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REVIEW OF WORKS RELATED TO FLOW FIELDS ACROSS UNDERWATER LAYING HYDRODYNAMIC STRUCTURE

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ABSTRACT

In fluid dynamics, vortex-induced vibrations (VIV) are motions induced on bodies interacting with an external fluid flow, produced by the motion producing periodical irregularities on this flow. The work here is mainly a review of the flow field that is aroused due to the phenomenon of vortex induced vibration on the horizontally placed cylinders. Many researchers have worked on it to dig out various other ways to get the flow fields related to flow past a cylinder. Main aspects here are to find out the related theories on which the works had been undertaken. From those researches it can be said that Acoustic Doppler velocimeter and Laser Doppler velocimeter have been a major tool to measure the velocities across the horizontal or vertical under water cylinders/pipes. Utilizing modern instruments such as Acoustic Doppler Velocimeter or Laser Doppler velocimeter the three dimensional velocities at every points around the cylinder (to take the measurement the cylinder is to be halted at discreet depths of the water channel) could be measured and the from the values of velocities the parameters such as vortex strength (vorticity and circulation), bed shear stress (which is important while dealing with the removal of sediments), turbulent kinetic energy and other relevant parameters by which the device could be further modified to harness more power. Consequently various stresses can also be found out in order to select appropriate cylinder and related structure in making of workable vortex induced vibration aquatic clean energy generator in shallow water channels, to access the positions of huge amount of silt depositions that may be diverted at the banks due to such hydrodynamic structures and many others related operations.

Keywords: vortex induced vibration, flow fields, silts deposition, hydrodynamic structure, horizontal or vertical under water cylinder.

INTRODUCTION

Studies unrevealing hydrodynamic forces around underwater pipes are increasingly gaining interest in view to its demand with respect to growth in technological invasion. Under water pipes are normally exposed to wave currents and they lead to the phenomenon of vortex induced vibration (VIV) that basically causes erosion of bed material beneath the pipes. Moreover, local scour underneath pipes rest on and across the riverbeds to convey oil, gas, water or any fluid frequently occurs by the adverse pressure gradient of flowing stream. Furthermore such effects is helpful in finding out the locations of silt deposition statistically and indirectly help in dredging process as found out by [1] along with transport of sediments/silts due to equilibrium scour was reflected in [2,3] against the damaging effects as viewed in reservoir and flow paths of river as elaborated in the research of [4,5]. The feature also gets much imperative when the discussion comes about estimating hydrological feasibility of a mini hydro power plant which can also be termed as green energy was covered in [6]. Scour may lead to an unsupported pipeline over an extensive distance ensuing in fatigue failure due to flow-induced vibration by wake-vortex shedding. Earlier many research had been carried out in the features of scouring by [7, 8] occurring at the base of the vertically mounted piers which are also related with the transport of sediments of the river beds from one locations to other locations in the disclosure of the works of [9-12]. In addition problem of vortex-induced vibration in the structures becomes an important issue in various fields of engineering, since it is cause of severe concern in the dynamics of riser tubes bringing oil from the seabed to the surface, in flow around heat exchanger tubes, in the dynamics of civil engineering structures such as bridges and chimneys, and situation relating to practical importance.

Henceforth, the crucial feature of pipeline design is the forecast of the amount of scour underneath such pipelines. Thus the assessment of forces on cylinders along the range of water depth becomes a crucial topic of interest. In recent times, instrument named Acoustic Doppler Velocimeter (ADV) had thrown commendable impact in the area of fluid dynamics. Mostly to assess the three-dimensional flow field and turbulence in laboratory applications, as well as in rivers, lakes and the ocean ADVs are known to be a special gift. As in its constructions ADVs typically consist of one emitter surrounded by a number of receivers, each one of them measured one protrusion of the velocity vector that helped in the research of [13-16].

This review study of the phenomena of vortex induced vibration for the underwater laying pipes is mainly concerned with the thought of ADV as measurement process as discussed in [17] that are helpfully appropriate for the assessment of flow fields and also computing and discussing velocity profiles happening due to flow pass through a horizontally placed submerged cylinder, that is placed before a hydraulic structure, i.e. a vertical plate and such types of assessment of the field is intensely worked out by [18,19].

