Vortex induce vibration essay sample

1. 1. Background of Study

Vortex induced motion (VIM) or vortex induced vibration (VIV) is an object vibration influenced by the vortex shedding. When fluid flow across the blunt body, wake formed behind the bluff object and resulting in vortex shedding. Due to the long periods of motions, the vortex induced vibration will commonly refer as vortex induced motion.

Vortex-induced motion is an important source of fatigue damage for blunt cylindrical body underwater especially for production risers. When the shedding frequency matches the body Eigen frequency, the body will begin to resonate and the body’s movement becomes self-sustaining. Continuing resonating will lead to material tiredness and the materials tend to fracture or fatigue.

Vortex shedding was one of the causes proposed for the failure of the Tacoma Narrows Bridge in 1940. During the winter of 2001, a thrill ride “ Vertigo” in Ohio suffered the vortex shedding result one of the three towers collapsed. On 1968, vortex shedding due to high winds caused the collapse of three towers at Ferrybridge power station.

Through countless of studies and researches, several vortex suppression methods developed designed to reduce the effects of vortex induced motion on blunt body. Commonly the fairing is used in reducing vortex shedding effect for cylindrical body. Fairing will effectively reduce the drag force and wake generated by fluid flow.

This research begins with the understanding on principles, parameters and consequence of vortex induced motion (VIM) or vortex induced vibration (VIV) then follow by conducting simulation. The analysis is simulated by CFD software which is ANSYS Fluent. The results obtained will be compared with the experimental results conducted by other researchers.

1. 2. Problem Statement

In carrying out the research, several issues need to be clarified:

i. The effects of waves and current on VIM

ii. The effects of cylinder dimension on VIM

iii. The effects fairing on vortex suppression

iv. Any suppression method is more effective than fairing

1. 3. Objective of Study

The objective of study as follow:

i. To investigate the influences of waves and current on VIM ii. To investigate the influences of cylinder dimension on VIM iii. To identify the effects of fairing on vortex suppression iv. To develop an effective method in vortex suppression

1. 4. Significant of Study

The important of this research is to develop an effective method for vortex suppression. The method will be able to suppress the vortex shedding more effectively compare to the other methods. Besides, this method will reduce the drag force and lift force generated by the vortex shedding. The forces are the main contribution to the material fracture. 1. 5. Scope of Study

The scopes of study of this research are listed as follows:

i. Investigate and understand the basic principles of VIM and VIV on circular cylinder ii. Analyses VIM using CFD simulation

iii. Develop an effective vortex suppression method

1. 6. Research Flow Chart

1. 7. Research Gantt Chart

LITERATURE REVIEW (1st Draft)

2. 1. Introduction

Vortex-induced motion (VIM) or vortex-induced vibration (VIV) is a phenomenon happens when fluid flow across a cylindrical body. When a fluid flow across a cylindrical body, an unsteady flow with oscillating motion formed behind the body is called shedding frequency. This shedding frequency will associated with formation of vortices. When the vortices are not formed symmetrically around the body, a time varying non-uniform pressure distribution will generate, resulting lift force acting on each side of body. As the time varying lift force continues acting on the body, the body will vibrate in inline and transverse to the flow. When the shedding frequency is close or equal to the Eigen frequency of the body, resonance occur and the vibration amplitude of the body is maximized. This phenomenon is called lock-in and fatigue tends to happen.

2. 2. Vortices Shedding Formation

As the fluid approaches the front side of the tube, the fluid pressure rises from the free stream value to the stagnation point value. The high pressure forces the fluid to move along the tube surface and boundary layers develop on both sides. The pressure force is counteracted by viscous forces and the fluid cannot follow the tube surface to the rear side but separates from both sides of the tube and form two shear layers. The innermost part of the shear layers are in contact with the tube surface and moves slower than the outermost part. As a result, the shear layers roll up.[1] A vortex is in the process of formation near the top of the cylinder surface. Below and to the right of the first vortex is another vortex which was formed and shed a short period before. Thus, the flow process in the wake of a cylinder or tube involves the formation and shedding of vortices alternately from one side and then the other. This phenomenon is of major importance in engineering design because the alternate formation and shedding of vortices also creates alternating forces, which occur more frequently as the velocity of the flow increases.[2]

Figure 2. 1: Vortex formation behind a circular cylinder.[2]

2. 3. Reynolds Number dependence

Generally the flow pattern around a circular cylinder can be characterized by the Reynolds number of the incident flow and by the location of points at which the flow separates from the cylinder surface which in turn depend on the state of the boundary layer (laminar or turbulent).[3] For viscous fluids the flow pattern is much more complicated and the balance between inertia forces and viscous forces is important.[3] The relative importance is expressed by the Reynolds number Re defined as Re = U∞Dυ≈inertial effectsviscous effects where U_∞ is the free stream velocity, D is the tube diameter and υ the kinematic viscosity of the fluid.

