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INFLUENCE OF CRACKS ON THE STRUCTURAL STABILITY OF CYLINDRICAL STEEL EQUALIZATION TANKS

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1. Introduction

Above-ground cylindrical steel tanks are indispensable assets in water and wastewater infrastructure. In equalization services, they buffer diurnal and industrial inflow variability, dampen “shock” pollutant loads, and stabilize downstream treatment functions, consistently shown to improve effluent quality and operational resilience [1].

Even when tanks are designed and operated within code provisions, long-term performance depends on how structural demand interacts with the service environment and maintenance practices. The technical literature documents characteristic failure modes – loss of containment by corrosion-induced wall thinning, local joint distress, and roof/shell instabilities – through forensic case studies that combine inspection, measurement, and finite-element analysis to reconstruct the damage sequence and define preventive measures [2].

Wastewater headspaces and wetted zones present particularly aggressive conditions for carbon and stainless steels due to variable pH, dissolved sulfides, chlorides, and microbiologically influenced corrosion. Recent reviews emphasize corrosion monitoring and mitigation as central to lifecycle reliability of storage and process tanks in treatment facilities [3].

Within this broader context, this study focuses on durability-oriented design, inspection, and risk-informed maintenance programs for tanks operating in wastewater service, drawing on established roles of equalization, observed failure mechanisms, and evidence from prior research and case histories.

2. Tank Description and Methods

2.1 Geometry, construction, and service

The investigated subject of this paper is an above-ground cylindrical steel equalization tank (nominal diameter 8.0 m, total height 17.6 m), assembled from bolted, factory-coated panels arranged in twelve courses (I–XII). Courses I–V use thin panels (t = 2.5 mm), course VI intermediate panels (t = 2.99 mm), and courses VII–XII thicker panels (t = 3.4 mm). The tank operates at atmospheric pressure in wastewater service with variable filling. Thin panels (2.5 – 2.99 mm) show low yield/UTS levels (~270–315 MPa), while the 3.4 mm panels exhibit significantly higher strength (ReH = 420 MPa, Rm = 571 MPa), consistent with micro alloyed composition.

2.2 Finite-element model of the tank

FE [4] model of the tank was created with course-wise thickness zoning (I–XII), simply supported at the base ring to prevent rigid-body motion, as shown in Fig. 1. The model is created within Simcenter Femap [5] software using 2D plate finite elements and consists of 278204 elements and 278832 nodes. The average element size is approximately 40 mm.

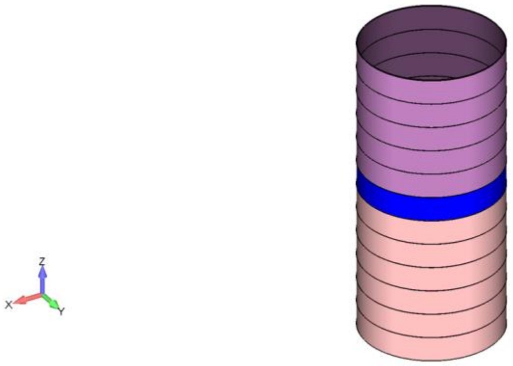

Fig.1 FE model with course-wise thickness zoning (I–XII)

2.3 *Experimental monitoring and initial crack modeling*

In service conditions, digital radiography was performed on representative wall samples, which revealed localized corrosion defects of varying extent. Pitting was observed both on exposed steel surfaces and beneath silicone-coated regions, including at the lap joints of bolted connections. Metallographic analysis (Fig. 2) of corroded samples confirmed the absence of an effective anticorrosive layer and showed progressive surface and subsurface degradation. In advanced cases, coalescence of pits led to detachment of larger fragments of metal, resulting in discontinuities resembling through-thickness cracks.

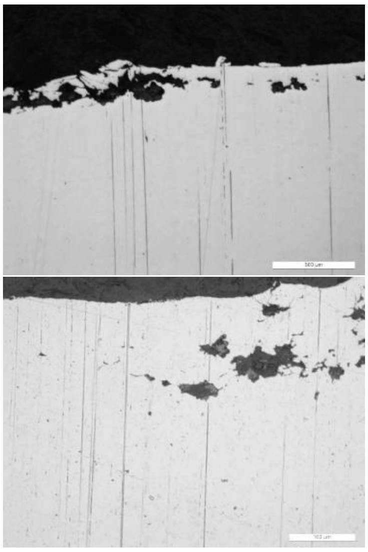

Fig. 2. Cross-sectional surface micrograph

Based on these inspection findings, a finite-element model of the tank was developed with an explicitly introduced initial crack in the ring 2 region (Fig. 3).

