정사각봉의 진동에 의한 유동해석

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NUMERICAL FLOW VISUALIZATION ANALYSIS AROUND AN OSCILLATING SQUARE CYLINDER

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In this paper, a flow visualization analysis has been carried out on an oscillating square section cylinder, numerically, using a commercially available code CFD-ACE. In this study, the square cylinder is forced to oscillate at different frequencies of excitation, viz., fe/fo=0.5, 1.0 and 2.0 (where, fe is the excitation frequency provided to the cylinder and fo is the natural vortex shedding frequency from the stationary cylinder at a particular Reynolds number (=5200). In all the cases, the peak-to-peak amplitude of oscillation is kept at 32% of the side dimension of the square cylinder. These studies are conducted to understand the influence of frequency of oscillation on the flow field features around the cylinder, particularly the mode of vortex shedding. Results indicate that, the flow field around a square cylinder is very much influenced by the excitation frequency, in particular the vortex shedding mode. It is also found that, the vortex street parameters are significantly influence by the oscillation frequency. Comparison with earlier reported experimental studies has also been attempted in this paper. In appears that, such a numerical exercise (as performed in this paper) is first of its kind. It is believed that, these studies would enable one to understand the mechanisms underlying the flow-induced vibrations of a square section cylinder.

Keywords : CFD, Square Cylinder, Shear Layer, Vortex Shedding, Oscillation frequency

1. Introduction

Flow-induced vibration is a possible phenomenon in situations where a bluff body is subjected to a fluid flow. Generally, 'bluff' structures from which flow separates from a wider section of the body are likely to undergo these vibrations, if they are flexibly supported. This topic has been a research focus for many researchers basically because of its practical relevance; applications could be cited in heat exchanger tube bundles, tall chimneys, towers, buildings, bridges etc. Among bluff sections, square section is an interesting section primarily because of its wide application possibility. Many civil structures, especially buildings have square cross section geometry. Unlike circular section, square section poses additional aerodynamic challenges that it could be subjected to galloping excitation even in its isolated condition. This is in fact a very serious problem in case of tall buildings subjected to wind-induced dynamic excitation (including galloping) where these vibrations would possibly hamper public comfort and safety. Similar concern exists in the case of bridges also. Hence, it is important to consider its aerodynamics from the practical point of view. On the aerodynamic characteristics of a square section, some studies have been reported in the literature (Otsuki et al (1974), Obasaju (1983), Ribeiro and Blessman (1992), Ajith Kumar and Gowda (2006)). However, most of these studies were focusing on features like mean and fluctuating pressures acting on their side faces, base pressure and Strouhal number characteristics, vibratory response characteristics etc. On the intrinsic flow field features of an oscillating square cylinder particularly on the vortex shedding mode and mechanism, only a few studies have been attempted so far (eg., Ongoren and Rockwell (1988), Luo (1992), Ajith Kumar and Gowda (2007)). But, again, these were all experimental studies. It has been observed that, there is a

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scarcity of numerical attempts.

In the present paper, a numerical flow visualization analysis is performed on a square section cylinder as it oscillates over a full cycle at different frequencies of excitation. Numerical experiments were conducted for 3 values of fe/fo, viz., 0.5,1.0 and 2.0 (where 'fe' is the excitation frequency and 'fo'is the natural vortex shedding frequency from a stationary cylinder at the specified Reynolds number). This has been carried out in an attempt to bring out the influence of excitation frequency on the flow field features by numerical means. A commercially available code namely CFD-ACE+ is used for this purpose adopting first order upwind scheme. It is pointed out that, the flow is treated as laminar in the numerical analysis. All the results pertain to a Reynolds number (based on the side dimension of the cylinder) value of 5200.

