IOP Conf. Series: Materials Science and Engineering 463 (2018) 032006 doi:10.1088/1757-899X/463/3/032006

Uneven Base Sediment Influence and Environment Temperature Changes on the Intensely Strained State Tank Wall

V N Kononov[1], A A Shamaeva[1], N A Lukina[1]
[1]North-Eastern Federal University n.a. M.K.Ammosov, Yakutsk, Russia;

E-mail: [1]kononov-vn@mail.ru; [2]shamayafan@mail.ru; [3]lukina-7171@mail.ru

Abstract. This paper describes the possibility of taking into account additional forces caused by temperature operating fluctuations and uneven base sediments on permafrost grounds based on the analysis of the branch pipe welded joints stress state with a wall in vertical cylindrical tanks and the stress intensity factor calculations.

1. Introduction

Reservoirs for oil storage facilities are especially dangerous objects. Even a small leak of petroleum products is fire hazardous and can cause environmental damage. In this regard, special requirements should be imposed for the cracking opening when designing, construction and operating these objects, in particular, vertical steel cylindrical (TVS) tanks.

2. Relevance and issue scientific significance with a brief literature review.

Regional features consideration of exploitation of TVS in the Far North conditions: a large amplitude of daily and annual temperature fluctuations, uneven base sediment caused by a change in the permafrost soils state during operation. Investigations and the stress-strain state analysis of tanks structures elements in the Far North are carried out in the works [1, 2, 3, 4, 5, 6, 8, 14, 17, 18, 19, 20, 21].

3. Problems formulation.

We offer the following approach to the determination of the stress intensity factor (FSI) in a branch pipe welded joints and a wall in the technical diagnosis of steel vertical cylindrical tanks in operation based on the tanks check up results analysis and the resistance experimental studies to welded joints fracture with crack-like defects.

4. Theoretical part.

The fragile cracking and its opening is determined through local stresses, depending on K_I - the stress intensity factor at detachment which are determined by the formula proposed by G.R. Irwin [11]

$$\sigma_y = \frac{K_1}{\sqrt{2\pi \cdot r}}, \text{ so } K_1 = \sigma_y \cdot \sqrt{2\pi \cdot r}.. \quad (1)$$

At the highest point the cracks stress are determined by the function

$$\sigma_y = f(P, L, l) \cdot f(r) \cdot f(\theta), \quad (2)$$

where $f(P, L, l)$ - function of the loading method, the size of the part and the crack; $f(r)$, $f(\theta)$ - functions of coordinates.

The parts rigidity condition with cracks in the material fragile state according to the G.R.Irwin criteria is $K_l \leq K_{lC}$, (3)

where K_{lC} is the critical value of the FSI.

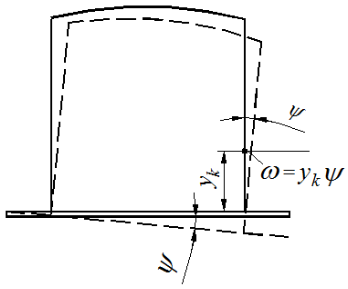
Therefore, the calculation value change K_I immediately affects the material structure strength. The value change of K_I depends on the change in the local stress-strain state of the element and the material properties. According to the numerous studies results plastic properties are reduced and fragility is increased for many steel grades in steel structures operating at low temperatures in conditions of the Far North [12, 13, 20].

The tendency to fragile crash exacerbates the various origins concentration stress zones from constructive flaws or manufacturing technology violations.

One of the dangerous places in the tank is the branch pipe connection place to the wall by a welded seam [2, 3, 4] with a high micro crack probability which may crack opening cause under certain conditions.

There are additional forces at the branch pipe connection place to the tank wall from uneven base settling and annual, daily fluctuations in the ambient temperature.

Studies have shown that tanks [1,3,5,14], for a long time operated in areas with permafrost soils, their bases sediments depending on the soil fraction are uneven. In this case, the walls of the vertical tank are inclined to the same angle ψ - the base which is caused by the uneven sediment. When the wall inclination angle coincides with the direction of the branch pipe, the tank wall takes a radial linear deformation $\omega \cong \Psi \cdot y_k$ and an angular φ= Ψ_0 (Figure 1.a), these deformations cause a concentrated radial force Q and a concentrated moment M_y in the tank wall (figure 1.b).



