AERODYNAMIC STUDIES ON A MULTISTORIED BUILDING MODEL

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A PROJECT REPORT PRESENTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF DEGREE IN MECHANICAL ENGINEERING

SCHOOL OF ENGINEERING AND INFORMATION TECHNOLOGY
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DECLARATION

I certify that this thesis is the only work of mine except certain statement or information of which I have explained the source of it.

28 APRIL 2006

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ABSTRACT

Wind tunnel tests on structural models are needed when the full-scale structures cannot be tested or analysed. Very few industrial structures can be analysed accurately, particularly when they have solid and not lattice faces. Objects of tunnel tests include bridges, chimneys, vehicles, buildings, and radars. The model under investigation is non-aerodynamic building model. The wind tunnels tests on the building model are carried out to include flow visualization, pressure distributions on the various faces of the building and drag coefficient. Flow visualization tests are carried out by using the woollen tuft technique at three different speeds and at three different yaw angles. Flow visualization by wool tuft technique is able to show the characteristic of the flow around the building. Pressure distribution tests on the building model are carried out by using the wind tunnel technique and Bernoulli Principle. Around 164 static pressure ports available on all faces of the building are connected to a water tube manometer. Results showed high pressure along the centre line of the front surface of the building. CFD (Computational Fluid Dynamic) analyses of the flow visualization, pressure distribution and drag coefficient are carried out by using Cosmosflowork 2004. Some modifications are made on the shape of building to reduce the value of drag coefficient. The computational results of flow visualization and pressure distribution are compared with the experimental results.

Keyword: Wind tunnel test, tall building, flow visualization, pressure coefficient, CFD, drag coefficient.

ABSTRAK

Ujian terowong angin pada model struktur adalah diperlukan apabila stuktur skala penuh tidak boleh diuji atau dianalisi. Bilangan struktur kilang yang dapat dianalisi dengan tepat adalah kecil, terutamanya untuk permukaan kekisi dan pepejal. Objek untuk ujian terowong angin adalah termasuk jambatan, corong, pengangkutan, bangunan dan radar. Model untuk penyelidikan adalah model bangunan. Ujian terowong angin pada model bangunan adalah termasuk pengambaran pengaliran, penyebaran tekanan pada permukaan bangunan model dan pekali pengheretan. Ujian pengambaran pengaliran dijalankan dengan menggunakan teknik bulu pada tiga jenis kelajuan dan tiga jenis sudut berlainan. Pengambaran pengaliran yang menggunakan teknik bulu dapat mempersembahkan sifat pengaliran di sekeliling bangunan. Ujian penyebaran tekanan pada permukaan model bangunan adalah dijalan dengan menggunakan teknik terowong angin Prinsip Bernoulli. 164 lubang tekanan statik pada semua permukaan model bangunan adalah disambungkan kepada tiub manometer air. Keputusan menunjukkan takanan tinggi pada garis tengah permukaan depan model bangunan. Analisis CFD untuk pengambaran pengaliran, penyebaran tekanan dan pekali heretan akan dijalankan dengan menggunakan Cosmosflowork 2004. Pengubahsuaian dibuat pada bentuk model bangunan untuk mengurangkan nilai pekali heretan. Keputusan komputer untuk pengambaran pengaliran dan penyebaran tekanan dibandingkan dengan keputusan eksperimen.

Kata kunci: ujian terowong angin, bangunan tinggi, pengambaran pengaliran, penyebaran tekanan, CFD, pekali heretan.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

σ_y	Normal stress in y-direction
σ_z	Normal stress in z-direction
τ	Shear stress
τ_{yx}	Shear stress in y to x direction
τ_{zx}	Shear stress in z to x direction
τ_{xy}	Shear stress in x to y direction
τ_{zy}	Shear stress in z to y direction
τ_{xz}	Shear stress in x to z direction
τ_{yz}	Shear stress in y to z direction

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Wind loads have become particularly significant because of the increasing number of high-rise buildings. Other factors have also contributed to the importance of wind in design: light-weight low-slope roofs, curtain wall construction and the appearance of special structure having aerodynamic shapes.

Some tall buildings that extend into regions of high wind velocity have swayed excessively in strong winds. Improperly anchored light-weight roofs have been sucked off bodily by wind forces, and roofing materials have been lifted by high local suctions and eventually peeled from large areas of roofs. These and many other problems have emphasized the importance of the clearer understanding of winds and its effects.

