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STATE-OF-THE-ART AND PROSPECTS OF MANUFACTURING WELDED TANKS FOR OIL STORAGE IN UKRAINE (REVIEW)

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The critical analysis of rationality of the further construction of vertical welded tanks for oil storage of 20–50 thous. m^3 capacity with the use of coiled sheet (blanks) panels is given. It is shown that the application of coiling method during erection of tanks of large capacity in 1970–1985 was largely dictated by the foreign economic circumstances. The production capacities for manufacture of coiled sheet panels, created in those years, continued to dictate the need for construction of coiled tanks also in the period of economic stability in the country. The drawbacks of coiled tanks and the proposed ways of their elimination are considered. After the collapse of the USSR the construction of tanks for oil storage of separate sheets began in the CIS countries. On the example of tanks with a protective wall the possibility of improving their reliability is shown applying the new steels of increased and high strength. The proposals for the constructive improvement of the separate elements of tanks of large capacity and the new grades of steels, recommended for them are given. 26 Ref., 1 Table, 5 Figures.

Keywords: *cylindrical tanks, coiled sheet panels, vertical site butts, low-cycle loading, restoration of wall serviceability, high-quality steels, sheet-by-sheet erection of wall*

In the recent years the periodic publications on welded steel structures deal with an active discussion regarding the rationality of applying the coiling method during construction of cylindrical steel tanks of a large capacity (V = 20–50 thous. m^3) and the search for optimal solutions for improvement of their geometrical shape [1]. A great part of coiled tanks was constructed in the USSR in the 1970–1985 years. The construction of tanks was closely connected with transportation of large volumes of Syberian oil to the European territory of the Soviet Union. Those were the years of military and economic struggle of two world systems, the years when the time was one of the most important factors in development of the country economy. The state needed to construct the main oil pipelines with the tank parks of large capacity in the shortest term in order to supply the Syberian oil to constructing objects of large oil chemistry and to the world market for filling the country budget. Under those conditions the problems of construction quality and the guaranteed service life of tanks were often sidelined.

Before discovery of the Syberian oil, during oil production of about 50 million tons per year, there was no demand for the tanks of more than 10 thous. m^3 capacity in the country. Under those conditions the quality of coiled tanks at $V \leq 5$ thous. m^3 completely satisfied the consumers. At the same time to satisfy a high demand for oil, there was a mass construction of tanks of 50–100 thous. m^3 capacity at a high technical level in the countries of Europe and in Japan. The oil was transported by tankers with displacement ranging from 50 to 150 thous. m^3 and that fact dictated namely a large capacity of tanks.

By 1970 in the system of the Ministry of Assembly and Special Construction Works the technical capacities were created allowing manufacturing the coiled sheet panels for more than 20 tanks VST (vertical steel tank) of 50 thous. m^3 per year only in one mill [2]. Under the conditions of urgent need in creating tank parks of large capacity there was no time for study and mastering foreign experience. Also from the point of view of the present time it should be confessed, that application of coiling method under that situation provided realization of an important state task, though with a rather low quality and the service life of not more than 20 years.

At the same time, even when that problem was no longer urgent, the construction of tanks of 20–50 thous. m^3 capacity with a considerably low quality was persistently continued [3]. However, that fact has its explanation as well: the Ministry of Erection and Special Construction Works established full monopoly for the whole cycle of tanks manufacture. The mentioned agency worked out the norms on erection of coiled tanks, the tanks were manufactured at the plants of the Ministry and erected by the own organizations. Already at the stage of designing the steel structures of tanks there was a necessary requirement for providing the possibility of applying the coiling method during their manufacture and erection [4]. Beginning from 1965, all the tanks with the capacity of not more than 20 thous. m^3 were constructed of coiled sheet panels. The intention of the Ministry-monopolist is natural and understandable. At its enterprises the large, highly-specialized production capacities were created intended only for manufacture of coiled panels. No one supports the refuse from manufacture of tanks applying coiled panels. The experience just convinced [3, 5] that it was rational to apply them for tanks with a wall thickness of not more than 8 mm. In practice, these are the vessels with the capacity of not more than 3 thous. m^3. Regarding the refuse from shop automatic welding, we should note that in the recent years for the walls and bottoms of tanks of large capacity the sheets of sizes of up to 2.5×8.0 m at the thickness of 8–30 mm are used. The sheets are welded using automatic and mechanized welding, which allows producing high-quality welded butt joints of the wall at an acceptable welding speed.

