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Integrity Assessment of Dented Aboveground Steel Storage Tank After Hydrostatic Testing

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Abstract— **Hydrostatic testing is an essential method for the quality control of storage tanks in industry, especially for new construction tanks. However, dents and other geometric imperfections were found at a new 50,000-kiloliter aboveground steel storage tank during hydrotest. This paper presents a comprehensive structural integrity assessment of that experienced shell denting during hydrostatic testing. To evaluate the tank's fitness for service (FFS), a Level 3 assessment was conducted following API 579-1/ASME FFS-1 Part 8 standards. In addition, finite element analysis was conducted to simulate the elastic stress distribution and fatigue behaviour under various loading conditions, including hydrostatic pressure, wind, and seismic loads. Results revealed that shells 7 and 8 experienced stress increases of up to 2282% compared to the undistorted condition, with von Mises stress remaining below the allowable limits. A fatigue analysis confirmed that stress amplitudes were below the fatigue threshold, resulting in infinite fatigue life. Furthermore, discharge simulation indicated improper dewatering could induce external pressure exceeding the material's yield strength, leading to localised plastic deformation. Nevertheless, the dented tank was structurally sound and compliant with API 650 and API 579-1/ASME FFS-1 criteria. The study highlights the importance of proper discharge procedures and confirms that no immediate repairs are required for the continued safe operation of the tank.**

Keywords— Buckling Behavior, Fatigue Assessment, Finite Element Analysis, Fitness-for-Service, Hydrostatic Testing, Shell Denting, Storage Tank, Structural Integrity, Von Mises Stress

I. INTRODUCTION

The hydrocarbon processing industry in Indonesia has a long-standing history, having developed over the past five decades. It has been crucial in supporting the nation's energy infrastructure and industrial development. As part of this sector, storage facilities for hydrocarbons in fluid form are of paramount importance for operational efficiency and safety.

Since the 1920s, atmospheric welded above-ground storage tanks (ASTs) have been widely employed as standard infrastructure for containing crude oil and refined hydrocarbon products. These tanks are typically constructed with large capacities and are strategically located near refineries, depots, and ports. Due to their size and exposure to various operational loads and environmental conditions, the structural integrity of these tanks is a critical concern.

Hydrostatic testing is an essential method for the quality control of storage tanks in industry; hydrostatic testing is universally known and accepted as a means to demonstrate the fitness of a pressurised component for service. Oil storage tanks and derivatives must be evaluated by hydrostatic testing for leaks in sideways welds, possible cracks and failures that may have occurred during construction or assembly. Buckling behaviour on the aboveground steel storage tank subjected to a hydrostatic test was previously investigated by Hassanzadeh and Rahmani [1], Mainier, et al. [2], Niloufari, et al. [3].

During hydrostatic testing, buckling of tanks under uniform external pressure is usually caused by operational problems during the discharge of the liquid contents, so a partial vacuum is produced [4]. Large storage tanks are designed to withstand only a small amount of internal pressure, not vacuum (external pressure on the tank wall). Collapsing a large tank with a small amount of vacuum is possible. Many reports of tanks collapsing due to something as simple as pumping fluid out while the tank vent is blocked. The tank in Figure 1 collapsed because the tank vent was blocked by sheet plastic, wax, or a bee nest [5].

In this paper, a newly constructed 50,000-kiloliter above-ground storage tank reported experiencing a dent on its wall during the hydrostatic testing within the construction phase. Dents and other geometric imperfections are widely known to have a substantial detrimental effect on the buckling strengths of shells. Such occurrences pose serious safety and operational risks, necessitating immediate investigation and evaluation of the tank's structural adequacy. The geometric imperfection to buckling behaviour was numerically assessed by Chen, et al. [6], Golzan and Showkati [7], Guggenberger [8], Herucakra, et al. [9], Hong and Teng [10], Pircher, et al. [11], Showkati and Ansourian [12], Rathinam and Prabu [13] and through

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laboratory testing by Niloufari, et al. [3], Aghajari, et al. [14], Fatemi, et al. [15], Maali, et al. [16], Maali, et al. [17], and it is found that imperfection parameters such as the depth, length, width and angle orientation of the dent; roundness are sensitively affecting the buckling strength of the tank.

Recent research investigated shell and solid element in finite element analysis (FEA) [18], fatigue assessment for pipeline dents [19], two case studies using multiple real-life dent features in FEA [20] and experimental and numerical tests for the use of a spherical cap to restore the ultimate strength of dented hemispheres under external hydrostatic pressure [21].

To date, prior research has been limited to the analysis of standard hydrostatic testing, without accounting for dented conditions, either through numerical modelling or experimental investigation. No studies have yet examined hydrotest scenarios involving internal vacuum conditions, where the tank is subjected to external pressure leading to inward denting. In response to this gap, the present study conducts a finite element analysis to evaluate the structural response under such conditions, based on a real-world incident observed in the field.

This study aims to apply a finite element approach following API 579-1/ASME FFS-1 standards to determine the fitness-for-service (FFS) of the affected tank [22]. By integrating geometric data from field measurements with a validated simulation model, this paper seeks to provide a comprehensive assessment of the tank's structural performance and recommend possible mitigation or repair strategies if required. The findings are expected to contribute to safer and more efficient tank operations within the hydrocarbon industry.

II. METHOD

A. Physical Iinspection

The deformation was measured at two critical positions on the tank shell. Table 1 summarises the results of these dimensional assessments, which revealed buckling magnitudes of approximately 35 mm at shell 7 (135°) and shell 8 (140°). These deviations exceed the permissible tolerance specified in Section 7.5.3 of the American Petroleum Institute (API) Standard 650 [23], which governs the design and construction of welded tanks for oil storage.

Given the extent of the distortion and its potential impact on the tank's load-bearing capacity, a more rigorous assessment is warranted. Standard visual and dimensional inspections are insufficient to conclude the tank's fitness for operation. Therefore, a detailed structural analysis using finite element methods (FEM) is essential to simulate the stress distribution and deformation behaviour under operational loads.

