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EVALUATION OF STRENGTH OF OIL PIPELINES WITH DEFECTS TAKEN INTO CONSIDERATION

Damages of oil pipeline's sections during the maintenance put it often out of operation or cause temporary stops, which as the result involves considerable financial costs. Therefore, the elaboration of efficient methods is an actual task for the estimation of possible consequences of damages and destructions of some sections and oil pipeline as a whole taking into account real defects.

Such estimation requires a fulfillment of complex research works, both of destruction mechanisms and kinetics of growth of weary defects and cracks.

Depending on the consequences, caused by a damage of the pipeline's section, they are classified for "hazardous" and "non-hazardous".

Damages can be divided conventionally into 3 classes:

- The damages, related to an insufficient strength, for ex., due to an incorrect application of structural norms or accidental overloads;
- The damages, related to macroscopically not localized accumulation of defects like corrosion sores or erosions;

Among main methods of making prognosis of resource of the oil pipeline became methods based on the mechanics of destruction. A statistic nature of the distribution of heterogeneities in the details of machines brings to the fact that natural full-scale tests of the details with the usage of their results for a further estimation of the resource are first and foremost.

The process of appearance of weary destruction is convenient to examine, dividing it into four stages, as it is shown in Fig.1.

A traditional approach to making prognosis of weary strength in its simplest form is shown in Fig.2 and includes in itself static and cyclic tests of oil pipeline's sections and its separate parts.

The traditional method of safety estimation of the period of service of the oil pipeline's sections confirmed its correctness for a number of years, preventing appearance of damages during the maintenance.

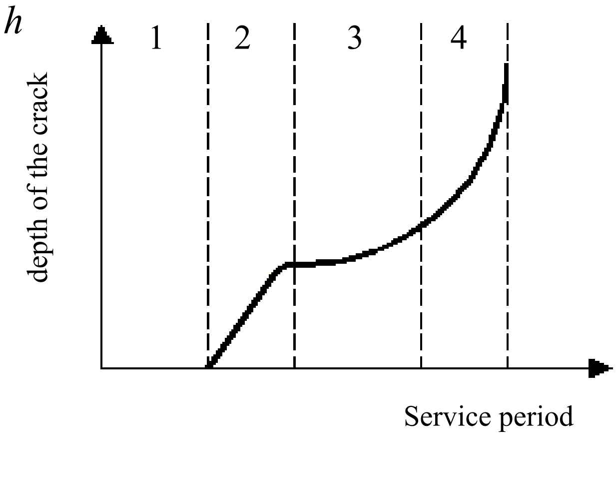

Fig.1. Weary destruction stages

1 - Stage of the crack's origin;
2 - Growth of short cracks;
3 - A stable growth of long cracks;
4 - A quick growth of cracks and ruptures

However, two main problems aroused for the last years, related with this method:

- It was found out, that most of the materials contain heterogeneities, which is especially actual with a aroused tendency of the application of high-strength materials;
- Traditional methods require removal out of the maintenance and repair of all sections of the pipeline when “hazardous defects” are founded.
  As the result of this, most of the damaged sections are removed out of the maintenance with a considerable unused part of the safety period of service due to a static destruction nature; meanwhile a degree of the pipeline usage in this case is not high.

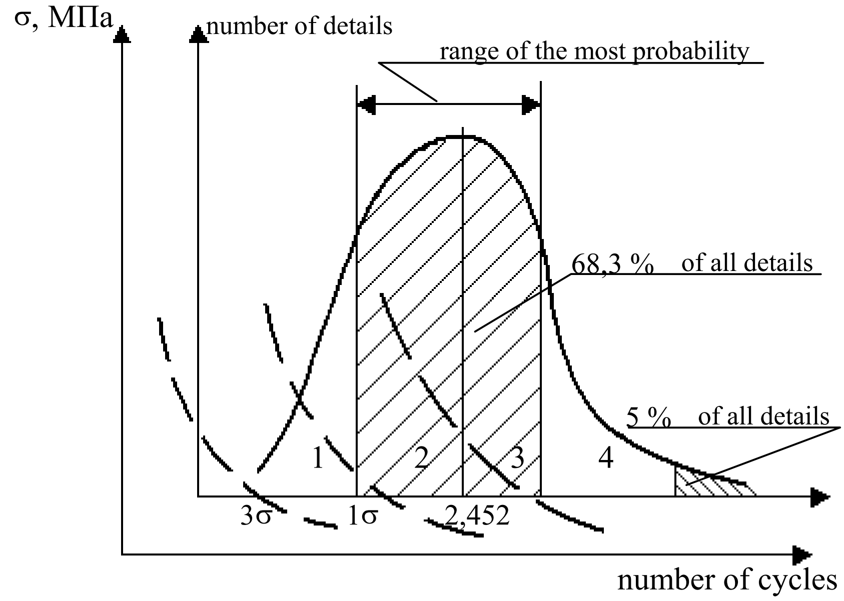

Fig.2.