When a cylinder placed in a water channel then at the upstream the flow will undergo a turbulent boundary layer separation and consequently rolls up to form a horseshoe vortex system across the cylinder in the work of [20]. Such flow happens in a diversity of events, such as flow around bridge piers, around buildings and structures

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(stacks, cooling towers, gas tanks), and at different types of junctions.

Ever since Leonardo da Vinci first observed Vortex Induced Vibration (VIV), circa 1500 AD in the form of "Aeolian Tones," engineers have been trying to spoil vortex shedding and suppress VIV to prevent damage to equipment and structures. Furthermore, Von Karman at Cal Tech proved that the Tacoma Narrows bridge collapse in 1940 was due to VIV. This fluid-structure interaction phenomenon occurs due to the nonlinear resonance of cylinders or spheres through vortex shedding lock-in. VIV is also called synchronization between vortex shedding and cylinder or sphere oscillations. In this paper, the terms VIV, synchronization, vortex shedding lock-in, and nonlinear resonance are used alternating to refer to the same phenomenon. Many a times this phenomenon can be used to generate green energy as discussed in the works of [21-23] which aids to development of the rural India by the power of its electricity.

In the condition of the constant Strouhal number, when the vortex shedding frequency for a stationary cylinder approaches the natural frequency of oscillation of the cylinder from below, the cylinder will start oscillating and vortex shedding will start to correlate along the cylinder axis. This leads to a large increase in the forces acting on the cylinder. By increasing the current velocity further, the vortex shedding frequency will finally jump back to the linear curve defined by the Strouhal number. The changes taking place in the vortex shedding frequency in the synchronization ranges. In this range, vortex shedding frequency and the oscillation frequency, collapse into the natural frequency of the system in flow. It is interesting to note here that sustained oscillations extend over a range of velocity values and the vortex shedding is controlled by the vibrating cylinder like types of research carried out by [24-26]. While discussing about the environmental aspects in the natural water channels then the knowledge of the sediment loading and scouring also comes into play where due to various types of obstructing piers the movement of river bed sediments are visualized in the series of works done by [27-30]. Today the scenario of the natural channels in the world specially in India is very critical since the water depths of such channels are decreasing day by day due to immense sediment loading. Works by [31-33] shows how to develop special types of fundamental open channel discharge measuring devices. Utilizing these types of devices shows that the discharges natural streams and channels have decreased with the water depth. So, the assessment of sediment loading becomes much important while viewing the environmental aspects in the natural water channels [34-37].

MECHANISM OF VORTEX SHEDDING AND VORTEX INDUCED VIBRATION

The most important feature of the flow regimes described for the vortex-shedding phenomenon is common to all the flow regimes for Re > 40. For these values of Re, the boundary layer over the cylinder surface will separate due to the adverse pressure gradient imposed by the divergent geometry of the flow environment at the rear side of the cylinder. As a result of this, a shear layer is formed, as sketched in Figure-1. As seen from Figure-1, the boundary layer formed along the cylinder contains a significant amount of vorticity. This vorticity is fed into the shear layer formed downstream of the separation point and causes the shear layer to roll up into a vortex with a sign identical to that of the incoming vorticity. (Vortex A in Figure-1). Likewise, a vortex, rotating in the opposite direction, is formed at the other side of the cylinder (Vortex B). It has been mentioned in the previous section that the pair formed by these two vortices is actually unstable when exposed to the small disturbances for Reynolds numbers Re > 40. Consequently, one vortex will grow larger than the other if Re > 40. The larger vortex (Vortex A in Figure-2a) presumably becomes strong enough to draw the opposing vortex (Vortex B) across the wake, as sketched in Figure-2a. The vorticity in Vortex A is in the clockwise direction (Figure-1), while that in Vortex B is in the anti-clockwise direction. The approach of velocity to the opposite sign will then cut off further supply of vorticity to Vortex A from its boundary layer. This is the instant where Vortex A is shed. Being a free vortex, Vortex A is then convected downstream by the flow. Following the shedding of Vortex A, a new vortex will be formed at the same side of the cylinder, namely Vortex C (Figure-2b). Vortex B will now play the same role as Vortex A, namely it will grow in size and strength so that it will draw Vortex C across the wake (Figure-2b). This will lead to the shedding of Vortex B. This process will continue each time a new vortex is shed at one side of the cylinder where the shedding will continue to occur in an alternate manner between the sides of the cylinder.