Throughout 1992–2011 the associates of the PWI carried out an evaluation of the technical condition of more than 200 coiled tanks with a capacity of 3–50 thous. m^3 at the oil parks in Ukraine. The inspection showed that after 15–20 years of service they completely exhausted their service life and required a complex capital repair [6]. Only the condition of separate tanks of the capacity of not more than 5 thous. m^3 was evaluated as satisfactory. The main reason was the presence of a large angular deformation f in the vertical welded site joints of the wall (f = 30–50 mm on base of 500 mm) and the presence of horizontal corrugations and dents in the middle and upper parts of the wall surface (Figure 1). For over 60 years the attempts of site workers to find an acceptable way to impart a design curvature to the end sections at the wall thickness of 10–18 mm, were not successful.

The cause for formation of corrugations on the wall during uncoiling the coil was considered by the authors in the publication [7]. It was shown on the concrete tank that with the difference in marks of any points of the outer contour of the bottom from the horizontal by 30–40 mm, which are accepted in the norms [8], the formation of corrugations on the middle and upper wall areas is inevitable. The panel, welded of separate sheets, represents a rectangle with dimensions of about 18×30 m, where 18 m is the height of the wall. As is observed in practice, it is impossible to impart a profile of the outer contour of the bottom with a difference in the marks of the circumferential basement of up to 40 mm without fractures arising on the thinner upper girths of the wall.

To improve the serviceability of vertical site butts of the wall of coiled tanks it was important to establish the scientifically grounded tolerances for angular deformations in them. The accepted tolerances had to ensure that welded joints would work out the designed service life in the conditions, which exclude the appearance of low-cycle fatigue in them. In 1987 at the PWI a special composite specimen for a low-cycle testing of welded joints applying angular

Figure 1. Formation of corrugations and dents on the wall after deployment of coils. 5 thous. m^3 tank with a vertical wall

deformation was developed (Figure 2). The tests of specimens of steels 16G2AF, 09G2S and VSt3sp [9] with different value of angular deformation allowed obtaining the dependence of N_{cr} on value of angular deformation in the extended range of values f. N_{cr} is the number of loading cycles of specimen before arising a visually observed crack of 3–4 mm length in the welded joint. However, the tolerances for angular deformations, developed at the PWI, were included into the new norms for erection of tanks [10] as the recommended ones. Such a record allowed the project developers to take those values f, which were easily reached by site workers. As a result, in the norms [8, 11], the recommended values for vertical site butts of the wall were excluded. In the norms a new record appeared that the value f was accepted according to the requirements of the project «Metal Structures» (MS) of the standard [12], which allows the construction of coiled tanks with a service life of not more than 15–20 years. In the standard, one tolerance for the value of angular deformation f = 1/2 inch on the 1 m long template was accepted.