2. Result and Discussion

Numerical flow visualization results are obtained for a square cylinder when it is oscillated, employing a non-dimensional amplitude value (a/B; 'a' is the peak-to-peak amplitude and 'B' is the side dimension of the cylinder) of 0.32. The results are obtained for different values of fe/fo and are discussed below

2.1 Flow structure at fe/fo=1.0

Fig.1 shows the mode of vortex shedding at fe/fo=1.0 as the cylinder oscillates from TDC (Top Dead Center) to BDC (Bottom Dead Center) and again back to TDC thus complete one cycle. It could be seen that, a vortex nucleates at the top shear layer (vortex V1) and grows in size as the cylinder traverses. As the cylinder moves (during the first half of the oscillatory cycle) and V1 grows, its center moves closer to the base of the cylinder. The vortex V1 appears to have attained it's saturation size at BDC. In the second half of cycle (BDC to TDC again), V1 seems to undergo a stretching, moving away from the cylinder base (due to the action of curling of the bottom shear layer). At TDC (oscillatory cycle end), the fully grown vortex seems to get separated farther away from the cylinder base with the feeding shear layer (top) coming closer to the top side face. It was seen that, in the beginning of the second cycle (not presented here), V1 got detached from the feeding shear layer and shed downstream. In the mean while, vortex already formed at the bottom shear layer (in the previous cycle) moves farther downstream during the cylinder oscillatory traverse (TDC to BDC) and get shed at near BDC. This mode of shedding repeats over cycles and is found to be somewhat similar to that observed by Ajith Kumar and Gowda (2007) (hereafter referred to as A&G). Strouhal number is calculated to be 0.137 and is evaluated from the velocity fluctuations in the wake (Fig.2). Fig.3 shows the pressure distribution on the side faces (top & bottom) which exhibits a definite periodicity and hence, indicates that the cylinder could be subjected to sustained oscillations, if flexibly mounted. Previous investigators (Luo (1992), Ajith Kumar and Gowda (2005)) have suggested that, at fe/fo=1.0, the vortices are shed due to the instantaneous reattachment of shear layers on to their corresponding sides thus cutting off further vorticity supply to the growing vortex. However, this could not be observed in the present case. Further, when compared to the experimental results of A&G, the shear layers are found to be more inwardly curving (deflecting).