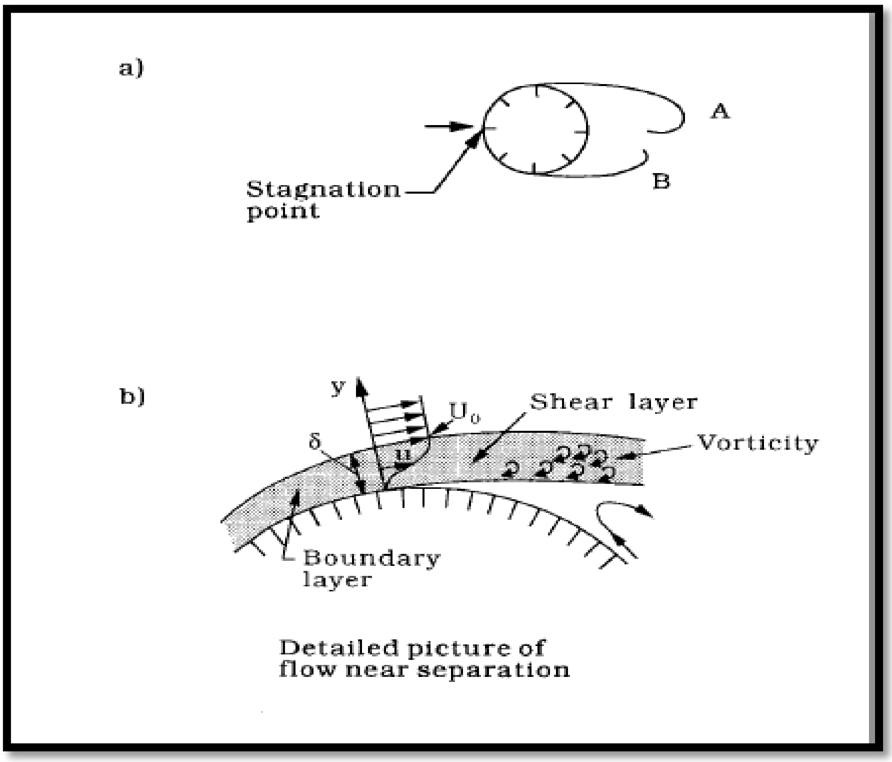

Figure-1. The shear layer on both sides roll up to form the lee-wake vortices A and B. [38]

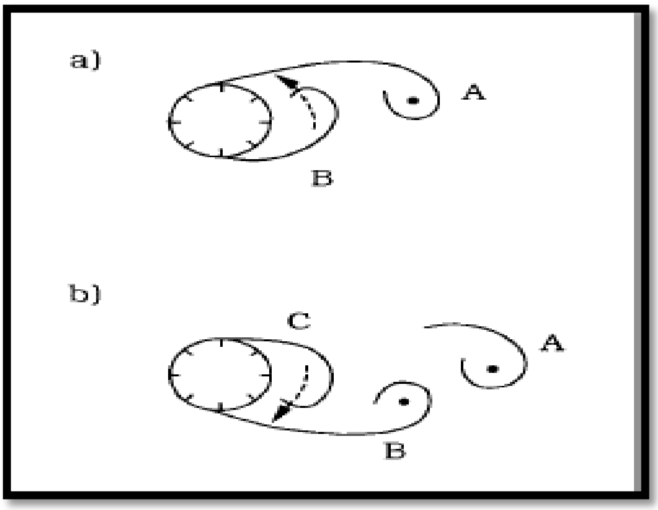

Figure-2. (a) Prior to shedding of Vortex A, Vortex B is being drawn across the wake. (b) Prior to shedding of Vortex B, Vortex C is being drawn across the wake. [38]

In fluid dynamics, vortex-induced vibrations (VIV) are motions induced on bodies interacting with an external fluid flow, produced by - or the motion producing - periodical irregularities on this flow.