At the presence of fatigue cracks in the vertical site joints of wall of the majority of coiled tanks of 10–50 thous. m^3 capacity (Figure 3, *a*) an urgent need for their repair appeared. All the specialists understood that this is a rejection of coiled technology in construction and the angular deformation (Figure 3, *b*), can not be eliminated by repair of the weld. At the initial stage of service of tanks with angular deformations, the proposals on repair were reduced to local unloading of welded joint from the circumferential forces by mounting the rigid horizontal stiffeners in the weld zone [13]. Such a solution resulted in an additional concentration of stresses in the welded

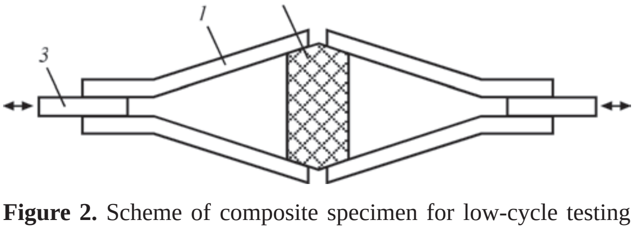

Figure 2. Scheme of composite specimen for low-cycle testing of welded joints with angular deformation: *1* — elements being tested; *2* — damper; *3* — element for fixing in the pulsator

Figure 3. 10 thous. m^3 tank with a vertical wall: fatigue cracks along the weld fusion zone (*a*); angular deformations in the vertical butt welded joint of the wall (*b*)

joint and after one or two years of service near the end regions of stiffener welds the fatigue cracks began to appear. In a number of cases several repairs of welded joints were performed by means of their partial (in girths) cutting out and welding-in of special inserts [14]. In the process of works the inadmissible deviations of geometric shape were formed on the adjacent areas of the wall. To eliminate them, a system of horizontal and vertical stiffeners with tension bars was mounted on the wall, which significantly reduced the serviceability of the wall (Figure 4).

The obtained results showed that to eliminate or reduce the local deformation of the wall after welding-in inserts, it is necessary to know the stressed state of inserts and the adjacent regions of the wall. The evaluation of stressed state of a wall area of the tank during replacement of a site butt on it with separate inserts was carried out at the PWI [15]. The calculation was carried out for the tank of the capacity of 50 thous. m^3, the project of the Central Research and Design Institute of Metal Structures named after N.P. Melnikov (Moscow), the metal of the wall was steel

Figure 4. Improvement of geometric shape of the wall of the coiled 20 thous. m^3 capacity vertical wall tank with a fixed roof applying local air holes

16G2AF, taking into account the specific technology of welding-in of inserts. The evaluation of risk of buckling of a flexible plate was performed using an approximate energy method, according to which the risk of buckling will be high, if $E = U + W < 0$, where E is the total energy of the elastic system; U is the potential bending energy for the given region; W is the work of membrane welding stresses.

The obtained diagrams of residual stresses are given in the work [15]. The calculation results allowed evaluating the probability of wall buckling in the repair area. Based on the obtained results, a special technology for replacing a vertical butt with inserts in one line along the girths with the scatter of vertical welds was developed at the PWI. The technology was tested many times in practice, as for example in vertical steel tanks of 50 thous. m^3 with floating roof at the oil refinery in Mozyr at the linear production-dispatching station «Lisichansk», when the replacement of all site butts was performed; in the vertical steel tanks of 20 thous. m^3 with fixed roof at the oil pumping stations of Kremenchug, «Snigirevka», «Avgustovka» and many other. After repair all the tanks were put into operation with a project level of loading and the service life of at least 20 years.

After more than 30 years of unsuccessful experience in construction of tanks of 20–50 thous. m^3 capacity of coiled sheet panels, the proposals of some authors [16, 17] regarding the possibility of applying the coiling method also in future, while using their inventions, are rather questionable. However, the proposals to improve the serviceability of the wall are based on significant local violations of its rigidity, geometric shape, changes in the laminar flow of the force flow of circumferential stresses. Finely, this will lead to the appearance of new zones of stress concentration, fracture nuclei and propagation of fatigue cracks on the wall.