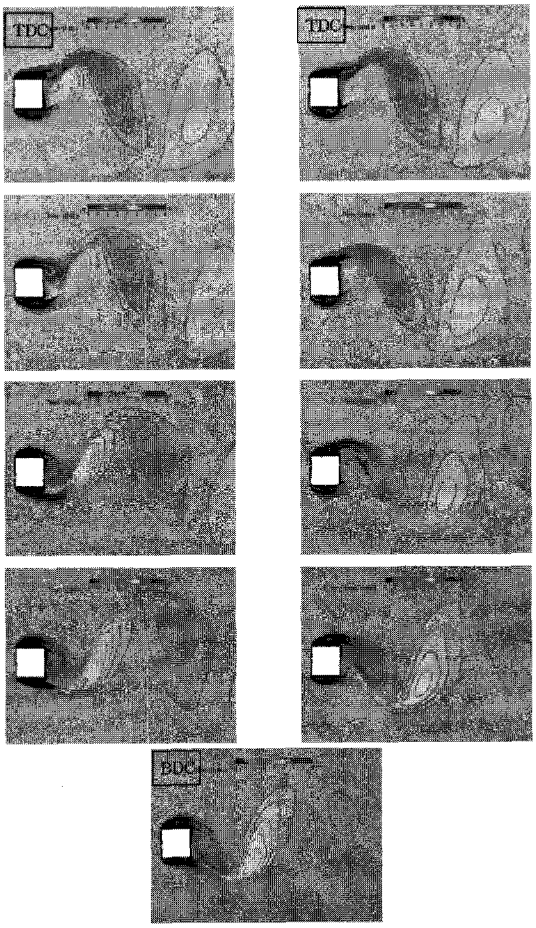

Fig. 1 Votex shedding sequence; fe/fo=1.0

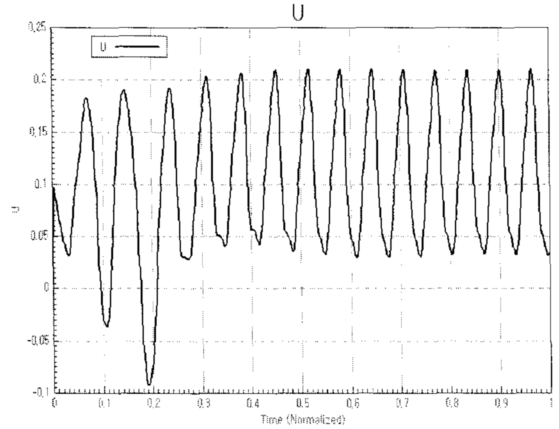

Fig. 2 velocity fluctuations in the wake;0~20sec

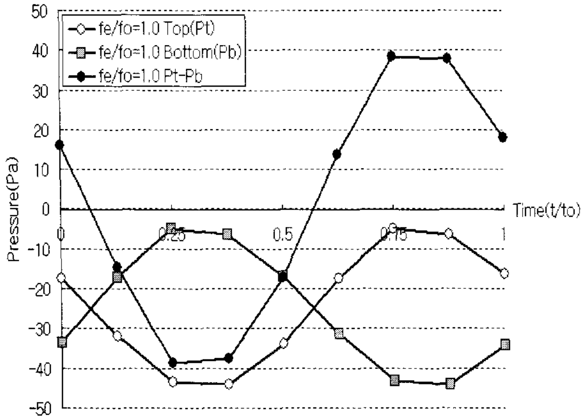

Fig. 3 Average pressure distribution on the cylinder side faces (to: period of oscillation); fe/fo=1.0

2.2 Flow structure at fe/fo=0.5

For this case, the sequence of vortex shedding is given in Fig. 4. Quite interestingly, as the cylinder oscillates (TDC to BDC), a new vortex appears to originate in the top shear layer at the midway during the cylinder traverse and grows in size thereafter (V1).In the meanwhile, another nascent vortex is found to nucleate in the bottom shear layer (near TDC) which could be seen to get detached (shed) downstream at near BDC. But, yet another vortex forms in the bottom shear layer (at BDC) which registers a continuous growth thereafter (V2). Both V1 and V2 are found to closely interact with each other at near TDC (cycle end) and thereafter, surprisingly, they co-exist in similar configurations and strengths on either sides of the cylinder during the entire second cycle of oscillation (but, not presented here). Again, at the end of second cycle, both these vortices were found to undergo stream-wise spreading, particularly V1. Also, both V1 and V2 appear to get shed and new vortices start nucleating (in the shear layers) during the first half of the third cycle. But, at present, the underlying mechanism of shedding is not clear and need further investigation. From the analysis performed on 5 typical oscillatory cycles, it was noticed that, there is a cycle-to-cycle variation in the flow field features. But, in general, it could be observed that, the vortices grow to a very large size compared to that at fe/fo=1.0. This could be attributed to the longer feeding time (due to lower excitation frequency) available for vorticity supply. Also, the near-wake constitution with similar shear layer configurations and equi-sized vortices indicate a possibility of near- equal pressure distribution (on

