CHAPTER 1

INTRODUCTION

1.1 GENERAL

Wind engineering of long span bridges has been an evolving science as wind forces realised by these structures are significant in comparison with other loads. Like other slender line-like civil engineering structures, bridges are also subjected to mean and fluctuating wind forces, except that the bridge structure is horizontal. Hence the theory that is applicable to other line-like type of structure is equally applicable to bridges (Einar Strommen, 2006). The criterion for design of long span bridges against wind is often governed by aerodynamic instability. Generally speaking, bridge aerodynamic phenomenon is the results of wind-structure interaction. It has been established by many researchers that the characteristics of aerodynamic stability of bridge are under the influence of several factors, such as, structural natural frequencies, frequency ratio between different modes, deck geometry, wind conditions, etc., (Lakshmi Parameswaran, 2002). The structure should be able to absorb the energy due to dynamic action of wind through various modes of vibration and frequency of oscillation of structure. If the energy absorbed by the structure is larger than the dissipated energy through structural damping, the amplitude of vibration will continue to increase, leading to destruction. For example, a (wind-sensitive) structure might have been designed to withstand a certain level of mean wind pressure. But the structure may fail even at a lesser wind pressure, if there is structural oscillation at a particular frequency in relation to its natural frequency of
vibration. This kind of event can happen over a certain range of wind speed as wind contains energy at all frequencies, even upto 10 Hz during extreme event as reported (Shanmugasundaram et al, 1999). The typical example of such type of failure is the well-known Tacoma Narrows Bridge failure in the year 1940. Since all structures that are exposed to wind will oscillate under some disturbances, it is apparent that a designer has to predict the critical wind speed below which the structure is aerodynamically stable and safe (Peter King, 2003a).

The aerodynamic force consists of two components namely the pressure forces normal to the surface of the body and the skin friction or shearing force tangential to the surface of the body. The pressure depends on geometry of the body, its characteristic dimension relative to wind flow and wind angle. In aerodynamics of bridges, the concerned forces are lift and drag and one component of moment that act on the body. The skin friction is generally negligible in aerodynamic problems of bridges (Simiu & Scanlan, 1986). Wind induced aerodynamic and aeroelastic effects play a major role while designing a structure to maintain static equilibrium. The aerodynamic stability involving wind and motion induced responses are vortex shedding, torsional divergence, galloping, flutter and buffeting (Simiu & Toshio 2006). Buffeting is the random response of the bridge due to wind forces associated with the pressure fluctuations on the bridge deck caused by the turbulence of the wind flow over the section. In other words, buffeting can be defined as the unsteady loading of a structure by turbulence intensity present in the oncoming flow and not self-induced. Similarly, when the bridge faces the flow, separation of flow occurs on the surface of the structure causing vortices to be shed alternately on either side of the structure. These vortex induced oscillations give rise to fluctuating across wind forces and moment. Galloping is a large amplitude oscillation which occurs in a non – circular or a bluff section in a direction normal to the direction of wind flow. The negative
aerodynamic damping which adds energy to the oscillating structure causes galloping. Torsional divergence is an instance of a static response of a structure. The instability effect is static and not dynamic. It is simply a problem of losing torsional stiffness due to interaction effects with the air flow. The types of aeroelastic oscillations are vortex shedding, galloping and flutter. When these oscillations occur in an uniform flow without external disturbances, they are said to be self-excited oscillations. The former two types of oscillations are characterized by a separated flow in the rear of the body, i.e. the flow that does not follow the contour of the solid body. Whereas the third type of self excited oscillation – flutter, involves frequency dependent damping and stiffness in isolation or in a combined mode.

With the construction of longer spans, wind forces are realised to be significant for design of bridges in comparison with other loads. Mass and stiffness were the tools of early designers to make up for a lack of understanding of the action of wind on the bridges that they were designing. Often it was common practice to use highest instantaneous velocity recorded on an anemometer for this wind speed, which is sufficient for a stiff structure, but incapable of dealing with turbulent buffeting and instability. Long span bridges exhibit complex behavior in which the translational and torsional modes are often strongly coupled. In particular, the design of the deck may play a significant role in the coupling of the modes. Traditionally, the analysis of the bridge structure due to wind is studied using wind tunnel experiments. There had been many cases of bridge failures reported before the introduction of wind tunnel tests on bridges (Ref.: http://dmoz.org/Science/Technology/Structural_Engineering/Bridge/Failures/).