Since 1991, the dictate on construction of tanks under the standard projects was cancelled. The main figure then was the customer, and the main requirements for the tanks were the quality of erection, the designed service life of at least 40–50 years and the increased environmental safety. Since 2001, in the CIS countries, the tanks of large capacity began to be constructed everywhere using the sheet-by-sheet method and with the designed service life of at least 40 years (Figure 5). In Russia, the tanks were constructed «on a turn-key basis» by foreign companies [18]. In the Republic of Belarus on the Druzhba oil pipeline, two capacities of $V = 75$ thous. m^3 were constructed by the Polish company, and six capacities of $V = 50$ thous. m^3 were made by Belarusian erecting organizations [19]. The project of MS of the tank and the author's supervision were carried out by the PWI specialists. The construction coincided with the beginning of a wide application of tanks with a protective wall and a double bottom. Replacing the traditional fire dike with a protective wall provided a significant increase in the capacity of the oil park at the same areas, and a double bottom had to prevent oil from spilling to the environment. The presence of additional requirements to the tanks with a protective wall for prevention of the avalanche fractures of the main tank wall in the standards [8, 11] demanded for a scientific confirmation of the fact that new steels applied for the wall would guarantee the fulfillment of the standard requirements. With this aim, at the PWI the experimental investigations on resistance to propagation of tough fatigue crack of welded butt joints of steels of C390 strength class: 06GB and 09G2SYuch-U [20, 21] (having $KCV_{-40} \geq \geq 170$ J/cm^2) were carried out. On the full-scale specimens under the conditions of cyclic loading, the process of initiation and propagation of a fatigue crack from the initial notch along the fusion line was investigated. It was shown that at the final critical stage of its propagation the formed through crack had a small area of a stable (predictable) state. The length of that area by a number of cycles Nz = 300 and the periodicity of loading of tanks equal to a one loading during three days, provides a guaranteed detection of a crack by the oil spot during visual inspection of the wall in accordance with the requirement of the acting regulations on service of tanks [14]. The detection of fatigue cracks in vertical welded butt joints of the wall at the subcritical stage of their propagation almost prevents the extended fractures and full opening of the wall. This provides a clear specification of the functional purpose of a main (inner) and a protective wall of the tank. The main wall: providing static strength and prevention of extended tough fractures, the protective wall: providing static strength of the tank during its filling with oil, poured from the main tank.

Figure 5. Erection of wall of 50 thous. m^3 vertical wall tank with a floating roof applying sheets of 2.5×8.0 m

The issue of the hard contour conditions influencing the tough properties (KCV_{-40}) of the circumferential welded joints of branch pipes and manholes during their cutting-in to the first girth of the wall was also investigated. This mainly relates to the sheet rolled metal of the lower girths of the wall, which are supplied in the state after hardening with tempering: steel 06GB 390 and 06GB 355 [22] and normalized steel 09G2SYuch-U [26]. The steels 06GB390 and 06GB355 are attractive by a low carbon content and high standard values of $KCV_{-40} \geq 120$ J/cm^2 (in fact 300 J/cm^2 and more in the thicknesses of up to 50 mm). There were expectations that high tough properties of sheet metal largely compensate the increased welding deformations in the metal of circumferential weld, which arise during welding in hard contour. The branch pipes were welded-in with preheating of edges applying the electrodes OK Autrod 12.51. However, after the branch pipes with a diameter of 400 mm were welded-in into a 26 mm thick wall girth, in the circumferential welds the cold cracks appeared. To eliminate them, a rather complicated welding technology was applied, including preheating of edges, pinning of initial passes and postweld heating of welded joint. It should be noted that the sheet rolled metal of steels supplied in the state after hardening with tempering, according to the technical conditions, has $\sigma_y/\sigma_t \leq 0.85$ for the thicknesses of 25 mm and more, and ≤ 0.90 for the thicknesses smaller than 25 mm. In accordance with the requirement of standards [8, 12], the ratio σ_y/σ_t should not exceed 0.75. In the steels proposed in these standards, the required ratio is fulfilled only for the normalized sheet steels at the present time.