B. Fitness for Service Assessment of Shell Distortion

The fitness-for-service (FFS) assessment procedure of this report's shell distorted steel storage tank follows API Recommended Practice 579-1/ASME FFS-1 Part 8 – Assessment of Welded Misalignment and Shell Distortions. Level 3 assessments are intended to evaluate components with general shell distortions, complex component geometries and/or loading. Level 3 assessment involves detailed stress analysis techniques, including fatigue and numerical stress analysis.

The stress analysis for a Fitness-for-Service Assessment in this report is performed to evaluate the plastic collapse of the distorted steel storage tank. API Recommended Practice 579-1/ASME FFS-1 Annexe 2D – Stress Analysis for a FFS Assessment provides the assessment procedure of stress analysis, which is based on ASME Boiler and Pressure Vessel Code, Section VIII, Division 2 Part 5 [24].

Figure 1. The Tank Vent Was Blocked By A Bee Nest, Wax And A Plastic Sheet.

TABLE 1.
SUMMARY OF BUCKLING DIMENSIONAL MEASUREMENT RESULTS

Picture	Location	Shell no.	Orientation	Buckling Dimension	Buckling Magnitude
	A	6	135°	Length: 3840 mm	-10 mm
		7		Width: 5600 mm	**-35 mm ***
		8			-15 mm
	B	7	145°	Length: 2020 mm	-15 mm
		8		Width: 2150 mm)	**-35 mm ***
	C	6	155°	Length: 2925 mm	-10 mm
		7		Width: 5600 mm	-18 mm
		8			-8 mm
	D	6	200°	Length: 2700 mm	-8 mm
		7		Width: 1500 mm	-18 mm

*) exceed allowable tolerance (API 650 Spec 7.5.3)

A.1. Elastic Stress Analysis: A Protection Against Plastic Collapse

An elastic stress analysis to evaluate protection against plastic collapse results from the elastic analysis of the component subjected to a defined loading condition, which is categorised and compared to the associated limiting value. The maximum distortion energy yield criterion shall establish the equivalent stress. In this case, the equivalent stress is equal to the von Mises equivalent stress given by the equation:

$$S = \sigma_e = \frac{1}{\sqrt{2}}\sqrt{(\sigma_{max} - \sigma_{min})^2 + \sigma_{max}^2 + \sigma_{min}^2} \qquad (1)$$

where

$$\sigma_{max} = \frac{(\sigma_x + \sigma_y)}{2} + T_{max}$$

$$\sigma_{min} = \frac{(\sigma_x + \sigma_y)}{2} - T_{max}$$

$$T_{max} = \sqrt{\frac{(\sigma_x - \sigma_y)^2}{4} + \tau_{xy}^2}$$

$$\sigma_x = S_x + \frac{M_x}{Z}$$

$$\sigma_y = S_y + \frac{M_y}{Z}$$

$$\tau_{xy} = S_{xy} + \frac{M_{xy}}{Z}$$

where the membrane stresses are expressed in Sx, Sy and Sxy, the bending moments are expressed in Mx, My and Mxy, and the plastic section modulus is expressed in Z

A.2. Stress Linearization

An elastic stress analysis result may be used to compute the equivalent linearised membrane and bending stress for comparison to the limit. The local primary membrane stress category plus primary bending equivalent stress (PL + Pb) is selected as the evaluated and corresponding allowable membrane stress limit.

To evaluate protection against plastic collapse, the computed equivalent stress shall be compared to the corresponding allowable value as follows:

$$(P_L + P_b) \leq 1.5S_m \qquad (2)$$

where the stress category of local primary membrane equivalent stress is expressed in PL, the stress category of primary bending stress is expressed in Pb, and the allowable equivalent stress is expressed in S_m.

C. Fatigue Assessment

A shell-distorted steel storage tank fatigue assessment may be performed under the cyclic loading (the Level 2 assessment) procedure as mentioned in the API Recommended Practice 579-1/ASME FFS-1.

API Recommended Practice 579-1/ASME FFS-1 Part 14 – Assessment of Fatigue Damage has provided several fatigue damage assessment methods based on their assessment level as presented in Figure 1. Three methods may be involved during the level 2 fatigue assessment.

