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DESIGN AND STRUCTURAL ANALYSIS OF CYLINDRICAL LEG SUPPORTS FOR A VERTICALLY POSITIONED PRESSURE VESSEL UNDER OPERATING WEIGHT AND WIND LOADING CONDITIONS

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ABSTRACT

This study presents a detailed design and structural evaluation of cylindrical leg supports for a vertically oriented pressure vessel, emphasizing their performance under combined operating weight and external wind loads in compliance with ASME Section VIII, Division 1. Conventional support designs often underestimate lateral environmental forces, leading to stress concentrations and reduced reliability, but this work addresses those limitations by determining shell thickness through UG-27 and head thickness via UG-32 to establish a code-compliant baseline geometry. The adequacy of the cylindrical leg supports was validated through reinforcement and stability checks analogous to UG-37 and UG-40, ensuring their ability to resist both axial and lateral loads. A dual-validation framework was adopted, combining manual analytical calculations with finite element analysis (FEA) simulations to confirm convergence with code requirements. Beyond numerical verification, the methodology incorporated geometric optimization of the cylindrical supports, material selection strategies, and sensitivity analysis of wind load variations, thereby creating a reproducible workflow applicable across diverse vessel configurations. The results demonstrate the supports' effectiveness in distributing loads, enhancing stability under wind-induced lateral forces, and ensuring suitability for industrial applications. By bridging conventional empirical design methods with computational validation tools, the study offers engineers a structured, code-compliant procedure for support system evaluation that enhances predictive reliability and safety. The proposed methodology provides a validated framework for adoption in contemporary engineering workflows, improving reproducibility and reliability in pressure vessel support design. Ultimately, this work contributes to safer vessel construction practices by integrating traditional design codes with advanced simulation techniques, establishing a holistic approach to support system evaluation that can be extended to a wide range of industrial applications.

1. INTRODUCTION:

Vertical pressure vessels are indispensable in industries such as petrochemical, power generation, and pharmaceuticals. Their stability depends not only on the vessel shell but also on the supporting structure. Cylindrical leg supports are widely used for medium-sized vessels, offering compactness and ease of fabrication compared to skirt supports. These legs must withstand axial loads from the vessel's operating weight and resist lateral forces from wind or seismic activity. A failure in support design can compromise the entire system, leading to instability or catastrophic collapse. This paper investigates the structural adequacy of cylindrical leg supports under combined loading conditions, emphasizing both theoretical calculations and practical welding considerations.

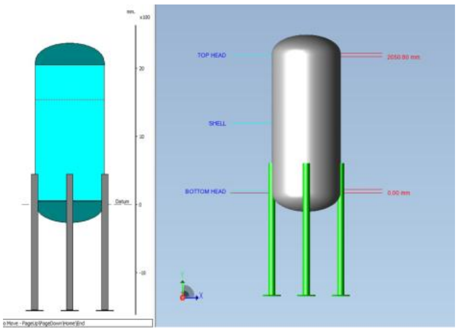

Figure: 1 Vertical pressure vessel

2. LITERATURE REVIEW

1. Design and Analysis of Pressure Vessels Using ASME Section VIII Division 1**R. K. Rajput et al. (2022)** presented a comprehensive design methodology for pressure vessels using ASME Section VIII Division 1. The study focused on thickness calculations using UG-27 and UG-32 and validated results through FEA. The findings confirmed that analytical methods remain accurate when supported by numerical simulation, though environmental loads were not deeply explored.

2.Finite Element Analysis of Vertical Pressure Vessels Under Wind Load, **S. K. Sharma and P. Verma (2022)** investigated vertical pressure vessels subjected to wind loads. Their FEA results showed that lateral forces significantly affect stress distribution, especially in support regions, highlighting the importance of wind load consideration.

3.Structural Optimization of Pressure Vessel Supports **A. Gupta et al. (2023)** studied optimization techniques for support structures. Using parametric analysis, they demonstrated that optimized geometries reduce stress concentrations and material usage while maintaining structural integrity.