With the old simplified approach, the total effect of wind was often represented merely by a uniform lateral pressure on the windward side of a building and suction on the leeward wall.

Wind loads present a challenge when designing very tall structures. Even in relatively light winds, a building behaves as a very large sail, and is subjected to large aerodynamic loads that push the building to one side.

Wind loads vary around the world. Meteorological data collected by the national weather services are one of the most reliable sources of wind data. Factors that effect the wind loads include building height and size, direction of prevailing winds, velocity of prevailing winds and the positive or negative pressure due to the architectural design features. All of these factors are taken into account when the lateral loads on the facades are calculated.

1.2 AIM OF PRESENT INVESTIGATION

The architect is mostly concerned with the wind environment in the immediate vicinity of the particular building bring designed. In many cases, even when the buildings are exposed, it is usually possible to provide canopies, local wind breaks, sealed arcades, etc. to achieve satisfactory wind condition in adjacent areas.

The study of flow fields induced around buildings has increased in recent years mainly because some large building have been erected which, because of combinations of shape, height and isolation, have induced wind flows in public accessways and recreational areas much higher than could be reasonably tolerated. Hence, it has become common practice now to submit building design proposals to wind tunnel testing to determine the likely wind environment around the buildings and to modify and add protection to achieve acceptable conditions.

However, it is important to realize the worst features of the tall rectangular building to avoid some unpredictable accident. To overcome the problem it is often necessary to undertake major configuration changes, such as reducing height, changing planform or setting a tower well back on a podium. It is obviously that this type of problem cannot be solved easily after a building has been constructed and must be taken into account in the very design stages.

1.3 PROJECT OBJECTIVE

It is explicitly that the problem must be solved before the building has been constructed. All of the considerable problems must be taken account at the early design stage. The building design proposal needs to be submitted to the wind tunnel testing.

The objectives of the present investigations are

1) To visualise the flow over the building model.
2) To determine the pressure distribution along the centre line of the building model.
3) To carry out CFD investigation on the same building model to determine the flow pattern over the building.
4) To determine the formation of vortices, separations zones and drag force experienced by the building.
5) To suggest practical means of reducing the drag force acting on the building.
6) To compare experimental and numerical result.

All of the above objectives are intended to be achieved at various of angles of attack to which a normal tall building is subjected to.

1.4 PROJECT SCOPE

The project scope is listed as below.

Chapter 1 of the thesis gives a general introduction to the topic of investigation and the objective of the present investigation.

Chapter 2 of the thesis gives a brief review of previous investigations carried out on flow visualization, followed by pressure distribution on the building and drag coefficient of the building against the wind.

Chapter 3 of the thesis gives a relative study of the present investigation.

Chapter 4 of the thesis gives the explanations on the project methodology like experimental setup, experimental procedures and the computational setup.

Chapter 5 of the thesis gives the experimental and computational results following by the discussions and the comparison of the result.

Chapter 6 of the thesis deals with the conclusion and future recommendation based on the present investigations.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Aerodynamic studies on the multi-storied building by the experimental or computational investigations have been one of the fundamental interests to the researchers in the area of fluid mechanics, right from the beginning of the 19^{th} century. Significant investigations have been carried out to establish the aerodynamic studies on the multi-storeyed building.

2.2 WIND PRESSURE ON TALL BUILDING

Full-scale studies are without doubt a powerful tool to analyze wind effects on structures. Recently several groups have been engaging in this subject and their results were reported here and there. Full-scale studies of wind pressures on a tall prismatic building under a strong wind are illustrated herein. The records which were obtained from a propeller-vane anemometer and wind pressure transducers provided on the structure during the highest gust are analyzed.

Makino, et al. (1971) obtained the results from the full-scale studies under the wind of about 20 m/s. They reported that the wind pressures on the leeward surface were nearly uncorrelated to the wind but greatly influenced by the wakes of the structures. Well correlated ranges of the leeward elevation were estimated as within about 20 meters. Periodic changes of the wind pressures which might be caused by Karman vortices were clearly observed on the cross-correlations of the records from the windows along the mean wind direction. Vortex excitations were not synchronized to the natural frequencies of the structure. A predominant Strouhal number of the structure was considered to be about 0.1.

