CALCULATION OF SERVICE'S CONDITIONS OF WALL OF VERTICAL CYLINDRICAL TANKS WITH GEOMETRICAL DEFECTS

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Oil and oil products storage vertical steel tanks (VST) are hazardous industrial facilities. According to the ruling documents of Rostekhnadzor during operation VST is to be inspected and found defects are to be eliminated.

The existing regulations establish criteria of permissible defects: dents on the wall, VST's wall vertical deviations, angularities on the wall etc. However, exploiting organizations haven't got an ability to perform repair operations immediately as usual. VST having wall defects operation is allowed basing on calculations performed by expert organization. Moreover, VST having wall defects operation is allowed on the assumption that:

1) there are no stress limits exceeding in the wall metal;
2) there is no steady loss in the VST wall;
3) there is no local wall steady loss (buckle).

Thereby, in order to give well-grounded conclusion of further VST with wall defects operation possibility expert organization must perform calculations, which sustain that said terms is met with measured during technical diagnostics actual parameters of VST wall defects and external environment conditions: wind and snow loads, mutual VST constructions influence.

The article illustrates a technique, developed by CJSC "VNIIST-Diagnostika", which allow to determine permissible operation conditions of VST with wall defects. Result of using technique is shown on example of wall stress-deformed state calculation.

In the capacity of example for calculations VSTFD-10000 has been chosen. It is a vertical steel tank with floating deck having capacity of 10000 m3. Initial data of VSTFD-10000 is:

1) radius 17.1m, wall height 12m. designed oil level 10.48m, oil density - 900kg/m^3;
2) wall is made of 8 belts with height of 1.5m each;
3) wall material was 09G2S (yield stress of 325MPa) for first and second belts and for other belts material was St3 (yield stress - 245MPa);
4) steel thickness varies from 12mm on first belt down to 6mm on eight belt;
5) measurements of wall vertical deviations, wall edge leveling, dent parameters of empty tank.

During diagnostics of empty tank there was revealed a dent in the vicinity of 5th and 6th belts with length 3 m, height 3m, maximum dent tongue 78mm. Maximum deflection height is to be less or equal to 39mm. Thereby, the dent with intolerable maximum deflection height was revealed.

In order to calculate VSTFD-10000 wall stress-deformed state with intolerable dent there was identified its geometry shape by local dent tongue measurements on a grid with step of 20sm in the vicinity of the dent (fig. 1).

Vertical distance to node , mm	Dent tongue, mm															
	Horizontal distance to node , mm															
0	0	0,2	0,4	0,6	0,8	1	1,2	1,4	1,6	1,8	2	2,2	2,4	2,6	2,8	3
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0,2	0	0	0	0	1	3	1	3	2	3	0	0	0	0	0	0
0,4	0	0	0	0	3	7	9	12	13	12	9	5	0	0	0	0
0,6	0	0	2	3	6	10	13	26	29	25	18	11	3	2	0	0
0,8	0	1	9	10	15	19	24	37	38	36	27	19	10	8	1	0
1	0	4	15	19	23	27	35	46	49	46	36	28	26	18	4	0
1,2	0	7	21	29	36	35	46	53	59	53	49	45	34	21	7	0
1,4	0	9	26	37	45	52	57	68	69	67	64	55	42	26	13	0
1,6	0	11	27	40	56	61	68	78	78	69	60	57	41	28	12	0
1,8	0	8	23	33	45	53	56	69	69	68	57	49	35	22	9	0
2	0	6	17	26	36	42	46	54	57	59	46	38	24	16	8	0
2,2	0	4	12	18	24	31	32	46	46	48	38	26	16	9	5	0
2,4	0	2	5	11	18	20	27	31	32	33	26	17	11	5	1	0
2,6	0	0	1	7	10	15	16	12	12	15	12	9	8	1	0	0
2,8	0	0	0	2	2	11	9	8	3	4	3	3	2	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

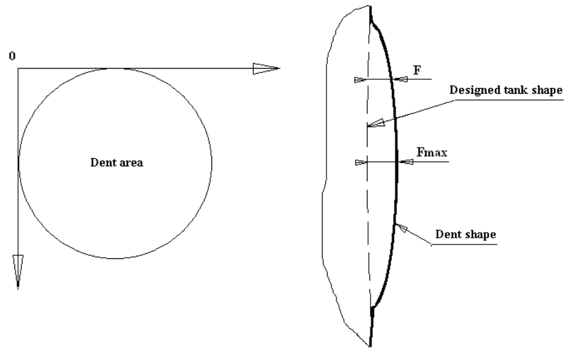

Figure 1. Results of measurement of dent deflection parameters on a grid with step of 20cm and its schematic shape.

