

Analysis of Wind Load Effects on Steel and Concrete Buildings at Different Angles Using ANSYS

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Abstract

This study aims to analyze the impact of wind on two distinct structures—one constructed of steel and the other of concrete—when subjected to varying wind angles. We utilized ANSYS Workbench to evaluate the structural response of these buildings during wind exposure at angles of 0°, 45°, and 90°. We employed modal analysis to determine the natural frequencies and mode shapes of both structures, followed by static and harmonic response evaluations to assess their deflection, stress levels, and safety under wind pressure. The objective is to evaluate the response of the two materials to wind originating from various directions. The findings indicate that the steel structure exhibits superior wind resistance, characterized by enhanced flexibility and safety, whereas the concrete structure is more rigid but has a greater propensity for failure at specific wind angles.

Keywords: Wind, Steel, modal analysis, wind direction

1. Introduction

This study investigates the impact of wind loads from various angles on steel and concrete structures utilizing ANSYS Workbench [1]. Both buildings are designed at a height of 100 mm, although they differ in material stiffness—steel (200 GPa) is significantly stiffer than concrete (17–30 GPa) [2]. Modal analysis determines natural frequencies and mode forms, thereafter conducting harmonic and

static structure studies under 0.01 MPa wind pressure at angles of 0°, 45°, and 90° [3]. The results analyze deformation, stress, and safety, facilitating the evaluation of how material selection and wind direction influence structural performance [4, 5].

2. Methodology:

This study employed ANSYS Workbench to examine the response of steel and concrete structures to oblique wind loads.

The two 100 mm tall models with fixed bases were meshed utilizing the multizone approach. Modal analysis determined natural frequencies and mode shapes, elucidating the vibrational properties of each material. Subsequently, wind loads of 0.01 MPa were exerted at angles of 0°, 45°, and 90° during both harmonic and static analysis. The total deformation, stress, and safety factor were analyzed to assess the structural performance of steel compared to concrete under varying wind directions.

Material Properties Overview

Property	Steel Building	Concrete Building
Density	Lower (~7850 kg/m ³)	Higher (~2400 kg/m ³)
Elastic Modulus	High (~200 GPa)	Medium (~25–30 GPa)
Damping Ratio	Low (1–2%)	High (5–10%)
Flexibility	High (more slender and flexible)	Lower (more rigid)
Natural Frequency	Higher	Lower

3. Results and Discussions

(i) On concrete structure

The modal study indicated that the steel structure exhibited reduced natural frequencies attributable to its increased slenderness and diminished stiffness-to-mass ratio.

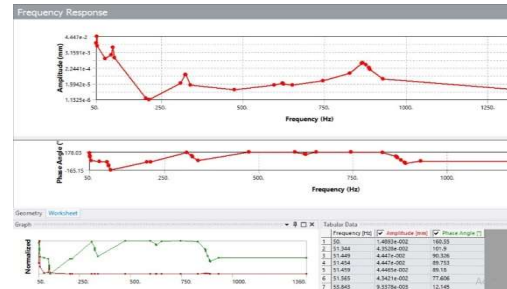


Figure 1(a): For 0 phase angle

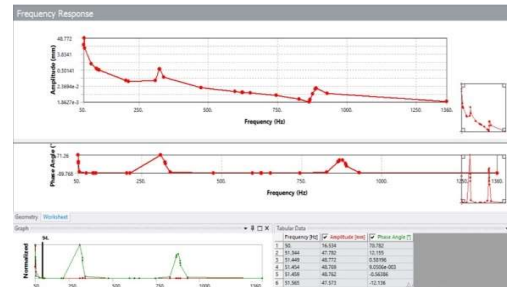


Figure 1(b): For 90 phase angle

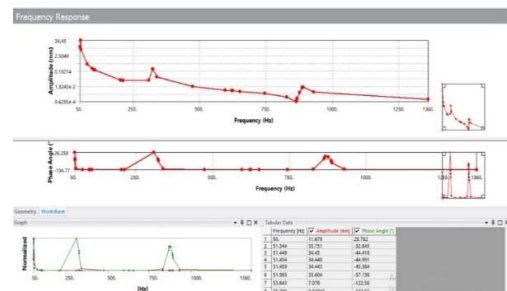


Figure 1(c): For 45 phase angle

The mode forms exhibited predominant bending and torsional vibrations.

The harmonic response demonstrated increased amplitude at resonance,

underscoring its adaptability and the necessity for adequate damping under dynamic conditions.

