FEM Application in Geometrically Non-linear Analysis of Local Shape Defects on Steel Cylindrical Tank Walls

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Summary In the many economically based reasons any natural engineering investigations of huge steel storage tanks and other structures of such kind of buildings are very expensive. Natural inspection of tank dents (volumes of tanks were from 1 000 to 50 000 m^3, diameter of dents were from 0,40 to 4,50 m, a depth – up to 120 mm) has shown that the usage of semi-empiric analytical expressions from existing design standards is rather complicated.

The main objective of the presented is to complete and review some information about the strain/stress analysis of steel cylindrical tanks and additionally, to investigate dependence the geometrical non-linearity, when local shape defects on the thin walls are taken into account.

Introduction

Operation of huge volume steel tanks is always connected with a full control of their state and diagnostics. A thin-walled shell of such structures requires a careful maintenance and repair, if necessary. In practice, it is rather difficult to make and use such kind structures avoiding considerable deviations from the design requirements. In time, different common damages, local defects and other imperfections are accumulated. They have a tendency to increase due to non-observance of all the requirements and standards during mounting, as a result of the supports shrinkage and insufficient control of the process running. Constant inspection and elimination of such shortcomings is considered to be a common practice during the operation of huge volume structures. To simplify visual inspection, special requirements to the defect values defined by the technical standards [1-3] are provided. By their features local shape, defects of steel cylindrical tanks are close to those of the pipes thus, in practice, local defects of the pipes can be successfully applied with respect to the tanks [4]. Therefore, for the analysis of local shape defects (dents, bulges and so on) a more exact description [5, 6] is recommended.

Natural Investigation of Local Shape Defects

In many cases more important influence of such defects in various technical collapses is observed in combination with poor-quality steel or near welded zones. Practically, to study the influence of local shape defects on tank thin walls, the descriptions of 84 cylindrical steel tank crashes have been investigated [7]. In general, the most valuable 16 factors have been considered (Fig. 1). This research has proved that the most important errors may be as follows (an additional number points to the number of references in the expert reports) the defects of welded joints – 47; low temperature – 28; the disturbance in realisation of a corresponding project – 24; poor quality of steel – 25; the differences of temperatures – 21; stress concentration – 16; the differences of pressures – 11; violation of operating conditions – 9; supports shrinkage – 7; the influence of corrosion – 8; non-observance of the initial test conditions – 9. In many cases, the local shape defects may be described as an additional factor. On the other hand, this factor should be taken into account during the analysis of mechanical behaviour of a geometrically non-perfect structure.

Figure 1: Examples of local shape defects on a wall of steel cylindrical tanks

Besides, the local shape defects are not considered to be uncommon phenomenon. For example, an industrial complex of 78 thin-walled cylindrical tanks has been considered designed for light oil products [7]. A great part of local geometric defects has been disclosed on the first (lowest) strip of the tanks. Generally, 286 defects have been detected, 106 of which had highest geometrical parameters in comparison with those limited by the standards: 95 dents and 11 bulges. In particular: 41 dents and 3 bulges have been found on walls of 420 m^3 volume tanks; 24 dents and 6 bulges – on walls of 700-3350 m^3 tanks; 26 dents and 2 bulges – on 5000 m^3 tanks; 4 dents – on the tanks of more than 5000 m^3 volume.

On the other hand, practically a lot of tanks with the defect values exceeding those allowable by the standards [1-3, 5, 6] are used, and this fact, as it follows from the observations, does not cause deterioration of the tanks state [7]. For the investigation of each specific case or a group of such problems a series of simplifying assumptions are introduced taking into consideration a physical sense and the peculiarities of an individual situation [4, 8-13].

However, the developments of accurate analytical models [4, 7-10, 12-14] are particularly essential for the state investigation of the structures to be used. To date, such solutions are of special concern for practicing engineers.

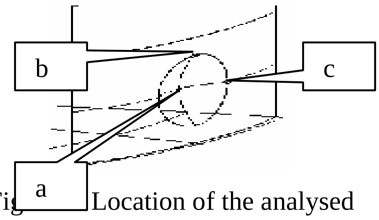
Engineering Analysis Based on Inspection Results

The practical observations prove [8, 14,] that accumulation of the defects becomes the main reason of a failure if the tank is being used for 20-25 years.