In the same year (1971), Takeuchi, et al. (1971) recorded together the actual wind pressure and its response on a tall building under strong wind with wind speed on it. They showed the distribution of wind pressure over faces of the building and compared with the results obtained from the wind tunnel tests. Also from statistical point of view the records were analyzed. From the results of the analyses the following facts could be mentioned. Windward face carries almost the entire wind load. Wind pressure coefficient of windward side is larger than that at leeward side. The maximum value of the mean wind pressures appears at the centre of the windward face. The larger the mean wind pressures, the larger the deviation from the normal distribution. Under strong wind, sometimes the building shows translational vibration and at the other time shows torsional motion.

2.3 INFLUENCE OF ADJACENT BUILDINGS TO WIND

To understand the modifications of airflow by high-rise buildings in urban area, Ishizaki and Sung (1971) conducted the wind tunnel experiments on the modification of airflow in the gap between the two same size model buildings. The wind speed in the gap shows the maximum value at a certain separation distance. The maximum value of the relative wind speed observed in the experiment is 1.4 and this value decreases with increasing width of the gap, and also with increasing length of the model buildings in the direction of wind.

2.4 WIND EFFECTS ON TALL BUILDINGS

Kolousek and Pimer (1975) presented a theoretical solution of free vibration of tall building structures. Since the structure is solved as a general three-dimensional system, the modes of free vibration are not two-dimensional. In addition to a general, unsimplified solution of the system they outlined a simplified procedure which assumes the floors of the storeys to be stiff in their plane and elastic in the direction perpendicular to that plane. The second part deals with forced vibration produced by wind effects. Since the cross spectral densities of load acting on the building, are not known, an approximate solution is derived in which the building is replaced by a simple model with three degrees of freedom, and expressions are obtained of the power spectral density of the deflection. They also deduced an expression of the torque producing rotation of the building about the vertical axis. According to these results, even if a building is not wholly symmetrical, the response to wind loads is not a spatial mode of vibration but one composed of plane vibration and a torsional component. A detailed analysis of simultaneous records of displacements of four point of the sixteenth storey has revealed two kinds of response: one without the torsional component, the other with the torsional component. Torques deduced in the second part, were evaluated and their dependence on the mean wind velocity at the height of the building top was established. The response of another tall building – one with a reinforced concrete supporting structure – is also shown to be composed of plane vibration and torsion.

Models of tall buildings of constant rectangular cross-section have been subjected to simulated strong winds in a boundary layer wind tunnel by Saunders and Melbourne (1975). These models were standing clear of the upstream roughness and were orientated with one face perpendicular to the incident mean wind. The cross-wind displacement spectrum of each model was measured and the non-dimensional cross-wind force spectral density was calculated. Velocity spectra near the wake of some of the models were measured. From the measurements and analysis, it has been concluded that for tall rectangular buildings under conditions similar to those tested i.e, is the cross-wind motion of these buildings is primarily due to the energy available in the high frequency side-band of the mechanism of vortex shedding. That is, the cross-wind motion of these buildings is predominantly due to wake excitation. The non-dimensional cross-wind force spectral densities of these buildings are insensitive to the level of motion for reduced velocities up to at least 10 m/s. With the result, the effect of the level of motion on the cross-wind aerodynamic input can be neglected for rectangular-sectioned buildings.

Dalgliesh and Marshall (1972) made the research relevant to the prediction of tall building behaviour in response to wind is reviewed under the development of wind tunnel techniques for building aerodynamics. A distinct phase of wind tunnel testing to assist in the design process involved a rigid, pressure-tapped model. This model is used to determine the envelope of maximum positive and negative pressures over the building surfaces for the whole range of possible wind directions for use in the design of glass and cladding. It appears that modelling rules may need further refinement, and that scaling effects may occur in relation to flows along a building surface. The interaction of turbulence in the oncoming flow with the turbulence and flow distortion produced on the building surface at separation and reattachment lines is yet to be explored, but there are indications of significant increases in the severity of surface pressure fluctuations.

2.5 NEW TECHNIQUE FOR EVALUATING THE FLUCTUATING LIFT AND DRAG FORCE DISTRIBUTION ON BUILDING STRUCTURE

Ellis (1975) reported a new approach to the problem of finding the distribution of the fluctuating lift and drag forces and their cross correlations with height on a building structure. The technique is based on the experimental measurement of dynamic strains and accelerations at various node points on a model with a specially calibrated transducer, and using these to evaluate the unsteady aerodynamic forces. The calibrated core therefore acts as a multi-force transducer. To check the computer programs used in the evaluation, known pseudo random loads were applied to the model using vibrators and their spectra predicted using the measured response of the structure.

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