Figure 2. 2 shows the principal description of vortex shedding from a smooth circular cylinder in uniform flow for the major Reynolds number regimes.

Figure 2. 2 Regimes of fluid flow across a smooth tube.[3, 4] At Reynolds numbers below 1, no separation occurs. The shape of the streamlines is different from those in an inviscid fluid. The viscous forces cause the streamlines to move further apart on the downstream side than on the upstream side of the tube. [1] In the Reynolds number range of $5 \le Re \le 45$, the flow separates from the rear side of the tube and a symmetric pair of vortices is formed in the near wake.[1] As the Reynolds number is further increased the wake becomes unstable and Vortex Shedding is initiated. At first, one of the two vortices breaks away and then the second is shed because of the nonsymmetrical pressure in the wake. The intermittently shed vortices form a laminar periodic wake of staggered vortices of opposite sign. This phenomenon is often called the Karman vortex street.[1] In the Reynolds number range $150 < Re < 300$, periodic irregular disturbances are found in the wake. The flow is transitional and gradually becomes turbulent as the Reynolds number is increased.[1] The Reynolds number range $300 < Re < 1. 5\cdot105$ is called subcritical (the upper limit is sometimes given as $2\cdot105$).

The laminar boundary layer separates at about 80 degrees downstream of the front stagnation point and the vortex shedding is strong and periodic.[1, 3] With a further increase of Re, the flow enters the critical regime. The laminar boundary layer separates on the front side of the tube, forms a separation bubble and later reattaches on the tube surface. Reattachment is followed by a turbulent boundary layer and the separation point is moved to the rear side, to about 140 degrees downstream the front stagnation point. As an effect the drag coefficient is decreased sharply.[1] The range 1. 5·105 Re3. 5·106, referred to the literature as the transitional region, includes the critical region (1. 5·105 Re3. 5·105) and the supercritical region (3. 5·105 Re3. 5·106). In these regions, the cylinder boundary layer becomes turbulent, the separation points move aft to 140 degrees, and the cylinder drag coefficient drops abruptly.[3] Laminar separation bubbles and three-dimensional effects disrupt the regular shedding process and broaden the spectrum of shedding frequencies for smooth surface cylinders.[3, 5] In the post-critical Reynolds number range (Re3. 5·106), regular vortex shedding is re-established with a turbulent cylinder boundary layer. The vortex shedding persists at Reynolds number as high as 1011.[3, 6]

2. 4. Strouhal number dependence

When the shedding frequency is near the Eigen-frequency of the structure, the resonance will occur and the structure appears to sing. A dimensionless number, the Strouhal number Sr, is commonly used as a measure of the predominant shedding frequency fs. The definition is Sr= fsDU∞ where D is the diameter of a circular cylinder or tube in cross flow and U∞ is the free stream velocity. The Strouhal number of a stationary tube or circular cylinder is a function of Reynolds number but less of surface roughness and free stream turbulence as shown in Figure 2. 3.

Figure 2. 3: Strouhal number versus Reynolds number for circular cylinders. [4]

Most of the Strouhal number data were derived from the measurements of the velocity fluctuations in the wake, while fewer data were derived from the lift force spectra. However, that lift force spectra are a more direct measure of the force characteristics than wake velocity measurements.[3] The behavior of the Strouhal number is stable for a wide range of Reynolds numbers, except around 106(transitional region) where significant scatter occurs in the test data.[3] Vortices are frequently shed in this region and the Strouhal number is near to 0. 2. In the transitional region, the Strouhal number becomes scattered varying from 0. 05-0. 5. Delany & Sorensen (1953) found a sudden increase of their values of Strouhal number to 0. 45 and then a decrease to 0. 3 at about the same Reynolds number of 2·106. This indicates the transition to postcritical flow conditions. Bearman (1969) measured a similar value of S= 0. 46. [3] Also in the transitional range, Achenbach and Heinecke (1981) found that smooth stationary cylinders had a chaotic, disorganized, high-frequency wake and Strouhal number as high as 0. 5. Cylinders with some roughness (surface roughness e/D= 3·10-3 or greater, where e is the characteristic surface roughness) had organized, periodic wakes with Strouhal numbers S= 0. 25.[3] In the Reynolds number range 250 < Re < 2×105 the empirical formula Sr= 0. 1981-19. 7Re

