Volume XXIX 2026
MBNA Publishing House Constanta 2026



Scientific Bulletin of Naval Academy

SBNA PAPER • OPEN ACCESS

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To cite this article: Birsan Dan-Catalin, Birsan Elena-Adina, Scientific Bulletin of Naval Academy, Vol. XXIX 2026, pg. 270-276.

Submitted: 23.04.2026
Revised: 28.08.2026
Accepted: 25.09.2026

Available online at www.anmb.ro

ISSN: 2392-8956; ISSN-L: 1454-864X

doi: 10.21279/1454-864X-26-I1-025
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Vortex-induced oscillations in offshore structures. A case study on helideck dynamics

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Abstract. The primary objective of this study is to investigate the dynamic response and structural integrity of offshore helicopter landing platforms subjected to wind-driven vortex-induced oscillations. Marine and offshore structures operate in harsh environmental conditions where strong, continuous air currents pass through their tubular supports, creating alternating shedding vortices. This aerodynamic phenomenon can induce severe structural vibrations that accelerate material fatigue and compromise the overall safety of the platform. To evaluate this critical vulnerability, the tubular supporting framework was assessed by combining an analytical estimation of the natural frequencies of the individual tubular members — based on the closed-form beam natural-frequency formulation of DNV-RP-C205, using the tabulated natural-frequency factors an for the assumed support conditions — with a normative vortex-induced-oscillation check performed in accordance with DNV-RP-C205 (Section 9). The in-line and cross-flow stability criteria were verified through the reduced velocity VR and the stability parameter Ks. The results show that several of the original tubular members fall within the critical reduced-velocity range for cross-flow vortex shedding, the mode that typically governs fatigue, indicating a susceptibility to lock-in resonance in the fatigue-critical base region of the cantilevered frame. The study further shows that a modest increase in member stiffness, achieved by enlarging the wall thickness or the diameter of the affected pipes, shifts their natural frequencies and reduced velocities outside the critical band, thereby removing the resonance risk and improving the long-term integrity of the helideck support without a significant weight penalty.
Keywords: vortex; oscillations; helideck structure.

1. Introduction

The exploitation of marine resources and offshore operations critically depend on safe and efficient infrastructure, among which helicopter landing platforms (helidecks) play a vital role. These structures are continuously exposed to extreme environmental conditions, rendering them susceptible to complex aerodynamic and hydrodynamic loads. One of the most severe challenges to the structural integrity of offshore components is represented by Vortex-Induced Vibrations (VIV) or Oscillations (VIO), a dynamic phenomenon that occurs when a fluid flows past a bluff body, generating alternating vortex shedding (Williamson and Govardhan, 2004; Sarpkaya, 2004).

Fundamental fluid dynamics demonstrate that, at specific wind or marine current velocities, the vortex shedding frequency can synchronize with the natural frequency of the structure, triggering a destructive phenomenon known as "lock-in" or resonance (Bearman, 1984; Zdravkovich, 1997). In the specific case of helidecks, which are frequently supported by spatial lattice structures composed of slender tubular members, the interaction with strong winds generates significant transverse cyclic forces (Blevins, 2001; Sumer and Fredsøe, 2006). Evaluating this phenomenon requires a detailed analysis of dimensionless

parameters, such as the Reynolds number and the Strouhal number, which are essential for accurately predicting the onset of these vibrations in the oceanic environment (Vandiver, 1993).
The operational safety of these cantilevered platforms is a priority, as continuous oscillations induce mechanical stresses that lead to the rapid accumulation of fatigue damage at the welded tubular joints. For this reason, international standards emphasize the necessity of a rigorous assessment of environmental loads and impose strict aerodynamic and structural design criteria for offshore helicopter landing areas (DNV, 2017; API, 2014; UK CAA, 2021). Nevertheless, accurately modeling the aerodynamic interaction within complex supporting lattices and predicting the dynamic response remain major engineering challenges.
In this context, the present case study aims to investigate the dynamic response and structural integrity of a helideck exposed to vortex-induced oscillations. By combining an analytical estimation of the natural frequencies of the tubular supporting lattice (closed-form beam formulation of DNV-RP-C205) with a normative vortex-induced-oscillation assessment based on DNV-RP-C205, this paper evaluates the critical conditions for the onset of resonance, the resulting susceptibility to fatigue at the welded tubular joints, and the effectiveness of practical stiffness-based mitigation solutions for these hazardous vibrations.