For a more complete evaluation of influence of hard contour on the values of impact toughness of weld metal and the fusion zone of steels 09G2SYuch-U and 06GB, the additional investigations were carried out. Imitating the welded joint of the wall with the branch pipe and the conditions of hard contour, the plates of these steels of 26 mm thick were welded applying the electrodes LB-52U of 3.2 mm diameter. One plate was heat-treated: tempering at the temperature of 620 °C with one hour holding. The specimens were manufactured of each plate for testing on KCV_{-40} along the fusion line and weld metal. The details of the test results are considered in the work [21]. The Table given the final test results. The test results show that a high tempering of insert assembles, in accordance with the standards for wall thickness exceeding 25 mm, reduces the value of impact toughness KCV_{-40} for these steels to 10 %. This gives grounds to suggest that while obtaining a larger number of statistic data the issue of application of heat treatment at the wall thickness of 30 mm and more for the considered steels, as is accepted for pressure vessels, can be relevant [23].

The obtained results provide a determined scientific grounding for the tendency prevailed in the recent years, that for the tanks of large capacity the normalized sheet rolled metal of steels of strength class C350–420 at actual values of KCV_{-40} ≥150 J/cm^2 with the content of carbon of 0.14–0.18 % and sulfur of less than 0.01 % should be applied. The presence of higher carbon somewhat complicates and increases the cost of welding technology applied for these steels. The welded joints of wall of these steels are made using welding wire of the type OK Autrod 13/28 ESAB with a nickel content of 2.4 %. In this regard, the more attractive are the sheet normalized rolled metal 09G2SYuch-U and 09KhG2SYuch-U of the steel class C 355–420 with a reduced content of carbon (0.10–0.13 %), increased content of manganese (1.9–2.2 %) and microalloying with cerium (0.001–0.050 %), developed at the PWI [24].

With the use of the sheet normalized steel 09G2SYuch-U390 in accordance with the project and at the supervision of the PWI specialists, in the Republic of Belarus two vertical steel tanks of 50 thous. m^3 with a floating roof were constructed with a protective wall (Figure 5). In the main tank the first (l = 26 mm) and the second (l = 22 mm) wall girths, and in the protective tank the first one (l = 21 mm) were made of this steel. In accordance with the factory certificates for the sheet l = 26 mm, the value of impact toughness was KCV_{-40} = 173–204 J/cm^2. The application of preheating of edges and mechanized shielded-gas welding (Ar + 20 % CO_2) with the solid wire EMK 6 ER 70 S-6 eliminated the occurrence of cold cracks in welded joints of the wall and in the welds after welding-in of branch pipes and manholes. After additional investigations of welded joints taking into account the presence of hard contour, the solution was taken to refuse from a high tempering of insert assembles and manholes. The assembly of the bottom hatch was subjected to heat treatment, as was envisaged [12].

Influence of hard contour conditions on the value of toughness of welded butt joints of 06Gb and 09G2SYuch-U steels of 26 mm thickness

Welding conditions	Heat treatment presence	KCV_{-40}, J/cm^2	
		09G2SYuch-U	06GB
In free state	Absent	317.1–416.9 / 351.7×3	338.5–342.2 / 350.7×3
	High tempering	303.4–329.3 / 316.1×3	341.1–339.3 / 340.2×3
Hard contour	Absent	338.3–337.5 / 338.3×3	340.1–339.2 / 340.6×3
	High tempering	338.7–273.4 / 308.1×3	343.3–248.2 / 311.3×3
Note. Notch location is fusion line.			

The author's supervision of erection of four tanks of 50 thous. m^3 capacity, having a protective wall [19], revealed a number of significant drawbacks regarding the design and serviceability of the two-layered central part of the bottom. The two-layer bottom was used at the request of the customer. The assembly and welding of one sealed compartment of the bottom per one shift, provided by the project to prevent moisture from entering the compartment, was often an unreal task. Having ten compartments on the bottom, it was almost impossible to succeed in ten dry days at the construction area. Therefore, the ends of the compartments remained open until the moisture evaporated completely during solar heating of the upper bottom. It was necessary to refuse also the control of sealing the compartments by vacuum. When the tank is filled the vacuum does not react to the presence of leakage in the upper bottom. In winter, in the interlayer space, the moisture condenses, which leads to a sharp drop in vacuum. Therefore, to check sealing the sensors with a response to the presence of hydrocarbon vapors were mounted into the signal pipes.