Main structural strength theories, based on the approaches of mechanics of destruction, propose researching of the following questions:

1. The estimation of size of the initial crack, the presence of which is probable in the material;
2. The examination of a stressed condition and the estimation of power destruction parameters, taking into account geometry and a crack inclination angle, influence of the structural concentrator and a volume of the condition under stress;
3. The estimation of the characteristics of the growth of a material’s cracks, out of which the detail is made.

   In order to elaborate a prognosis model, an exact evaluation and calculations of stresses in the detail are necessary.

   Modern technologies of the strength calculation of the oil pipeline sections are presented in the paper, based on the modern CAD/CAM/CAE complexes and the last achievements in the mechanics of a deformed solid body and in the mechanics of destruction.

   A computing end-element ANSYS 5.5.3.[1] was used for a numeric calculation of the stressed-deformed condition in the field of oil pipeline’s defects.

STATEMENT OF THE TASK

The calculation of stresses in the field of the defect at the section of the pipeline was executed as per the equation:

$$\{\sigma\} = [D]\ \{\varepsilon^{el}\}, \tag{1}$$

since $\{\sigma\} = [\sigma_x\ \sigma_y\ \sigma_z\ \sigma_{xy}\ \sigma_{yz}\ \sigma_{xz}]$ - vector of stresses
$[D]$ -Matrix of elasticity;
$\{\varepsilon^{el}\} = \{\varepsilon\} - \{\varepsilon^{th}\}$ -massif of elastic deformations;

The deformations were defined as follows:

$$\{\varepsilon\} = \{\varepsilon^{th}\} + [D]^{-1}\ \{\sigma\}, \tag{2}$$

vector of the temperature deformations is defined as the correlation

$$\{\varepsilon^{th}\} = \Delta T\ [\alpha_x\ \alpha_y\ \alpha_z\ 0\ 0\ 0\ ]^T, \tag{3}$$

since α_x- coefficient of the temperature expansion towards the central line x,
$\Delta T = T - T_0$;
T – current temperature in the concerned point;
T_0-temperature, when no deformation occur.
The matrix $[D]^{-1}$, normalized per columns, shall be recorded as:

$$[D]^{-1} = \begin{vmatrix} 1/E_x & -\nu_{xy}/E_y & -\nu_{xz}/E_z & 0 & 0 & 0 \\ -\nu_{yx}/E_x & 1/E_y & -\nu_{yz}/E_z & 0 & 0 & 0 \\ -\nu_{zx}/E_x & -\nu_{zy}/E_y & 1/E_z & 0 & 0 & 0 \\ 0 & 0 & 0 & 1/G_x & 0 & 0 \\ 0 & 0 & 0 & 0 & 1/G_y & 0 \\ 0 & 0 & 0 & 0 & 0 & 1/G_z \end{vmatrix} \tag{4}$$

Let’s rewrite the equation (2) in the detailed form:

$$\left.\begin{aligned} \varepsilon_x &= \alpha_x\ \Delta T + \sigma_x / E_x - \nu_{xy}\ \sigma_y / E_y - \nu_{xz}\ \sigma_z / E_z\ ; \\ \varepsilon_y &= \alpha_y\ \Delta T + \sigma_y / E_y - \nu_{xy}\ \sigma_x / E_y - \nu_{yz}\ \sigma_z / E_z\ ; \\ \varepsilon_z &= \alpha_z\ \Delta T + \sigma_z / E_z - \nu_{xz}\ \sigma_x / E_z - \nu_{yz}\ \sigma_y / E_z\ ; \\ \varepsilon_{xy} &= \sigma_{xy} / G_{xy}\ ; \\ \varepsilon_{yz} &= \sigma_{yz} / G_{yz}\ ; \\ \varepsilon_{xz} &= \sigma_{xz} / G_{xz}\ , \end{aligned}\right\} \tag{5}$$

since ε_x - deformation toward the central line X;

ε_{xy} - deformation of shear in plane x-y;

σ_x - of stress towards central line x

σ_{xy} - stress of shear in plane x-y;

Components with other indices are received by a cyclic shear (x-y-z).

