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DETERMINATON OF REASONS OF PERMANENT DEFORMATION ON BOTTOM SHELL PART OF CONTAINER AND SUGGESTION OF MEASURES FOR ITS FURTHER OPERATION

URČENIE PRÍČIN TRVALEJ DEFORMÁCIE PLÁŠŤA NÁDRŽE A NÁVRH OPATRENÍ PRE JEJ ĎALŠIE PREVÁDZKOVANIE

Abstract

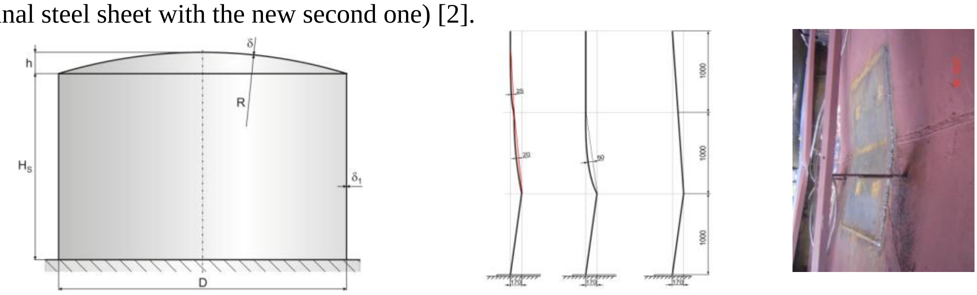
During the operation of the tank its shell was deformed in plastic area. In order to assess its further operation there were determined residual stresses in the shell and by the finite element method as well as by the experimental methods the analysis of stresses was performed. On the base of these results were suggested simple improvements of design that allow further operation of tank.

Abstrakt

Pri prevádzke veľkoobjemovej nádrže došlo k trvalej deformácii jej plášťa. S cieľom posúdenia jej ďalšieho prevádzkovania boli určené zvyškové napätia v plášti a výpočtom MKP ako aj tenzometrickým meraním počas prevádzky bola vykonaná analýza napäťových pomerov v plášti nádrže. Na základe získaných výsledkov z pevnostného overenia boli navrhnuté jednoduché konštrukčné úpravy umožňujúce jej ďalšie prevádzkovanie.

1 INTRODUCTION

After approximately three years of operation of re-designed tank for hot water (Fig.1a) was found out that the shell of tank has permanent deformation in location of weld between the first and the second steel sheets (Fig.1b). It has to be said that immediately after beginning of operation there were some small permanent deformations caused by reconstruction works (during welding of the first original steel sheet with the new second one) [2].



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a) b)

Fig. 1 Analyzed tank. a) tank dimensions, b) permanent deformation of tank shell in location of the first and the second sheet with approximated shapes of meridian lines 1,2,3

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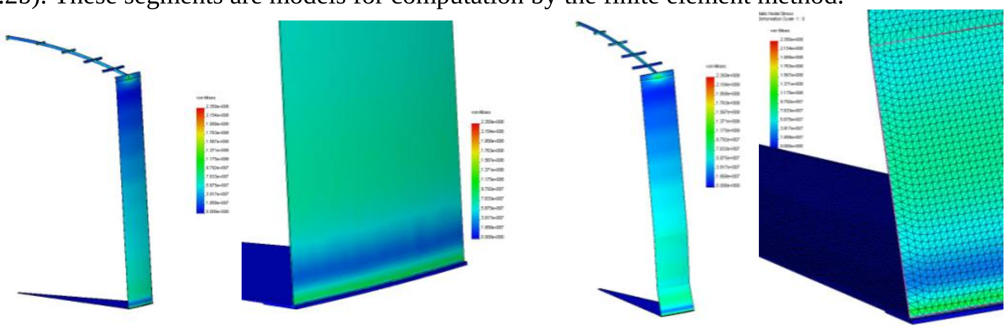
In the paper are given results gained by numerical and experimental methods [6,7,8].