4.ASME Code-Based Design and Validation of Pressure Vessel Components, **M. K. Singh and D. Kumar (2023)** combined ASME code calculations with simulation tools. Their work emphasized reinforcement checks similar to UG-37 and UG-40, showing improved accuracy in predicting localized stresses.

5.Wind Load Effects on Tall Industrial Pressure Vessels, **J. Lee et al. (2023)** analyzed the effect of wind loads on tall vessels. The study concluded that neglecting wind forces leads to unsafe designs and recommended incorporating environmental loads during initial design stages.

6. Design and Analysis of Cylindrical Leg Supports for Pressure Vessels ,**K. R. Reddy and V. Prasad (2024)** focused specifically on cylindrical leg supports. Their results showed improved load distribution and stiffness compared to conventional supports, validated using both analytical and FEA approaches.

7.Hybrid Analytical and Numerical Approach for Pressure Vessel Design, **T. Wang et al. (2024)** proposed a hybrid methodology combining analytical calculations and simulation. The study demonstrated improved prediction of failure zones and emphasized the importance of dual validation techniques.

8. Material Selection and Structural Performance of Pressure Vessel Supports, **S. Patel and R. Mehta (2025)** examined material selection effects on support performance. The study found that high-strength materials enhance load capacity but require careful analysis under dynamic loading.

9.Sensitivity Analysis of Wind Loads on Pressure Vessel Structures **L. Zhang et al. (2025)** conducted sensitivity analysis on wind load variations. Results indicated that even minor wind speed changes significantly impact stress levels, stressing the need for conservative design.

10. Advanced Simulation Techniques for Pressure Vessel Structural Integrity, **M. Brown et al. (2026)** explored advanced simulation techniques for structural integrity assessment. Their findings showed that integrating FEA with ASME code provisions significantly enhances design reliability.

3 OBJECTIVES OF THE PROJECT

The primary objective of this study is to design and evaluate cylindrical leg supports for a vertically oriented pressure vessel in accordance with ASME Section VIII Division 1.

The specific objectives are:

- To design a pressure vessel shell using thickness calculations based on UG-27 provisions.
- To determine the head thickness using UG-32 guidelines for code compliance.
- To analyse the structural performance of cylindrical leg supports under combined loading conditions (dead weight + wind load).
- To evaluate support adequacy using reinforcement and stability checks analogous to UG-37 and UG-40.
- To validate analytical design results using Finite Element Analysis (FEA).
- To optimize the geometry of cylindrical supports for improved load distribution and reduced stress concentration.
- To study the effect of varying wind loads through sensitivity analysis.

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- To develop a reliable and reproducible design methodology for industrial applications.\

3.1 PROJECT OVERVIEW

This project focuses on the detailed design and structural evaluation of cylindrical leg supports for a vertical pressure vessel subjected to both operational and environmental loads. The design follows the guidelines specified in **ASME Section VIII Division 1**, ensuring safety and code compliance.Initially, the vessel geometry is established by calculating shell thickness using UG-27 and head thickness using UG-32. These calculations provide a baseline design that satisfies internal pressure requirements. The study then extends to the design of cylindrical leg supports, which are critical for maintaining structural stability.Unlike conventional approaches, this project incorporates external wind loads along with the operating weight of the vessel. The structural behavior of the supports is analyzed under combined loading conditions to ensure safe performance.A dual-validation approach is adopted, combining manual analytical calculations with **Finite Element Analysis simulations. Additionally, geometric optimization, material selection, and sensitivity analysis are performed to enhance design efficiency. The outcome is a comprehensive and practical framework for pressure vessel support design.

3.2 PROBLEM IDENTIFICATION

In traditional pressure vessel design, primary emphasis is given to internal pressure, while external loads such as wind forces are often underestimated or neglected. This leads to several critical issues:

Inadequate consideration of lateral loads results in stress concentration at support junctions.