The analysis of assembly of the double bottom showed that its structure is very metal-consuming and labor-intensive in manufacture. The total design thickness of the bottom of tanks was 8 + 11 = 19 mm (vertical wall tanks of 75 and 50 thous. m^3 with a floating roof [19]) at the thickness of the outer, contour, bottom (edges) was 20 mm. There is a clear disregard of the principle of maximum concentration of metal in one element. With leakage of the sealed compartment, the removal of oil and its vapors from it is complicated. The experience, gained over 20 years in service of tanks of a capacity of 20 thous. m^3 with a thickness of edges of 9 mm [25], convincingly showed that such thickness in the presence of anticorrosion coating is quite sufficient to maintain its impermeability over 40 years. This is confirmed also by the norms of the

OJSC «AK Transneft» [26], where the thickness of the edge and the central part of the bottom of tanks of a large capacity is accepted as equal to 9 mm.

On agreement with the customer, in two similar tanks of the third stage of construction, the bottoms were accepted as single-layer of 12 mm thickness [19]. The application of a single-layer thickened central part of the bottom significantly reduced the metal consumption and the volume of site works and increased its reliability. Taking into account the experience gained in the construction of tanks in the Republic of Belarus, the PWI realized the projects of vertical 50 thous. m^3 tank with a floating roof for its construction at the linear production-dispatching station «Brody», the vertical 20 thous. m^3 tank with a floating roof at the oil pumping station «Avgustovka» (the customer is PJSC «Ukrtransneft»), for capital repair of the vertical 50 thous. m^3 tank with a floating roof (PJSC «Ukrtatnafta», Kremenchug). In all the mentioned objects the application of the new tested steels and design solutions was provided.

Based on the mentioned analysis of the performed works for evaluation of technical condition of the coiled tanks of the capacity of 5–50 thous. m^3 after their service during 15–20 years and proposals on construction of tanks with a protective wall and a guaranteed service life of at least 40 years, the following conclusions can be made:

● tanks for storage of oil and oil products with the thickness of lower girth of wall of 10 mm and more, assembled of coiled sheet panels, do not meet the requirements of existing standards as to the geometric shape of wall and the estimated service life of 20 years;

● application of coiled sheet panels during erection of wall of tanks should be limited in the standard of Ukraine by a thickness of the lower girth of not more than 8 mm;

● in the standard of Ukraine ([8], Table 13), it is necessary to state clearly the requirements to the local angular deformations of vertical welds of the wall. The admissible value of deflection f on the 500 mm base for the entire wall should be indicated not in the project of MS, but in the standard;

● the list of steel grades recommended in the standard of Ukraine (DSTU B V.2.6-183:2011, Table 7) should be supplemented with the new steels of strength class C355–440: 06GB355; 06GB390 (delivery in the state of hardening with tempering); 09G2SYuch-U390; 09KhG2SYuch-U440 (delivery in the as-normalized state).