2 STRESS ANALYSIS BY THE FINITE ELEMENT METHOD

As mentioned before, in the paper is investigated vertical cylindrical tank with the spherical roof and its basic dimensions are given in accordance with Fig. 1a: inside diameter $D = 14\,289\ mm$, height of cylindrical part $H_s = 9\,208\ mm$, roof high $h = 1100\ mm$, roof radius (spherical) $R = 24\,500\ mm$, thickness of cylindrical shell $\delta_1 = 6$ to $8\ mm$, thickness of roof shell $\delta = 4\ mm$, volume for water surface height $H = 9108\ mm$, $1475\ m^3$, material S235 ($R_{eH\,min} = 235 MPa$, $R_{m\,min} = 340 MPa$) [3,4].

The roof of tank consists of steel shell with thickness δ = 4 *mm*, which is welded to the steel framework of the roof by intermittent chain welds. The framework of roof is created from outer and internal rings, polygonal rings and radial ribs. The storage tank is loaded during operation by self-weight of structure; hydrostatic pressure of the contained liquid and by pressure (or under pressure) above liquid surface in accordance with working conditions defined by service manuals, climatic loading (snow, wind). It must be mentioned that during operation of storage tank it is due to the steam above liquid surface maintained pressure 1.5 kPa ensured by the control system of the tank. The computation by the finite element method was accomplished for the case of ideal geometry as well as for the shell with permanent deformation according to Fig.1b. There were considered all loading types for water surface height 8 870 mm. In Fig.2 are shown equivalent stresses in the segment of the tank and in bottom part of tank with ideal shell (Fig.2a) as well as with deformed shell (Fig.2b). These segments are models for computation by the finite element method.



a) b)

Fig. 2 Equivalent stresses in the tank shell a) ideal geometry, b) shell with permanent deformation

3 STRESS ANALYSIS IN LOCATIONS OF PERMANENT DEFORMATION DETERMINED BY EXPERIMENTAL METHODS

3.1 Assessment of residual stresses by the hole drilling method

For the measurement of residual stresses the sheet specimen with dimensions approximately 310 x 450 mm containing horizontal weld between the first and the second steel sheet was taken (Fig.1b). Residual stress measurements were provided on external as well as internal side of tank shell at the distance 40 mm from weld axis, in locations labeled as 1, 2, 3 and 4 (Fig.3). Strain gages RY21 were applied by adhesive X60 and they were covered by paint SG-250. Drilling was realized by hole drilling equipment RS-200 with strain gage apparatus P-3 (Fig.4a). Hole after drilling is shown in Fig.4b. Determination of residual stresses during drilling (hole diameter 3,2 mm, depth 4,5 mm) was accomplished according to code ASTM E 937-01, by integral method and Method of Power Series, respectively [5,7]. Maximal residual stress determined according to ASTM was in location 1 and it reaches positive value almost 95 MPa.

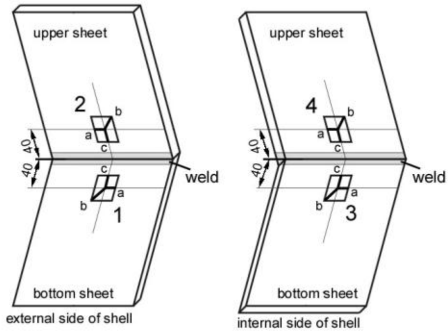
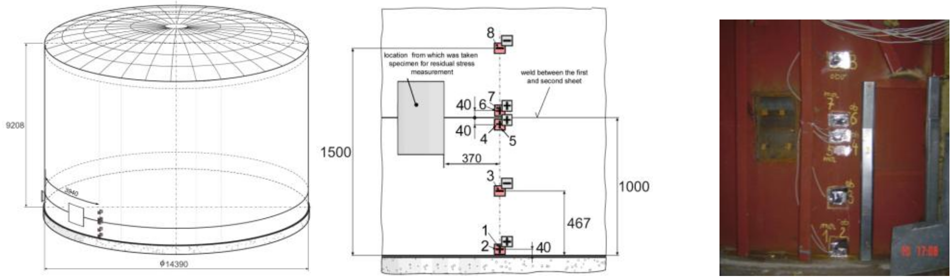


Fig. 3 Location of strain gages on specimen taken from the tank.