$F_{max\ f}$ = 78mm - maximum dent tongue of the dent.

F - local dent tongue in a grid nodes.

In order to identify dependence between VST wall stress-deformed state and maximum dent tongue measured on the empty tank there was performed a calculation series. During the series maximum dent tongue varies (F_{max}) from 7.8mm up to 273mm with step of 7.8mm. 35 dents model with equal length, height, shape, location on the tank wall and different maximum dent tongue have been made.

Calculation of stress-deformed state was performed by modeling of the VSTFD wall with finite element technique simulation tool ANSYS.

The following finite element model boundary condition was applied:

1) All DOFs at the wall lower part as wall-bottom assembly;

2) linear uniform distributed load N from weight of roof and snow at the wall upper part;

3) hydrostatic pressure on all finite elements from bottom up to designed oil level of 10.48m;

4) vapor pressure P_v = 200Pa.

Linear uniform distributed load N was defined as:

$$N = \frac{P_{roof} + P_{snow}}{2\pi R} = 23481\ N/m \qquad (1)$$

where P_{roof} = 538290N - weight of roof with stationary equipment;

$P_{snow} = 0.9 \cdot p_s \cdot S$ - weight of snow;

$S = \pi R^2$ - roof area;

p_s = 2400Pa - normative snow load at ground level.

Material model was defined with multilinear stress-strain dependence.

There ware a total of 35 model solutions performed for dent with maximum dent tongue from 7.8mm (which is 10% from $F_{max\ f}$) up to 273mm with step of 7.8mm. Each model was loaded with hydrostatic pressure of designed oil level 10.48m during simulation. Mid-layer and top-layer stresses and radial displacements of the wall have been observed and calculated.

Fig. 2 represents a results of solution of the model with maximum dent tongue of 78mm at loads of designed oil level 10.48m hydrostatic pressure.

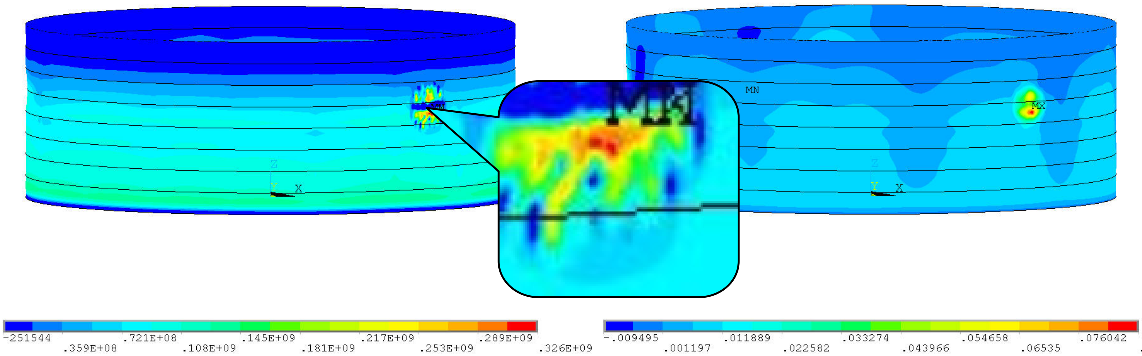

Figure 2. VSTFD wall with the dent top-layer stresses (on the left) and radial displacements (on the right) distribution.

Fig. 3 represents dependence between maximum 1st principal stress (mid-layer and top-layer) in dent area at loads of designed oil level 10.48m hydrostatic pressure and maximum dent tongue measured on empty tank.

Top-layer stresses grow almost linear while maximum dent tongue varies from 7.8mm to 50.9mm and become equal to the yield stress of St3 steel (245MPa) at maximum dent tongue of 50.9mm. Further rise of maximum dent tongue causes top-layer metal plastic deformation at the bottom area of the dent (check accent note at fig. 2).