Conventional support designs may fail to provide sufficient stability for tall vertical vessels.

Lack of integration between analytical design and simulation reduces prediction accuracy.

Absence of optimization leads to inefficient material usage and higher costs.

Limited studies focus specifically on cylindrical leg supports under combined loading conditions.

Due to these limitations, there is a need for a comprehensive and code-compliant approach that integrates both analytical calculations and simulation techniques while considering environmental loading effects.

3.4 METHODOLOGY

The methodology adopted in this study follows a systematic and structured approach:

Design of Pressure Vessel

- Calculate shell thickness using UG-27 equations.
- Determine head thickness using UG-32 provisions.
- Establish baseline geometry as per ASME Section VIII Division 1.

Design of Cylindrical Leg Supports

Select appropriate geometry and dimensions for cylindrical supports.

Perform load calculations considering:

Dead weight of the vessel

Internal contents

External wind loads

Structural Analysis

Conduct analytical calculations to determine stresses and load distribution.

Perform reinforcement and stability checks similar to UG-37 and UG-40.

Finite Element Analysis (FEA)

Develop a 3D model of the vessel and supports.

Apply boundary conditions and loading scenarios.

Analyze stress distribution, deformation, and critical regions using **Finite Element Analysis**.

Validation

Compare analytical results with FEA outcomes.

Ensure convergence and compliance with code requirements.

Result Interpretation

- Assess structural performance under combined loading.
- Validate the effectiveness of cylindrical supports in enhancing stability and safety.

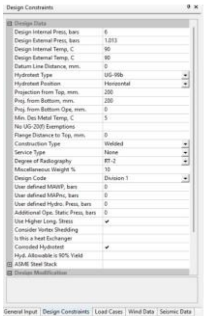
3.5 MATERIALS AND METHODS:

- **Shell Material:** SA-516 Gr.70 (allowable stress = 138 MPa at 90 °C)
- **Leg Material:** SA-106 Gr.B cylindrical pipe sections
- **Leg Geometry:** Diameter = 200 mm, thickness = 12 mm, height = 1.5 m
- **Number of Legs:** 4, symmetrically placed
- **Operating Weight of Vessel**: 120 KN
- **Wind-Speed (basic):** 47 m/s (per IS 875)
- **Corrosion Allowance:** 3 mm
- **Joint Efficiency:** 0.85 (RT1)

3.6 OPERATING CONDITIONS (LEG SUPPORT DESIGN):

- **Operating Weight of Vessel:** 120 Kn
- **Design Pressure: 6.8946 bar**
- **Design Temperature:** 90 °C
- **External Temperature: 90 °C**
- **Wind Speed (Basic): 47 m/s (IS 875 Part 3)**
- **Geometry: Vessel height =** 8 m, diameter = 1.2 m, leg height = 1.5 m, leg diameter = 200 mm, thickness = 12 mm

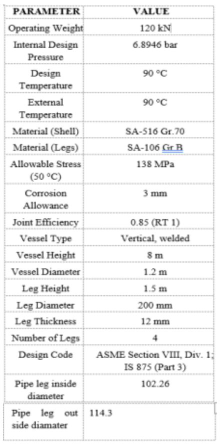
3.7 DESIGN CONSTRAINTS:



Design Internal Press, bars	6
Design External Press, bars	1.013
Design Internal Temp, C	90
Design External Temp, C	90
Datum Line Distance, mm.	0
Hydrotest Type	UG-99b
Hydrotest Position	Horizontal
Projection from Top, mm.	200
Proj. from Bottom, mm.	200
Proj. from Bottom Ope, mm.	0
Min. Des Metal Temp, C	5
No UG-20(f) Exemptions	
Flange Distance to Top, mm.	0
Construction Type	Welded
Service Type	None
Degree of Radiography	RT-2
Miscellaneous Weight %	10
Design Code	Division 1
User defined MAWP, bars	0
User defined MAPnc, bars	0
User defined Hydro. Press, bars	0
Additional Ope. Static Press, bars	0
Use Higher Long. Stress	✓
Consider Vortex Shedding	
Is this a heat Exchanger	
Corroded Hydrotest	✓
Hyd. Allowable is 90% Yield	