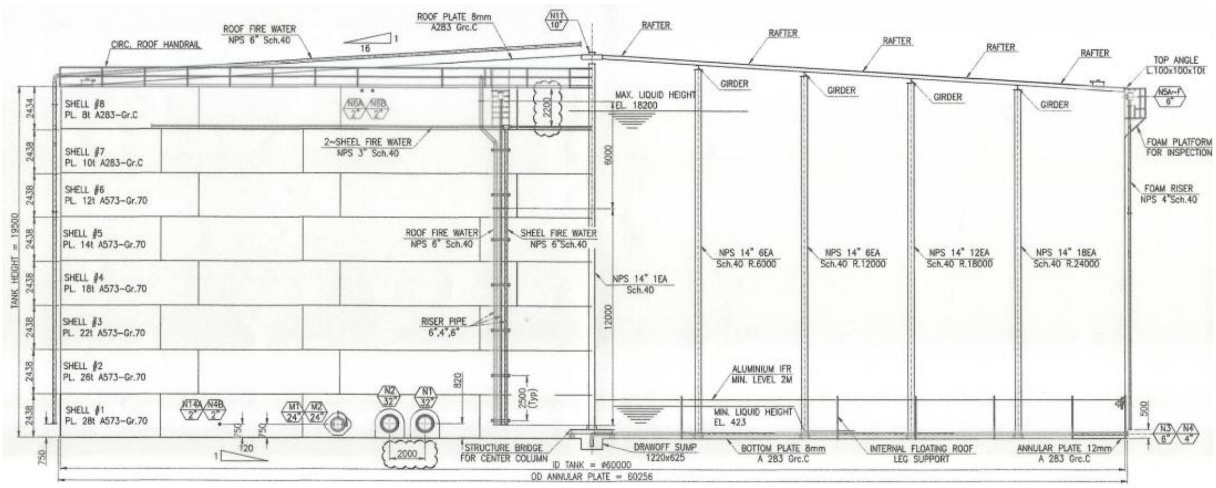

Figure 2. Tank General Arrangement

TABLE 2.
TANK STRUCTURE DESCRIPTION

Part	Description	Steel Grade	Yield Strength	Ultimate Strength
Beam	WF-350x175x7x11	SS400	248.21 MPa (36 Ksi)	399.90 MPa (58 Ksi)
Main Rafter	WF-300x150x6.5x9	SS400	248.21 MPa (36 Ksi)	399.90 MPa (58 Ksi)
Secondary Rafter	WF-300x150x6.5x9 WF-250x125x6x9	SS400	248.21 MPa (36 Ksi)	399.90 MPa (58 Ksi)
Purlin	UNP-150x75x6.5x10	SS400	248.21 MPa (36 Ksi)	399.90 MPa (58 Ksi)
Bracing	L-80x80x8	SS400	248.21 MPa (36 Ksi)	399.90 MPa (58 Ksi)
Support	WF-350x175x7x11 WF-300x150x6.5x9 WF-250x125x6x9	SS400	248.21 MPa (36 Ksi)	399.90 MPa (58 Ksi)
Column	14-inch SCH40	ASTM A53 Grade B	240 Mpa (35 Ksi)	415 MPa (60 Ksi)
Shell Course 1	Thickness 28mm	ASTM A573 grade 70	289.58 MPa (42 ksi)	482.63 MPa (70 ksi)
Shell Course 2	Thickness 26 mm	ASTM A573 grade 70	289.58 MPa (42 ksi)	482.63 MPa (70 ksi)
Shell Course 3	Thickness 22 mm	ASTM A573 grade 70	289.58 MPa (42 ksi)	482.63 MPa (70 ksi)
Shell Course 4	Thickness 18 mm	ASTM A573 grade 70	289.58 MPa (42 ksi)	482.63 MPa (70 ksi)

Part	Description	Steel Grade	Yield Strength	Ultimate Strength
Shell Course 5	Thickness 14 mm	ASTM A573 grade 70	289.58 MPa (42 ksi)	482.63 MPa (70 ksi)
Shell Course 6	Thickness 12 mm	ASTM A573 grade 70	289.58 MPa (42 ksi)	482.63 MPa (70 ksi)
Shell course 7	Thickness 10 mm	ASTM A283 Grade C	206.84 MPa (30 ksi)	379.21 MPa (55 ksi)
Shell course 8	Thickness 8 mm	ASTM A283 Grade C	206.84 MPa (30 ksi)	379.21 MPa (55 ksi)
Bottom & annular	Thickness 8 mm	ASTM A283 Grade C	206.84 MPa (30 ksi)	379.21 MPa (55 ksi)
Roof plate	Thickness 8 mm	ASTM A283 Grade C	206.84 MPa (30 ksi)	379.21 MPa (55 ksi)

Method A: Fatigue assessment using elastic stress analysis and equivalent stress was selected in this case. In this method, the fatigue damage and remaining life is computed based on effective total equivalent stress obtained from linear elastic stress analysis, and using fatigue curve of Fatigue Curve for Carbon, Low Alloy, Series 4XX, High Alloy Steel, and High Tensile Strength for temperature not Exceeding 700° F - σ_uts≤80 ksi.

The adequate total equivalent stress amplitude is used to evaluate fatigue damage based on the linear elastic stress analysis results. The controlling stress for fatigue is the primary plus secondary plus peak equivalent stress amplitude, which is defined as one-half of the primary plus secondary peak stress equivalent stress range. $(P_L + P_b + Q + F)$, calculated for each cycle in the loading history.

D. Study Case: 50.000 KL Above Ground Tank

C.1. Structure Description

Figure 2 illustrates the general arrangement of the structural construction of the 50,000 KL above-ground storage tank, while Table 2 presents a detailed description of the tank's structural components.

C.2. Analysis Criteria and Loading

The load shall be combined by API Standard 650, 13th Edition 2021, as presented in Table 3.

TABLE 3.
APPLIED LOAD COMBINATION

Load Case	Load Combination	Condition	Allowable Stress
Design Load Condition			
201	$1.0D_L + 1.0F$	Stored fluid load	$S_m = \frac{2}{3}F_y$
301	$1.0D_L + 0.6Wx$	Wind	
302	$1.0D_L - 0.6Wx$		
303	$1.0D_L + 0.6Wz$		
304	$1.0D_L - 0.6Wz$		
401	$1.0D_L + 0.6Wx + 1.0P_e$	Wind and external pressure	
402	$1.0D_L - 0.6Wx + 1.0P_e$		
403	$1.0D_L + 0.6Wz + 1.0P_e$		
404	$1.0D_L - 0.6Wz + 1.0P_e$		
501	$1.0D_L + 1.0L_r + 1.0P_e$	Live Load and External Force	
502	$1.0D_L + 0.4L_r + 1.0P_e$		
601	$1.0D_L + 1.0F + 1.0Ev + 1.0Ehx + 0.3Ehz$	Seismic	
602	$1.0D_L + 1.0F + 1.0Ev + 1.0Ehx - 0.3Ehz$		
603	$1.0D_L + 1.0F + 1.0Ev - 1.0Ehx + 0.3Ehz$		
604	$1.0D_L + 1.0F + 1.0Ev - 1.0Ehx - 0.3Ehz$		
605	$1.0D_L + 1.0F + 1.0Ev + 1.0Ehz + 0.3Ehx$		
606	$1.0D_L + 1.0F + 1.0Ev + 1.0Ehz - 0.3Ehx$		
607	$1.0D_L + 1.0F + 1.0Ev - 1.0Ehz + 0.3Ehx$		
608	$1.0D_L + 1.0F + 1.0Ev - 1.0Ehz - 0.3Ehx$		
609	$1.0D_L + 1.0F - 1.0Ev + 1.0Ehx + 0.3Ehz$		
610	$1.0D_L + 1.0F - 1.0Ev + 1.0Ehx - 0.3Ehz$		
611	$1.0D_L + 1.0F - 1.0Ev - 1.0Ehx + 0.3Ehz$		
612	$1.0D_L + 1.0F - 1.0Ev - 1.0Ehx - 0.3Ehz$		
613	$1.0D_L + 1.0F - 1.0Ev + 1.0Ehz + 0.3Ehx$		
614	$1.0D_L + 1.0F - 1.0Ev + 1.0Ehz - 0.3Ehx$		
615	$1.0D_L + 1.0F - 1.0Ev - 1.0Ehz + 0.3Ehx$		
616	$1.0D_L + 1.0F - 1.0Ev - 1.0Ehz - 0.3Ehx$		
Hydrostatic Test Condition			
701	$1.0D_L + 1.0H_t$	Hydrostatic test load	$S_m = \frac{3}{4}F_y$