Different design codes and instruction manuals confine the presence of tank defects by their external appearance, e.g. [3]: if the defect diameter does not exceed 1.5 m the dent value must not be over 15 mm; with 1.5 to 3.0 m diameter this value should not exceed 30 mm; in case of 3.0 to 4.5 m diameter the dent allowable sag is not more than 45 mm; the defects of more than 4.5 m diameters are not considered to be local. Analogously, the defect values are standardized by the design and scientific organizations of such famous international companies as British Gas, Shell, American Petroleum Institute and so on [1, 6], e.g.: the dent depth should not exceed ½ inch for a three-foot defect. Such requirements do not take into account many important factors such as: the tank shell thickness; the defect location; causes of its occurrence; loading frequency etc. At the present time, when specifying the design standards and operating rules, it is necessary to describe the influence of local defects on the strain state more precisely [17-20].

The analytical methods suggested to solve the problems [10, 12] are based on assumptions common in engineering practice [13]. Unfortunately, the determination of stress concentration using this model is not quite exact. The local shape defects of the tanks are very similar to those of the pipes as far as their physical characteristics are concerned [4].

The location of the most dangerous points (Fig. 2) has been selected on the basis of inspection practice for steel cylindrical tanks considering also the features of the task given and the results of the observation and study published in other papers [8-10].



Fi Location of the analysed points: midpoint (a); contour upper point (b); contour side point (c)

Numerical Results of Non-linear Mechanical State

As an efficient approach one can consider duplicating of the analytical methods by numerical ones and, vice versa, as such comparisons considerably improve both means of the solution [15, 16]. A middle point of the semi-spherical dent has been analyzed (Fig. 3) with relative radius $\beta = 1$ (curves 1, 2, 3), $\beta = 3$ (curves 4, 5, 6), $\beta = 5$ (curves 7, 8, 9) and sag $\gamma = 2, 9, 16$. Relative radius β and sag γ were determined dependently to tank radius and wall thickness [16]. In the each case of relative radius three non-geometrical solution by the FEM were performed, when $\gamma = 2$ (curves 1, 4, 7), $\gamma = 9$ (curves 2, 5, 8), $\gamma = 16$ (curves 3, 6, 9). Time dependence between loading factor *f* and relative displacement $\psi = \frac{U_x}{U_{x,nom.}}$ was determined. Loading factor *f*=1 is equal to full load (Fig. 3). Displacements U_x into normal axis of the wall surface were checked. Maximum displacements 15 – 20 mm are given when relative radius $\beta = 1,3,5$ and sag $\gamma = 2$ (curves 1, 4, 7). Whereas, maximum displacements 15 – 65 mm with factors $\beta = 1,3,5$ and sag $\gamma = 16$ (curves 3, 6, 9).

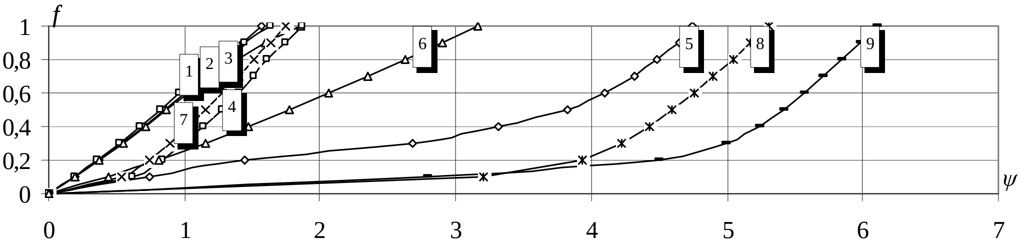


Figure 3: Variation of the displacements on the semi-sphere dent, midpoint

Whereas, while maximum displacements with $\beta = 1,3,5$ and sag $\gamma = 16$ are between 15 – 65 mm (curves 3, 6, 9). On the basis on the investigation the results have been drawn that defect is much more sensitive to sag than to relative radius.

Conclusions

The above presented research has been shown:

1. Natural inspections of the cylindrical tank defects have been proved that investigations of the dents are practically important.

2. The dent-defect in the presented cases is much more sensitive to sag than to relative radius.
3. The maximum displacement was obtained when $\beta = 1$, $\gamma = 16$ is $\psi = 1{,}9$, when $\beta = 3$ $\gamma = 9$ is $\psi = 4{,}7$, when $\beta = 5$, $\gamma = 16$ is $\psi = 6{,}1$.

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