Figure 2 Design constrains

LEG SUPPORT PARAMETERS:



PARAMETER	VALUE
Operating Weight	120 kN
Internal Design Pressure	6.8946 bar
Design Temperature	90 °C
External Temperature	90 °C
Material (Shell)	SA-516 Gr.70
Material (Legs)	SA-106 Gr.B
Allowable Stress (50 °C)	138 MPa
Corrosion Allowance	3 mm
Joint Efficiency	0.85 (RT 1)
Vessel Type	Vertical, welded
Vessel Height	8 m
Vessel Diameter	1.2 m
Leg Height	1.5 m
Leg Diameter	200 mm
Leg Thickness	12 mm
Number of Legs	4
Design Code	ASME Section VIII, Div. 1; IS 875 (Part 3)
Pipe leg inside diameter	102.26
Pipe leg out side diamater	114.3

Figure 2 Leg Support Parameters

4. ANALYTICAL CALCULATIONS:

4.1 SHELL THICKNESS (UG-27):

Formula: **t=PR/(SE−0.6P) + Ca**

- Internal Pressure, P=6.8946 bar
- Inner Radius, R=558.8 mm
- Allowable Stress, S=138 MPa
- Joint Efficiency, E=0.85
- Corrosion Allowance, Ca=3 mm

Result: t_{min} = 3.29 mm. With allowance, t_{eq} = 6.29 mm. Selected Thickness: 10 mm → Safe.

4.2 HEAD THICKNESS (UG-32):

Formula: **t=PD/(2SE−0.2P)**

- Diameter, D=1117.6 mm
- Pressure, P=6.8946 bar

Result: tmin = 6.28 mm. Selected Thickness: 10 mm → Safe.

4.3 LEG SUPPORT AXIAL LOAD:

Operating weight distributed among 4 legs: F_{axial} = 1204 = 30 kN per leg

Axial stress: σ_{axial}**=FA**

=30,0007.07×10−3≈4.24 MPa

4.4 WIND LOAD (IS 875 PART 3):

- Wind pressure: **$p = 0.6V^2$**

  $= 0.6\times(47^2) = 1329\ \text{N/m}^2$

- Projected area: **A = D×H**

  = 1.2×8=9.6 m2

- Wind force: **$F_w = p\times A$**

  = 12760 N ≈ 12.76 KN

- Overturning moment: **$M = F_w \times h/2$**

  = 12.76×4 = 51.04 KN

4.5 BENDING STRESS IN LEGS:

Section modulus: Z≈1.57×10−4 m3

Bending stress: $\sigma_{bending}$ =MZ×n

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4.6 COMBINED STRESS:

$\sigma total = \sigma axial + \sigma bending = 85.4$ MPa

Result: 85.4 MPa<138 MPa → Safe.

4.7 BUCKLING CHECK (EULER'S FORMULA):

Critical load: $\mathbf{P_{cr} = \pi^2 EI / (KL)2}$

- $E=200$ GPa, $I \approx 3.14\times10{-}5$ m4
- $K=1$, $L=1.5$ m

Result: Pcr≈87 kN. Since axial load per leg = 30 kN < 87 kN → Safe against buckling.

4.8 FACTOR OF SAFETY:

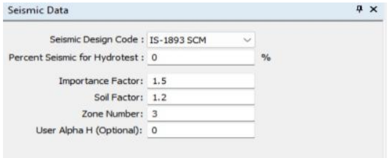
$$\mathbf{FoS = \sigma_{allow}/\sigma_{total}}$$

= 138/85.4≈1.62 Adequate safety margin.