Dead loads, D_L, consist of the weight of all tank construction materials, a 10% load factor added to the structural self-weight to account for the weight of unmodelled structures such as bolts, nuts, gusset and stiffener plate.

Other factors may also affect the response of the structure. Tanks and tank farms are frequently located in coastal areas to facilitate transfer from/to ships, or because of the proximity to offshore oil production. This may cause exposure to wind, which is more severe than inland.

Since the aboveground steel storage tank facility is located in the coastal area (Figure 3) near the transfer from to shop, this may expose the wind load to more severe conditions than those occurring inland [25]. The wind load, W, shall be calculated in accordance with the wind load provision of ASCE/SEI 7-22 [26]The wind pressure distribution of 3 3-second gust based on a 2% annual probability being exceeded (50-year mean recurrence interval) of 27.84 km/hour wind speed is presented in Figure 4.

Figure 3. Location of above ground tank facility

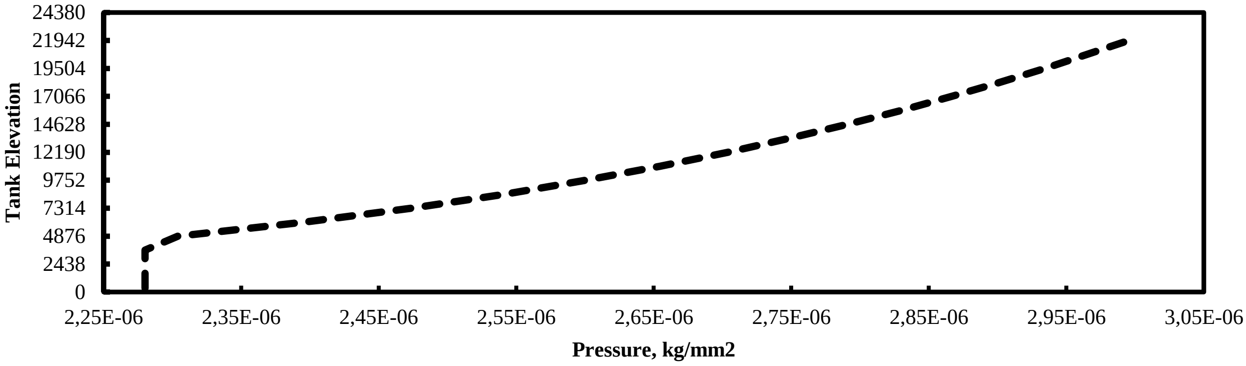

Figure 4. Wind pressure distribution

Hydrostatic Test load, H_t, is the load due to filling the tank with water to design liquid level, the fluid density considered to simulate hydrostatic test is 1.0 10-6 kg/mm3 of fresh water density, and the stored liquid load, F, is the load due to filling the tank to design liquid level with the liquid with design specific gravity. The fluid density considered to simulate stored liquid load is 7.15 10^{-7} kg/mm^3 of diesel fuel density. The hydrostatic and stored liquid (design) force distribution for a 50.000 KL tank is presented in Figures 4 and 5.

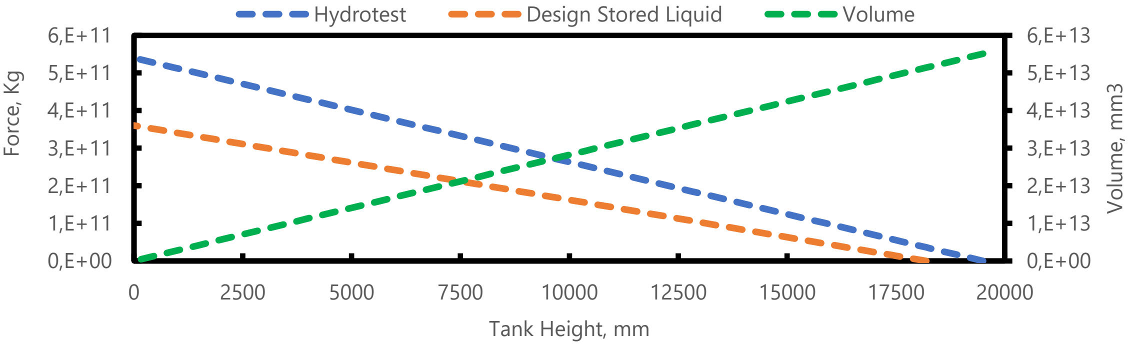

Figure 5. Weight distribution of the design stored liquid and hydrostatic test condition

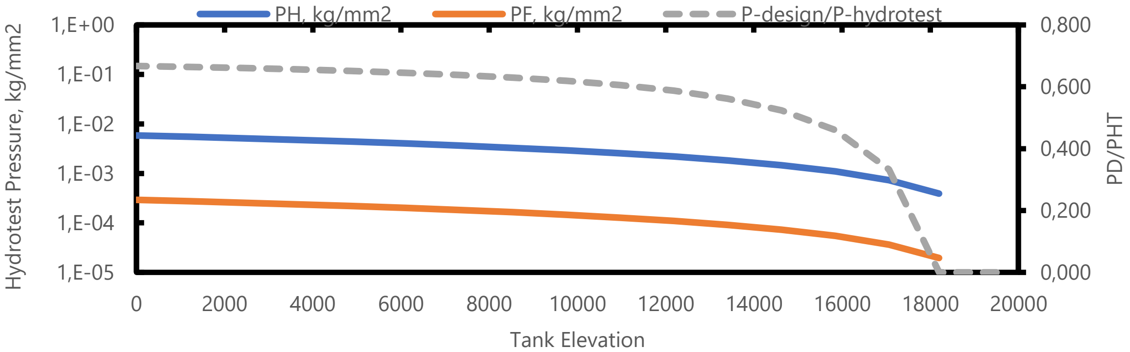

Figure 6. Distribution of hydrotest pressure at tank Shell and $P_{Design}/P_{Hydrotest}$ ratio

