論文の内容の要旨

論文題目　A Numerical Study of Aeroelastic Instability and Vortex Induced Vibrations for Long Span Bridge
（長大橋の空力不安定振動と渦励振の数値予測に関する研究）

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Safe design of large civil engineering structures like cable-stayed bridges require understanding of the dynamic response under unsteady wind loads. Presently, wind tunnel testing is considered to be the most effective means of determining aerodynamic characteristics of proposed bridge sections during design process. However, the extent of data available from these tests is insufficient to comprehensibly explicate the complex flow mechanisms involved. This study aims to employ the use of computational fluid dynamics for elaborating those aspects of bridge engineering that still needs ameliorate understanding to help the designing of bridges. Comprehensive investigations are conducted on flutter and vortex induced characteristics of bridges considering its interaction with section width ratio, geometrical improvements of sections, small section attachments and aerodynamic countermeasures along with yaw angles of attack, respectively. Thus, broadening the on hand knowledge of bridge aerodynamics and increasing the capability of CFD methods for design process as an efficient alternative of wind tunnel approach. A streamline box girder section of cable stayed bridge, Nanjing Bridge, and a non-streamline box girder section, Trans-Tokyo Bay Bridge, are selected as examples to conduct investigations on the aero elastic instability and vortex induced vibrations.

A review of past studies about flutter and vortex induced vibrations using wind tunnel testing and computational fluid dynamics was conducted to identify the shortcoming of these fields. In light of this review, following objectives of this study are identified. First inclusion of section attachments for clear understanding of influence of such details on the aerodynamic behavior of bridge sections as well as suitable methods needed to numerically model different kinds of wind tunnel testing facilities. And guidance to model small section attachments present in real bridges is needed. Secondly, to elaborate the influence of the section width, use of fairing and small section attachments on the mechanism of aero elastic instability. And, for vortex-induced vibrations, understanding of the amplitude suppression mechanism of aerodynamic control measures and yaw angle of attack is identified as a goal for this research.

New modeling techniques to introduce the small section attachments, and appropriate representation of testing boundary conditions, as used in wind tunnel are developed to setup the numerical wind tunnel. To include small section attachments, a schematic use of hybrid grid, including both structured and unstructured grids, is proposed around the complex geometry. To determine aero elastic stability of bridges, there are three kinds of sectional model tests used that are i) static test, ii) forced vibration test and, iii) free vibration test. Use of sliding grid is introduced in the field of computational bridge engineering in order to meet the oscillatory conditions for forced and free vibration tests. Also boundary conditions for the forced/free vibration cases with and without yaw angle of attack are proposed.

Understanding of contribution of section attachments likes handrails, etc. to aerodynamic coefficients is required in order to achieve best aerodynamic configuration. The inclusion of such attachments to accurately model their influence on aerodynamic coefficients proves to be very difficult because of very small size compared with section itself. Investigation on the presence of such reveals a drastic increase in drag coefficient of bridge section at lower angle of attacks and, the lift and moment coefficients are reduced at higher angle of attacks. For the accurate modeling of section attachments, in contrast to conventional methods, this study proposes a method to use sub-domains containing large number of grids in vicinity of small attachments only, and introduce a wake region of about 8 to 10 times the dimension of small attachments. This proposed method avoids the need of larger computational facility and longer time required to obtain gird independent solution.

Achieving higher critical velocity is desirable for the aeroelstic stability of bridge. Critical flutter velocity depends upon width to depth ratio, geometrical configuration of section and small section attachments. Comprehensive investigations are conducted to acquire higher critical velocity for sections with smaller width to depth ratio. Increase in aspect ratio showed stabilizing effect by reducing the section width ratio subjected to negative pressure. Fairings are introduced at both ends of section with low aspect ratio that results in higher critical velocity by smooth separation of flow subjecting smaller width of section to negative pressure. For streamline section used, absence of section attachments does not alter flutter characteristics, as the separation point does not change for smaller rotational angle used in analysis. Careful selection of rotational angles, based on steady analysis, should be made to account for influence of such details. Introduction of 3D model has considerably improved prediction of flutter characteristics than 2D models.

Bridges experiencing VIV require reduction in amplitude of vibration to meet design criterion for serviceability reasons. These vibrations are suppressed by use of aerodynamic vibration control measures (AVCM) and, also depend upon yaw angle of attack. Though several studies have shown use of AVCM on case-by-case basis, but vibration suppression mechanism of such measures is still unclear. AVCM like fairing and double flap are used to understand the controlling mechanism of VIV observed in Trans-Tokyo Bay Bridge. In contrast to fairing, use of double flap resulted in reduced amplitude of vibration and mean pressure distribution from free vibration showed flow reattachment on upper surface. Examination of steady aerodynamic coefficients shows presence of sharp positive slope for lift coefficient in case of fairing, whereas change in positive slope of lift force to a negative slope in double flap case was identified to be responsible for reduced amplitude of vibration. Vortex shedding frequency is found to change with increase in yaw angle and results in reduced velocity that falls outside range critical reduced velocities. Finally, a method is proposed, based on identification of critical reduced velocity, to efficiently predict maximum amplitude of vibration.

In short, this study focuses on introduction of new modeling techniques and flow mechanism corresponding to aero elastic instabilities and vortex induced vibrations. An accurate inclusion of small attachments requires not only introduction of fine grid but also wake region behind such details. Flutter characteristics are found to be dependent on the section width, and use of fairings results in more stable section by improving the surface pressure distributions. To fairly include effect of section attachments on flutter characteristics, investigations on steady aerodynamic coefficients should be examined to identify the range of rotational angles representing influence of section attachments. Examination of the steady aerodynamic coefficients provides deep insight of amplitude suppression mechanism of AVCM. Change in vortex shedding frequency with increase in yaw angle accounts for the reduced amplitude of vibrations. Finally based on this study, recommendations for the future studies are listed.