OPEN ACCESS
International Journal of Emerging Science and Engineering (IJESE)
ISSN: 2319-6378 (Online), Volume-11 Issue-8, July 2023

Effect of Ovality on the Buckling Behavior of Thin-Walled Liquid-Filled Conical Tanks

Girmay Mengesha Azanaw

***Abstract:** This study investigates the influence of ovality on the buckling behavior of thin-walled liquid-filled conical tanks through comprehensive numerical simulations. The structural stability of conical tanks is of paramount importance in various engineering applications, such as storage vessels and aerospace structures. However, the presence of ovality, characterized by deviations from perfect circularity, can significantly affect the structural response and integrity of these tanks. To explore the effects of ovality, a finite element analysis (FEA) approach is employed, considering various ovality levels in the tank geometry. A comprehensive parametric study is conducted, varying key parameters such as tank dimensions, material properties, and liquid filling levels. The buckling behavior of the tanks is assessed by examining critical buckling loads and corresponding deformation modes. Results from the numerical simulations reveal that even trim levels of ovality can substantially reduce the buckling load capacity of conical tanks. As ovality increases, the onset of buckling occurs at lower applied loads, leading to premature structural failure. The presence of liquid filling further exacerbates the buckling phenomenon, with the liquid sloshing effect amplifying the structural response. The study also examines the impact of various materials on the buckling behaviour of conical tanks subjected to ovality. It is found that the material stiffness and yield strength play a crucial role in determining the critical buckling load and mode shape. Furthermore, the effect of liquid fill level is explored, demonstrating that higher fill levels increase the vulnerability to buckling.*

***Keywords:** Buckling behavior, Conical tanks, Ovality, Thin-walled structures, Finite element analysis, Liquid-filled structures.*

I. INTRODUCTION

Thin-walled liquid-filled conical tanks are widely used in various industries for storage and transportation purposes. The buckling behavior of such tanks is of critical importance as it directly impacts their structural integrity and stability [2]. One significant factor that can affect the buckling behavior is the ovality of the tank, which refers to the deviation from a perfect circular cross-section. Understanding the effect of ovality on the buckling behavior is crucial for designing safe and reliable tanks.

Manuscript received on 15 June 2023 | Revised Manuscript received on 10 July 2023 | Manuscript Accepted on 15 July 2023 | Manuscript published on 30 July 2023.
*Correspondence Author(s)
Girmay Mengesha Azanaw*, Department of Civil Engineering, Aksum University, Aksum, Ethiopia, E-mail: mengeshagirma696@gmail.com, ORCID ID: 0009-0009-7187-6572

In recent years, there has been growing interest in studying the influence of ovality on the buckling behavior of thin-walled liquid-filled conical tanks [3]. Previous research has primarily focused on the buckling analysis of perfect circular tanks, neglecting the impact of ovality. However, in practical applications, tanks often experience various degrees of ovality due to manufacturing processes, material properties, and external loading conditions. The presence of ovality introduces additional complexities to the buckling behavior of conical tanks, as it alters the stress distribution and deformation patterns [7]. Consequently, it is essential to investigate the effect of ovality on the critical buckling load, buckling mode shapes, and failure mechanisms of these tanks. By understanding these effects, engineers and designers can make informed decisions regarding the design, optimization, and maintenance of thin-walled liquid-filled conical tanks [5]. Therefore, the purpose of this study was to examine the effect of ovality on the buckling behavior of thin-walled liquid-filled conical tanks. The research aims to provide valuable insights into the influence of ovality on the structural performance and stability of these tanks, contributing to the development of more accurate and robust design guidelines. To achieve this objective, a comprehensive numerical investigation was conducted. The primary aim is to evaluate the buckling behaviour of thin-walled, liquid-filled conical tanks under various ovality conditions. This involves determining the critical buckling loads and associated deformation modes through finite element analysis. Investigate Ovality Effects: The study aims to quantitatively analyze the influence of ovality on the structural response of conical tanks. By varying the ovality levels, the objective is to identify the critical level at which buckling occurs and understand the corresponding failure mechanisms. Examine Parametric Sensitivity: The research aims to investigate the sensitivity of buckling behaviour to key parameters, including tank dimensions, material properties, and liquid fill levels. By systematically varying these parameters, the objective is to assess their impact on the buckling capacity and deformation modes. Provide a Comparative Analysis: The research objective is to compare the buckling behaviour of conical tanks under varying ovality levels. This includes analyzing the critical buckling loads, mode shapes, and failure patterns to determine the relative vulnerability and sensitivity of tanks to ovality-induced buckling.

II. LITERATURE REVIEW

The buckling behavior of thin-walled liquid-filled conical tanks has been the subject of extensive research due to their wide range of applications in industries such as oil and gas, chemical processing, and aerospace [1]. Several studies have investigated various factors influencing the buckling behavior of these tanks, including geometrical imperfections, material properties, and loading conditions [10]. However, the specific effect of ovality on the buckling behavior of thin-walled liquid-filled conical tanks remains relatively unexplored. Most research in this area has focused on the buckling analysis of perfect circular tanks, neglecting the practical aspect of ovality commonly observed in real-world applications [6]. Ovality can result from manufacturing processes, material deformation, or external loads and can significantly affect the structural performance and stability of conical tanks. Understanding the impact of ovality on the critical buckling load, mode shapes, and failure mechanisms is crucial for the safe and efficient design of these tanks. Previous studies on the buckling behavior of cylindrical shells and conical shells have demonstrated the influence of ovality on their stability and load-carrying capacity. These studies have highlighted the importance of considering the effect of ovality in the design and analysis of thin-walled structures. However, limited research has specifically addressed the buckling behavior of thin-walled liquid-filled conical tanks with ovality[4]. Some researchers have investigated the effect of various imperfections, including ovality, on the buckling behavior of cylindrical tanks. However, the transition from cylindrical to conical geometry introduces additional complexities due to the changing curvature and stress distribution [9]. Therefore, specific research on the buckling behavior of conical tanks with ovality is essential to fill the existing knowledge gap and provide practical insights for engineers and designers [8]. In conclusion, although extensive research has been conducted on the buckling behavior of thin-walled tanks, the effect of ovality on the buckling behavior of thin-walled liquid-filled conical tanks remains relatively unexplored. This research aims to contribute to the existing knowledge by investigating the impact of ovality on the critical buckling load, mode shapes, and failure mechanisms of these tanks. By addressing this research gap, valuable insights will be gained into the design, optimisation, and maintenance of thin-walled liquid-filled conical tanks, thereby ensuring their structural integrity and safety in various industrial applications.