2. Materials and methods

2.1. Vortex-Induced Vibration (VIV) Evaluation Methodology

To evaluate the susceptibility of the structure to vortex-induced oscillations, the calculation methodology was aligned with the recommended standards in the Det Norske Veritas normative, DNV-RP-C205 (Section 9: Vortex Induced Oscillations). Aerodynamic analysis involves the evaluation of two distinct phenomena: in-line vibrations and cross-flow vibrations.
A fundamental parameter in this evaluation is the structural damping ratio (ζ), which has been defined at a value of 0.0015, specific for welded steel structures in air. Based on this, the logarithmic decrement of damping (δ) is calculated according to the relationship $\delta=2\pi\zeta$.

2.2. Stability criteria for In-line vibrations

In-line vibrations may occur when:

$$\frac{0.3}{S_t} < V_R < \frac{0.65}{S_t} \quad (1)$$

In-line vibrations may only occur for small stability parameters, i.e. Ks < 2. The stability parameter is defined as:

$$K_S = \frac{2 \cdot m_e \cdot \delta}{\rho \cdot D^2} \quad (2)$$

where:
ρ = mass density of surrounding medium (air/gas or liquid) [kg/m^3];
D = member diameter (m);
m_e = effective mass per unit length of the member [kg/m];
δ = the logarithmic decrement (= $2\pi\zeta$);
ζ = the ratio between damping and critical damping;
$\delta = \delta_s + \delta_{other} + \delta_h$;
δ_s = structural damping;
δ_{other} = soil damping or other damping (rubbing wear);
δ_h = hydrodynamic damping.
Structural damping (δ_s) is due to internal friction forces of the member material and depends on the strain level and associated deflection. For wind exposed steel members, the structural damping ratio ($\delta s/2\pi$) may be taken as 0.0015, if no other information is available.

2.3. Stability criteria for cross flow vibrations
Cross flow vibrations may occur when:

$$\frac{0.8}{St} < V_R < \frac{1.6}{St} \quad (3)$$

where:
$V_R = U_w /(f_n D)$ is the reduced velocity [-];
St = Strouhal number [-];
U_w = wind velocity [m/s];
f_n = natural frequency of member [1/s];
D = characteristic cross-sectional dimension [m].

3. Case Study

This chapter describes the methodology adopted for the analysis and its application to a representative real-world helideck structure, the metal structure of the helicopter deck to be installed on the drilling vessel. The helicopter deck is suitable for operating a SIKORSKY S92A helicopter.

3.1. Structural Model of the Helideck
The case study focuses on the supporting structure of a helicopter landing platform (helideck), consisting of a grid of tubular elements. According to the design data, three critical structural elements, defined as tubular bars (Bar 1, Bar 2 and Bar 3), were analyzed. The material used for the entire superstructure is steel, with a density (ρ) of 7850 kg/m³ and a modulus of elasticity (E) of 2.1×10^{11}N/m^2. The initial outer diameters (D) vary as follows: 457 mm for Bar 1, 355.6 mm for Bar 2 and 318 mm for Bar 3. The working fluid is air, evaluated at a temperature of 10°C, corresponding to a density (ρ) of 1.25 kg/m^3.
Steel used in the structural design is High Tensile steel Grade HT36 with a minimum yield point of 355 N/mm^2 for helideck structure and supporting reinforcements, API 5L Grade X52 for pipe.
In Figure 1, the 3D model of the helideck structure and the pipes considered for the vortex calculation can be seen.

