PREDICTION OF BASIC WIND SPEED FOR OMAN

By

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In the name of Allah the Most Merciful, the Most Compassionate.

Alhamdulillah, praise to Allah, prayer and peace be upon the messenger of Allah prophet Mohammed (peace be upon him).

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LIST OF SYMBOLS

a	Scale factor
V_s	Basic wind speed
v_h	Mean wind speed at height **h** above ground
v_r	Mean speed at reference height h_r
V_{sit}	Site wind speed
V_{des}	Design wind speed
H	Height above ground
h_r	Reference height
K	The exponent for best-fitting curve , shape factor
$	United States Dollar
Q_s	Wind stagnation pressure
P	Design wind pressure
P	Probability of exceedance
C_e	Combined height , exposure and gust factor coefficient
C_q	pressure coefficient for the structure or portion of structure under consideration
I	Importance factor
M_d	Directional multiplier
$M_{z,cat}$	Terrain / height multiplier
M_s	Sheilding multiplier
M_h	Hill shape multiplier
M	Rank number

N	Sample size
C_{fig}	Aerodynamic shape factor
ρ_{air}	Density of air
C_{dyn}	Dynamic response factor
P_E	Probability of exceedence
T_R	Return period
y	Reduced variate
F_u	Cumulative distribution function of the sample
U	Typical reading of the wind speed
σ	Variance of the data sample
$\mu = \bar{x}$	Mean of the sample

LIST OF ABBREVIATIONS

CUBiC	The Caribbean Uniform Building Code
BNS	Barbados standards
ASCE	American Society for Civil Engineers
ISO	International Organization for Standardization
ENV	The European Code
AS	Australian Standards
AIJ	Architectural Institute of Japan
BS	British Standards
MS	Malaysian Standards
UBC	Uniform Building Code
CP3	Canadian Code
MOIO	Ministry of Information – Oman
MIS	Method of Independent Storms
POT	Peaks Over Threshold Method
CV	Coefficient of Variation
PR	Pareto Method
GR	Gringorten Method
GM	Gumbel Method
CN	Cunnane Method
GPD	Generalized Pareto Distribution
DGANM	Directorate General of Air Navigation and Meteorology
WMO	The World Meteorological Organization

RAMALAN KELAJUAN ANGIN ASAS DI OMAN

ABSTRAK

Negara Oman dianggap unik kerana demografi dan ciri persekitaran yang jarang terdapat di negara lain. Oman juga sedang pesat membangun dan terdapat pelbagai pembinaan yang terkemuka dalam beberapa tahun kebelakangan. Oman masih tiada kod piawaian untuk beban angin yang dperlukan untuk rekabentuk bangunan. Di Oman, jurutera pada kebiasaannya menggunakan kod piawaian reka bentuk dari luar negara seperti BS8110 dan BS6399 untuk mendapatkan nilai halaju angin asas. Amalan ini adalah kurang wajar kerana perbezaan iklim dan keadaan geografi Oman berbeza dengan luar negara. Maka, tujuan kajian tapak telah dijalankan untuk menghasilkan peta halaju angin asas bagi Oman menggunakan data halaju angin harian yang diperolehi dari 13 stesen meteorologi di seluruh Oman. Ciri angin telah diperolehi secara statistik untuk memperolehi nilai purata, selisih piawaian, kesongsangan, kurtos dengan menggunakan perisian SPSS. Tiga kaedah berstatistik iaitu kaedah Gumbel, Gringorten and Cunnane telah digunakan untuk dua taburan berbeza (Gumbel dan Generalized Pareto Distribution) menggunakan tiga jenis data berlainan (Semua data, kaedah Puncak melepasi Ambang (POT), and kaedah Ribut Tak Bersandar (MIS). Nilai maksima yang diperolehi dari pelbagai kaedah ini telah disyorkan untuk menentukan halaju angin asas di Oman. Disamping data halaju angin asas harian untuk kesemua 13 stesen meteorologi, hanya terdapat satu stesen iaitu Lapangan terbang Muscat yang mempunyai data halaju angin asas setiap jam yang telah dianalisa dalam kajian ini. Nilai halaju angin asas yang diperolehi untuk stesen Muscat menggunakan MIS ialah 31.2 m/s. Halaju angin asas yang disyorkan untuk tujuan rekabentuk bangunan di Oman

adalah seperti berikut; Muscat (33 m/s), Salalah (36.5 m/s), Nizwa (33.5 m/s), Saiq (33.5 m/s), Sohar (32 m/s), Sur (31 m/s), Buraimi (34 m/s), Masirah (33.5 m/s), Thumrait (25.4 m/s), Khasab (32 m/s), Ibra (34.5 m/s), Ibri (33.5 m/s), and Qarn Alam (29.5 m/s) Peta kontor halaju angin asas untuk Oman telah dihasilkan menggunakan perisian ArcGIS untuk kegunaan perekabentuk struktur dengan harapan nilai beban angin di Oman tidak lagi bergantung kepada kod luar negara.