III. METHODOLOGY

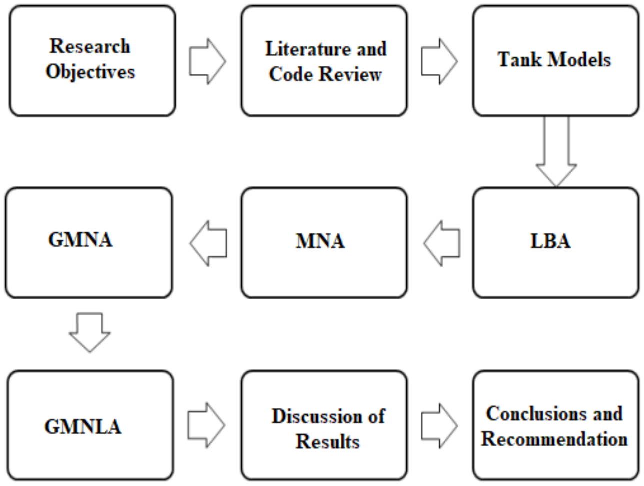

Figure 3.1 Flowchart showing used Methodology

A. Geometry Modelling:

The conical tank geometry is created in a 3D modelling software using Abaqus, taking into account the desired dimensions and ovality levels. The tank is discretized using a finite element mesh, ensuring adequate resolution for accurate numerical simulations.

B. Material and Geometry Properties:

The mechanical properties of the tank material, such as Young's modulus and Poisson's ratio, are defined based on the material under consideration. The material behaviour can be either linear elastic or nonlinear, depending on the specific material model used.

C. Boundary Conditions:

The appropriate boundary conditions are applied to simulate the tank's practical loading and support conditions. The base of the tank is fixed to prevent rigid body motions, while the top may be subjected to various loading scenarios, such as hydrostatic pressure or vertical compressive loads.

D. Buckling Analysis:

Nonlinear buckling analysis is performed using the finite element method to determine the critical buckling load and mode shape of the tank. The applied load is incrementally increased until the tank experiences buckling or reaches a predetermined limit. Various ovality levels are considered, and the buckling behavior is compared under different loading and geometric configurations.

E. Post-processing and Analysis:

The results from the finite element analysis are post-processed to extract critical buckling loads and mode shapes. The deformation patterns and displacement fields are visualized to understand the structural response and failure modes.

A comparative analysis is conducted to evaluate the influence of ovality on buckling behaviour, considering various parameters, including tank dimensions, material properties, and liquid fill levels.

The described methodology enables a detailed investigation of the effect of ovality on the buckling behaviour of thin-walled, liquid-filled conical tanks. The use of finite element analysis and fluid-structure interaction allows accurate representation of real-world conditions. It provides valuable insights into the structural response and integrity of conical tanks under ovality-induced buckling.

IV. RESULTS AND DISCUSSION

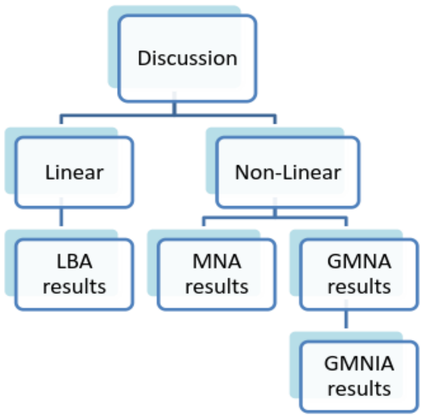

Figure 4.1 Flowchart showing discussion of different analysis types

Ovality Effects on Buckling Behavior:

The numerical simulations reveal that even trim levels of ovality can substantially reduce the buckling load capacity of conical tanks. As ovality increases, the onset of buckling occurs at lower applied loads, leading to premature structural failure.

The level of ovality has a significant influence on the buckling modes. With higher ovality, the tank experiences local buckling and deformation at the regions of maximum ovality, resulting in localised failure.

Understanding the load-carrying capacity of conical tanks concerning imperfection amplitude is crucial for accurate design. In this study, the relationship between (σx, GMNIA σX, Rcr 1) and out-of-roundness was investigated using finite element software Abaqus. The non-dimensional ovality imperfection, e1t, was varied from 0 to 70, while several degrees of out of roundness, ur, were analyzed up to 0.0713.

The plotted (σx, GMNIA σX, Rcr 1) versus out-of-roundness in Figure 4.12 demonstrates the effects of ovality imperfection on the buckling capacity of conical tanks. It is observed that as the imperfection amplitude increases, the load-carrying capacity of the conical tank decreases. Even a slight out-of-roundness can have a significant impact on the buckling capability.

For instance, a conical tank with an out of roundness of only 0.0713, in addition to geometric and material nonlinearity, can reduce the buckling capability by 34% and 19.9% for pinned and fixed bottom supported conical tanks, respectively, with specific geometric parameters (h' (tan β) = 3 and r1t (cos β) = 700). This reduction in capacity is substantial, highlighting the importance of considering imperfections during structural design.

Furthermore, the (σx, GMNIA σX, Rcr 1) versus out of roundness plot, obtained through geometrically and material nonlinear finite element analysis on an imperfect tank, reveals that an out of roundness of 0.010 already causes a reduction in load carrying capacity of 29.2% and 15% from the elastic critical buckling load for pinned and fixed bottom supported liquid-filled conical tanks, respectively. As expected, the buckling loads of conical tanks decrease as the imperfection amplitude increases, and this rate of decrease is more pronounced for higher values of imperfection amplitudes. This is due to the imperfection amplitude affecting the critical part of the cone, particularly the lower region.

In conclusion, the results underscore the significance of considering imperfections, particularly ovality imperfections, in the design and analysis of conical tanks. The study provides insights into the effects of imperfection amplitude on the load-carrying capacity of the tanks. Designers and engineers must account for these effects to ensure the structural integrity and safety of conical tanks, especially when aiming to achieve optimal performance and reliability.

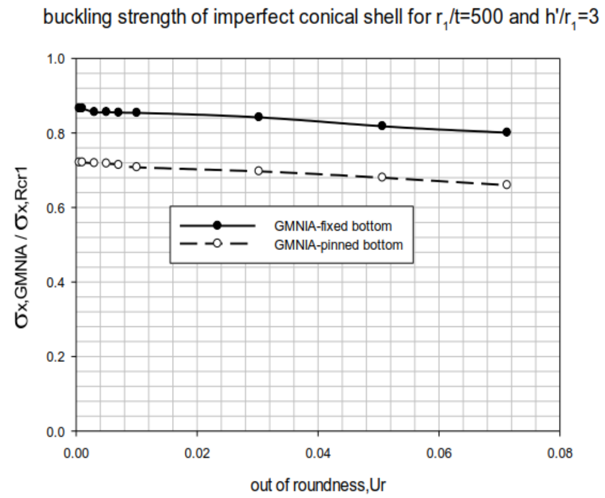

Figure 4.12 Effect of ovality and geometric and material non linearity on LFC tanks

The discussed results highlight the importance of understanding the load-carrying capacity of conical tanks about changes in imperfection amplitude, specifically focusing on ovality imperfections. The analysis was performed using the finite element software Abaqus, considering a non-dimensional ovality imperfection ranging from 0 to 70.

The (σx, GMNIA σX, Rcr 1) versus out-of-roundness plot reveals the effects of ovality imperfection on the buckling capacity of conical tanks. The results demonstrate that as the imperfection amplitude increases, the load carrying capacity of the tank decreases. Even a slight out-of-roundness has a significant impact on the buckling capability of the conical tank.

