WIND, SEISMIC DESIGN AND ANALYSIS OF STATIC EQUIPMENT

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Abstract**—**The structural integrity of static process equipment is critically influenced by environmental loads, particularly wind and seismic actions. This paper presents an integrated, code-compliant methodology for wind and seismic design and analysis of two representative equipment types — a vertical Pressure Vessel and a horizontal Fixed Tube Sheet Heat Exchanger — in accordance with ASME BPVC Section VIII Division 1, IS-875 (wind loading), and IS-1893 (seismic loading). For the Pressure Vessel, a natural frequency of 26.9856 Hz confirmed rigid structure classification. Wind loading governs bending at the critical leg section (120.607 Kg-m vs. 45.125 Kg-m seismic, ratio 2.67:1). Wind deflection of 3.852 mm is well within the 10.500 mm allowable, and critical vortex-shedding velocities (658–717 km/hr) confirm zero vibration risk. For the Heat Exchanger, wind governs the saddle element (435.25 Kgf) while seismic governs regular shell elements (25.64 Kgf/element). A unified governing load comparison, code compliance summary, and recommendations for further work are presented, providing a practical framework for engineers performing multi-hazard static equipment design under Indian code conditions.

Keywords —*Wind Load, Seismic Load, Pressure Vessel, Heat Exchanger, IS-875, IS-1893, ASME BPVC, Seismic Coefficient Method, Static Equipment Analysis*

I. INTRODUCTION

Static equipment in process industries — pressure vessels, heat exchangers, storage tanks, and distillation columns — must withstand not only internal operating pressures but also significant external environmental loads. Wind and seismic forces represent major challenges to structural integrity, particularly in India where seismically active zones and high-wind coastal regions demand rigorous multi-hazard design approaches [1].

This study analyses two representative equipment types: a vertical Pressure Vessel and a horizontal Fixed Tube Sheet Heat Exchanger. Wind loads are computed per IS-875 Part 3 and seismic loads per IS-1893 (1984) Seismic Coefficient Method, with all structural calculations conforming to ASME BPVC Section VIII, Division 1. Analysis is performed using COADE Engineering Software, an industry-standard computational tool for static equipment design [10].

The objectives of this study are: (1) to model both equipment items and apply IS-875 wind loads for their respective wind zones and terrain categories; (2) to determine element earthquake loads via the IS-1893 SCM for operating and empty conditions; (3) to compute wind/seismic shear, bending moment distributions, wind deflection, and critical vortex-shedding velocities for the Pressure Vessel (4) to compare governing load cases for both equipment types; and (5) to provide a unified, software-validated design framework for static process equipment in India.

II. LITERATURE REVIEW

A. Wind Load Provisions under IS-875

IS-875 Part 3 is the primary Indian standard for wind load calculation on industrial equipment. Davenport [1] established the theoretical basis for terrain roughness effects on atmospheric boundary layer wind profiles, underpinning IS-875 exposure and height factors (k1, k2, k3). Krishna and Prem Krishna [2] provided comprehensive commentary on IS-875 Part 3 for industrial vessels and stacks. Vickery and Basu [3] investigated vortex-induced vibrations on process columns, establishing lock-in resonance criteria relevant to the Pressure Vessel assessment.

B. Seismic Design Using IS-1893

IS-1893 (1984) provides the Seismic Coefficient Method (SCM) for lateral earthquake forces on industrial structures. Arya, Ajmani and Boen [4] evaluated industrial facilities in Indian earthquakes, establishing recommendations that influenced the Importance Factor I = 1.5 applied in this study. Merovich [5] demonstrated that the SCM is conservative for short, rigid structures (f > 1 Hz), consistent with the Pressure Vessel natural frequency of 26.9856 Hz.

C. Combined Structural and Pressure Vessel Analysis

Bednar [6] provides the most widely cited procedures for combined structural and pressure analysis of process vessels, covering wind and seismic load translation into shell and skirt stresses per ASME BPVC. Moss and Basic [7] explicitly addressed IS-875 and IS-1893 integration into ASME BPVC design calculations. Zick [8] established saddle support design principles for horizontal vessels; Brownell and Young [9] extended these to wind and seismic effects directly applicable to the heat exchanger's analysis.