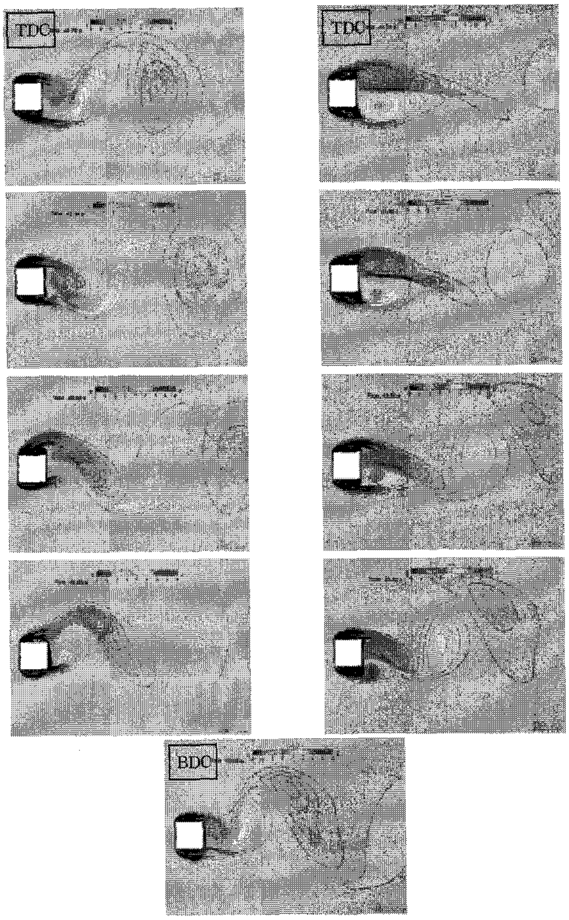

Fig. 4 Votex shedding sequence; fe/fo=0.5

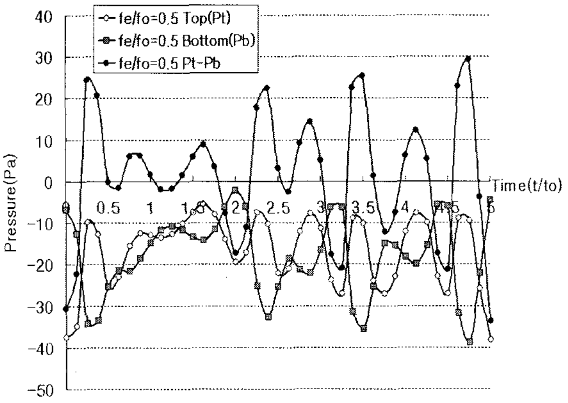

Fig. 5 Average pressure distribution on the cylinder side faces (to: period of oscillation); fe/fo=0.5

either side) at some cycle intervals which could possibly lead to a dampening of oscillations. This is also clear in Fig. 5 which gives the pressure distribution over cylinder faces. Hence, it could be inferred that, at this frequency ratio (fe/fo=0.5), the cylinder would not possibly undergo further aerodynamic excitations such as galloping (large oscillations). A&G also have observed similar near-wake flow structure, i.e., large vortices of near-equal size occupying the wake with similar shear layer configurations. But, in the present case, the top shear layer is found to contribute only one vortex and bottom shear layer generates two vortices per cycle of oscillation (making dissimilar contributions) unlike that observed by A&G where each shear layer was found to generate two vortices per cycle of oscillation.

2.2 Flow structure at fe/fo=2.0

For this case, the sequence of vortex shedding is found to be very similar to that observed by A&G for fe/fo=2.0. Similar mode of shedding was also observed by Luo (1992) also, but for fe/fo=1.0. As seen in Fig. 6, a vortex originates at near TDC (cycle start) grows in size and finally get shed at near TDC (cycle end). On close observation, it appears that the vortices are getting shed due to the reattachment of shear layers on to their corresponding sides and hence, differ from the shedding mechanism suggested by Gerrard (1966). This, once again confirm the opinion of earlier investigators that, there could be other underlying mechanisms responsible for the shedding of vortices. At this excitation frequency, cycle-to-cycle consistency has been observed for the mode of vortex shedding unlike the case of fe/fo=0.5. The vortices shed are found to be of smaller size than those observed for the cases with fe/fo=0.5 and 1.0 indicating lesser amount of circulation contained in them. This could be attributed to the lesser vorticity feeding time available since the excitation frequency is higher. Pressure distributions (over cylinder side surfaces) are shown in Fig. 7 which indicates that the net upward force reaches a peak value at near the mid of the oscillatory cycle and it assumes a minimum value near the dead ends (TDC/BDC). In this case, similar to fe/fo=1.0, the flow field suggests that, the body oscillations would be sustained with time.