For instance, a conical tank with an out-of-roundness of only 0.0713, along with geometric and material nonlinearity, can reduce the buckling capability by 34% and 19.9% for pinned and fixed-bottom supported conical tanks, respectively, with specific geometric parameters. This reduction in capacity is substantial and underscores the importance of considering imperfections in tank design. The (σx, GMNIA σX, Rcr 1) versus out-of-roundness plot provides a typical representation of the relationship between these parameters obtained from a geometrically and materially nonlinear finite element analysis on an imperfect tank.

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

It is observed that even a small out-of-roundness of 0.010 can cause a reduction in load-carrying capacity of 29.2% and 15% from the elastic critical buckling load for pinned and fixed-bottom supported liquid-filled conical tanks, respectively.

The results confirm the expected behavior, where the buckling loads of conical tanks decrease as the imperfection amplitude increases. Moreover, the rate of decrease is more pronounced for higher values of imperfection amplitudes. This is attributed to the imperfection amplitude affecting the critical part of the cone, resulting in a greater reduction in load-carrying capacity.

Overall, these findings emphasize the significance of accurately assessing and controlling imperfections, particularly ovality imperfections, in the design and analysis of conical tanks. By considering the effects of imperfections, engineers can ensure the structural integrity and safety of conical tanks, avoiding premature buckling failure and designing more robust structures.

Upon examining Figures 4.13 to 4.20, it becomes apparent that the buckling imperfection reduction factor remains relatively constant as the ratio h'/r1 increases. However, as the imperfection amplitude increases, the sensitivity to imperfections becomes more pronounced. Notably, the impact of out-of-roundness on the buckling strength of slender liquid-filled conical tanks is particularly significant when the non-dimensional ovality imperfection e1t ranges from 30 to 70, with r1t (cos β) values ranging from 140 to 350.

It should be noted that in short cones, the behavior of the conical tank resembles that of a cantilever member. Therefore, the buckling behavior is determined by the boundary conditions. Short cones exhibit a more stable post-buckling response, resulting in a lower sensitivity to geometric imperfections. However, this more pronounced effect diminishes as the r1t (cos β) value increases from 700 to 1000. This is because ovality imperfections do not have an additional impact on buckling at the base of conical tanks.

Overall, the analysis of Figures 4.13 to 4.20 provides insight into the relationship between buckling imperfection reduction, the h'/r1 ratio, imperfection amplitude, and out-of-roundness for different ranges of e1t and r1t (cos β) values. These findings contribute to a deeper understanding of the buckling behaviour of slender liquid-filled conical tanks, informing the design and analysis processes to ensure structural integrity and optimise performance.

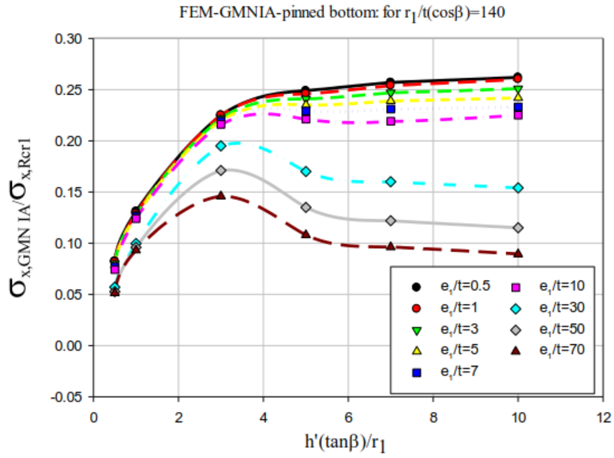

Figure 4.13 Variation of buckling Strengths of LFC tanks for $\frac{r_1}{t(\cos\beta)}$ =140-pinned

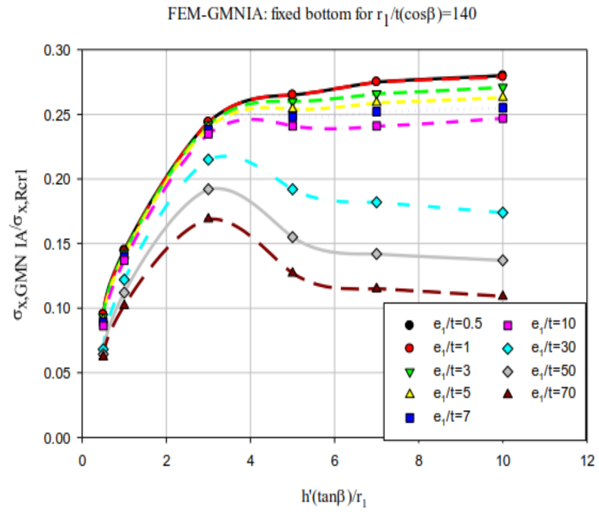

Figure 4.14 Variation of buckling Strengths of LFC tanks for $\frac{r_1}{t(\cos\beta)}$ =140-fixed

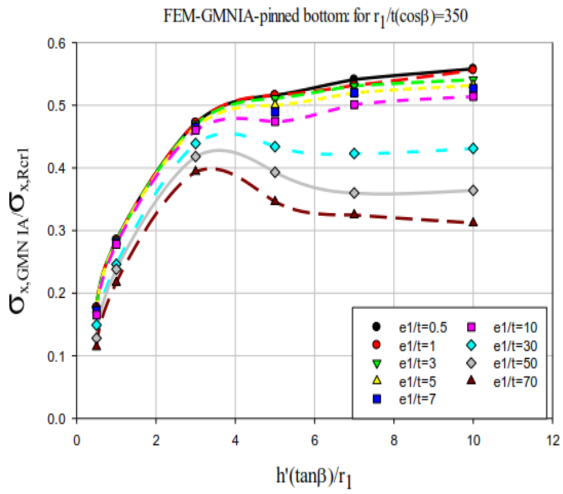

Figure 4.15 Variation of buckling Strengths of LFC tanks for $\frac{r_1}{t(\cos\beta)}$ =350-pin

Retrieval Number:100.1/ijese.B78160712223
DOI: 10.35940/ijese.B7816.0711823
Journal Website: www.ijese.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

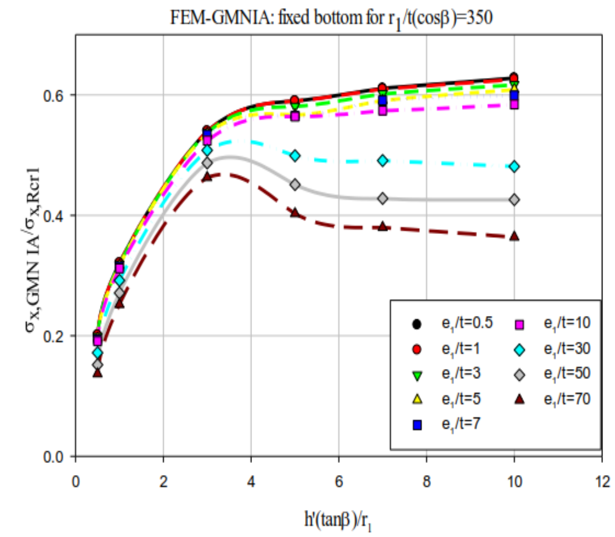

Figure 4.16 Variation of buckling Strengths of LFC tanks for $\frac{r_1}{t(\cos\beta)}$ =350-fix