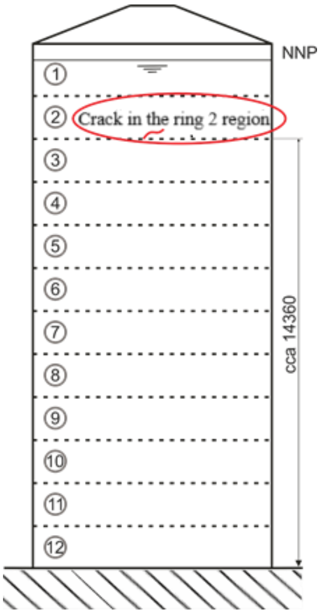

Fig. 3. Initial crack in the ring 2 region

2.4 *Loading and boundary conditions*

For design operating conditions, hydrostatic head of h = 17.0 m, liquid density ρ = 1000 kg/m^3 (wastewater), and gravitational acceleration g = 9.81 m/s^2 are considered.

The hydrostatic pressure distribution for h=17 m and ρ=1000 kg/m^3 is given in Fig. 4.

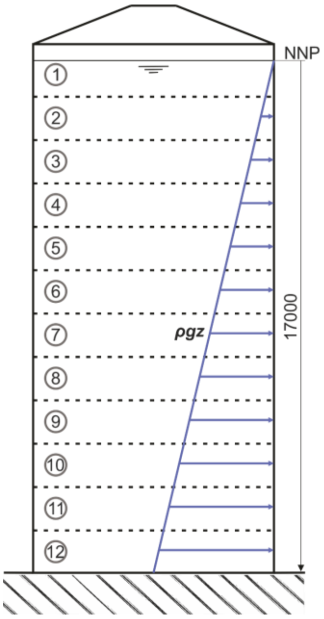

Fig. 4. Hydrostatic pressure diagram for h=17 m and ρ=1000 kg/m^3

3. Results and Discussion

3.1 *FEA results of tank without crack*

The von Mises stress distribution on tank model without crack is shown in Fig. 5. Peak stress values occur in the lower courses, where hydrostatic pressure is greatest, with maximum equivalent stresses reaching approximately 200 MPa.

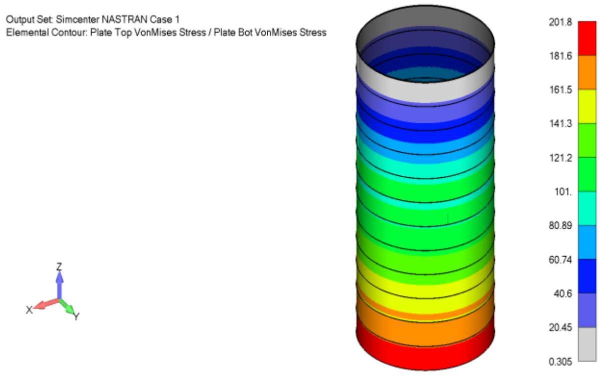

Fig. 5. Equivalent von Mises stress distribution in the intact tank model

3.2 *Effect of the crack on stress distribution*

When an initial crack was introduced in the ring 2 region, significant local stress amplification was observed. The von Mises stress field around the crack tip exhibits a highly localized concentration, with values exceeding 450 MPa (Fig. 6). This peak stress surpasses both the yield strength (R_{eH} = 270–315 MPa for thin panels) and the ultimate tensile strength of the 2.5 mm wall panels.

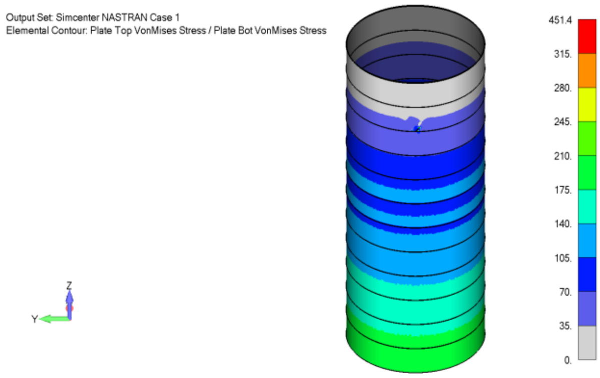

Fig. 6. Equivalent von Mises stress distribution in the tank model with modeled crack in the ring 2 region

Fig. 7 provides an enlarged view of the stress state in the region of ring 2, highlighting the localized stress concentration around the modeled crack. The contour plot clearly illustrates the redistribution of equivalent stresses in the vicinity of the defect, where sharp gradients develop as a result of crack–tip effects. The crack perturbs the otherwise smooth hoop stress distribution, introducing discontinuities across the ring joint.