1. Barvinko, A.Yu. et al. (2016) Application of sheet quality steel of higher strength in oil storage tanks. *Montazhn. i Spets. Raboty v Stroitelstve*, **1**, 2–8.
2. Biletsky, S.M., Golinko, V.M. (1983) *Industrial manufacture of oversized welded sheet structures*. Kiev: Naukova Dumka.
3. Kupreishvili, S.M. (2013) Vertical cylindrical tanks with floating roofs. *Montazhn. i Spets. Raboty v Stroitelstve*, **2**, 2–16.
4. *SNiP 2.09.03–85*: Construction of industrial enterprises, 33.
5. Barvinko, Yu.P., Golinko, V.M. (2009) To the 60th anniversary of industrial application of the technology of manufacturing cylindrical tanks from coiled blanks. *The Paton Welding J*., **2**, 26–28.
6. Barvinko, Yu.P., Barvinko, A.Yu., Kargin, A.Yu. (2006) Restoration of tanks for oil storage with walls from coiled blanks of 20 thous. m^3 and 50 thous. m^3 capacity. *Montazhn. i Spets. Raboty v Stroitelstve*, **10**, 5–13.
7. Barvinko, Yu.P., Barvinko, A.Yu. (2013) On possibility of application of coiled blanks in modern tank building. *Ibid*., **11**, 2–7.
8. *DSTUB V.2.6-183.2011*: Vertical cylindrical steel tanks for oil and oil products, 77.
9. Biletsky, S.M. et al. (1992) Improvement of resistance to low-cycle fatigue of vertical welded butt walls of cylindrical tanks with angle deformations. *Avtomatich. Svarka*, **7/8**, 41–46.
10. *VSN 311–89:* Assembly of vertical cylindrical steel tanks for storage of oil of 100 to 50000 m^3 volume. 33–37, 60.
11. *GOST R 52910–2008*: Vertical cylindrical steel tanks for oil and oil products, 52.
12. (2007) *API STANDARD 650*: Welded steel tanks for storage of oil products, 410.
13. Popovsky, B.V., Ritchik, G.A. (1986) Ensuring of geometric shape of coiled tank walls in zones of site welds. *Montazhn. i Spets. Raboty v Stroitelstve*, **11**, 12–15.
14. (1988) *Operating rules of tanks and instructions for their repair*. Moscow: Nedra.
15. Makhnenko, V.I., Barvinko, A.Yu., Barvinko, Yu.P. et al. (2002) Estimation of stressed state of the wall of coiled vertical cylindrical tanks in welding-in of insert plates. *The Paton Welding J*., **5**, 2–6.
16. Kupreishvili, S.M. (2015) Oil production and state-of-the-art of modern tank building. *Montazhn. i Spets. Raboty v Stroitelstve*, **10**, 2–11.
17. Doroshenko, F.E. (2016) Problems of ensuring of geometric accuracy of vertical steel tank bodies. *Ibid*., **5**, 2–7.
18. Kupreishvili, S.M. (2016) Classical vertical cylindrical tank. *Montazhn. i Spets. Raboty v Stroitelstve*, **7**, 2–11.
19. Chernikov, O.P. et al. (2014) Modern tank building in Belarus Republic. *Ibid*., **12**, 9–13.
20. Barvinko, A.Yu., Barvinko, Yu.P. (2016) On possibility of prevention of avalanche fractures of wall of cylindrical tanks for oil storage using steel sheets with higher values of impact toughness. *Tekhn. Diagnostika i Nerazruch. Kontrol*, **2**, 44–49.
21. Poznyakov, V.D., Barvinko, A.Yu., Barvinko, Yu.P. et al. (2012) Cold resistance and lamellar fracture resistance of welded joints on steel 06GB-390. *The Paton Welding J*., **3**, 35–39.
22. *TU U 27.1-05416923-085:2006*: Sheet products being welded from quality steel of 355-590 strength classes for machine building. Term of validity 12-31–2016, 11.
23. *OST 26 291*: Welded steel vessels and apparatuses. General specifications.
24. *TU 14-1-5065–2006*. Modification 1. Thick plates of low-alloy steel of grades 09G2SYuch; 09G2SYuch-U; 09KhG2SYuch; 09KhG2SYuch-U.
25. *Typical project TP 704-1-70*: Vertical cylindrical steel tank for oil and oil products of 20000 m^3 capacity. Moscow: TsNII PSK, 1972.
26. *RD 16.01-60.30.00-KTN-026-1–04:* Codes of design of vertical steel tanks for oil storage of 1000–50000 m^3 capacity. Moscow.

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