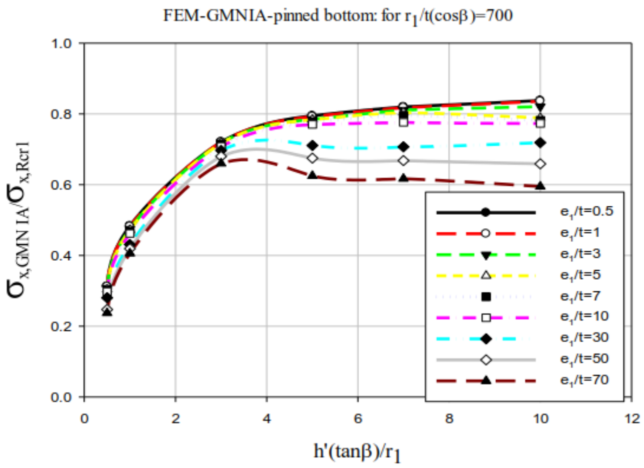

Figure 4.17 Variation of buckling Strengths of LFC tanks for $\frac{r_1}{t(\cos\beta)}$ =700-pin

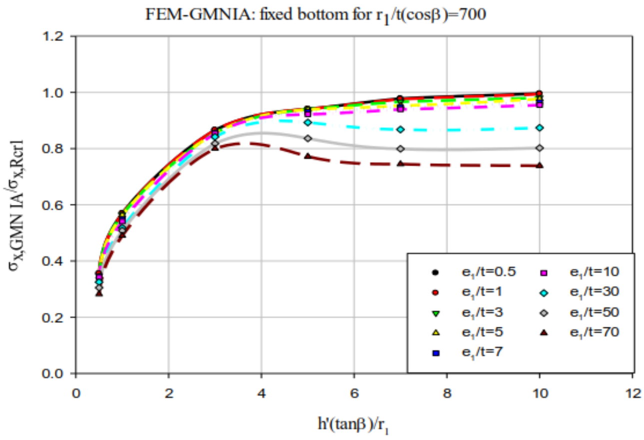

Figure 4.18 Variation of buckling Strengths of LFC tanks for $\frac{r_1}{t(\cos\beta)}$ =700-fix

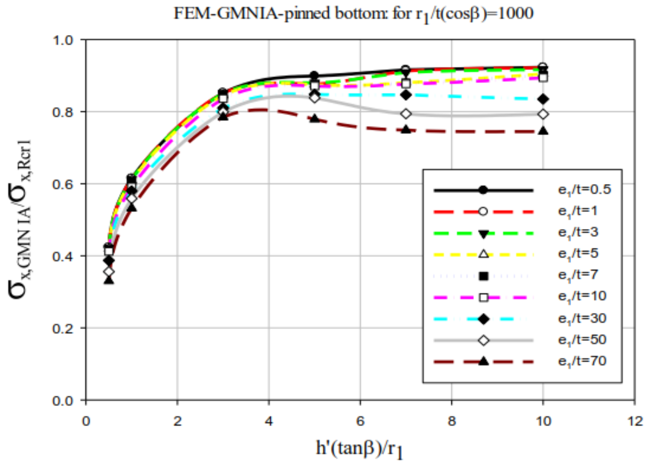

Figure 4.19 Variation of buckling Strengths of LFC tanks for $\frac{r_1}{t(\cos\beta)}$ =1000-pin

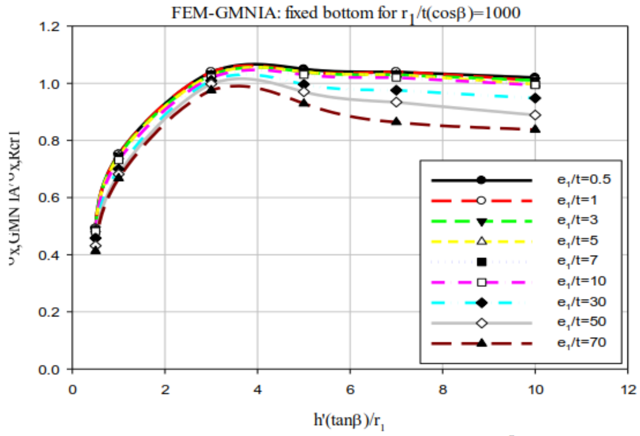

Figure 4.20 Variation of buckling Strengths of LFC tanks for $\frac{r_1}{t(\cos\beta)}$ =1000-fix

The analysis of Figures 4.13 to 4.20 provides valuable insights into the buckling behaviour of slender, liquid-filled conical tanks. One notable observation is that the buckling imperfection reduction factor remains relatively constant as the ratio h'/r1 increases. This suggests that the impact of this ratio on the buckling behaviour is not significant within the considered range. However, as the imperfection amplitude increases, the sensitivity to imperfections becomes more pronounced. This highlights the importance of accurately considering imperfections in the design and analysis of conical tanks, especially when dealing with higher imperfection amplitudes. Furthermore, the results highlight the significant impact of out-of-roundness on the buckling strength of slender liquid-filled conical tanks. This impact is particularly prominent when the non-dimensional ovality imperfection e1t ranges from 30 to 70, with r1/t (cos β) values ranging from 140 to 350. Designers must account for out-of-roundness carefully and its effects on the buckling behaviour of conical tanks in this range, as it can have a substantial influence on their structural integrity and load-carrying capacity.

Additionally, the analysis highlights the behavior of short cones, which resemble cantilever members due to their boundary conditions. Short cones exhibit a more stable post-buckling response, resulting in a lower sensitivity to geometric imperfections. This finding offers valuable insights for the design and analysis of short conical tanks, suggesting that they may exhibit superior buckling performance compared to longer cones under specific conditions.

However, it is worth noting that the more pronounced effect of out-of-roundness diminishes as the r1/t (cos β) value increases from 700 to 1000. In this range, the ovality imperfections do not have an additional effect on the buckling behavior at the base of conical tanks. This finding suggests that other factors may become more significant in determining the buckling strength of conical tanks with higher r1/t (cos β) values.

In conclusion, the analysis of Figures 4.13 to 4.20 contributes to a better understanding of the relationships between buckling imperfection reduction, the h'/r1 ratio, imperfection amplitude, and out-of-roundness for different ranges of e1t and r1/t (cos β) values. These insights are valuable for optimizing the design and analysis processes of slender liquid-filled conical tanks, ensuring their structural integrity, and enhancing their performance in practical applications.

Figure 4.21 presents the plot of (σx, GMNIA σX, GMNA) versus h' (tan β)/r1. The subsequent figures illustrate the impact of varying ovality imperfections on the strength of thin-walled, liquid-filled conical tanks. The findings indicate that the ultimate strength of a liquid-filled conical tank is influenced by the degree of ovality imperfection. As the ovality imperfection increases, the ultimate strength of the tanks progressively decreases. For instance, with a fixed bottom and e1t = 70, the reduction in ultimate strength amounts to 61.21% for r1/t (cos β) = 140, 41.39% for r1/t (cos β) = 350, 26.03% for r1/t (cos β) = 700, and 21.68% for r1/t (cos β) = 1000. These results demonstrate that the load-carrying capacity of conical tanks decreases as the ovality imperfection increases.