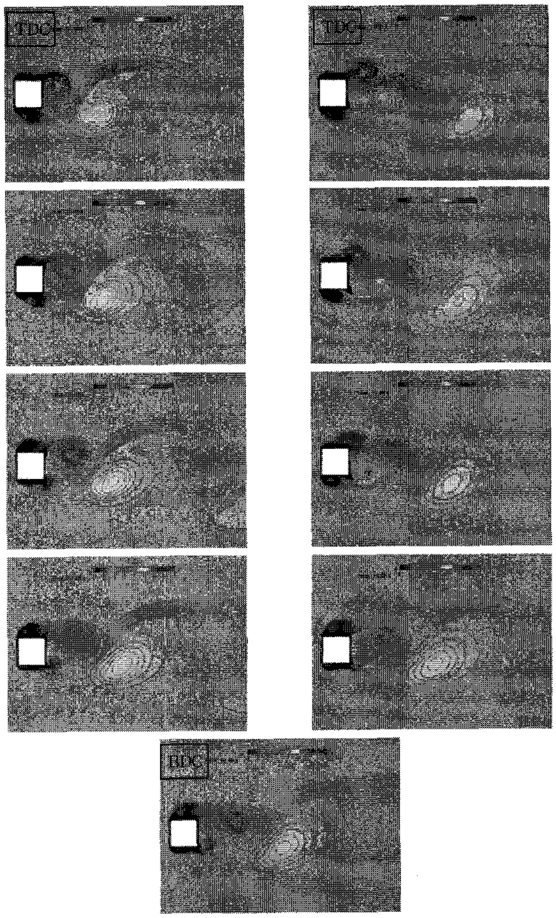

Fig. 6 Votex shedding sequence; fe/fo=2.0

C_L and C_D (Coefficients of Lift and Drag) values are plotted in Fig. 8 against fe/fo. The figure illustrates that, both assumes their respective maximum values at fe/fo-1.0, the harmonic excitation case. This could be attributed to higher synchronization achieved between the body oscillation and vortex shedding at fe/fo=1.0.

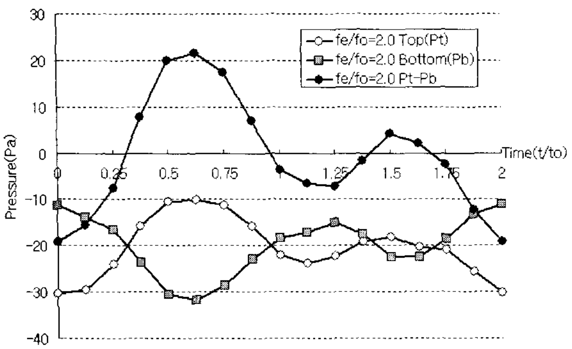

Fig. 7 Average pressure distribution on the cylinder side faces (to: period of oscillation); fe/fo=0.5

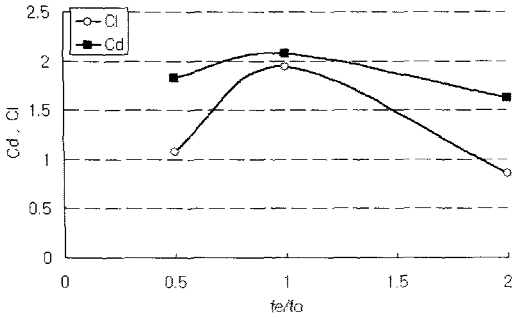

Fig. 8 Variation of C_D and C_L with fe/fo

Discrepancies with the experimental results of A&G could be attributed to the fact that, in the present analysis, the flow is treated as laminar whereas, in the actual case, it is turbulent (at Re=5200).

3. Conclusion

From the numerical flow visualization analysis conducted on an oscillating square cylinder, the following conclusions are drawn:

1. The near wake flow structure is significantly influenced by the excitation frequency (fe) imposed on the cylinder. The flow field features particularly the mode of vortex shedding is found to depend on the ratio between the excitation frequency and natural vortex shedding frequency (fe/fo).
2. At fe/fo=1.0, the lift and drag coefficients are found to attain their peak values indicating greater synchronization between body oscillation and vortex shedding.
3. The vortex size seems to have an inverse relationship with the oscillation frequency.
4. At low excitation frequencies, there could be more inconsistencies in the near-wake flow structure than at higher oscillation frequencies.

Acknowledgments

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