A classical example is the VIV of an underwater cylinder. You can see how this happens by putting a cylinder into the water (a swimming-pool or even a bucket) and moving it through the water in the direction perpendicular to its axis. Since real fluids always present some viscosity, the flow around the cylinder will be slowed down while in contact with its surface, forming the so-called boundary layer. At some point, however, this boundary layer can separate from the body because of its excessive curvature. Vortices are then formed changing the pressure distribution along the surface. When the vortices are not formed symmetrically around the body (with respect to its midplane), different lift forces develop on each side of the body, thus leading to motion transverse to the flow. This motion changes the nature of the vortex formation in such a way as to lead to a limited motion amplitude (differently, than, from what would be expected in a typical case of resonance).

VIV manifests itself on many different branches of engineering, from cables to heat exchanger tube arrays. It is also a major consideration in the design of ocean structures. Thus study of VIV is a part of a number of disciplines, incorporating fluid mechanics, structural mechanics, vibrations, computational fluid dynamics (CFD), acoustics, statistics, and smart materials. They occur in many engineering situations, such as bridges, stacks, transmission lines, aircraft control surfaces, offshore structures, thermowells, engines, heat exchangers, marine cables, towed cables, drilling and production risers in petroleum production, mooring cables, moored structures, tethered structures, buoyancy and spar hulls, pipelines, cable-laying, members of jacketed structures, and other hydrodynamic and hydro acoustic applications. The most recent interest in long cylindrical members in water ensues from the development of hydrocarbon resources in depths of 1000 m or more.

Vortex-induced vibration (VIV) is an important source of fatigue damage of offshore oil exploration and production risers. These slender structures experience both current flow and top-end vessel motions, which give rise to the flow-structure relative motion and cause VIV. The top-end vessel motion causes the riser to oscillate and the corresponding flow profile appears unsteady.

One of the classical open-flow problems in fluid mechanics concerns the flow around a circular cylinder, or more generally, a bluff body. At very low Reynolds numbers (based on the diameter of the circular member) the streamlines of the resulting flow is perfectly symmetric as expected from potential theory. However as the Reynolds number is increased the flow becomes asymmetric and the so-called Kármán vortex street occurs. Much progress has been made during the past decade, both numerically and experimentally, toward the understanding of the kinematics (dynamics) of VIV, albeit in the low-Reynolds number regime. The fundamental reason for this is that VIV is not a small perturbation superimposed on a mean steady motion. It is an inherently nonlinear, self-governed or self-regulated, multi-degree-of-freedom phenomenon. It presents unsteady flow characteristics manifested by the existence of two unsteady shear layers and large-scale structures.

There is much that is known and understood and much that remains in the empirical/descriptive realm of knowledge: what is the dominant response frequency, the range of normalized velocity, the variation of the phase angle (by which the force leads the displacement), and the response amplitude in the synchronization range as a function of the controlling and influencing parameters? Industrial applications highlight our inability to predict the dynamic response of fluid-structure interactions. They continue to require the input of the in-phase and out-of-phase components of the lift coefficients (or the transverse force), in-line drag coefficients, correlation lengths, damping coefficients, relative roughness, shear, waves, and currents, among other governing and influencing parameters, and thus also require the input of relatively large safety factors. Fundamental studies as well as large-scale experiments (when these results are disseminated in the open literature) will provide the necessary understanding for the quantification of the relationships between the response of a structure and the governing and influencing parameters.

It cannot be emphasized strongly enough that the current state of the laboratory art concerns the interaction of a rigid body (mostly and most importantly for a circular cylinder) whose degrees of freedom have been reduced from six to often one (i.e., transverse motion) with a three-dimensional separated flow, dominated by large-scale vortical structures.

Consider the flow of fluid around a smooth cylinder. For velocities exceeding laminar flow, the inertia of the fluid starts to become significant and, as the fluid stream passes the topmost part of the cylinder, it is unable to negotiate the rear half of the cylinder. Hence the fluid tends to separate from the top surface and peel off in a clockwise motion as it approaches the rear end of the cylinder, ending up as a shed vortex (it will peel off in a CCW motion from the bottom surface). For a given velocity of flow, this model suggests the vortex formation time will be proportional to the distance around the cylinder (or its diameter) and thus the frequency of vortex formation will be inversely proportional to the diameter. Furthermore, if the flow velocity increases, the frequency of vortex formation will likewise increase, leading to a direct relation between the two. This is what Strouhal found empirically in 1878.