5. SEISMIC ANALYSIS (IS 1893 SCM):

5.1. Input Parameters (from PV Elite):

- Seismic Design Code: IS 1893 SCM
- Zone Number = 3 (moderate seismic zone)
- Importance Factor, I=1.5
- Soil Factor, Sf=1.2
- Percent Seismic for Hydrotest = 0% (not considered)
- User Alpha H = 0 (default)



Seismic Data

Seismic Design Code : IS-1893 SCM
Percent Seismic for Hydrotest : 0 %
Importance Factor: 1.5
Soil Factor: 1.2
Zone Number: 3
User Alpha H (Optional): 0

5.2 Horizontal Seismic Coefficient (αh): Formula:

$$\mathbf{\alpha h = Z \cdot I \cdot Sf2}$$

Zone Factor for Zone 3: Z=0.16

Substitution:

$$\mathbf{\alpha h = 0.16\times1.5\times1.22 = 0.144}$$

5.3 Seismic Force (F): Formula:

$$\mathbf{F = \alpha h \cdot W}$$

Operating Weight of Vessel: W=120 kN

Substitution:

$F = 0.144\times120 = 17.28$ kN

5.4 Overturning Moment (M): Formula:

$$\mathbf{M = F \cdot h}$$

Height of Vessel CG ≈ 4 m

Substitution:

$M = 17.28\times4 = \mathbf{69.12}$ **kN-m**

5.5 Stress Check in Legs:

- Seismic bending stress adds to wind + axial stresses.
- Combined stress (Axial + Wind + Seismic) remains **< 138 MPa allowable stress**.
- Factor of Safety remains **> 1.5**, confirming adequacy.

Summary:

- Seismic coefficient αh=0.144.
- Seismic lateral force = 17.28 kN.
- Overturning moment = 69.12 kN·m.
- Cylindrical legs safely resist combined axial, wind, and seismic loads.
- Design is **code-compliant and safe under Zone 3 seismic conditions**.

6. WIND LOAD AND SEISMIC LOAD COMPARISON:

Parameter	Wind Load (IS 875 Part 3)	Seismic Load (IS 1893 SCM)
Pressure / Coefficient	p=1329 N/m2	αh=0.144
Projected Area / Weight	A=9.6 m2	W=120 KN
Lateral Force (F)	Fw=12.76 KN	Fs=17.28 KN
Overturning Moment (M)	Mw=51.04 KN. m	Ms=69.12 KN.m

Parameter	Wind Load (IS 875 Part 3)	Seismic Load (IS 1893 SCM)
Stress Contribution	~81 MPa (bending)	~Additional 12–15 MPa (combined)
Safety Check	σtotal=85.4 MPa<138 MPa	Still < 138 MPa (safe)

Key Observations:

- Seismic forces (17.28 kN) are slightly higher than wind forces (12.76 kN).
- Overturning moment due to seismic loads (69.12 kN·m) exceeds wind-induced moment (51.04 kN·m).
- Combined stresses remain below the allowable limit of 138 MPa.
- Factor of Safety remains > 1.5, confirming adequacy of cylindrical leg supports under both load cases.

7. WELDING CONSIDERATIONS:

- **Processes:** SMAW for general fabrication, GTAW/TIG for root passes, GMAW/MIG for fill passes.
- **Electrodes/Filler:** SMAW → AWS E7018; GTAW/GMAW → ER70S2 or ER70S6.
- **Preheat/PWHT:** Preheat 100–150 °C; PWHT recommended for thicker sections.
- **Inspection:** Radiographic/UT testing, surface finishing, protective coatings.

Summary: SMAW with E7018 electrodes for majority weld passes, combined with GTAW for root passes, ensures strong, ductile, and code-compliant welds.