1.2 NEED FOR PRESENT INVESTIGATION

It is reported by Xiang Haifan and Ge Yaojun (2007) that the recent long-span bridge projects in China include thirty-eight completed suspension
bridges, cable-stayed and arch bridges with a main span over 400 m, and eighteen major bridges are under construction. The construction of longer span bridges is presently in the increasing trend and the increase in span length of such bridges results in remarkable decrease in their natural frequencies and the ratio between the fundamental torsional and vertical mode frequencies. Advancement in analytical and experimental approaches to the design of bridges for wind effects has allowed construction of longer and longer span bridges than previously thought possible. It may soon surpass the 3 km mark with the construction of a bridge across the Straits of Messina in Italy. This renders long span bridges very susceptible to the actions of dynamic wind. The interaction between wind and the bridge structure has been poorly understood for several centuries and the design for wind effects is largely based on empirical approach of trial and error. The dynamic effects of wind can be thoroughly addressed only with the use of dynamically scaled models in the wind tunnel (Tanaka & Davenport, 1982). A section model is commonly used to investigate the following:

- The dynamic response to vortex shedding
- To ensure that the section is aerodynamically stable to an acceptably high wind speed
- To determine its response to turbulence

The construction of longer span bridges in India is also presently showing an increasing trend. There are about 9 cable stayed bridges in the country as listed below (Ref.: http://www.spanconsult.com, www.indian-architecture.info)
• Akkar bridge in Sikkim with two span length of 76.2 m.
• Vidya sagar situ in Kolkata with a span length of 130 m.
• Yamuna bridge in U.P., with span length of 85 m.
• Second Hooghly bridge in Kolkata with 457 m span length.
• The Dwaki cable suspension bridge near Megalaya-Bangladesh.
• 500 m span Zuari Bridge on NH-17 at Cortalim, Goa.
• Cable Stayed Bridge (KRPuram, Bangalore) - length 230 m, width 23.4 m.
• Cable stayed bridge over Yamuna at Naini, 1610 m long, 260 m deck span.
• Bandra-Worli Sea Link, Mumbai, 150m span, twin tower cable-stayed bridge.

There are only limited wind tunnel testing facilities to conduct aeroelastic stability on bridge decks related to boundary layer wind. Particularly, there is almost no facility to carry out such studies using wind tunnels in India (Prem Krishna 2001). Moreover, the complications involved in developing the static and dynamic test facility and in the analysis needs a special attention. The following sections attempt to focus more on particularly the behavior of bridge deck among other elements (like pylon structures, cables, etc.) of a bridge due to wind loads and its associated parameters affecting the stability is analysed using spectral characteristics, frequency and damping.
1.3. OBJECTIVE AND SCOPE OF RESEARCH

The objective of this thesis is to study the aerodynamics of bridges through wind tunnel testing under forced vibration. Foremost is the development of experimental techniques to define the wind loading for design of long span bridges due to wind. The development of experimental techniques for various types of sectional models of bridges to describe the parameters from which representative wind loads can be developed and the stability can be checked is also an objective. The scope of the work to realise the above objectives are:

- Simulation of atmospheric wind in wind tunnel.
- Development of static and dynamic test rig facilities.
- Measurement of static coefficients - lift, drag and moment at several positive and negative wind angles.
- Development of simple methodology to interpret the results in terms of stability of the bridge deck under forced vibration.
- Broad understanding on flutter related issues with presence of background excitation.

1.4 ORGANISATION OF THE THESIS

In an endeavour to fulfill all the above objectives the investigations are carried out and are enclosed in six chapters. A detailed chapter-by-chapter overview is given below:
Chapter 1: INTRODUCTION

This chapter introduces the scope by situating the subject, highlighting the need and identifying the problem and objectives.

Chapter 2: LITERATURE REVIEW ON BRIDGE AERODYNAMICS

The conventional treatment of wind loading theory on design of long span bridges is dealt in detail in this chapter. Two different design aspects on static loading and the aerodynamic stability using static test rig and dynamic test rig are reviewed. The phenomena concerned with bridge aerodynamics, namely, galloping, buffeting, vortex shedding, flutter, etc., have been replicated from the latest literature available. The data in this chapter forms the basis for the work presented in the subsequent chapters.

Chapter 3: DEVELOPMENT OF TEST FACILITY

The present experimental investigation has been carried out in two parts, using static and dynamic test rigs. Rigs to measure drag, lift and moment using rigid sectional models has been designed and developed. A dynamic sectional model rig has also been designed and fabricated. The test rig has provisions to attach springs, add inertial mass and dampers at desired locations. The design of these test rigs and calibration details of the load cell are explained in this chapter.

Chapter 4: WIND TUNNEL EXPERIMENTS

The experimental details on simulation of boundary layer in wind tunnel, measurement of pressure and force coefficients on static sectional
model of a bridge deck and measurement using dynamic test rig for the same bridge cross section studied using the rigid model are included in this chapter.

Chapter 5: ANALYSIS OF TEST DATA AND CRITICAL EVALUATION

This is a major chapter devoted to analysis of data acquired from static test rig and dynamic test rig, mainly to the extraction of flutter derivatives from wind tunnel tests. The chapter also describes the theory to identify flutter derivatives and has critically evaluated the test results. The sub-divisions include computation of aerodynamic coefficients based on static test rig, analysis of pressure and force data, evaluation of Strouhal’s number, analysis of measured data for evaluation of frequency and damping based on dynamic test rig, and analysis for flutter derivatives.

Chapter 6: CONCLUSIONS

This chapter includes summary of major contributions, conclusions and suggestions for further research.