Digital simulations of stresses and deformations when analyzing defects in the elements of the oil pipeline by the method of end elements [2], as a rule, are connected with the solution of linear homogenous equations, meanwhile "a frontal method" is widely used there. The application for calculations of special methods of storage and handling of matrixes discharged of large sizes increased considerably the velocity of calculations and minimized the volume of the required disc memory. When making numeric researches of the pipeline's sections with the defects found out, for which presence of large discharged matrixes is typical, iteration methods founded the biggest spreading, which modify matrixes preliminary for receiving of approximate decision of the system of linear homogenous equations.

A variety of iteration methods were used in this work for the decision of discharged matrixes – the method of stipulated conjugated gradient [2]. In comparison with the frontal method, which decides the equation method directly, the method of stipulated conjugated gradients firstly transforms the equations system into the form: $\{P\}=\{u\}^T[K]\{u\}-\{u\}^T[F]$ by means of multiplication of each part of matrix equation by $\{u\}^T$ and displacement of items in one side. The application of the method of stipulated conjugated gradients reduces the time of the decision of the task in comparison with the application of the frontal method in dozen times and it is more efficient, provided the bigger is the size of the calculated model of the oil pipeline.

The results. The geometry of the pipeline's section is described by means of a mixed marginal representation and parametric cubic equations. Building of a spacious structure of the pipe's section with a defect was carried out in the medium of pre-processor PREP7 with the usage of the system of the commands of the creation and edition of graphic primitives, among which are as follows: building of cross lines of arbitrary surfaces and volumes, making them roundish, finding out geometric curves and etc.

An example of end-element model of a section of the pipe of the oil pipeline is shown in Fig.1, which is the subject of the given numeric examination.

The generation of volumetrical ultimate-element model of the oil pipeline's section was executed, as a rule, by means of 20-unit ISO- parametric elements of the second order. The simulated defects of the oil pipeline were distinguished both as per a location place, by a form, as well as per a depth of bedding. The SDS calculation in the element of the oil pipeline in a volumetric execution was made both without a defect taken into consideration and with a defect located in the most hazardous places of the oil pipeline's section.

The case was examined with a section of the oil pipeline being under 15,0 MPa.

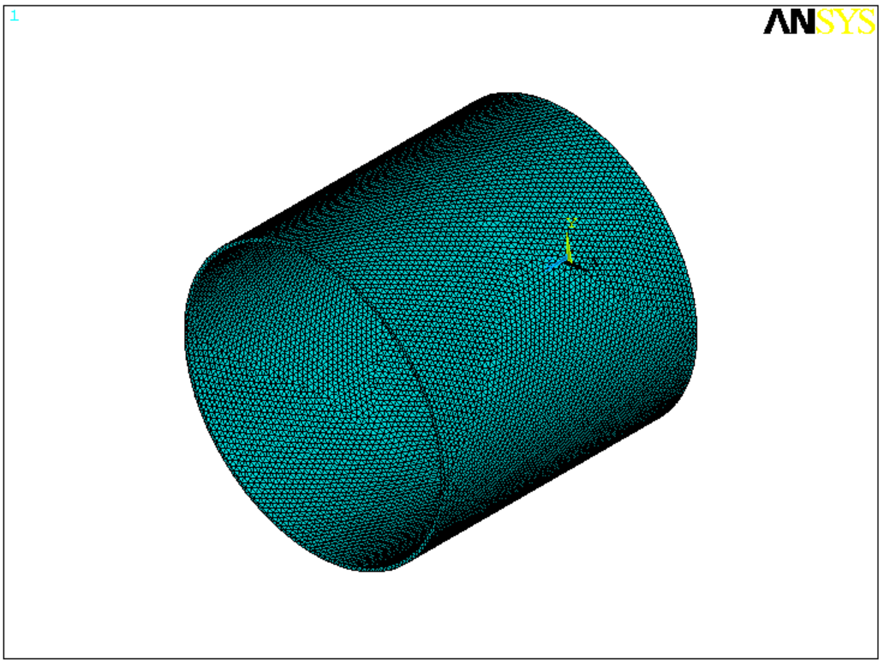

Fig.3. Ultimate-element model of a section of the oil pipeline

As the result of the numeral analysis of MKE, ISO- strips of stressed-deformed condition were received (Fig.3), besides this, animation pictures (deformed condition) were realized for the representation of the operation of a section of the oil pipeline under pressure. Fig.3 shows a distribution of ISO-strips in the element of the oil pipeline's section in case of the beginning of a destruction due to the internal pressure, when a length of the crack reaches a value of l=0.5 m.

