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Computational Analysis of Vortex Shedding and Flow Suppression in Cylindrical Profiles for Offshore Applications

Authors
J.J.Maurice[1] Orji C. U[2]. M. Inengiyemiema[3]
[1]Department of Marine Engineering, Akwa Ibom State University Ikot Akpaden, Nigeria
[2,3]Department of Marine and Offshore Engineering, Rivers State University, Rivers Stat,e Nigeria
Corresponding Author:josephmaurice@aksu.edu.ng

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ABSTRACT: Vortex shedding around structures is a phenomenon that is observed when a blunt or bluff body is placed in the path of a flowing fluid. This phenomenon can give rise to the formation and shedding of vortices near or at the body's natural frequency of oscillation. This can create a phenomenon known as the Karman vortex street. This research investigated the phenomenon of vortex shedding in cylindrical structures, which is critical in Marine and Offshore Engineering applications. Using ANSYS FLUENT for 2D simulations, four different cylindrical structures: smooth circular cylinders, helical-straked cylinders, cactus-shaped cylinders, and inner-grooved cylinders with equal diameters of 0.5m respectively, were considered in this research study. The simulations are performed at a Reynolds number of 126,050 with a fluid inlet velocity of 0.3 m/s, using the Reynolds Averaged Navier-Stokes (RANS) shear stress transport (SST) model. The results obtained showed a Smooth cylinder with a drag coefficient of 0.093 and a corresponding lift coefficient of 0.707, an inner grooved cylinder with a drag coefficient of 0.175 with a corresponding lift coefficient of 0.421, a cactus-shaped cylinder with a drag coefficient of 0.043 with a corresponding lift coefficient of 0.070, and a helical-straked cylinder with drag coefficient of 0.440 and lift coefficient of 0.463. The simulation results for the smooth cylinder and other modified cylindrical profiles were compared with numerical and experimental results from literature.

KEYWORDS: Vortex shedding, drag coefficient, lift coefficient, Ansys Fluent

I. INTRODUCTION

This paper focuses on the fluid dynamics of flow over a cylinder structure immersed in water. In the study of bluff body flows, one of the most noteworthy aspects is the presence of multiple distinct flow regimes. These flow regimes essentially represent an equilibrium between different forces that are at play within moving fluids. Vortex shedding is a phenomenon that manifests whenever a sufficiently blunt or bluff body is subjected to a fluid flow that results in the periodic formation and shedding of vortices near or at the body's natural frequency of oscillation.

When exposed to currents, cylindrical structures like risers, pipelines, and offshore platform members encounter unsteady flow-induced stresses. Downstream of bluff bodies, vortex shedding creates alternating vortices that produce oscillating lift and drag forces that could result in vortex-induced vibrations (VIV). This behaviour becomes crucial when the shedding frequency gets close to the structure's inherent frequency, causing resonance or "lock-in."

The effectiveness of vortex shedding suppression devices can vary significantly based on the structure and environmental conditions. The various suppression strategies encompass a range of devices designed to mitigate the detrimental effects of vortex shedding on offshore structures such as risers, mono-columns, and tension leg platforms.

[1] Various methods have been employed to mitigate or minimize this vibration phenomenon, including the use of devices like helical strakes, shrouds, axial slats, fairings, splitter plates, ribboned cables, pivoted guiding vane, and spoiler plates, as shown in Figure 1(Maimun, *et al*., 2021).

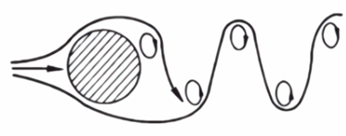

Figure 1: Typical Flow behind a Cylinder

II . LITERATURE REVIEW

The vortex shedding behind bluff bodies creates alternating vortices that form the classic von Kármán vortex street. The shedding frequency, f is related to flow velocity U and cylinder diameter D by the Strouhal number St = fD/U, which is around 0.2 for circular cylinders over a wide Reynolds number range. Several techniques have been investigated and employed to mitigate the effect of vortex shedding on these marine structures, such as strakes, shrouds, axial slats, fairings, splitters, and ribboned cables (Figure 2.10). The primary function of these devices is to disrupt the near wake, consequently disturbing the correlation between vortex shedding and vibration, thereby impeding the formation of vortex streets. Harris & Piersol, (2002) noted that while these interventions effectively reduce vortex shedding, they can also concurrently elevate the steady drag compared to what is measured on a stationary structure.