D.Research Gap

COADE/Hexagon is a widely adopted tool for pressure vessel design per ASME BPVC Divisions 1 and 2. Bhatt [10] documented its application for integrated IS-875/IS-1893 analysis in Indian petrochemical plants. However, unified worked examples covering both vertical pressure vessels and horizontal heat exchangers under Indian code conditions in a single validated study remain scarce — a gap this paper directly addresses.

III. EQUIPMENT DESCRIPTION

A. Pressure Vessel

The Pressure Vessel is a vertical process vessel comprising a cylindrical shell with a top head at elevation 2050 mm, supported on legs at datum. It is divided into three shell elements for analysis. Key parameters are summarized in Table 1.

Parameter	Value
Vessel Tag	Pressure Vessel
Orientation	Vertical
Top Head Elevation	2050 mm
Design Code	ASME BPVC Sec VIII Div 1
Support Type	Leg Supports
Head Weight	113.121 Kgf
Head Volume	233,555 cm³

Table 1: Pressure Vessel Equipment Parameters

B. Heat Exchanger

The Heat Exchanger is a horizontal fixed tube sheet heat exchanger on two saddle supports, with a main shell length of 5193 mm, divided into 10 elements for analysis. Key parameters are given in Table 2.

Parameter	Value
Equipment Tag	Heat Exchanger
Orientation	Horizontal
Main Shell Length	5193 mm
Elements	10
Support Type	Two Saddle Supports
Nozzle N1 Location	870 mm from left end
Base Elevation	400 mm

Table 2: Heat Exchanger Equipment Parameters

IV. METHODOLOGY

A. Wind Load Methodology (IS-875 Part 3)

Design wind speed at height z is computed as: $Vz = Vb \times k1 \times k2 \times k3$, where Vb is basic wind speed, k1 is risk factor, k2 is terrain/height factor, and k3 is topography factor. Height factor $pz = 0.6 \times Vz^2$ (Kgs/m²). Element Wind Load = Wind Area × Cf × pz. The Gust Response Factor was not applied because natural frequency exceeds 1.0 Hz for both equipment, satisfying IS-875 rigid structure criteria [14]. Wind parameters are summarized in Table 3.

Parameter	Pressure Vessel	Heat Exchanger
Vb (km/hr)	120	135
Wind Zone	2	2
Terrain Cat.	Cat. 1	Cat. 1
k1	1.06	1.06
Vz (m/sec)	37.27	41.93
pz (Kgs/m²)	83.29	107.59
Cf	0.700	0.700

Table 3: IS-875 Wind Load Input Parameters

B. Seismic Load Methodology (IS-1893 SCM)

The horizontal seismic coefficient is: $\alpha h = \beta \times I \times \alpha_0$, where β is soil factor, I is importance factor, and α_0 is basic seismic coefficient from IS-1893 Table 2. Element earthquake load = Earthquake Weight × αh. Seismic parameters for both equipment is given in Table 4.

Parameter	Pressure Vessel	Heat Exchanger
Zone No.	3	2
α_0	0.0400	0.0200
β (Soil Factor)	1.2	1.2
I (Import. Factor)	1.5	1.5
αh	0.0720	0.0360

Table 4: IS-1893 Seismic Coefficient Method Parameters

C. Wind Vibration Assessment (Pressure Vessel)

Wind-induced vibration was assessed using the Mahajan-Zorilla methodology [13] as implemented in Design. Vibration probability parameter: $Vp = W / (L \times Dr^2) = 1123 / (2100.00 \times 1120.600^2) \approx 0.000$. Since $Vp < 0.400 \times 10^{-6}$, no further vibration analysis was required.

D. Wind Deflection Methodology

Wind deflection at each element was computed using the cantilever beam analogy, per Zick and McGrath [11]. Computed deflections were compared against the allowable criterion of 6 inches per 100 feet of tower height (10.500 mm for this vessel).

