTM E 837 - 01* standard, measured with a Hottinger tensometric deck and methodology presented, were calculated the mechanical tensions systematized in Table 1.

Table 1. Mechanical tensions determined in situ by MTER in case of 2000 m^3 RCV

Point	σ N/mm²	σ N/mm²	β degrade
P_1	13,4	+90,3	$0,198^0$
P_2	-10,1	-106,9	$37,14^0$

The Particularities of Analyzed Case

The induced residual tensions by the technological proceeding of making through roll-on process of the mantle, represent approximately 45% of the technical ductility limit for used steel S235JR (OL 37.2 k). These important tensions are quasi-permanent, and therefore, according to the requirements of the new verification norms aligned to European codes, should be placing them in standardized groups of the action effects as well the final limit state, *FLS*, as the work limit state, *WLS*; it appeals to the superposition of action effects principle of - acceptable in elastic behavior - through factorized combination of residual tensions with resulted mechanical tensions from their own weight, permanent mechanical tensions, pressure, the weather - , seismic action a.s.o..

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Considerații privind analiza “ in situ “ a tensiunilor mecanice remanente prin metoda găurii oarbe (“blind hole”) la un echipament tehnologic

Rezumat

În lucrare se evidențiază prezența tensiunilor remanente în mantaua cilindrică verticală a rezervoarelor în construcție rulată, generate de procedeul tehnologic de execuție. Încercările experimentale sunt aplicate " in situ " pe un rezervor " nou " de tip standard de 2000 m^3 cu capac fix, amplasat pe o platformă industrială de transport produse petroliere. Se aplică metoda tensometriei electrice rezistive (MTER), procedeul hibrid experimental-numeric semidistructiv al găurii oarbe ("blind hole"). Pentru determinarea parametrilor dimensionali specifici caracteristicilor geometrice ale traductoarelor speciale utilizate, în lucrare se aplică un procedeu original de calibrare prin simulare numerică MEF, pentru diferite valori ale simplexurilor de atac D_0/D, h_i/D.