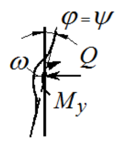


Figure 1. a) linear and angular reservoir wall deformations at the pipe connection point; b) additional efforts.

We define the concentrated radial force Q by the radial displacement ω with the approximate formula V.M. Darevsky [7,9]

at ζ=0, φ=0 и $\frac{R}{h} \gg 100$

$$\max\ \omega(0,0) = \left(\frac{1}{6}\cdot\lambda^3 + 0,802\cdot\chi^3\right)\cdot\frac{Q}{\pi E h} = \left\{\frac{l^3}{6R^S} + 0,802\cdot\left[3\cdot\left(1-\nu^2\right)\right]^{\frac{3}{4}}\cdot\left(\frac{R}{h}\right)^{\frac{3}{2}}\right\}\frac{Q}{\pi E h} = \omega \quad (4)$$

$$\text{So } Q = \frac{\omega\cdot\pi\cdot E\cdot h}{\left\{\frac{i^S}{6\cdot R^S} + 0,802\cdot\left[3\cdot\left(1-\nu^2\right)\right]^{\frac{3}{4}}\cdot\left(\frac{R}{h}\right)^{\frac{3}{2}}\right\}}, \text{ where } \chi = \sqrt[4]{3\cdot\left(1-\nu^2\right)}\cdot\sqrt{\frac{R}{h}}. \quad (5)$$

Knowing the radial concentrated power Q in a properly small area of the application point , the stress state is determined mainly from the action of the bending moments M_1 and M_2 with the asymptotic formula [6,7,8]

$$M_l' \cong M_2' \cong -\frac{1+\nu}{4\pi}\cdot Q\cdot \ln\rho = -\frac{1+\nu}{4\pi}\cdot Q\cdot \ln\frac{R}{r} = -\frac{1+\nu}{4\pi}\cdot\frac{\omega\cdot\pi\cdot E\cdot h}{\left\{\frac{l^3}{6R^3}+0,802\cdot\left[3\cdot\left(1-\nu^2\right)\right]^{\frac{3}{4}}\cdot\left(\frac{R}{r}\right)^{\frac{3}{2}}\right\}}\cdot\ln\frac{R}{r} \quad (6)$$

These moments cause axial and circumferential stresses σ_1 and σ_2 on the outer and the inner tank wall surface.

$$\sigma_1' \cong \sigma_1' \cong \mp\frac{3\left(1+\nu\right)}{2\pi}\cdot\frac{Q}{h^2}\cdot\ln\frac{R}{r} = \mp\frac{3\left(1+\nu\right)}{2\pi}\cdot\frac{\omega\cdot\pi\cdot E\cdot h}{\left\{\frac{i^3}{6R^S}+0,802\cdot\left[3\cdot\left(1-\nu^2\right)\right]^{\frac{3}{4}}\cdot\left(\frac{R}{r}\right)^{\frac{3}{2}}\right\}}\cdot\ln\frac{R}{r}. \quad (7)$$

The concentrated moment M_y with the vector in the circumferential direction is determined by the angle of inclination of the tank wall *Ψ*,, which is equated with the inclination angle of the branch pipe end at the connection with the tank wall.

So we get M_y from из $M_y = -\frac{El_x}{l_T}\cdot\left(3\varphi-3\theta\right)$ (8)

at $\varphi=\psi$ and $\theta=0$ get $M_y=-3\frac{El_x}{l_T}\cdot\psi$, where El_x – branch pipe rigidity, l_T – branch pipe length.