TABLE 4.
SEISMIC PARAMETER

Symbol	Description	Remark	Valie
c	Damping Ratio	-	5%
-	Site class	Medium Soil	SD
-	Risk category	-	IV
Ie	Importance Factor	-	1.5
PGA	Peak Ground Acceleration	Coordinate	0.2797 g
Ss	Short period MEC Response spectral acceleration parameter	Lat: -6.780755	0.5734 g
S1	Long period MEC response spectral acceleration parameter	Long: 111.957429	0.2488 g
Fa	Short period site coefficient	-	1.34128
Fv	Long period site coefficient	-	2.1024
Sms	Short period MEC Response spectral acceleration parameter	Fa.Ss	0.7691
Sm1	Long period MEC response spectral acceleration parameter	Fv.S1	0.5231
SDs	Short period response spectral acceleration parameter	2/3Sms	0.5127
SD1	Long period response spectral acceleration parameter	2/3Sm1	0.3487
-	Seismic design category	-	D
R	Response modification factor for Non-building Similar to Building	flat-bottom ground-supported steel tanks and self-anchored	2.5
Ct and x	Fundamental period of the structure coefficient	-	Ct = 0.0488, x = 0.75

Table 4 presents a summary of seismic parameter required for the static equivalent seismic load, E, based on Indonesian Seismic Provision of SNI 1726-2019 [27, 28].

III. RESULTS AND DISCUSSION

A. Fitness for Service Assessment

As presented in plot of stress above, generally, the dented condition produces significant stress increase on the shell plate of the tank at all load condition. Stress increases produced from the shell distortion are about 2% to 2282%. The critical locations with stress increase exceeding 100% occur between elevations 14628 and 19504 mm, corresponding to the shell courses 7 and 8. The most severe stress increase occurs under design stored fluid condition (Load case 201: DL + F), with the stress increase occurring over 22 times compared to the undistorted condition.

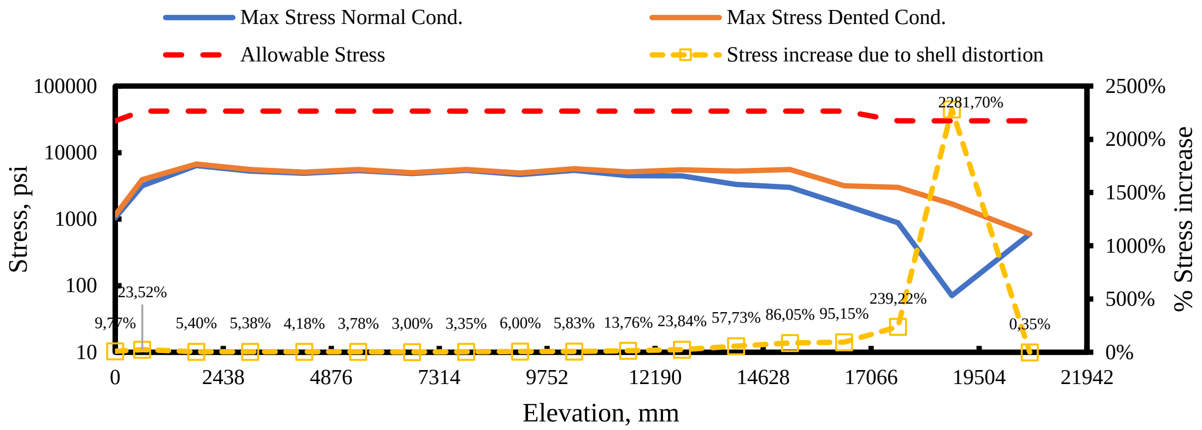

Figure 7. Stress Linearization Distribution along the elevation of the tank under the design fluid case condition

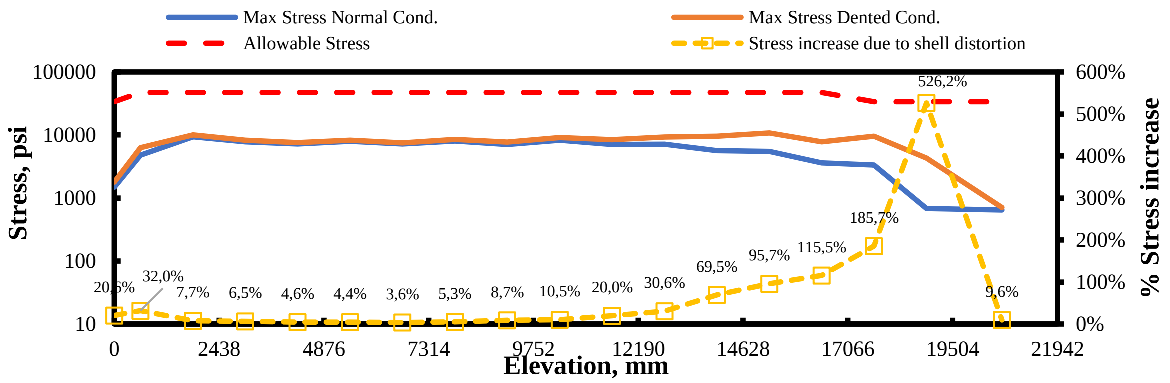

Figure 8. Stress Linearization Distribution along the elevation of the tank under the hydrotest case condition