V. RESULTS

A. Pressure Vessel — Natural Frequency and Gust Factors

Software computed the Pressure Vessel natural frequency as 26.9856 Hz — far exceeding the 1.0 Hz rigidity threshold per IS-875 Part 3. As a result, Gust Factors G(ope) = G(emp) = G(tst) = 1.000, eliminating gust factor computation.

B. Pressure Vessel — Wind Load Results

Element-wise wind load results are summarized in Table 5. The element from 20–30 mm governs (161.843 Kgf) due to its largest wind area (27,206.4 cm²). Total cumulative wind shear at support is 151.786 Kgf (operating).

From	To	Area (cm²)	pz	Load (Kgf)
10	20	4662.91	85.01	27.74
20	30	27206.4	85.01	161.84
30	50	3750.72	85.01	22.31

Table 5: Pressure Vessel Element Wind Loads (IS-875)

C. Heat Exchanger— Wind Load Results

Element wind loads for the Heat Exchanger range from 3.98 Kgf to 435.25 Kgf across 10 vessel elements. The saddle element governs with 435.246 Kgf due to its large projected area of 57,810.6 cm². Representative element loads are given in Table 6.

From	To	Area (cm²)	pz	Load (Kgf)
10	20	810.2	107.59	6.06
30	40	8305.9	107.59	62.53
50	Sadel	57810.6	107.59	435.25
80	90	529.1	107.59	3.98

Table 6: Heat Exchanger Element Wind Loads (IS-875)

D. Pressure Vessel — Seismic Load Results

Seismic analysis used IS-1893 SCM with αh = 0.0720 (Zone 3, I = 1.5, β = 1.2). The Legs-to-30 element governs seismic loading (44.37 Kgf operating, 30.80 Kgf empty) due to concentrated mass of 616.295 Kgf. The 30% reduction in seismic load under empty condition highlights the importance of checking both cases for anchor bolt design.

From	To	EQ Wt (Kgf)	Ope (Kgf)	Emp (Kgf)
10	20	162.0	11.67	11.67
20	Legs	154.1	11.09	7.70
Legs	30	616.3	44.37	30.80
30	50	146.4	10.54	10.54

Table 7: Pressure Vessel Seismic Element Loads (IS-1893 SCM)

E. Pressure vessel— Wind/Seismic Shear and Bending

Maximum wind bending at the critical Legs-to-30 section is 120.607 Kg-m, compared to earthquake bending of 45.125 Kg-m — a ratio of 2.67:1 in favor of wind, despite the Zone 3 seismic load with Importance Factor 1.5 (Table 8).

From	To	W-Shear (Kgf)	EQ-Shear (Kgf)	W-Bend (Kg-m)	EQ-Bend (Kg-m)
10	20	27.74	11.67	3.23	1.36
20	Legs	−151.79	−54.91	20.80	8.24
Legs	30	151.79	54.91	120.61	45.12

Table 8: Wind/Seismic Shear and Bending — Pressure vessel (Operating)

F. Pressure Vessel — Wind Deflection and Vortex-Shedding

Actual wind deflection at tower top: 3.852 mm. Allowable: 10.500 mm. Utilisation: 36.7% — PASS. Angular rotation: 0.00289 radians, confirming no risk to nozzle and piping connections [11]. Critical vortex-shedding wind velocities are 658–717 km/hr (1st mode) — approximately 5.5–6× the design wind speed of 120 km/hr. No vibration risk exists, and no helical strakes or dampers are required [12,13].

G. Heat Exchanger — Seismic Load Results

Seismic analysis used IS-1893 SCM with $\alpha h = 0.0360$ (Zone 2, $I = 1.5$, $\beta = 1.2$). Earthquake element load is uniform at 25.64 Kgf across all 11 elements (EQ weight 712.142 Kgf each). The uniform distribution is a direct consequence of equal element operating weights in the model.