Mid-layer stresses (fig. 3) grow almost linear as maximum dent tongue varies up to 85.8mm and exceed the allowed value of 162MPa as maximum dent tongue above 85.8mm.

There are two maximum allowed values for stresses of VSTFD wall:

1) for top-layer stresses σ_{top}:

$$\sigma_{top} \le R_{yn}, \qquad (2)$$

where R_{yn} - yield stress of steel St3 (245 MPa);

2) for mid-layer stresses σ_{mid}:

$$\sigma_{mid} \le \sigma_{max}, \qquad (3)$$

where $\sigma_{max} = m\dfrac{R_{yn}}{\gamma_m \gamma_n} = 162\ MPa$;

m = 0.8 - wall operation condition coefficient for upper belts;

γ_m = 1.1 - wall material safety factor;

γ_n = 1.1 - tank operation safety factor.

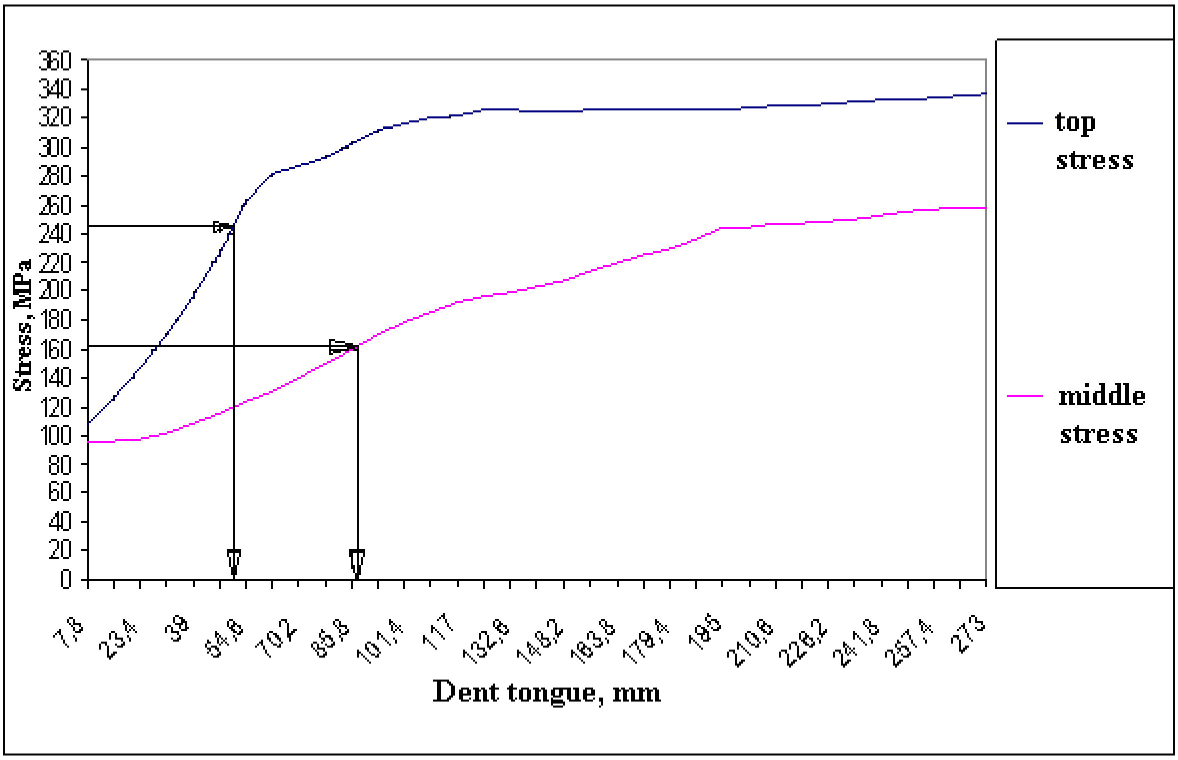

Figure 3. Dependence between maximum 1st principal stress (mid-layer and top-layer) and maximum dent tongue.