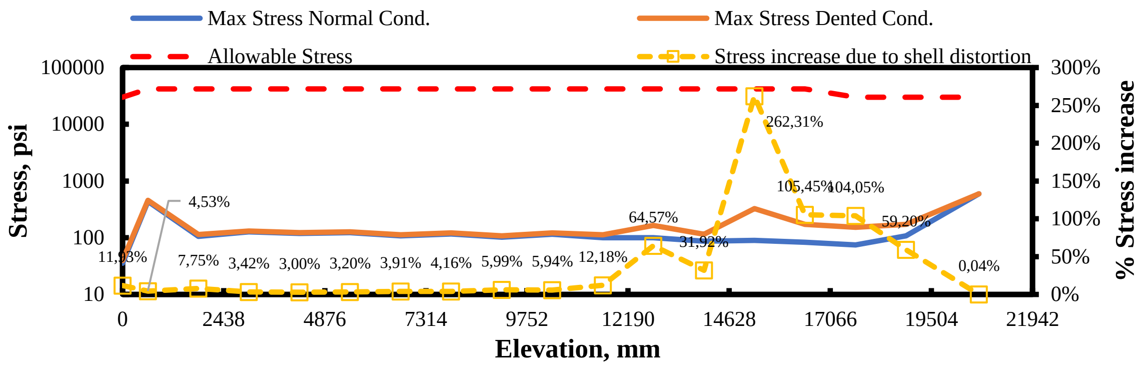

Figure 9. Stress Linearization Distribution along the elevation of the tank under wind load case condition

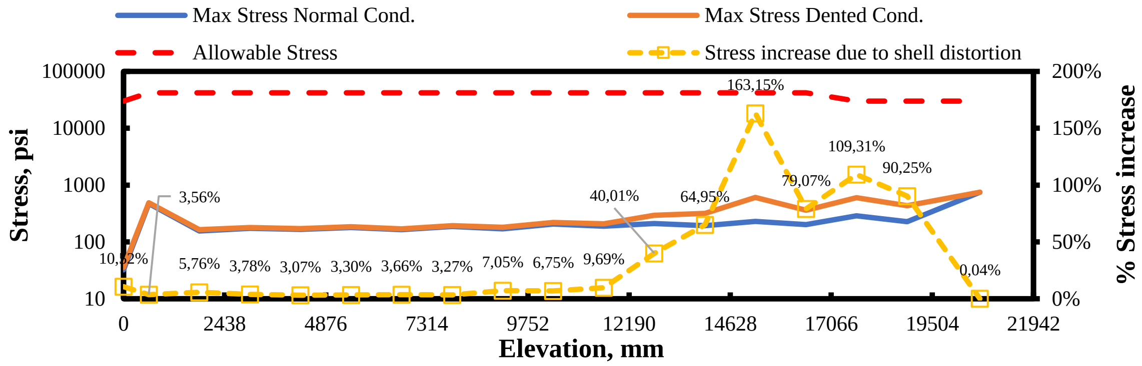

Figure 10. Stress Linearization Distribution along the elevation of the tank under wind and external pressure load case condition

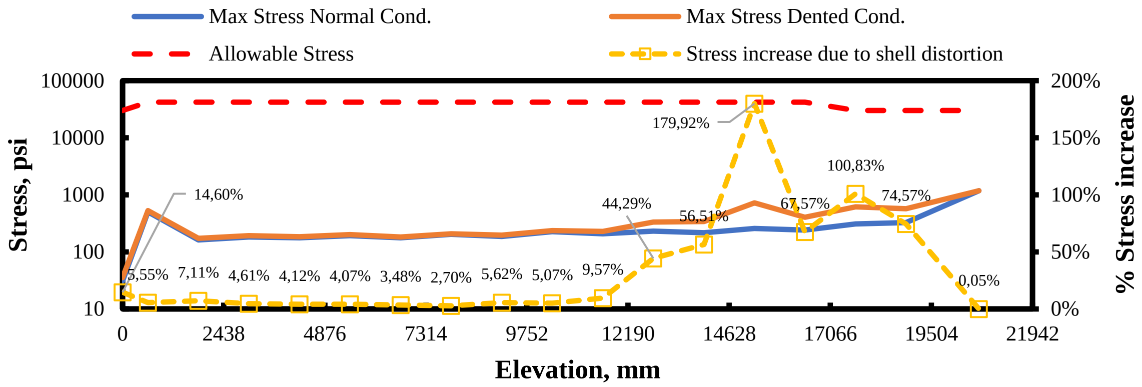

Figure 11. Stress Linearization Distribution along the elevation of the tank under Roof Live Load and external pressure load case condition

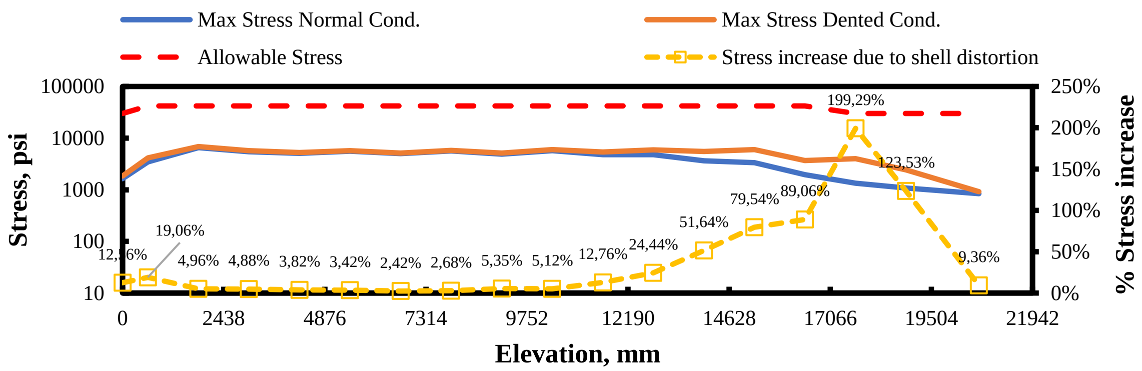

Figure 12. Stress Linearization Distribution along the elevation of the tank under seismic case conditions