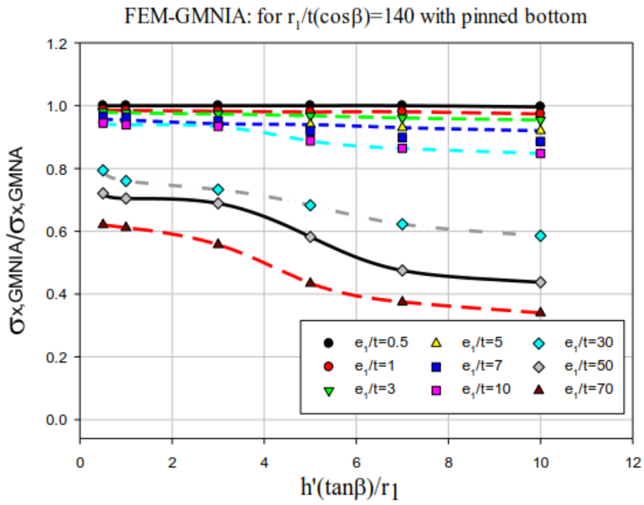

Figure 4.21 (a) Influence of ovality imperfection on buckling strength of LFC tanks

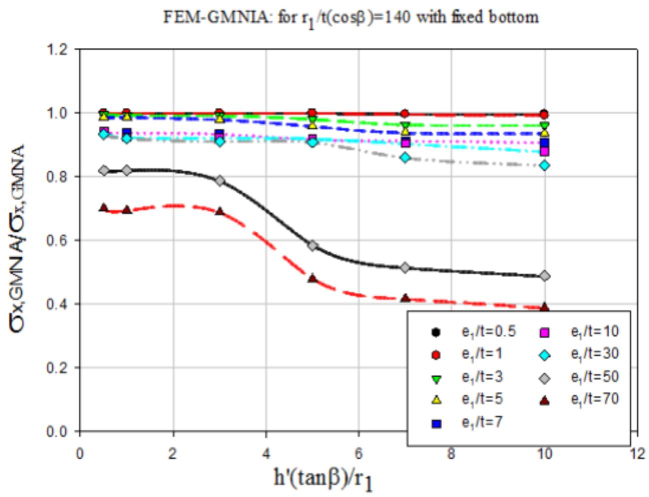

Figure 4.21 (b) Influence of ovality imperfection on buckling strength of LFC tanks

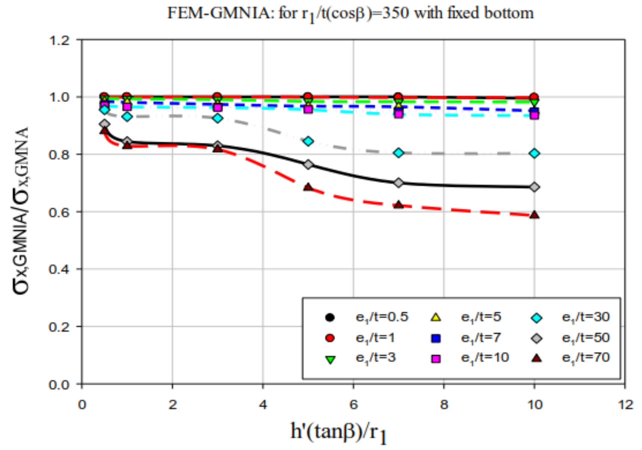

Figure 4.21 (c) Influence of ovality imperfection on buckling strength of LFC tanks

Furthermore, the figures illustrate how even a slight out-of-roundness can significantly affect the buckling capability of the tanks. These findings have significant implications for structural design, as they underscore the importance of carefully considering ovality imperfections to ensure the desired load-carrying capacity. As expected, the buckling loads of the conical tanks decrease with increasing imperfection amplitude, particularly at higher values of imperfection amplitude. This is because higher imperfection amplitudes tend to affect the lower rim part of the conical tank, which is the critical region.

The figures also depict the relationship curves of (σx, GMNIA σX, GMNA) to h' (tan β)/r1 for liquid-filled conical tanks with lower rim radius-to-thickness ratios ranging from 100 to 750. The load-carrying capacities vary significantly among different geometries due to the presence of initial geometrical imperfections. This emphasizes the influence of initial geometrical imperfections, such as ovality, on the load-carrying capacity of liquid-filled conical tanks, particularly when the liquid depth-to-lower rim radius ratio is large.

Based on these results, it is crucial to exercise caution to minimise significant initial geometrical imperfections during fabrication, assembly, and transportation processes. By addressing and mitigating these imperfections, the structural integrity and load-carrying capacity of liquid-filled conical tanks can be optimized, ensuring their reliable performance in practical applications.

Retrieval Number:100.1/ijese.B78160712223
DOI: 10.35940/ijese.B7816.0711823
Journal Website: www.ijese.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

International Journal of Emerging Science and Engineering (IJESE)
ISSN: 2319-6378 (Online), Volume-11 Issue-8, July 2023

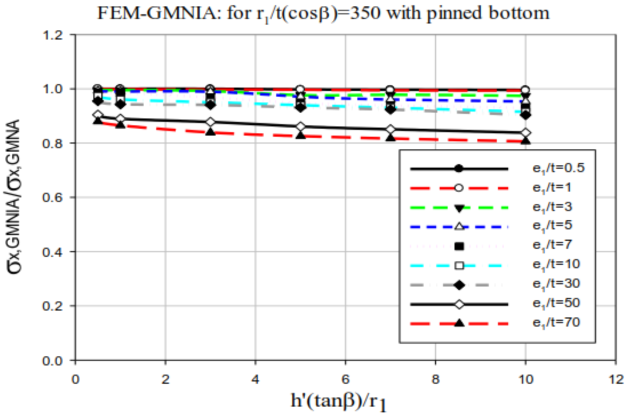

Figure 4.23 (d) Influence of ovality imperfection on buckling strength of LFC tanks

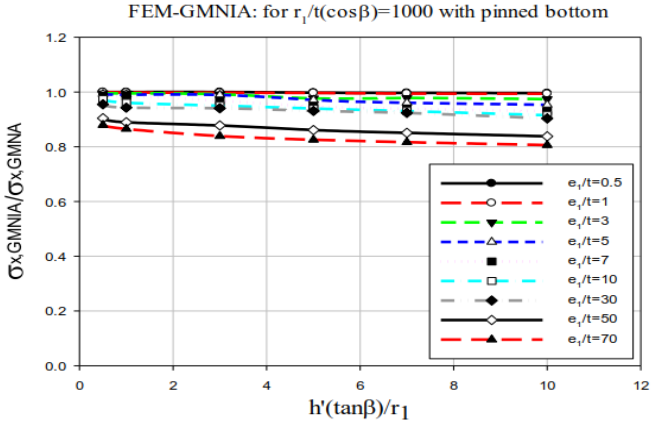

Figure 4.21 (h) Influence of ovality imperfection on buckling strength of LFC tanks