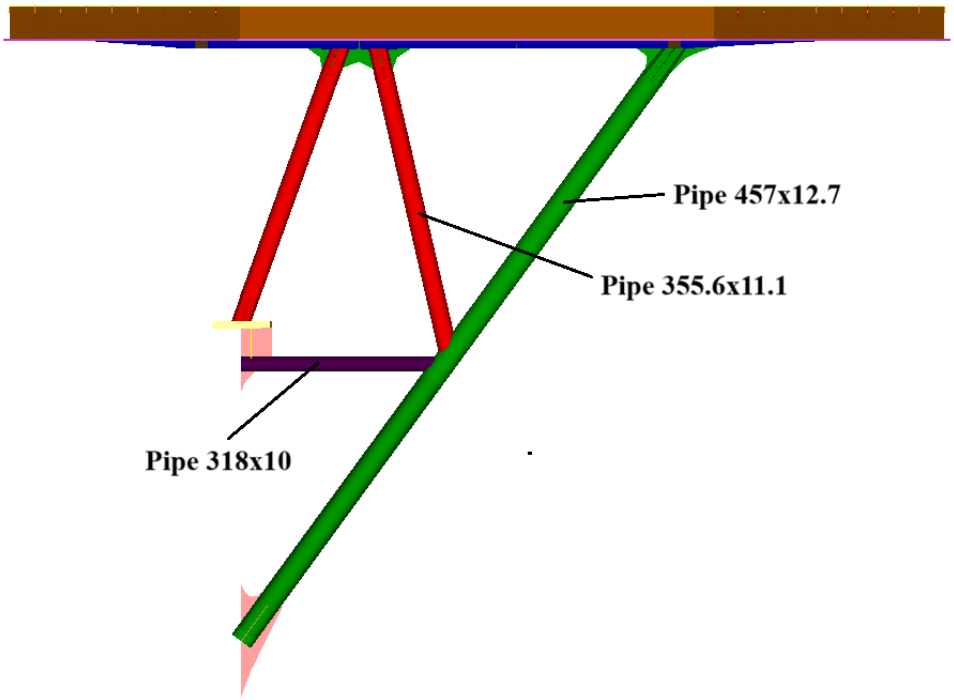


Figure 1. 3D model of the helideck structure

The wind velocity, U_w, was calculated for the middle of the member. The 1-minute mean speed with a return period of 1 year has been taken into consideration.
The natural frequencies f_n listed in Table 1 were estimated analytically rather than by finite element modelling. They were computed using the beam natural-frequency formulation of DNV-RP-C205, $f_n = (a_n / 2\pi)\cdot\sqrt{(E\cdot I / (m_e\cdot L^4))}$, where a_n is the natural-frequency factor tabulated in DNV-RP-C205 for the support condition assumed for each member (values given in the "Natural frequency factor, a_n" column of Table 1), E is the modulus of elasticity, I the second moment of area of the tubular cross-section, m_e the effective mass per unit length, and L the largest unsupported length of the member (column "Length, l" in Table 1). The material and section properties used in the calculation are those specified above ($E = 2.1\times10^{11}$ N/m^2, $\rho = 7850$ kg/m^3).
The results for the reduced velocity, V_R are shown in Table 1.

Table 1. Reduced velocity for members of helideck structure

Members	Mode shape	Natural frequency factor, a_n	Length l[m]	f_n [Hz]	U_w [m/s]	D [m]	V_R
Pipe 457.0x12.7	Simply supported	9.87	10.6	16.07	49.85	0.457	6.79
Pipe 457.0x14.2			10.6	29.64	49.85	0.457	3.68
Pipe 355.6x11.1			7.6	32.04	49.85	0.3556	4.38
Pipe 394.0x12.5			7.6	39.26	49.85	0.394	3.57
Pipe 318.0x10.0			4.8	63.85	49.22	0.318	1.98

For each pipe (chord and brace) cross section used in the support structure of the helicopter deck, a vortex calculation was carried out according to DNV-RP-C205 (Section 9: Vortex Induced Oscillations) and using the largest unsupported length.
The following simplified checking criteria are based on the following considerations:

- Critical wind velocity must be above of maximum wind velocity from DOC (Design Operating Conditions) environmental conditions (for broad band);
- The reference wind velocity was considered 36 m/s for DOC;
- For each pipe (brace or chord) were calculated the average velocity according to the minimum and maximum level from water line (9.5 m above BL);
- If the wind speed is close to the critical wind velocity, then the stability parameter must be above 20 to avoid the Lock-on effect.

The results are presented in the Figure 2.