In a properly small area of the branch pipe connection, the stress state of the tank wall from the concentrated moment M_y, the bending moments M_1' and M_2' are occurred. We determine it by formulas [7, 9, 10]

$$M_1' \cong -\frac{M_y}{4\pi R}\cdot\varsigma\cdot\bar{\rho}^2\cdot\left[2\cdot\left(1-\nu\right)\cdot\psi^2\cdot\bar{\rho}^2+1+\nu\right], \quad (9)$$

$$M_2' \cong -\frac{M_y}{4\pi R}\cdot\varsigma\cdot\bar{\rho}^2\cdot\left[2\cdot\left(1-\nu\right)\cdot\psi^2\cdot\bar{\rho}^2-1-\nu\right] \quad (10)$$

At the inner and outer surfaces points of the tank wall ζ = ± ζ, φ = 0 get $M_1' \cong M_2' \equiv \mp\frac{1+\nu}{4\pi}\cdot\frac{M_y}{R\varsigma}$ (11)

Stresses are equal

$$\sigma_1' \cong \sigma_2' \equiv \mp\frac{3\cdot\left(1+\nu\right)}{2\pi}\cdot\frac{M_y}{Rh^2\varsigma} = \mp\frac{3\cdot\left(1+\nu\right)}{2\pi}\cdot\frac{3El_x\cdot\psi}{l_T\cdot R\cdot h^2\cdot\varsigma} = \mp\frac{9\cdot\left(1+\nu\right)\cdot El_x\cdot\psi}{2\pi\cdot l_T R\cdot h^2\cdot\varsigma} \quad (12)$$

We get from the linear branch pipe deformation at the maximum fluctuations in the environment temperature

$$\Delta l_T = \omega\left(t\right) = \pm\alpha\cdot\Delta t\cdot l_T \quad (13)$$

Additional stresses will be equal

$$\sigma_1^t \cong \sigma_2^t \cong \mp\frac{3\cdot\left(1+\nu\right)}{2\pi}\cdot\frac{\left(\alpha\cdot\Delta t\cdot l_T\right)\cdot\pi\cdot E\cdot h}{\left\{\frac{l^s}{6R^s}+0,802\cdot\left[3\cdot\left(1-\nu^2\right)\right]^{\frac{3}{2}}\right\}}\cdot\ln\frac{R}{r} \quad (14)$$

The total additional voltage in the vertical tank wall caused by the uneven base sediment and ambient temperature fluctuations when all voltages signs are the same are equal

$$\sigma_i = \sigma_i' + \sigma_i'' + \sigma_i^t \quad (15)$$

$$\sigma_1 \cong \sigma_2 \cong \mp \left\{ \frac{3\cdot(1+\nu)}{2\pi} \cdot \ln\frac{R}{r} \left[\left(\frac{\pi \cdot E \cdot h}{\left\{ \frac{l^s}{6R^s} + 0{,}802 \cdot \left[3\cdot(1-\nu^2) \right]^{\frac{3}{2}} \cdot \left(\frac{R}{r} \right)^{\frac{3}{2}} \right\}} \right) \cdot (\omega + \alpha \cdot \Delta t \cdot l_t) \right] + \left(\frac{El_x \cdot \psi}{l_t \cdot R \cdot h^2 \cdot \varsigma} \right) \right\} \quad (16)$$

The total local tearing static stress at the incipient crack end is $\sigma = \sigma^{(1)} + \sigma^{(2)}$ (17)

Where $\sigma^{(1)}$ – stress from the initial operational load;

$\sigma^{(2)}$ - additional possible stresses.

Additional dynamic loads occur during the filling and draining oil products from the tank which must be considered when analyzing the tank wall strength at the branch pipe connection point $\sigma_y = K_Д \cdot \sigma$. Thus, the reservoir wall strength condition according to the stress intensity coefficient is

$$K_I = K_D \cdot \left(\sigma^{(1)} + \sigma^{(2)} \right) \cdot \sqrt{2\pi r} \le K_{1C} \quad (18)$$

5. Conclusion

Therefore, uneven sediment is one of the main factors determining the load-bearing capacity of reservoir thin-walled elements with crack-like defects.

The proposed valuation method provides the significant reduction possibility.

Thus, it is necessary to take into account additional forces occur from the large amplitude of every day and annual temperature variations and uneven base settling in calculating the long-term operation of the RVS for oil storage tanks.