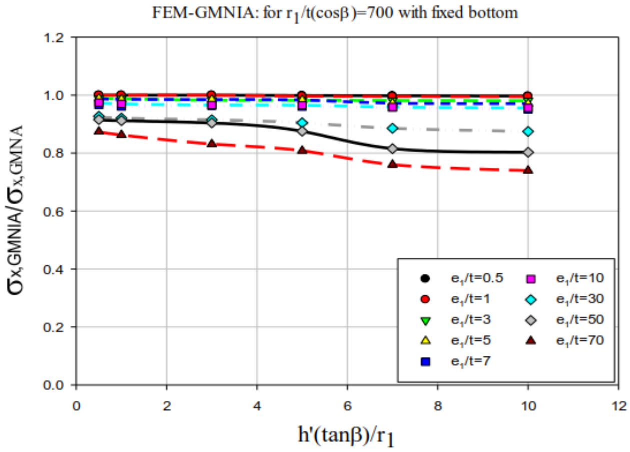

Figure 4.24 (e) Influence of ovality imperfection on buckling strength of LFC tanks

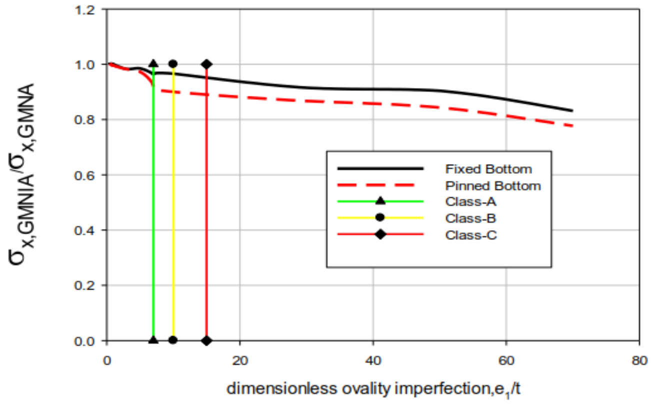

Figure 4.21 (i) Influence of ovality imperfection on buckling strength of LFC tanks

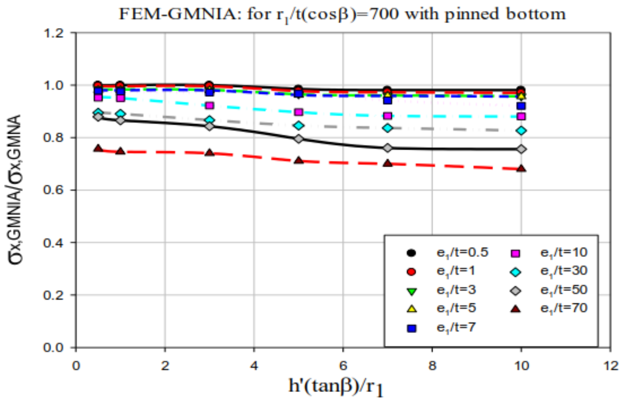

Figure 4.21 (f) Influence of ovality imperfection on buckling strength of LFC tanks

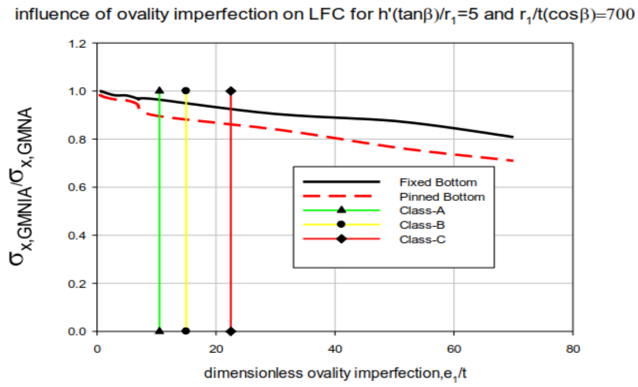

Figure 4.21 (j) Influence of ovality imperfection on buckling strength of LFC tanks

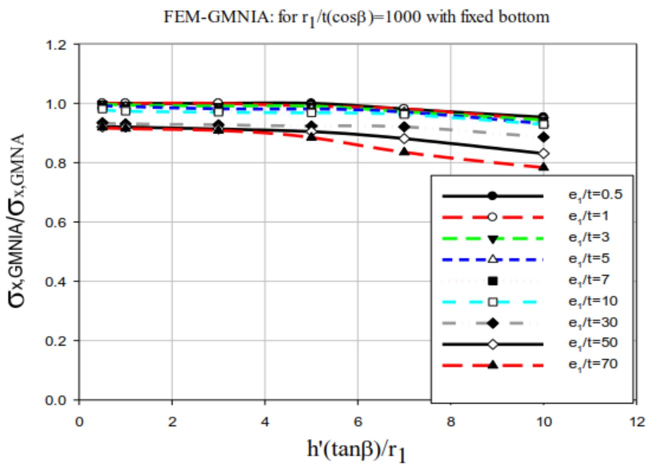

Figure 4.21 (g) Influence of ovality imperfection on buckling strength of LFC tanks

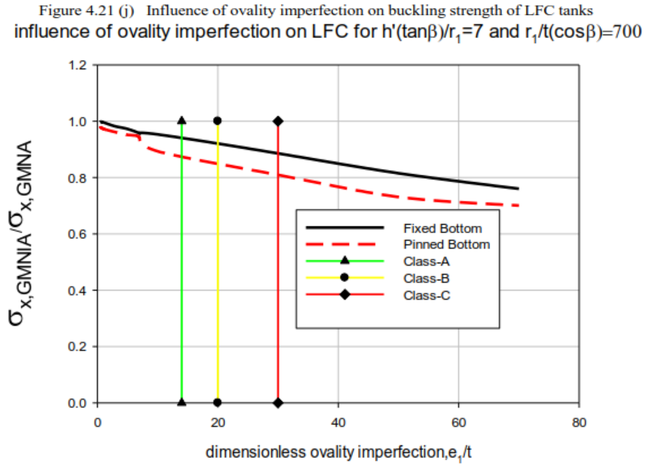

Figure 4.21 (k) Influence of ovality imperfection on buckling strength of LFC tanks

The results presented in Figure 4.21 and the subsequent figures provide valuable insights into the behavior of thin-walled liquid-filled conical tanks subjected to ovality

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

imperfections. The findings demonstrate that the ultimate strength of these tanks is significantly influenced by the degree of ovality imperfection. As the ovality imperfection increases, there is a progressive decrease in the ultimate strength of the tanks. For example, when considering a fixed bottom and e1t = 70, the reduction in ultimate strength is observed to be 61.21% for r1/t (cos β) = 140, 41.39% for r1/t (cos β) = 350, 26.03% for r1/t (cos β) = 700, and 21.68% for r1/t (cos β) = 1000.