The proportionality constant is called the Strouhal number and turns out to be a function of the Reynolds number. For that reason it is now known as the Strouhal-Reynolds number. It is very nearly equal to 0.2 for a large range of Reynolds numbers.

One can see the vortex shedding by shadow projection. Similar to a ripple tank, if a point light source is set up over the tank, then shadow patterns of the water's motion can be seen on the bottom of the water channel. Thus, not only can one demonstrate resonance oscillations of the cylinder, but one can also see the relative motion of the vortex eddies and the cylinder-they move in opposite directions. As with most fluid dynamics phenomena, the physics of vortex-induced vibrations is quite rich and very complicated-even in two dimensions. For example, various vortex wake modes are possible with fluid flow jumping from one mode to another. Additionally, the sideways motion of the object in the fluid affects the formation and/or shedding of vortices and can have a positive or negative feedback effect. Also, depending on the phase between object and fluid motion as well as their frequency difference, a lock-in or synchronization effect may or may not occur. Furthermore, the ratio of the object-to-fluid mass as well as damping forces have a significant effect, leading to parameters described in the literature as effective mass, critical mass, high-mass ratio, etc. is also an excellent resource for those that wish to go deeper into the subject matter and it can be quite deep indeed!

Vortex-induced vibrations are important in that they can have a strong influence in countless situations ranging from tethered structures in the ocean, pipes bringing oil from the ocean floor to the surface, aeolian harps, tall buildings, and chimneys, to name but a few. For example, the tallest building in the world, the Burj Khalifa in Dubai, UAE, incorporates a variation in cross section with height to help ensure that vortices are not shed coherently along the entire height of the building. The Tacoma Narrows Bridge collapse is discussed in practically every introductory physics course as a dramatic example of resonance. Although vortex shedding is often cited as being the culprit, Billah and Scanlan say that this is oversimplified physics and posit that the real culprit was flutter-a non-linear phenomenon in which the motion of the bridge was the source of self induced periodic impulses.

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FEATURE OF FLOW AROUND UNDER WATER HORIZONTAL CYLINDER/PIPE

Having already discussed the importance of study of flow around a cylinder, discussion of flow field around the cylinder also becomes important which can be discussed in the following ways:

Lift forces on submerged cylinders

Knowledge of hydrodynamic forces on pipelines is of increasing importance in connection with the rapidly increasing number of off-shore pipelines. These pipelines are normally exposed to a complex wave-current climate. Furthermore, the seabed may be erodible so that scour takes place under the pipe. Thus the evaluation of forces on cylinders some distance away from the bottom becomes of interest.

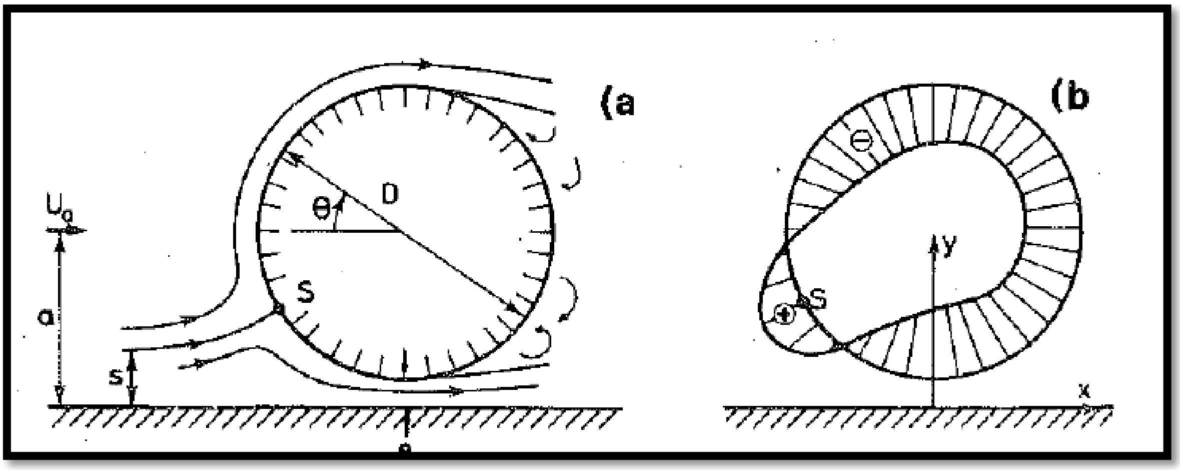

Figure-3. (a) Flow around cylinder, (b) Pressure distribution around cylinder. [39]