6. References

[1] Afonskaya G P, Prokhorov V A and Buslaeva I I 1995 *Establishment of a limit state for reservoirs operating in the North* Yakutsk: with. Dep. in VNIINTPI No. 11533 p.11

[2] Afonskaya G P, Kuzmin V R and Prokhorov V A 1996 *The model of brittle fracture of thin-walled structures. Int. conference "Metal-building - 96"*. (Donetsk, Makeyevka: DGASA. - vol. 1, pp.) 101-103

[3] Afonskaya G P, Nikolaeva A A, Prokhorov V A and Filippov V V 1997 *Systematization and modeling of structures refusals for oil products storage* (Yakutsk: YSU. Dep. in VINITI, 01.06.98. No. 1702.I98.) p.50

[4] Afonskaya G P 2000 *Influence of defects on the load capacity of tanks in the North*: diss. cand. tech. sciences. (IFTPS of the SB RAS, Yakutsk)

[5] Buslaeva I I and Prokhorov V A 1996 *Investigation of the causes of tank failures. Int. conference "Metal-building - 96"*. (Donetsk,Makeyevka: DGASA vol. 2. pp. 49-50)

[6] Buslaeva I I 2004 *Assessment of the bearing capacity of tanks in the presence of uneven sediments in the North*: diss. cand. tech. sciences. (IFTPS of the SB RAS, Yakutsk)

[7] Birger I A (ed.), Panovko Ya G (ed.). 1968 *Strength, stability, oscillations*. vol.2. (Moscow)

[8] Galeev V B 1981 *Operation of steel vertical tanks in difficult conditions* - (Moscow: Nedra. p.146)

[9] Darevsky V M 1952 *Solution of some problems in the theory of a cylindrical shell* PMM. vol. 16.issue.2. pp.28-29

[10] Darevsky V M 1964 *Determination of displacements and stresses in a cylindrical shell under local loads // Durability and dynamics of aircraft engines. Mechanical engineering*. Moscow: issue.1.pp. 23-83.

[11] J Irwin, P Paris and Ljubovits G (ed.). 1976 *Destruction of non-metals and composite materials. Fundamentals of the theory of crack growth and fracture*. Book.6. (Moscow The World)

[12] Kononov V N, Kovalchuk V A and Prokhorov V A 1978 *Investigation of the cold resistance of the material of the boom of the crane in the book "Destruction of metals and welded structures at low temperatures"* Yakutsk vol. 4.2. Pp .11-13.

[13] Kononov V N, Kovalchuk V A, Prokhorov V A and Yakovlev P G 1978 *Breakdown of excavator parts at low temperatures in the book "Destruction of metals and welded structures at low temperatures"* Yakutsk vol. 4.3 Pp. 15-17.

[14] Kononov V N, Buslaeva I I, Prokhorov V A and Kuzmin V R 2002 *Influence of change in operating temperature on the stress-strain state of vertical cylindrical tanks in the book "Proceedings of the 1st Eurasian Symposium on the Strength of Materials and Machines for the Cold Climate Regions"* Part 1. Yakutsk pp. 118 – 122

[15] Kononov V N, Kuzmin V R 1981 *Investigation of the strength of plates, rods with stress concentrators at low temperatures with allowance for cyclic loading.* Technical report No. 01790022635, (Yakutsk.)

[16] Kuzmin V R, Prokhorov V A 1986 Method for calculating effective stresses in elastoplastic deformation. *Machine Science* vol. 1. Pp. 66-71.

[17] Prokhorov V A 1999 *"Assessment of risk parameters for reservoir operation in the North"*: diss. Dr. tech. sciences. (Moscow)

[18] Prokhorov V A 1990 On the regularities of VAT in zones of stress concentration under low-cycle loading. *Proceedings of universities. Mechanical Engineering* vol.. 9. Pp. 33-36

[19] Rozenshtein I M 1995 *Accidents and reliability of steel tanks Moscow*: (Nedra)

[20] Solodar M B, Plishkin Yu S and Kuznetsova M V 1981 Metal structures for construction in the North - L.: (Stroiizdat)

[21] Filippov V V, Prokhorov V A, Argunov S V and Buslaeva I I 1993 Technical condition of storage tanks for oil products of the “Yakut oil product association”. *Izv.vuzov. Construction,.* vol. 7,8. Pp. 13-16