Fig. 4 Apparatus P-3 during drilling (left), hole in location 2 (right).

3.2 Strain gage measurements during operation of the tank

The operational regimes of storage tank are the following: filling up the tank by hot water; operation of storage tank that is based on regulation of water temperature by filling the tank by cold water (discharging) or by water which is more hot than the contained one in the tank (charging); discharging of water from the tank (maintenance, unavailability time and so on). During these processes the velocity of liquid surface height change can be determined by technological equipment of the tank. Regulation equipments ensure all regimes. For the realization of stress measurements were to the tank shell applied strain gages according to Fig.5. In locations 1,2,4,5,6,7 were for circumferential and meridian direction used strain gages HBM of type 10/120 XY-91, in locations 3,8 were for circumferential direction used strain gages 10/120 LY-11. Strain gage measurement was realized for the operation cycle of filling to water surface height 8 750 mm, charging and discharging (measurement time approximately 44 hours). In Fig.6 are given charts of time dependent stresses in individual locations during the first stage of tank filling.



a) b)

Fig. 5 Strain gages on the tank shell a) location of strain gages, b) applied strain gages

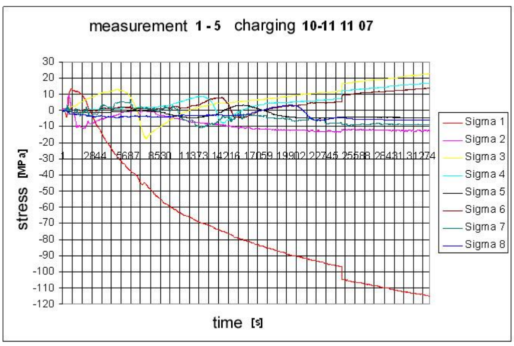


Fig. 6 Time dependent stresses in the first stage of tank filling.

4 CONCLUSIONS AND RECOMMENDATIONS

On the base of visual inspection, diagnostics, analysis, modeling, stress computations as well as analysis of load cycles modeled during experimental simulation can be stated that in the construction of carrying tank structure has been violated the following rules:

Levels of stresses determined by the finite element method that are due to deviation of meridian line of bottom sheet from vertical direction as well as due to imperfections of meridian line are higher by approximately 25–30% then those for ideal cylindrical shell.

Residual stresses measurements evaluated by three methods (code ASTM E 837-01, integral method, Method of Power Series) proved that maximum principal or equivalent stresses reach almost 100 MPa and therefore it is necessary to consider these values during the process of design evaluation. Extreme residual stresses are located in intimate distance from the both (internal and external) surfaces of the shell.

Strain gage measurements have shown that during the filling (for the water surface height 8750 mm) reaches the stress its maximum in location 1, where meridian stress from local bending moment exceeds 205 MPa and in other locations they do not exceed 80 MPa. For charging and discharging meridian pressing stress in location 1 reaches 225 MPa and stresses in other locations are not higher in their absolute value than 120 MPa.

On the base of results it is clear that from the point of view of strength danger area lies in junction of shell and bottom ring plate. Because location 1 is 40 mm above bottom ring plate, in the internal side of tank shell is the same tensile stress. In internal side of shell is situation worse due to residual tensile stresses that are added to stresses caused by operation and they results to value that exceed yield point of material. Inappropriate stress is connected with existing plastic deformations of the first and partially second sheet around measured locations. Further operation is possible only after improvements in design of tank, because it is necessary to decrease stresses by 15 to 20%. The improvements rely on replacement of deformed shell or in suitable reinforcement of shell in locations of permanent deformation. More details can be found in [1].

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