PREDICTION OF BASIC WIND SPEED FOR OMAN

ABSTRACT

Sultanate of Oman is a unique country with its distinct demographic and environmental characteristics typical to this country alone. It is also one of the fastest developing economies, giving rise to a spectacular construction spree seen over the last few years. Oman has no Code of Practices for Wind Loading for Buildings yet. Hence, many designers adopted foreign codes of practice such as the British Standards (BS8110, BS6399) in order to determine the value of basic wind speed for their building design. Such a practice is not appropriate on account of the prevailing differences in climatic and geographic conditions. Therefore, the aim of this study is to develop the value of basic wind speed map using collected daily wind speed from 13 meteorological stations all around Oman. The characteristics of wind speed data have been determined using statistical measures such as mean, standard deviation, skewness, and kurtoses using SPSS software. Three statistical methods namely Gumbel, Gringorten and Cunnane methods were used for two different distributions (Gumbel and Generalized Pareto Distributions) using three different data types (All data, Peaks over Threshold method (POT), and Method of Independent Storms (MIS). The maximum values determined using different methods are taken as the recommended basic wind speeds for Oman. Besides daily wind speed data for all 13 meteorological stations, the hourly wind speed data for Muscat Airport also had been studied in this research. The maximum basic wind speed produced from hourly data for Muscat using MIS-Gringorten method was 32.9 m/s. The recommended basic wind speeds for building design in Oman are as follows; Muscat (33 m/s), Salalah (36.5 m/s), Nizwa (33.5 m/s), Saiq (33.5 m/s), Sohar

(32 m/s), Sur (31 m/s), Buraimi (34 m/s), Masirah (33.5 m/s), Thumrait (25.4 m/s), Khasab (32 m/s), Ibra (34.5 m/s), Ibri (33.5 m/s), and Qarn Alam (29.5 m/s). The map developed using (ArcGIS) software for basic wind speed for Oman is a useful chart, and can be used by any structural designer in Oman and thus eliminating the usage of non-relevant values of basic wind speed taken from foreign codes.

CHAPTER 1

INTRODUCTION

1.1 General

The tall and light weight buildings are mostly affected by wind loads. As a consequence careful consideration is required in construction of such high rise structures. Besides, in order to build safe and economical structures, it is important to have a thorough understanding of wind characteristics and issues related to wind-structure interactions. Wind loads can be referred to as pressure on the windward face of the building, whereas, on leeward side it is generally presented as suction and is predicted based on the maximum velocity of the wind. However predicting the maximum wind velocity is a difficult but critical task because wind pressure varies with the square of velocity (Biggs, 1986). This problem can be overcome by predicting the basic wind speed of the actual measured wind in the location of proposed building construction. Structures subjected to high winds require realistic estimates of wind effects on components and wind load resisting systems. Low and high rise buildings show different responses for wind. For low rise buildings, the roof systems are exposed to higher loading than any other building structural element and are subjected to wind forces from many directions. This amplified pressure load could result roof lift, both in roof cladding and sheathing, leading to water intrusion and cause further content damages. High-rise buildings, in addition to the mean and the background loads, are subjected to resonant wind loads.

Several bridges around the world such as the Telford's Menai Straits Bridge in Wales (UK), Tacoma Bridge in Washington (USA), Brown's Brighton Chain Pier

(England) and Ellet's Wheeling Bridge in Ohio (USA) failed when subjected to extreme wind speeds. Figure 1.1 shows the failure of Tacoma Bridge. The 19th century experience with the failures of long span bridges and tall towers have made structural engineers more careful while addressing the influence of wind speeds (Davenport, 2002).