		Pipe 457x12.7	Pipe 457x14.2	Pipe 355.6x11.1	Pipe 394.6x12.5	Pipe 318x10
Input data	D [m]	0.457	0.457	0.3556	0.394	0.318
	t [m]	0.0127	0.0142	0.0111	0.0125	0.01
	ρ [kg/m^3]	1.25	1.25	1.25	1.25	1.25
	ρ_s [kg/m^3]	7850	7850	7850	7850	7850
	an	9.87	9.87	9.87	9.87	9.87
	E[N/m2]	2.1E+11	2.1E+11	2.1E+11	2.1E+11	2.1E+11
	U_0 [m/s]	36	36	36	36	36
	l[m]	10.6	10.6	7.6	7.6	4.8
	μ[kg/m]	139.16	45.30	54.00	55.00	55.00
	I[m4]	8.76E-04	9.69E-04	3.57E-04	5.46E-04	2.30E-04
	Ks	10.05	11.20	11.25	11.42	11.33
	In-line vibrations	No	No	No	No	No
Mod 1	f_n [Hz]	16.07	29.64	32.04	39.26	63.85
In-line vibrations	z1 [m]	37.8	37.8	37.8	37.8	34
	T [m]	9.5	9.5	9.5	9.5	9.5
	z [m]	28.3	28.3	28.3	28.3	24.5
	U(z,t) [m/s]	49.85	49.85	49.85	49.85	49.22
	St	0.2	0.2	0.2	0.2	0.2
	Lower limit	1.5	1.5	1.5	1.5	1.5
	V_R	6.79	3.68	4.38	3.57	2.20
	Upper limit	3.25	3.25	3.25	3.25	3.25
	Check	No	No	No	No	No
Cross-flow vibrations	Lower limit	4	4	4	4	4
	V_R	6.79	3.68	4.38	3.22	1.98
	Upper limit	8	8	8	8	8
	Check	Yes	No	Yes	No	No
	Uw* [m/s]	29.38	54.17	45.57	61.87	81.22
	Check	Risk	No	Risk	No	No

Figure 2. Vortex-induced vibration (VIV) check of helideck pipework

The results presented in the table indicate that the initial pipe configurations do not uniformly satisfy the vortex-induced vibration (VIV) acceptance criteria, particularly in the cross-flow direction, which is typically the governing mode for fatigue damage.

For the Pipe 457×12.7, although in-line vibrations are not critical, the cross-flow response falls within the critical reduced velocity range, triggering a vortex shedding resonance condition. This is further confirmed by the associated hydrodynamic parameter U^*, which places the system within a regime susceptible to dynamic amplification and fatigue risk. Consequently, this configuration is deemed inadequate from a VIV standpoint.

A similar behaviour is observed for the Pipe 355.6×11.1, where the calculated reduced velocity also lies within the critical lock-in region for cross-flow vibrations. The corresponding check indicates a failure to meet acceptance criteria, implying a high likelihood of fatigue damage accumulation over time.

To mitigate these issues, both pipes were replaced with configurations of increased stiffness:

- Pipe 457×14.2 (increased wall thickness);
- Pipe 394.0×12.5 (increased diameter and section properties);

These modifications result in:

- higher structural stiffness (reflected in increased EI);
- altered natural frequencies;
- reduced velocity V_R, shifting the system outside the critical vortex shedding range.

As a result, the revised configurations successfully avoid resonance in both in-line and cross-flow directions. The updated reduced velocity values fall outside the critical intervals, and all verification checks are satisfied. Importantly, the cross-flow vibration risk is eliminated, which is the dominant design criterion for VIV.

4. Discussion

The vortex-induced-oscillation screening summarised in Table 1 and Figure 2 shows that the dynamic vulnerability of the helideck support is not uniform across its members but is concentrated in a small number of slender tubular elements. For the original Pipe 457×12.7 and Pipe 355.6×11.1 sections, the reduced velocity VR falls inside the cross-flow critical band defined in DNV-RP-C205, whereas the in-line criterion is comfortably satisfied. This ordering is consistent with the physics of vortex shedding: the cross-flow response is excited over a wider band of reduced velocities and at lower stability parameters than the in-line response, so that, for the low structural damping representative of welded steel members in air ($\zeta = 0.0015$), the cross-flow mode is almost always the governing fatigue mechanism.