Table 1: Response of concrete structure

	0 phase angle	For 90 phase angle	For 45 phase angle
Frequency (Hz)			
50.000	0.014893	16.534	11.679
51.344	0.043528	47.782	33.751
51.449	0.044470	48.772	34.45
51.454	0.044470	48.769	34.448
51.459	0.044465	48.762	34.443
51.565	0.043421	47.573	33.604
53.843	0.009338	10.021	7.078
76.306	0.001077	0.80512	0.56846
96.672	0.002010	0.37728	0.26534
100.940	0.007354	0.33409	0.23503

- Resonance peak occurs near 51.45 Hz, where the amplitude reaches approximately 0.044 m, significantly lower than steel's peak (~5.73 m).
- Beyond the peak, the amplitude sharply drops and remains low across higher frequencies, indicating limited vibration response.
- The phase angle transitions from positive to negative more gradually, reflecting higher damping and stiffness.

- Concrete demonstrates lower dynamic response at resonance, making it more stable and less susceptible to vibration-related issues in structural applications.

(ii) Analysis of Wind Load Effects on steel building

The modal analysis showed that the concrete building exhibited higher natural frequencies due to its greater stiffness and lower slenderness ratio. The mode shapes were dominated by bending with minimal torsional effects. Its harmonic response indicated lower amplitude at resonance, suggesting better inherent damping and rigidity under dynamic loads.

Table 2: Response of steel structure

Frequency (Hz)	Amplitude (m)	Phase Angle (°)
50.00	0.19077	43.81
75.94	1.2921	32.58
79.29	5.6185	-32.85
79.46	5.7348	-44.99
83.15	1.1782	-122.56
156.64	0.03870	-134.19
492.72	0.04517	-49.40

717.36	0.00217	-134.34
1158.40	0.0005831	-133.74
1356.60	0.00222	-59.43
1360.00	0.002267	-72.74

- Resonance peak occurs near 79.46 Hz, where amplitude is ~5.73 m, which is much higher than concrete's peak (~0.044 m).
- After the peak, amplitude drops but maintains moderate values until around 500 Hz.
- Phase angle shifts from positive to strongly negative, indicating dynamic stiffness and damping effects.
- Steel clearly shows greater vibration response near resonance, which could be critical in structural dynamics.

In the comparative investigation of dynamic response parameters, steel structures demonstrate a superior natural frequency compared to concrete structures, attributable to their reduced mass and enhanced stiffness. Conversely, concrete structures exhibit a decreased natural frequency due to their greater mass and intrinsic dampening properties. Under resonant conditions, steel structures exhibit higher amplitude peaks, especially near resonance, but concrete buildings have lower peaks due to superior damping capabilities. Steel structures

subjected to wind loads at a 45° angle exhibit a minor alteration in frequency response and increased amplitude responses in more flexible components, while concrete buildings maintain relative stability and demonstrate a diminished reaction across all wind directions. The phase angle in steel structures exhibits a more abrupt change at the resonant frequency, signifying increased sensitivity, whereas concrete structures demonstrate a more gradual phase variation, indicating greater resistance to dynamic excitation.

Steel constructions exhibit increased flexibility and more deformation under wind stress, particularly when the wind angle escalates, owing to the asymmetry in aerodynamic interaction. In contrast, concrete constructions are markedly more rigid and demonstrate considerably less deformation under comparable loading circumstances, providing enhanced structural stability against lateral wind forces.

4. Conclusions

The harmonic response analysis unequivocally indicates that steel constructions display markedly elevated amplitude responses at resonance frequencies, especially at 79.46 Hz, where the amplitude reaches approximately 5.73 m. Conversely,

concrete buildings exhibit significantly smaller amplitudes, with a peak response of merely ~ 0.044 m, signifying enhanced damping and stiffness properties.

This indicates that steel structures, although adaptable and simpler to erect for elevated or unconventional designs, are more vulnerable to dynamic forces such as wind loads, machinery vibrations, or seismic activity. Consequently, supplementary dampening systems or bracing mechanisms may be necessary in steel constructions to mitigate resonance effects.

Conversely, concrete structures, owing to their intrinsic rigidity and mass, exhibit greater resistance to vibration and dynamic loads, rendering them suitable for industrial edifices, foundations, and low-rise seismic-resistant designs where stability and vibration mitigation are paramount.

The findings assist structural engineers in choosing suitable materials according to the building's function, environmental factors, and anticipated dynamic loads. Steel is favored when flexibility, weight, and design velocity are critical. Concrete is optimal when vibration reduction and mass-driven stability are essential.

5. Reference

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