Thereby, maximum allowed dent tongue with current parameters (length, height, shape, location on the tank wall) is 50.9mm according to the maximum stress criteria (2, 3) for VSTFD-10000 operating on designed oil level. As far as measured during diagnostics maximum dent tongue is 78mm the further operation of the VSTFD-10000 on designed oil level is not permitted.

However, further operation of the VSTFD-10000 can be allowed if lowers oil level. In order to define maximum allowed oil level there are several wall stress-deformed state with oil level lowering to be performed. Figure 4 represents a results of maximum allowed oil level calculation for meeting the maximum stress criteria (2, 3) of the wall metal depending on the maximum dent tongue value. For current VSTFD-10000 stress criteria is met for the measured dent tongue 78mm if calculated oil level is 9m.

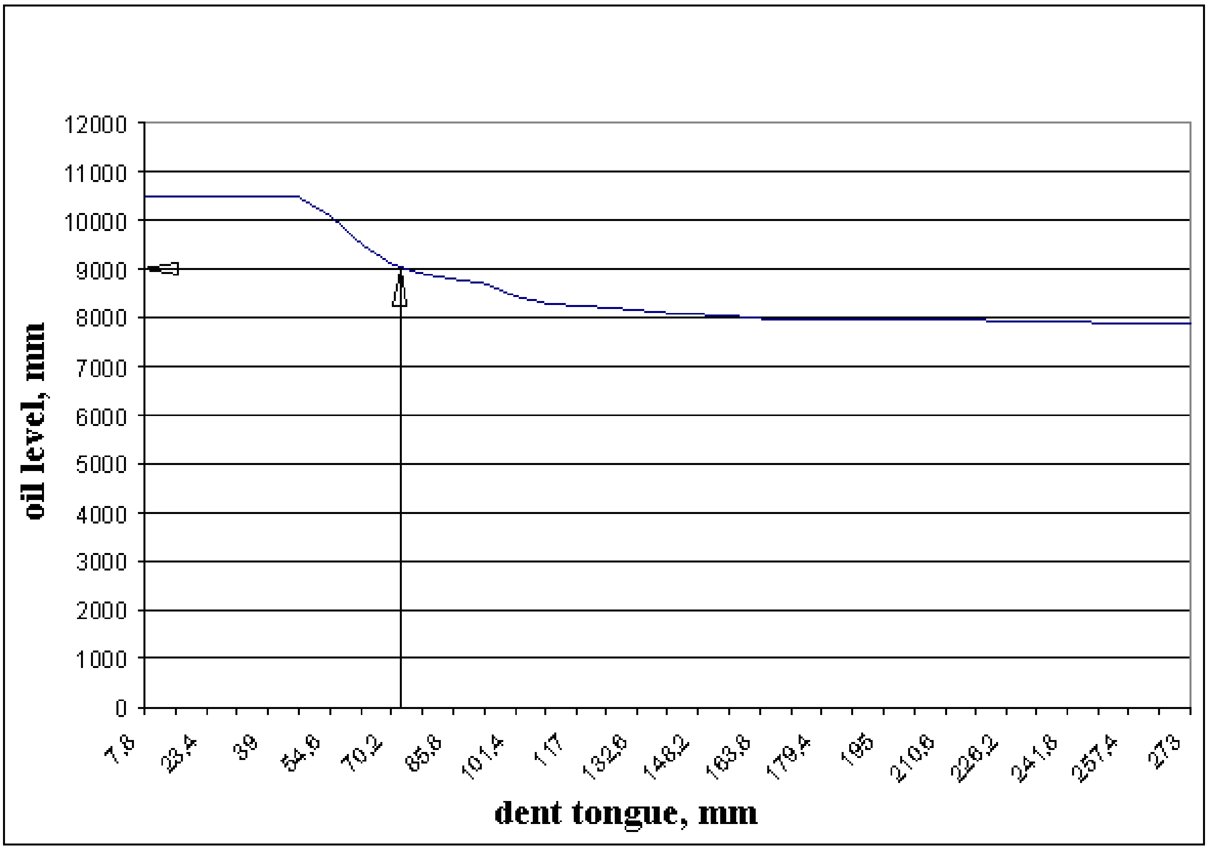

Figure 4. Dependence between maximum allowed oil level and maximum dent tongue.