From the potential theory it is know that due to flow separation the stagnation point which happens to be shifting as the gap between bed and submerged cylinder increase or decrease. Figure-3 visualizes the phenomenon of the flow and pressure distribution around the submerged cylinder.

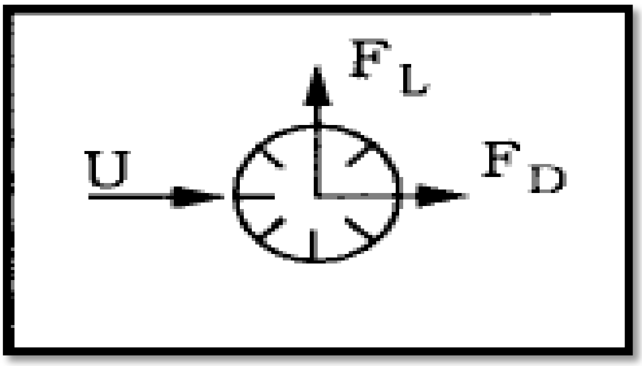

Figure-4. Drag and lift forces occurring in horizontal placed cylinder.

From Figure-4 the distribution of lift and drag forces are shown. Here U is the velocity in the direction of flow, FD is the drag force and FL is lift force. It says that the lift force is always perpendicular to the water flow across the cylinder.

CONCLUSIONS

The work here is mainly a review of the flow field that is aroused due to the phenomenon of vortex induced vibration on the horizontally placed cylinders. Many researchers have worked on it to dig out various other ways to get the flow fields related to flow past a cylinder. From the above the total phenomenon and the reasons of vortex shedding and consequently leading to vortex induced vibration is discussed. This study opens up two aspects of such phenomenon, since from the review it can be seen that in many works the concentration was confined to sediment transport occurring due to such pipes. Efforts were also made in earlier researches to break the vortices which occur due vortex shedding and further leads to vortex induced vibration that may lead to detrimental effect to the victimized structure. On the other hand the same phenomena become much more important to build up green hydro power. This was also reviewed above, and also here main efforts were taken to increase the flow induced vibration. To access such phenomenon experiments of [40] were done to prove the above statement and also to find the flow around the underwater laying cylinder in addition to structures like vertical plates. Moreover a device of a new concept in generation of Clean and Renewable Energy from Vortex Induced Vibration caused in a fluid flow which can also be called as Vortex Induced Vibration Aquatic Clean energy (VIVACE) [41] is capable of generating electricity in shallow water channels of low discharges and may also remove sediments in the water channel if it is required. Whenever there is water flow over a blunt object like cylinder alternate vortices are been shed around the cylinder which creates asymmetry and oscillatory lift to the cylinder and as a result cylinder oscillates perpendicular to its axis and transversely to the water flow direction. Here in this case the body or the cylinder is said to be under resonance i.e. the cylinder's natural frequency equals with the vortex shedding frequency due to fluid flow. The body that undergoes resonance due to flow induced vibration transmits the mechanical energy produced due to oscillations of the cylinder to a generator for conversion to electricity or directly to a mechanical or hydraulic form of usable energy via a transmission mechanism. To assess the above phenomenon and also to get the optimum output the hydrodynamic study especially the knowledge of flow phenomenon is very much important that comprises of the knowledge of the behavior of the wake vortices strength and the adverse pressure gradient that is leading to the lift movement of the cylinder. Utilizing modern instruments such as Acoustic Doppler Velocimeter the three dimensional velocities at every points around the cylinder (to take the measurement the cylinder is to be halted at discreet depths of the water channel) could be measured and the from the values of velocities the parameters such as vortex strength (vorticity and circulation), bed shear stress (which is important while dealing with the removal of sediments), Turbulent kinetic energy and other relevant parameters by which the device could be further modified to harness more power.

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