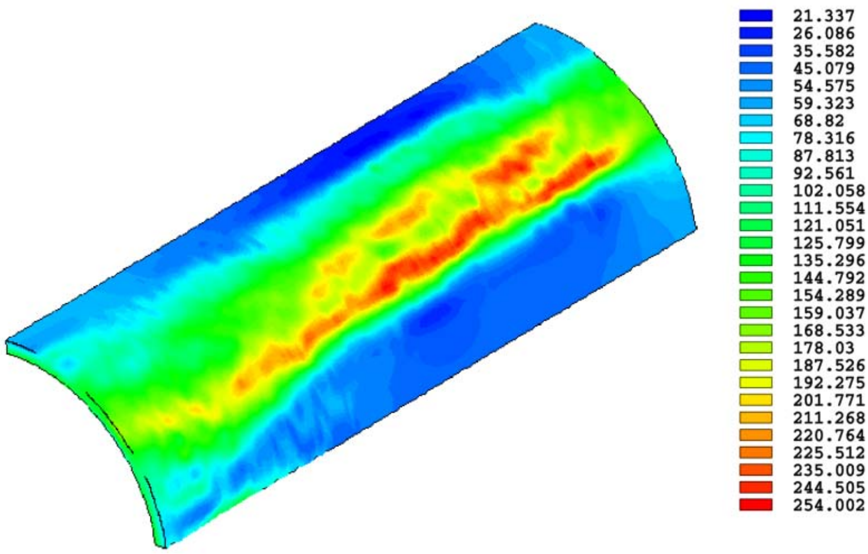

Fig.4. The distribution of strengths σ_{von} in the oil pipeline's section taking into consideration defects

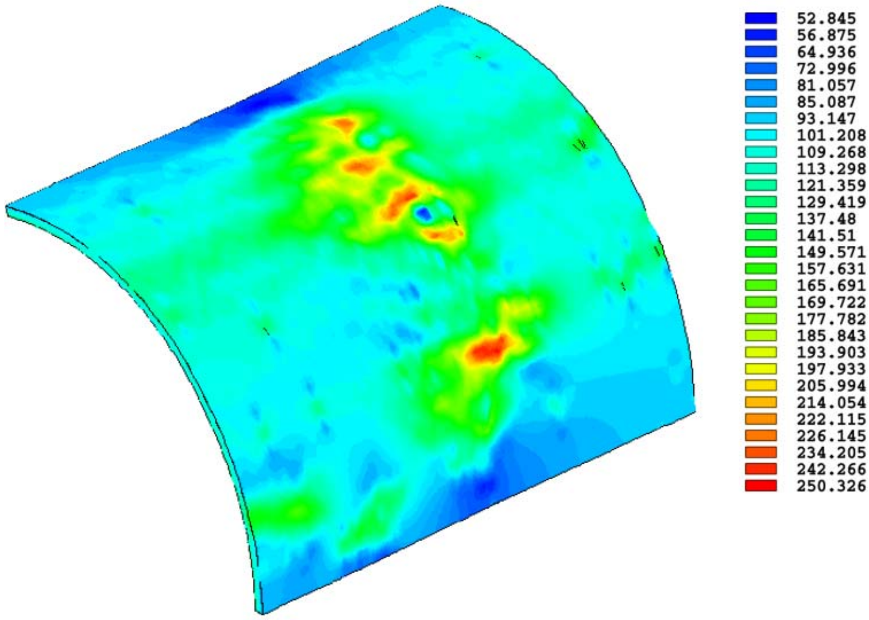

Fig.5. The distribution of strengths σ_i taking into consideration defects in the oil pipeline's section

CONCLUSIONS

An essential alteration of the stressed condition in the oil pipeline is ascertained with the growth of a length of the crack, especially in those places, where cracks appear on the surface, as well as there, where defects are available on the pipe's internal surface in the form of corrosion sores.

The efficiency of the usage of the calculation code ANSYS 5.5.3 of "Swanson Analysis System Inc." is shown for the estimation of a degree of damages during the maintenance. Both real marginal conditions in the oil pipelines and damages of sections were taken into account in the calculations.

Received estimations of stressed-deformed state are used for the subsequent calculation of the remaining resource and ranging of defects as per a degree of their danger to destruction.

The usage of the resource method as per condition allows to take into account properties of a damaged section of the oil pipeline more deeply, however, a caution must be taken when using this method, because it is related with the fact, that proposed methods give good results only when making prognosis of the service period for the mode of the growth of long cracks. The calculation results allowed implementing estimations of a danger to destruction and a remaining resource of the oil pipeline's sections with a high exactness, in case defects existing in them are found out, and calculating required periods for repair and substitution.

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