Now we will have a look on local wall steady loss - buckle. Local wall steady loss is relatively abrupt change of dent tongue value at a small loads increment.

Figure 5 shows example of dependence between displacements in dent area and oil level. Maximum dent tongue here is 132.6mm on empty tank. Evidently, the buckle occurs at oil level 8.3m.

Similar calculations were performed with maximum dent tongue varies from 7.8mm up to 273mm with step of 7.8mm (35 calculations total) and dependence between oil level with buckle occurrence and maximum dent tongue was found (fig. 6 as a result).

Figure 6 shows 3 sectors:

1) first sector shows that there is no buckle if maximum dent tongue value lies between 0mm and 117mm;

2) second sector shows that there is buckle occurs if maximum dent tongue value lies between 124.8mm and 241.8mm;

3) third sector shows that there is no buckle if maximum dent tongue value lies above or equal to 241.8mm at a designed oil level.

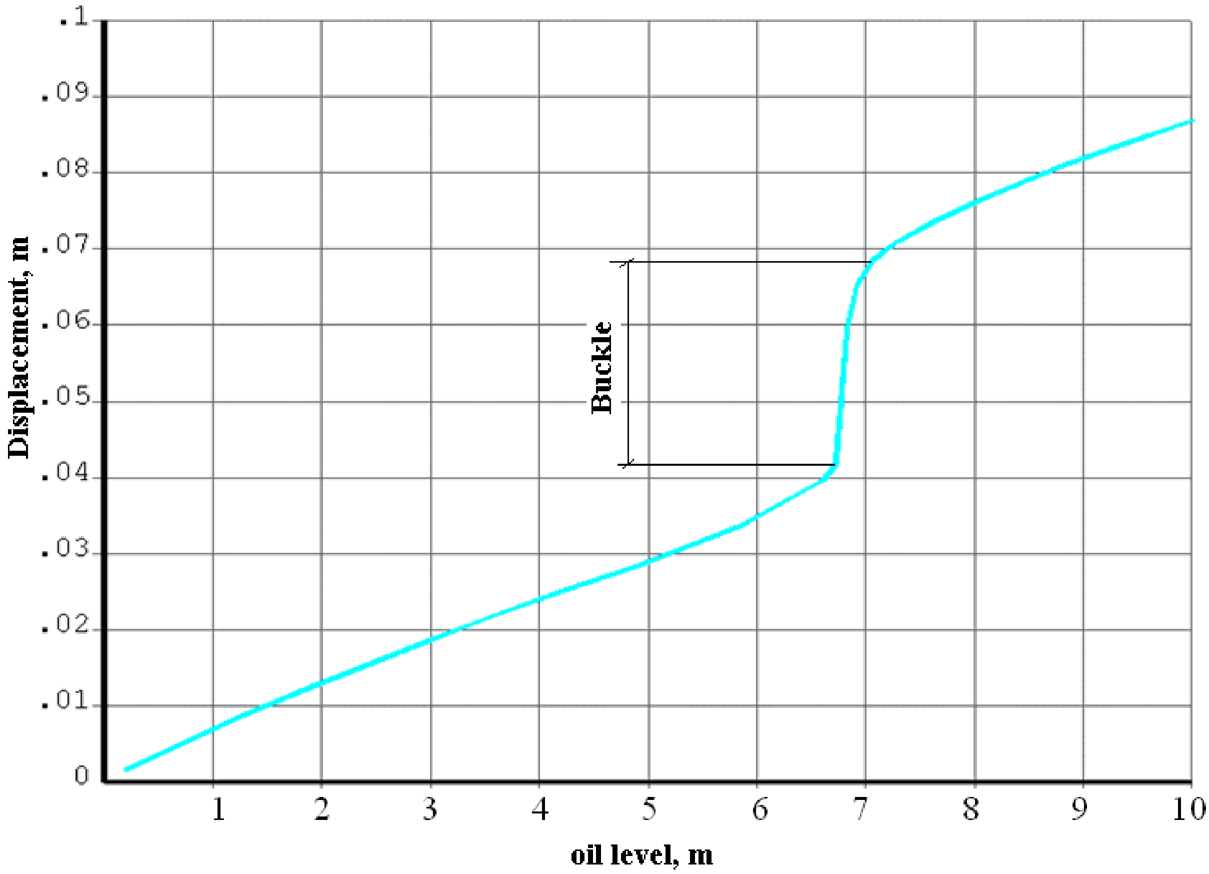

Figure 5. Dependence between displacements in dent area and oil level. Maximum dent tongue is 132.6mm.