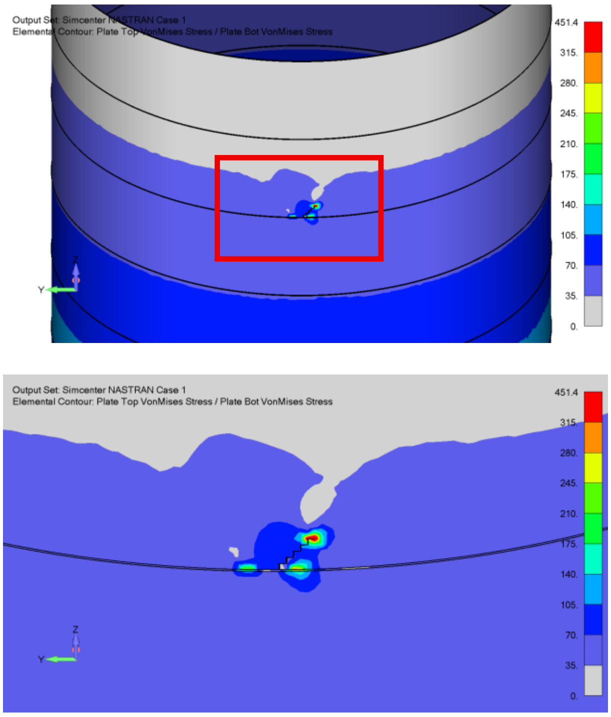

Fig. 7 Localized von Mises stress distribution around the modeled crack in ring 2

3.3 *Comparative assessment*

A direct comparison between the intact and cracked models highlights the pronounced influence of the defect. While the intact model remains in the elastic range with stresses below yield, the cracked configuration shows stress intensities well above the material capacity. These results suggest that even a relatively small initial crack at a ring joint can act as a critical trigger for structural instability, potentially leading to uncontrolled crack propagation and loss of containment.

The analysis emphasizes the importance of continuous inspection and early detection of cracks in bolted-panel tanks, as localized overstress conditions can develop rapidly under routine hydrostatic loading. Preventive maintenance and reinforcement of critical joints should therefore be prioritized in durability-oriented management of wastewater tanks.

4. Conclusions

This study presented a finite-element analysis of a cylindrical steel wastewater equalization tank, with particular emphasis on the effect of an initial crack at the ring 2 region. The intact model showed stress levels consistent with elastic shell theory, with maximum equivalent stresses remaining below the yield limit and displacements within acceptable serviceability ranges.

By contrast, the cracked configuration revealed highly localized stress intensification around the crack tip, with equivalent von Mises stresses exceeding both the yield and ultimate tensile strength of the thin (2.5 mm) wall panels. These results demonstrate that even small cracks introduced at course joints can act as critical defects, triggering localized plastification and posing a significant risk of crack propagation under routine hydrostatic loading.

The comparative assessment highlights the vulnerability of bolted, thin-walled steel tanks in aggressive wastewater environments, where defects can drastically alter the structural response. The findings emphasize the need for durability-oriented design, regular inspection, and risk-informed maintenance strategies to ensure the long-term reliability of such assets.

While the present study demonstrated the critical influence of localized cracks on the structural response of cylindrical steel wastewater tanks, several aspects merit further investigation:

- Fracture mechanics assessment – A full fracture mechanics analysis, including stress intensity factor (SIF) evaluation and crack growth simulations, would provide quantitative insight into the propagation potential under cyclic filling and emptying conditions.
- Material degradation effects – Incorporating corrosion-induced wall thinning, pitting, and microbiologically influenced corrosion into the finite-element framework would yield more realistic predictions of long-term performance of such structures.
- Experimental validation – Laboratory testing on representative bolted panel joints with artificial cracks would strengthen the numerical findings and help calibrate constitutive models for thin-walled steels.
- Monitoring and inspection strategies – Future work should explore the integration of non-destructive evaluation (NDE) methods, acoustic emission monitoring, and digital twins for early detection and life-cycle management of cracks.
- Mitigation measures – Structural retrofits, such as local reinforcement of ring joints or use of composite overlays, should be investigated as practical interventions to reduce stress concentration and delay crack propagation.

Overall, advancing the modeling, monitoring, and preventive maintenance of thin-walled steel tanks is essential for ensuring structural integrity and operational resilience in wastewater service environments.

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