These findings highlight the importance of carefully considering ovality imperfections in the design and analysis of conical tanks to ensure their desired load-carrying capacity. The decrease in the load-carrying capacity of the tanks as the ovality imperfection increases underscores the need for robust design practices that account for imperfection effects. Additionally, the figures demonstrate that even slight out-of-roundness can have a significant impact on the buckling capability of the tanks, further emphasizing the importance of maintaining geometric integrity. As anticipated, the buckling loads of the conical tanks decrease as the imperfection amplitude increases, particularly at higher values. This behavior can be attributed to the fact that higher imperfection amplitudes tend to affect the lower rim region of the conical tank, which is critical for structural stability.

The relationship curves presented in the figures, depicting (σx, GMNIA σX, GMNA) to h' (tan β)/r1 for tanks with varying lower rim radius-to-thickness ratios, reveal substantial variations in load-carrying capacities among different geometries. These variations are primarily attributed to the presence of initial geometrical imperfections. The results highlight the impact of initial geometrical imperfections, such as ovality, on the load-carrying capacity of liquid-filled conical tanks, particularly when the ratio of liquid depth to the lower rim radius is large. In light of these findings, it is crucial to exercise caution during the fabrication, assembly, and transportation processes to minimize significant initial geometrical imperfections. By addressing and mitigating these imperfections, it is possible to optimize the structural integrity and load-carrying capacity of liquid-filled conical tanks. Ensuring their reliable performance in practical applications. These results provide valuable guidance for engineers and designers involved in the construction and analysis of such tanks.

V. CONCLUSION

In conclusion, the analysis of the above Figures provides valuable insights into the behavior of thin-walled liquid-filled conical tanks subjected to ovality imperfections. The results demonstrate that the ultimate strength of these tanks is significantly affected by the degree of ovality imperfection. As the ovality imperfection increases, there is a progressive decrease in the ultimate strength of the tanks, with reductions ranging from 21.68% to 61.21% depending on the parameters considered.

These findings underscore the importance of carefully considering ovality imperfections in the design and analysis of conical tanks to ensure their desired load-carrying capacity. Design practices should account for imperfection effects to avoid compromising the structural integrity of the tanks. Furthermore, the figures highlight the significant impact of even slight out-of-roundness on the buckling capability of the tanks, underscoring the importance of maintaining geometric integrity.

As anticipated, the buckling loads of the conical tanks decrease with increasing imperfection amplitude, particularly at higher values of imperfection amplitude. This decrease can be attributed to the influence of higher imperfection amplitudes on the critical lower rim region of the tanks, which affects their overall stability.

The relationship curves presented in the figures also reveal substantial variations in load-carrying capacities among different geometries, primarily due to initial geometrical imperfections. This emphasizes the influence of initial geometrical imperfections, such as ovality, on the load-carrying capacity of liquid-filled conical tanks, particularly when the liquid depth-to-lower rim radius ratio is large. To ensure optimal performance, it is crucial to exercise caution during the fabrication, assembly, and transportation processes to minimize significant initial geometrical imperfections. By addressing and mitigating these imperfections, the structural integrity and load-carrying capacity of liquid-filled conical tanks can be optimized, thereby enhancing their reliability in practical applications.

Engineers and designers involved in the construction and analysis of conical tanks can benefit from these findings, as they provide valuable guidance for designing robust and efficient structures that meet the required load-carrying capacity and ensure safe operation in various applications. Future research in the field of thin-walled liquid-filled conical tanks subjected to ovality imperfections can build upon the insights gained from the current study. Here are some potential areas for further investigation:

Experimental Validation: Conducting experimental tests to validate the findings obtained from the analytical analysis would enhance confidence in the results. Experimental studies can provide additional data points and real-world validation of the behavior of liquid-filled conical tanks under various ovality imperfection scenarios.

Parametric Analysis: Extending the analysis to a broader range of parameters, such as different liquid depths, varying tank sizes, and different materials, would help in understanding the influence of these factors on the behaviour of the tanks. Investigating the effect of additional geometric imperfections, such as eccentricity or asymmetry, could provide a more comprehensive understanding of the structural response.

a) Numerical Simulations: Using advanced numerical methods, such as finite element analysis, to model the behavior of liquid-filled conical tanks can provide detailed insights into the complex structural response. Simulations can help in understanding the local stress distribution, deformation patterns, and failure mechanisms under different ovality imperfection scenarios.

Optimisation Techniques: Exploring optimisation techniques to improve the design of liquid-filled conical tanks, considering ovality imperfections, can lead to more efficient and cost-effective structures. By incorporating imperfection sensitivity analysis and considering multiple design variables, such as wall thickness distribution, reinforcement patterns, and material selection, optimal designs can be achieved that minimise imperfection effects.

Mitigation Strategies: Investigating practical mitigation strategies to

Retrieval Number:100.1/ijese.B78160712223
DOI: 10.35940/ijese.B7816.0711823
Journal Website: www.ijese.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

International Journal of Emerging Science and Engineering (IJESE)
ISSN: 2319-6378 (Online), Volume-11 Issue-8, July 2023

reduce ovality imperfections during fabrication, assembly, and transportation processes would be valuable. This could include developing guidelines and recommendations for quality control measures, handling procedures, and fabrication techniques to minimize the occurrence and impact of ovality imperfections.

Structural Health Monitoring: Implementing structural health monitoring techniques for liquid-filled conical tanks can provide real-time data on their structural integrity and performance. Monitoring techniques such as strain gauges, vibration sensors, or acoustic emission sensors can be employed to detect and assess the effects of ovality imperfections, providing early warnings of potential failures and enabling proactive maintenance strategies.

Further investigations can explore advanced numerical techniques and experimental validation to enhance the accuracy of ovality assessment and prediction in conical tanks. Considering more complex loading conditions, such as dynamic and seismic loads, can provide a comprehensive understanding of the buckling behavior under realistic scenarios. By addressing these research directions, we can further enhance the understanding and design methodologies for liquid-filled conical tanks subjected to ovality imperfections, leading to safer and more reliable structures in various engineering applications.

DECLARATION

Funding/ Grants/ Financial Support	No, I did not receive.
Conflicts of Interest/ Competing Interests	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, the article does not require ethical approval or consent to participate, as it presents evidence.
Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	I am the sole author of the article

REFERENCE

1. J. Singer et al. "Experimental methods in buckling of thin-walled structures", John Wiley & Sons, Inc., Canada, 2002. [CrossRef]
2. W.T. Koiter"On the stability of elastic equilibrium", Ph.D. Thesis, Polytechnic Institute Delft, 1945.
3. Wesley Vanlaere et al. "Numerical study of imperfect liquid-filled conical shells", Graz University of Technology, 2008. [CrossRef]
4. EN 1993-1-6 "Design of Steel Structures", Part 1-6: Strength and Stability of shells, European Committee for Standardization CEN, Brussels, 2007.
5. Vandepitte D. et al "Experimental investigation of hydrostatically loaded conical shells and practical evaluation of the buckling load". In: Proceedings of state-of-the-art colloquium, Germany, 1982. p. 375-99. [CrossRef]
6. Ashraf El Damatty"Nonlinear dynamic extension of consistent shell element and analysis of liquid filled conical shells", McMaster University, Canada, 1995.
7. Rotter, J.M. et al "Cylindrical shells under axial compression", Spon Press, London, 2007.
8. Arbocz, J. et al "The Effect of General Imperfections on the Buckling of Cylindrical Shells", Journal of Applied Mechanics, Vol. 6, No. 69, 1969, pp. 28-37. [CrossRef]
9. Guy A. M. E. et al. "Plastic buckling of conical shells with large geometrical imperfections", Department of Structural Engineering, Ghent University, 2007.
10. Medhanye B. Tekleab "Buckling of Thin-Walled Cylindrical & Conical Metal Shells: Analysis", Test Evaluation & Design, Doctoral Dissertation, Graz University of Technology, 2009.