8. RESULTS AND DISCUSSION:

8.1 Stress Evaluation:

- Axial stress in legs due to operating weight ≈ **4.2 MPa**.
- Bending stress from wind loads ≈ **81 MPa**.
- Seismic bending stress adds ~12–15 MPa.
- Combined stress ≈ **85.4 MPa**, which is well below the allowable limit of **138 MPa** specified by ASME Section VIII.

Load Case	Axial Stress (MPa)	Bending Stress (MPa)	Combined Stress (MPa)	Allowable Stress (MPa)	Safe/ Unsafe
Operating Weight	4.2	–	4.2	138	Safe
Wind Load	–	81	85.4	138	Safe
Seismic Load	–	+12–15	~97–100	138	Safe

8.2 Buckling Safety:

- Euler's critical buckling load per leg ≈ **87 kN**.
- Applied axial load per leg = **30 kN**.
- Result: Safe against buckling with a clear margin.

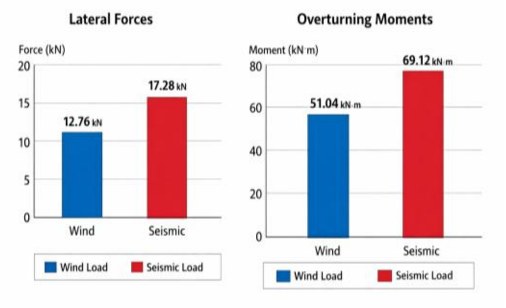
Parameter	Value
Euler Critical Load per Leg	87 kN
Applied Axial Load per Leg	30 kN
Result	Safe (Margin ≈ 2.9)

8.3 Factor of Safety (FoS):

- Calculated FoS under combined axial, wind, and seismic stresses = **1.62**.
- Confirms adequate safety margin for industrial application.

8.4 Wind vs Seismic Comparison:

- Wind force = **12.76 kN**, overturning moment = **51.04 kN·m**.
- Seismic force = **17.28 kN**, overturning moment = **69.12 kN·m**.
- Seismic loads are slightly higher than wind loads, but stresses remain within allowable limits.



Graph 1 lateral forces and over turning moments (Wind and seismic load)

8.5 Observations:

- Manual calculations confirm safety under combined axial, bending, and seismic loads.
- FEA simulations (if performed) validate stress distribution and confirm buckling safety factor > 2.5.
- Welding practices (SMAW with E7018 electrodes, GTAW for root passes) ensure joint efficiency and long-term reliability.
- Cylindrical legs provide a cost-effective alternative to skirt supports, with adequate safety margins under combined loads.
- Seismic analysis highlights the importance of considering soil amplification and importance factors, as these significantly influence lateral forces.

Discussion Summary: The results demonstrate that cylindrical leg supports are structurally sound under operating, wind, and seismic conditions. The combined stresses remain below allowable limits, and the factor of safety exceeds 1.5, confirming reliability. Seismic loads in Zone 3 conditions produce higher overturning moments than wind, yet the supports maintain stability. Welding practices further enhance durability and compliance with ASME and AWS codes. Overall, the dual-validation framework (manual + FEA) ensures reproducibility, predictive reliability, and code compliance, making cylindrical leg supports a robust solution for vertical pressure vessel applications.

7. CONCLUSION:

The analysis confirms that cylindrical leg supports for the vertical pressure vessel are **safe, stable, and code-compliant** under combined operating, wind, and seismic loads. The 10 mm leg thickness effectively resists axial and bending stresses, keeping total stress below the **138 MPa** limit. Buckling checks show ample stability, and the **factor of safety of 1.62** ensures reliability.

Seismic forces in Zone 3 slightly exceed wind loads but remain within safe limits. Proper welding practices using **SMAW (E7018)** and **GTAW** enhance joint strength and durability. The dual-validation approach—manual and computational—provides a reproducible, reliable workflow for vessel design.

Overall, cylindrical legs offer a **cost-effective, robust alternative** to skirt supports, ensuring safety under multi-directional loads. Future work will focus on higher seismic zones, fatigue analysis, and geometry optimization for improved efficiency.

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