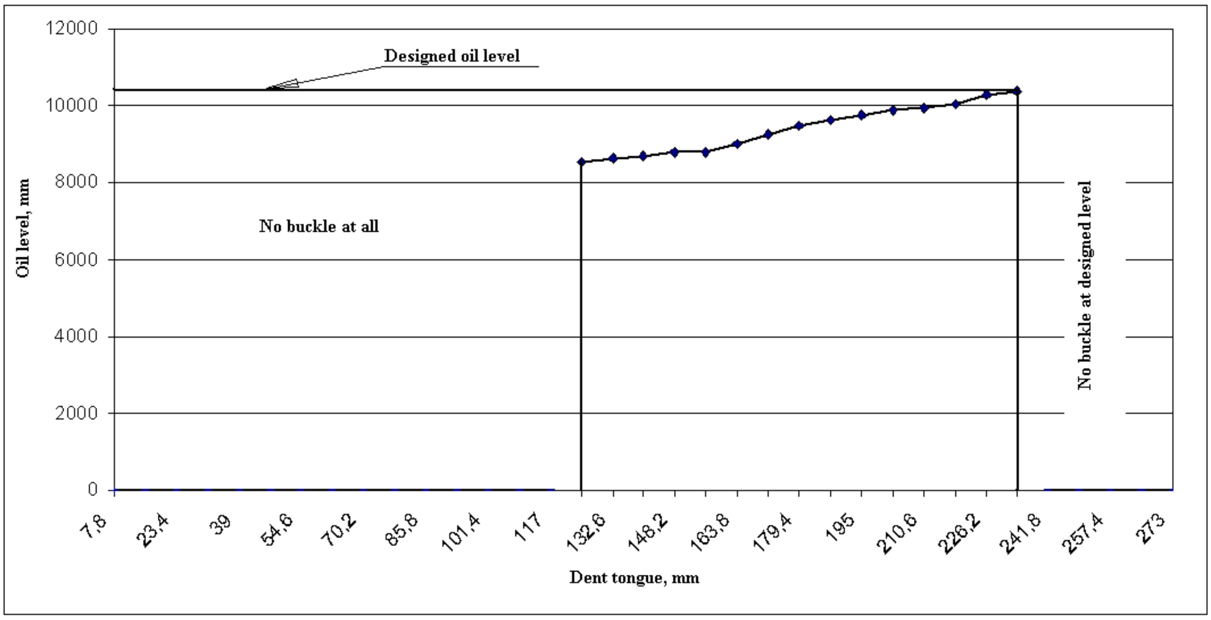

Figure 6. Dependence between oil level with buckle occurs and maximum dent tongue.

Thereby, maximum allowed dent tongue is 117mm by criterion of buckle absence for safety operation of the VST at a designed oil level. The presence of dent with maximum tongue 78mm does not prevent operation of the tank by the criterion of buckle absence.

Thus, it has concluded on the assumption of described above criteria and techniques that chosen VST is allowed to operate at a maximum oil level 9m without maintenance of the dent with maximum tongue value 78mm on it.

Practical conclusion from article is allowance of VST operation with lowering of oil level down to 9m instead of designed oil level 10.48m on the grounds of calculations performed by an expert organization. Maintaining organization may choose either repair the VST and operate it at a designed oil level or extend VST operation with calculated oil level.

CONCLUSION.

1. In order to explain possibility of further VST operation with geometry wall defects (dent and other deviations of VST wall geometry parameters from designed) it is necessary to approve performing calculations that with factual measured VST wall parameters and external environment conditions there are no intolerable stress values and wall steady provided.

2. Developed technique makes it possible to calculate allowable safety VST with wall defects operation conditions (loads, oil level etc.). Conclusion grounded on a such calculation allows to approve reasonability and safety conditions of further VST operations or determine amount of VST maintenance required.