VI. DISCUSSION

A. Governing Load Case Comparison

Table 9 presents the governing load case comparison for both equipment types. For the Pressure Vessel, wind governs bending at all sections due to high basic wind speed (120 km/hr) and concentrated vertical mass distribution. For the Heat Exchanger, wind governs at the saddle support (large projected area of 57,810.6 cm^2) while seismic governs at regular shell elements. These findings confirm that the governing load case is strongly site- and geometry-dependent.

Parameter	Pressure Vessel	Heat Exchanger	Governing
Wind Bending (Critical)	120.607 Kg-m	—	Wind
Seismic Bending (Critical)	45.125 Kg-m	—	Wind 2.67×
Max Element Wind Load	161.84 Kgf	435.25 Kgf	Wind (HE)
Max Element Seismic Load	44.37 Kgf	25.64 Kgf	Seismic (shell)
Governing — Shell	Wind	Seismic	—
Governing — Support	Wind	Wind	Wind both

Table 9: Governing Load Case Comparison

B. Rigid Structure Classification

Both equipment types qualify as rigid structures per IS-875 Part 3: Pressure Vessel at 26.9856 Hz and Heat Exchanger at 1146.09 Hz, both far exceeding the 1.0 Hz threshold. This eliminates gust response factor computation, simplifying analysis for both horizontal and vertical configurations — a finding often overlooked by engineers who apply gust factors conservatively without checking the rigidity criterion.

C. Code Compliance Summary

All code compliance checks are summarized in Table 10. The Pressure Vessel satisfies wind deflection (36.7% utilisation), vortex vibration ($Vp = 0.000 < 0.32 \times 10^{-6}$), and critical wind velocity criteria. Both equipment types confirm seismic coefficients as computed.

Check	Equipment	Actual	Allowable	Status
Wind Deflection	Pressure Vessel	3.852 mm	10.500 mm	PASS
Vortex Vibration (Vp)	Pressure Vessel	0.000	$< 0.32\times10^{-6}$	No Risk
1st Critical Wind Vel.	Pressure Vessel	658 km/hr	> 120 km/hr	PASS
Gust Factor (f > 1 Hz)	Pressure Vessel	26.99 Hz	> 1 Hz	N/A
Gust Factor (f > 1 Hz)	Heat Exchanger	1146 Hz	> 1 Hz	N/A
Seismic Coeff. αh	Heat Exchanger	0.036	Zone 2	OK
Seismic Coeff. αh	Pressure Vessel	0.072	Zone 3	OK

Table 10: Code Compliance Summary

VII. CONCLUSIONS

This study has demonstrated a comprehensive, integrated, and code-compliant methodology for wind and seismic design and analysis of two types of static process equipment. The following principal conclusions are drawn:

1. Both equipment types are classified as rigid structures per IS-875 Part 3 (Pressure Vessel: 26.9856 Hz; Heat Exchanger: 1146.09 Hz), eliminating gust response factor computation and simplifying analysis.
2. For the Pressure Vessel, wind loading governs bending at the critical Legs-to-30 section (120.607 Kg-m vs. 45.125 Kg-m seismic, ratio 2.67:1), despite Importance Factor 1.5 in Seismic Zone 3.
3. For the Heat Exchanger, wind governs at the saddle element (435.25 Kgf) due to large projected area; seismic governs at regular shell elements (25.64 Kgf/element). Both load cases must be retained for complete structural verification.
4. Wind deflection (3.852 mm) is 63.3% below the 10.500 mm allowable (utilisation 36.7%). Critical vortex-shedding velocity (658–717 km/hr) is 5.5–6× the design wind speed (120 km/hr), confirming zero vibration risk and no need for mitigation devices.
5. The governing load case is strongly site- and geometry-dependent. Site-specific, equipment-specific multi-hazard analysis is always required for reliable static equipment design.

6. Software provides an efficient, well-documented framework for integrated IS-875/IS-1893/ASME BPVC analysis, producing outputs directly traceable to codal requirements.

Future work should address: full ASME BPVC stress checks at shell, saddle, nozzle, and leg locations; extension to IS-1893 (2016) Response Spectrum Method; parametric studies across Indian wind and seismic zones; FEA of stress concentrations at nozzle junctions; and dynamic time-history analysis for near-fault seismic regions.

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