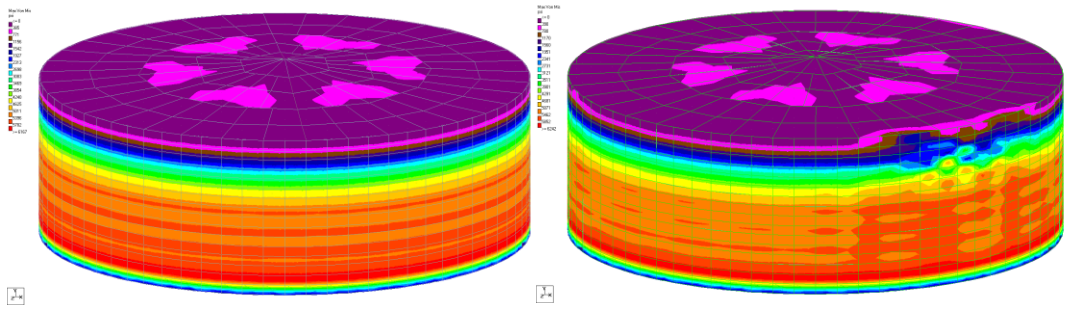

Figure 13. Plot of von Mises stress for normal (left) and dented (right)

In Figure 12, for critical location identification purposes, the von Mises stress is used to present the effect of shell distortion and stiffening at the tank plate, since the plot of six tensor membrane and bending stress at once (simultaneously) is relatively difficult to understand. The design stored fluid load case condition (LC 201 DL + F) is selected to be presented as the significant stress increase occurs under the following load case condition.

B. Fatigue Assessment

B.1. Discharge Analysis

As discussed in section 7 previously, the fuel storage tank capacity 50.000 KL are within acceptable against code check of API Standard 650 13th Edition 2021 requirement through the fitness for service assessment based on API Recommended Practice 579-1/ASME FFS-1 Part 8 – Assessment of Welded Misalignment and Shell Distortions API Recommended Practice 579-1/ASME FFS-1 Part 8 – Assessment of Welded Misalignment and Shell Distortions.

An additional assessment was conducted to investigate the cause of the dented plate found during the hydrotest activity. This assessment refers to the assumption that there is an inappropriate procedure during the dewatering or discharge process, which makes the conditions inside the fuel storage tank become a vacuum, and the tank will be subjected to significant external pressure of 1 atm. Load cases considered for this assessment are presented in Table 3. Figure 5 presents the reduction ratio of applied pressure during discharge analysis.

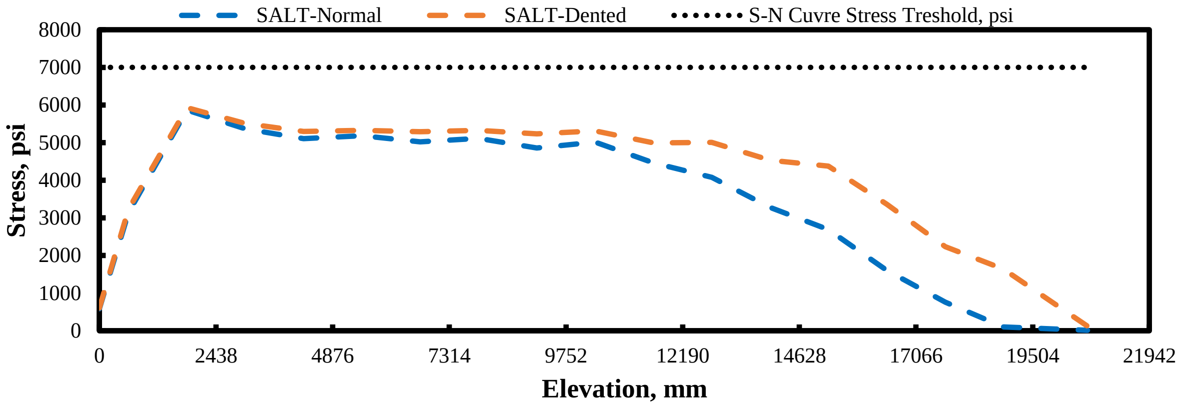

Figure 14. Plot of Alternating Stress produced from Fatigue Analysis

TABLE 5
SCENARIO FOR DISCHARGE SEQUENCE

Condition / Sequence	Load Case Combination
Sequence 1 (100%)	701 $D_L + H_T$
Sequence 2 (93%)	702 $D_L + H_{T-93\%}$ + Pe
Sequence 3 (88%)	703 $D_L + H_{T-88\%}$ + Pe
Sequence 4 (81%)	704 $D_L + H_{T-81\%}$ + Pe
Sequence 5 (75%)	705 $D_L + H_{T-75\%}$ + Pe
Sequence 6 (69%)	706 $D_L + H_{T-69\%}$ + Pe
Sequence 7 (63%)	707 $D_L + H_{T-63\%}$ + Pe
Sequence 8 (56%)	708 $D_L + H_{T-56\%}$ + Pe

Condition / Sequence	Load Case Combination
Sequence 9 (50%)	709 $D_L + H_{T-50\%}$ + Pe
Sequence 10 (44%)	710 $D_L + H_{T-44\%}$ + Pe
Sequence 11 (38%)	711 $D_L + H_{T-38\%}$ + Pe
Sequence 12 (31%)	712 $D_L + H_{T-31\%}$ + Pe
Sequence 13 (25%)	713 $D_L + H_{T-25\%}$ + Pe
Sequence 14 (19%)	714 $D_L + H_{T-19\%}$ + Pe
Sequence 15 (13%)	715 $D_L + H_{T-13\%}$ + Pe
Sequence 16 (0%)	716 $D_L + H_{T-0\%}$ + Pe