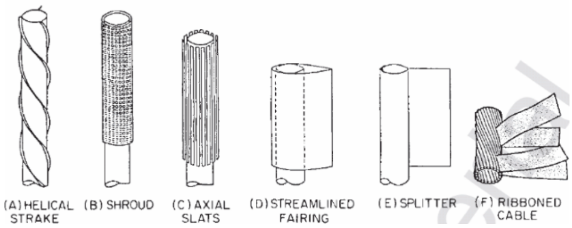

Figure 2: Methods of Reducing Vortex-Induced Vibration

The use of helical strakes can suppress vortex shedding, but pointed out the effect of increased drag force caused by excessive rotational angles and bending moments of the slender structures. An essential part of disturbing the flow pattern is the use of straps, which are external ribs usually placed in a helical pattern on cylindrical constructions. Strakes, especially in their helical configuration, minimize vibration amplitude to around 10-30% of the structure's diameter by generating shorter, weaker vortices (Bai & Bai, 2005). Except that using strakes has a significant disadvantage in that they contribute between 30 and 50 percent more drag force. The beneficial impact of lowering wave-induced fatigue by attenuating the dynamic response linked to vessel movements can offset the negative impact of this increased drag force (Chakrabarti, 2005).

Fairings, on the other hand, is also effective in suppressing vortex shedding at a much-reduced drag force, but it has limited application. Ivory Research (2019) agrees that fairings are designed to rotate to align with the current flow to reduce drag loading and successfully reduce vortex shedding. When employed on structural elements oriented in a near-vertical orientation, this design can be particularly effective. Fairings may virtually entirely suppress VORTEX SHEDDING and reduce drag force to as little as one-third of its initial value because of their capacity to rotate. Wang, *et al*, (2021) investigated the use of cactus-shaped cross sections in subcritical flow to suppress the vortex shedding. The study considers a steady current flowing past a circular and cactus-shaped cross-section stationary cylinder. Ansys Fluent commercial software was used to simulate the structure in 2D-flow field at a subcritical Reynolds number of 3900.

The shrouds worked by producing many tiny vortices. Due to the disruption of the normal vortex shedding, a street of weaker and smaller vortices that is just a few diameters downstream of the body forms (Ivory Research, 2019).

III METHODOLOGY

A. Geometry model

Four cylindrical profiles were modeled, each with diameter **0.5 m**:

1. Smooth cylinder
2. Helical-straked cylinder
3. Cactus-shaped cylinder
4. Inner-grooved cylinder

B. Computational Domain

A rectangular computational domain ensured sufficient upstream and downstream lengths to avoid boundary interference.

C. Mesh Generation

Hybrid unstructured meshes with O-grid refinement were used.

- Inflation layers: 10–40
- Skewness: < 0.5
- Orthogonal quality: > 0.7

D. Governing Equations

The incompressible unsteady flow was solved using the RANS equations with SST k-ω turbulence model.

Finite Volume Method (FVM) was applied in ANSYS Fluent.

E. Boundary Conditions

- Velocity inlet: 0.3 m/s
- Pressure outlet
- Cylinder wall: no-slip
- Far-field: symmetry

F. Validation

Hydrodynamic coefficients were compared with literature value at $Re \approx 1.26 \times 10$.

IV. RESULTS AND DISCUSSION

A. Hydrodynamic Coefficient

Profiles	Drag coefficient (Cd)	Lift coefficient (Cl)
Smooth	0.093	0.707
Helical-straked	0.440	0.463
Inner-grooved	0.175	0.421
Cactus-shaped	0.043	0.070

B. Discussions

1. Smooth Cylinder

Produced strong vortex shedding and high lift due to periodic alternating vortices

2. Helical strake

Significantly suppressed vortex shedding but increased drag drastically. Suitable only where drag penalty is acceptable.

3. Inner-Grooved cylinder

Provided moderate suppression of lift and drag, with noticeable modification of the separation point.

4. Cactus-Shaped Cylinder

Exhibited the best performance, offering:

- Lowest drag
- Lowest lift
- Highly stable wake
- Reduced vortex intensity

C. Validation

The table below compares the current drag and lift coefficient with typical values published in the literature for comparable Reynolds numbers and configurations in order to provide the validation of numerical foundation. The calculated drag coefficient at deviate by +4.5% from the conventional high-subcritical value falling within the usual experimental and numerical uncertainty limits documented in the other research. The yield of the Helical-strake shape is approximately 373% higher than that of the smooth cylinder. This higher value may be due to the aggressive strake dimensions, the 2-D RANS assumptions or the domain and mesh effect that tends to amplify flow separation in the absence of full 3-D turbulence structures. This is in contrast to the 30-50% drag penalty typically reported for conventional strake geometries.

In comparison to the smooth scenario, the current simulation shows an approximately 90% lift reduction and corresponding approximate of 54% reduction in the drag for the Cactus-shaped profile.

Geometry	Cd (This study)	Cd (Literature)	% Difference vs Literature	Cl (This study)	Cl (Literature)	% Difference vs Literature
Smooth cylinder	0.093	0.089 (canonical)	+4.5 %	0.707	0.70	+1.0 %
Helical strakes	0.440	0.20–0.25 (typical)	+76–120 %	0.463	0.20–0.30 (typical)	+54–132 %
Cactus-shaped cylinder	0.043	0.040–0.060 (reported range)	−7.5 % to +7.5 %	0.070	0.06–0.08 (reported range)	−12.5 % to +16 %
Inner-grooved cylinder	0.175	0.12–0.18 (reported range)	0 % to +45 %	0.070	0.05–0.08 (reported range)	0 % to +40 %