APPENDIX

Appendix I: List of Symbols and Acronyms:

The symbols listed below are those that appeared in this thesis report. They are either of general interest or of particular specification. Only one meaning is assigned to each symbol unless otherwise defined in the text where it occurs.

h' Liquid depth
r Top Radius
t Thickness of the tank
u,v,w Displacements in x, θ and z-directions
e Ovality Imperfection
λ Linear critical buckling load factor
$\sigma x,cr$ Elastic Critical buckling stress
ν Poisson's ratio
σx Meridional stress
σθ Hoop stress
r1 Radius of the lower rim
β Apex half angle of the cone
γ' Specific weight of the liquid
GMNA Geometrically and Materially Non-linear Analysis
GMNIA Geometrically and Materially Non-linear Analysis with Imperfection
GNA Geometrical nonlinear analysis
LA Linear elastic analysis
LBA Linear elastic Bifurcation Analysis
LPF Load proportional factor
MNA Materially Non-linear Analysis
S4R 4-node general-purpose Abaqus shell element
S8R 8-node doubly curved thick tank, reduced integration
LFC Liquid-filled cone
B.C. Boundary condition

Appendix II: Numerical verification of Eurocode Design Rule

Numerical verification of the design rule is performed here by applying the rule to three cone geometries. In this investigation, quality classes A, B, and C are assumed to exist. The geometries are given in Table 3. In the numerical model, the lower rim is pinned, and the upper rim is free to deform. The simulations are geometrically and materially nonlinear and include geometrical imperfections (GMNIA). The buckling strength reduction factor χ can be derived from the capacity curve, which is given by the following equations:

Table 1: Values of the fabrication quality parameter Q [-]

Quality	Description	Q
Class-A	Excellent	40
Class-B	High	25
Class-C	Normal	16

Table 2: Values for Ovality imperfection amplitude parameters

Quality Class	Description	$U_{r,max}$ for different diameter ranges		
		$d \le 0.50m$	$0.5m \le d \le 1.25m$	$1.25m \le d$
Class-A	Excellent	0.0140	$0.007 + 0.0093(1.25 - d)$	0.0070
Class-B	high	0.020	$0.010 + 0.0133(1.25 - d)$	0.0100
Class-c	normal	0.030	$0.015 + 0.0200(1.25 - d)$	0.0150

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

Table 3: three geometries of conical tanks

$r_1/t(\cos\beta)=350$			$r_1/t(\cos\beta)=700$			$r_1/t(\cos\beta)=1000$		
γ'(N/m3)	h' (m)	r1(m)	γ'(N/m3)	h' (m)	r1(m)	γ'(N/m3)	h' (m)	r1(m)
0	15	2.5	0	15	5	0	15	7.5
9050.9	15	2.5	4525.44	15	5	3016.96	15	7.5
18101.76	15	2.5	9050.9	15	5	6033.92	15	7.5
27152.64	15	2.5	13576.32	15	5	9050.88	15	7.5
36203.52	15	2.5	18101.76	15	5	12067.84	15	7.5
45254.4	15	2.5	22627.2	15	5	15084.8	15	7.5

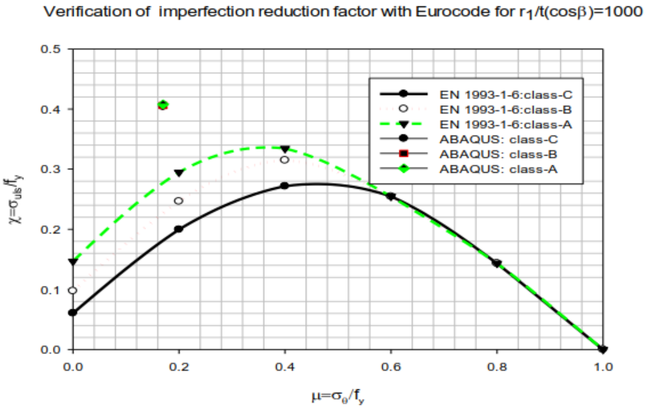

Figure 4.27 comparison of eurocode rule with numerical analysis for $r_1/t(\cos\beta)=1000$

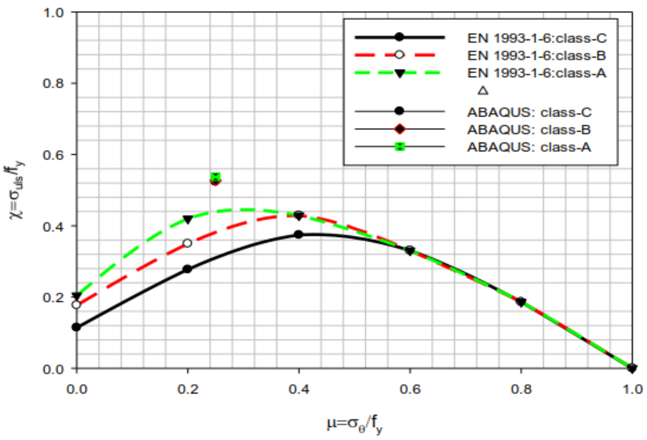

Figure 4.28 comparison of eurocode rule with numerical analysis for $r_1/t(\cos\beta)=700$

The ratios of the characteristic meridional buckling stresses σx, GMNIA/σxRk, allow for determining whether the design rule leads to conservative results for these geometries. The results of these numerical simulations are summarised in the previous figures and indicate that, with the inclusion of yielding, the design rule yields conservative results for all geometries.

From previous figures, it is evident that ovality imperfection shapes in liquid-filled conical tanks can lead to failure stresses that exceed those predicted by the design rule; therefore, the design rule appears to be conservative. These results suggest that the Eurocode design procedure may, in all cases, underestimate the buckling stress, which is safe. This implies that geometric ovality imperfection on liquid-filled conical tanks for different quality classes considered in this study is already incorporated into the Eurocode design rule. In addition, the Eurocode design procedure is based on extensive experimental research, combined with theoretical investigation, and thus has a solid underpinning.

AUTHOR PROFILE

Mr. Girmay Mengesha Azanaw is a lecturer at Aksum University, Institute of Technology, Department of Civil Engineering, Aksum, Ethiopia. He completed his M.Sc. at the Ethiopian Institute of Technology, Mekelle University, in 2017. He received a B.Sc. in Civil Engineering from Mekelle University's Ethiopian Institute of Technology in 2013. He published one research paper in an international Journal. His research interests include developing a digital twin for the Application of structural engineering and structural health monitoring systems.