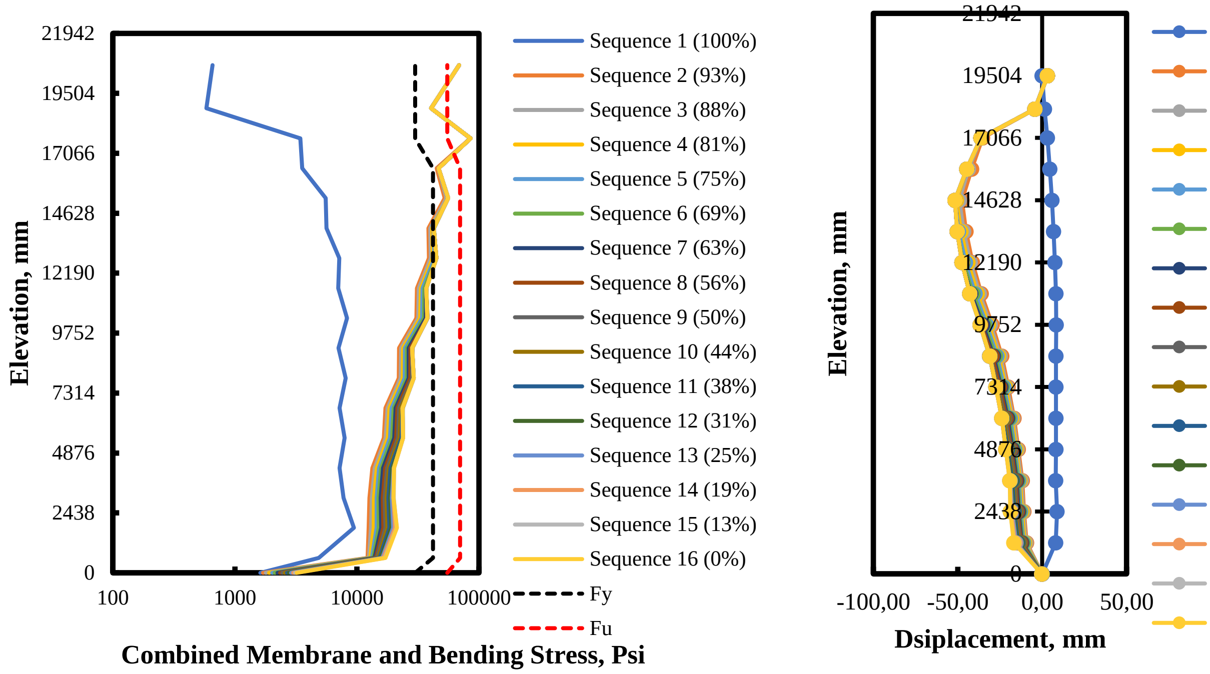

Figure 15. Stress Linearization Distribution along the elevation of the tank under discharge condition (left) and Excessive displacement under discharge condition (right)

The results of the discharge analysis of the tank subjected to entirely external atmospheric pressure during the dewatering of the hydrotest activity are summarised in Table 5. It is shown that the external atmospheric pressure subjected to the vacuum tank produces significant stress (combined 6 stress tensor of membrane and bending moment) on a plate, even exceeding the yield strength of the material, which may lead to plastic deformation of the plate. The critical location is between 1428 mm and 19504 mm elevations, or equal to tank course numbers 7 and 8. The stress also increases from the higher elevation to the lower elevation plate as the water level decreases within the discharge sequence, creating an opposing force against the external pressure. Figure 11 presents linearised stress (combined 6-tensor of membrane and bending moment) distribution along the tank elevation. Figure 12 presents excessive displacement of the tank's shell during the improper discharge process. The analysis shows that the displacement value is negative, indicating the direction of displacement sunken toward the tank with a magnitude of displacement up to 52 mm.

IV. CONCLUSION

An integrity assessment was performed for the dented fuel storage tank cap. 50.000 KL in accordance with the fitness for service assessment based on API Recommended Practice 579-1/ASME FFS-1 Part 8 – Assessment of welded misalignment and shell distortion. Generally, the fuel storage tank has adequate strength and meets the requirements of the elastic stress analysis: protection against plastic collapse in accordance with API Recommended Practice 579-1/ASME FFS-1 Annexe 2D and code check requirement of API Standard 650, 13th Edition 2021. Result of elastic stress analysis: protection against plastic collapse is summarised as normal and dented conditions.

In normal conditions, maximum combined 6-tensor of membrane and bending moment is 9.35 ksi under load case 701: 1.0DL + 1.0HT occurs on the elevation 610 mm (shell course 1), which meets the standard requirement with the maximum allowable stress of 47.25 ksi.

In dented condition: maximum combined 6-tensor of membrane and bending moment is 10.772 ksi under load case 701: 1.0DL + 1.0HT occurs on the elevation 15238 mm (shell course7), which meets the standard requirement with the maximum allowable stress of 47.25 ksi.

Stress increases due to shell distortion are between 2 and 2282%. The significant stress increase over 100% is located at 16457 mm to 18895 mm, equal to shell courses 7 and 8.

Result of fatigue assessment based on API Recommended Practice 579-1/ASME FFS-1 Part 14 – Assessment of Fatigue Damage in term of allowable fatigue cycle found that fatigue damage are between range of 99 to 5930 psi, and it is below the S-N Curve stress threshold as 7000 psi resulting the infinite number of allowable fatigue cycles at all tank plate.

The discharge analysis shows that improper dewatering/discharge procedure within the hydrotest activity will produce significant stress that exceeds the yield and tensile strength of the material, which is suspected to lead to plastic deformation of the tank plate. Critical location of tank subjected to fully atmospheric external pressure (1 atm) between 1428 mm and 19504 mm elevations, equal to tank course numbers 7 and 8.

It is concluded that the current condition of the fuel storage tank Cap is as follows: 50.000 KL is acceptable and meets the fitness for service assessment requirement and code check of API Recommended Practice 579-1/ASME FFS-1 and API Standard 650, 13th Edition 2021. Fatigue is an insignificant factor affecting the life of the fuel storage tank.

Since the integrity of the aboveground steel storage tank with the current dented condition has been demonstrated through the fitness for service assessment, no further repair is required. In addition, it is important to ensure that the tank venting is not blocked to avoid the appearance of a vacuum condition during the hydrostatic testing process.

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