The onset of resonance identified in the analysis corresponds to the classical lock-in condition, in which the Strouhal-controlled shedding frequency approaches the natural frequency of the member and the fluid excitation synchronises with the structural motion. Because the shedding frequency scales with the wind speed and with the inverse of the member diameter, while the natural frequency is fixed by the stiffness and mass distribution of the member, the proximity of the two frequencies, and therefore the value of VR, is highly sensitive to the geometric properties of each pipe. This explains why members of similar diameter but different natural frequency exhibit markedly different behaviour in Table 1.

The mitigation strategy adopted here exploits exactly this sensitivity. Replacing the two critical members with stiffer sections, Pipe 457×14.2 (greater wall thickness) and Pipe 394.0×12.5 (greater diameter and second moment of area), raises the flexural rigidity EI and hence the natural frequency fn of each member. Since the reduced velocity $VR = Uw/(fn \cdot D)$ is inversely proportional to fn, the increase in natural frequency lowers VR and displaces it below the cross-flow critical range for the design wind speed. The result is a support configuration in which neither the in-line nor the cross-flow criterion is violated and in which the dominant cross-flow fatigue risk is removed without a significant increase in structural weight. This is a more robust and more readily verifiable solution than add-on aerodynamic devices, whose performance would itself require dedicated experimental or numerical substantiation.

From a design perspective, these findings reinforce the value of a fast, standards-based vortex-induced-oscillation screening at the earliest stage of the structural layout, before member sizes are frozen. The strong dependence of the response on small changes in wall thickness or diameter, together with the narrow band of critical reduced velocities, means that resonance-prone configurations can be identified and corrected economically by local resizing rather than by global redesign. This behaviour is in line with the established vortex-shedding literature for slender cylinders (Blevins, 2001; Zdravkovich, 1997) and with the stability-parameter framework of DNV-RP-C205.

It should be emphasised that the present assessment is deliberately confined to an analytical (closed-form) estimation of the members' natural frequencies combined with the semi-empirical, normative criteria of DNV-RP-C205; it does not resolve the unsteady flow field around the lattice by computational fluid dynamics, nor does it quantify the accumulated fatigue life. These simplifications are appropriate for a design-screening study and lead to conservative, code-compliant decisions, but they cannot capture flow interference between closely spaced members, three-dimensional shedding, or the amplitude-dependent nature of lock-in. A fully coupled fluid-structure (CFD-FEM) simulation, supported by wind-tunnel data and an explicit fatigue-damage calculation, is therefore identified as the natural continuation of this work and is recommended before the mitigated design is qualified for the most severe operating envelopes.

5. Conclusions

The study demonstrates that relatively modest increases in pipe stiffness, either through wall thickness or diameter, can significantly improve VIV performance by:

- Shifting natural frequencies away from excitation frequencies
- Reducing susceptibility to lock-in phenomena
- Eliminating fatigue-critical vibration regimes

The replacement solutions are validated as structurally adequate and compliant with vortex shedding design requirements, ensuring improved long-term integrity and operational reliability.
The present study highlights the critical importance of early-stage VIV assessment in the design process of offshore structures, particularly for aerodynamically exposed components such as helideck supporting frames. The integration of standardized design approaches, such as those recommended by DNV, with numerical simulations provides a robust framework for identifying resonance-prone configurations before fabrication and installation.
The results underline the sensitivity of vortex-induced response to relatively small geometric variations, emphasizing that even minor adjustments in wall thickness or diameter can lead to significant improvements in dynamic performance. This finding supports the adoption of optimization-driven design strategies aimed at balancing structural efficiency with vibration mitigation.
The combined analytical natural-frequency and normative (DNV-RP-C205) methodology applied in this study proves to be an effective and computationally efficient screening tool for capturing the vortex-shedding excitation mechanism and the associated structural response.

Acknowledgements

Author contributions: Conceptualization: B.D.C.; Methodology: B.E.A.; Investigation: B.D.C.; Writing original draft: B.E.A.; Writing review and editing: B.D.C.; Supervision: B.D.C.

Funding: this research received no external funding.

Conflict of interest: The Authors declare no conflict of interest.

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