is sometimes recommended for estimation of the Strouhal number.[2] It has been suggested to introduce a universal Strouhal number based on the distance between the shear layers. Over a large Reynolds number range a Strouhal number of about 0. 2 is then valid regardless of the body geometry.

[2] Vortex shedding from a stationary cylinder in the post-critical region does not occur at a single distinct frequency, but rather wanders over a narrow band of frequencies and it is not constant along the span. An average Strouhal number value of 0. 25 is suggested.[3] 2. 5. Reduced Velocity

Reduced velocity is a determination of the velocity ranges where the vortex shedding will be in resonance with Eigen frequency of the object. VR= U∞fiD where U∞ free stream velocity, fi is the ith natural frequency of the member and D is member diameter. For low reduced velocities, there exists on initial branch associated with a 2S vortex shedding mode (two single vortices shed per cycle) and the means forces and cylinder response are in phase. For intermediate and larger reduced velocities there exists an upper and a lower branch associated with a 2P vortex shedding mode (two pairs of vortices per cycle).[7]

Figure 2. 4: Sketch of the “ three-branch” response model

However, very few three-dimensional numerical results have been able to accurately reproduce the three-branch response model obtained from experiments. Some have successfully predicted the 2P shedding mode in the lower branch[8], but this result has only been observed at large mass-damping parameters, small aspect ratio and moderate Reynolds number. In general, the task of capturing numerically the large amplitude response of the upper branch for low mass-damping systems with large aspect ratio has remained out of reach.[7]

2. 6. Lift Coefficient

Lift force is sinusoidal component and residual force. Parameter of lift force normally is used to determine the lift coefficient, CL. $CL= FL12\rho DLV2$ where FL is the time-average of the drag force, FL(t), ρ is the fluid mass density, D is the cylinder diameter, L is the cylinder length and V is the flow velocity. Lift is the transverse component of force occurring at the vortex shedding frequency. Lift will be influenced by body motion, and there is considerable evidence demonstrating the influence of body on lift force frequency and correlation. But it is an applied force which owes its existence to the character and strength of the hydrodynamic wake formed by flow around the body.[3] Lift force also can be expressed in the form of motion as equation stated below $FL= m+az+2m\zeta\omega zz+Kz$

where ζ is the damping factor of the cylinder, ωz is the cylinder circular natural frequency and K is the spring constant. The time varying lift force on the oscillating cylinder may have a phase, Φ difference. Then lifting amplitude will become, $z= Az\sin(2\pi fst+\Phi)$

where Az is maximum motion amplitude.

Concerning the fluid dynamics part of the problem the Reynolds number Re can play an important role here because flow separations are often Reynolds number dependent, even if the bodies have sharp edges. This has already been observed and explained for the approach span cross section of the Great Belt Bridge (Schewe & Larsen 1998). High Reynolds number dependence is observed from numberless of experiments and researches. The reason for this dependence is that, the state of the boundary layer has a far-reaching influence on the entire flow field about a body. Both the state of the boundary layer and the location of transition are often responsible for the formation, length, and shape of separation bubbles.[9]

In particular when the symmetry is broken, i. e. the cross section is asymmetric or the angle of incidence α is not zero, the behavior of the separated flow that depends on the Reynolds number can be different on the upper- and the lower side of the section. Thus global values, like the lift coefficient CL, for example, can be affected by the Reynolds number. This in turn can have a large influence on the derivatives, which are differential values and thus sensitive to small variation of the underlying CL(α) curve, the latter are, in addition, typically nonlinear in case of bluff bodies. In general the derivatives and the nonlinearities are determining the type and strength of possible flow induced vibrations.[9] Over countless experiments and researches, a large number of results had been published to attempt the relationship between the lift coefficient and Reynolds number.