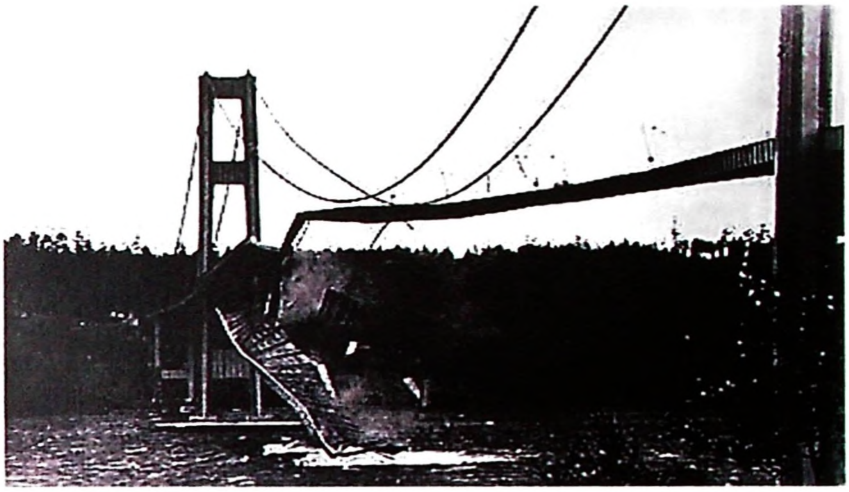

Figure 1.1: Failure of Tacoma bridge (Wikipedia, 2008)

Several interesting developments have taken place over the last five decades while evaluating the wind loading effects in structural design. Wind loading has remarkably evolved from being a simple notion of static drag forces to that involving more complicated models encompassing aerodynamics, structural mechanics, dynamics, climate, meteorology and reliability issues. The study of these domains of influence is a necessary pre-requisite in modern construction industries.

The 1950's structures were gigantic structures having relatively heavier structural members. Moreover, the construction material used was weaker and had lower strength. The heavy masonry and stone facades on buildings, use of heavy reinforced concrete deck systems on bridges rendered these massive structures to have higher dead loads. In addition to this, the use of non-structural components resulted in much stiffer structure which made it more difficult to estimate the usefulness of these non-structural elements. There was little or no emphasis on early designs to study the criticality of wind forces which in present times are reported in the form of dynamic problems requiring serious attention (Davenport, 2002).

In most countries of the world the safety of buildings and structures in extreme winds is achieved through the provisions of codes of practice and regulations. One key component of such codes is the appropriate design wind speed for the particular site being studied.

1.2 Wind

Wind refers to any flow of air above the earth's surface in a roughly horizontal direction. Wind is always named according to the direction from which it blows. For example, wind blowing from west to east is a west wind. The temperature difference between areas in the earth causes pressure difference. Air flows from areas of high pressure to adjacent areas of low pressure, the greater the difference in pressure, the greater the force and the stronger is the wind (National Research Council, 1993).

The steepest pressure gradients might not generally influence the steady wind conditions. The flow is usually directed parallel to the isobars (lines connecting points of equal pressure) rather than perpendicular to those lines. This is attributed to earth's rotational movement which tends to deflect the wind to the right in the northern hemisphere (to the left in the southern); this deviating effect is also known as Coriolis force. It requires considerable amount of time for the wind to fully develop. Initially, the wind flows perpendicular to the isobars, which later gets deflected to the right over time. When steady state is attained, the wind is observed to flow parallel to the isobars. The Coriolis force and frictional drag force then balance the pressure gradient, plus or minus centrifugal force if path is a curve.

Strong winds are usually accompanied by rain or snow or sometimes thunder and lightning and they are popularly known as thunderstorms. These thunderstorms in turn can result in the formation of tornados (rapidly spinning column of air) at certain places on earth (Liu,1991).

Like many natural phenomena wind has many advantages that benefit mankind, but it has also many disadvantages which may cause great harm to mankind. Strong winds are capable of causing damage to property and even loss of life.

1.3 Geographical Location of Oman

The Sultanate of Oman rests in the South-Eastern corner of the Arabian Peninsula between the latitudes 16° 40′ and 26° 20′ North and longitudes 51° 50′ and 59° 40′ East. Its coastal line spans a distance of about 3,165 kms from the Strait of Hormuz in the North to the borders of the Republic of Yemen, surrounded extensively by three seas; the Arabian Gulf, Oman Sea and the Arabian Sea which is part of the Indian Ocean. On its south-west boundary lies the Republic of Yemen, Kingdom of Saudi Arabia lies to its west and its North and West is flanked by UAE. The Sultanate of Oman is the third largest county in the Arabian Peninsula having a total area of the

309,500 km^2 (Oman National Census Centre, 2012). Figure 1.2 shows the map of Oman.

Figure 1.2: Map of Oman (World map finder, 2008)

1.4 Oman Climate

The climate of Oman is hot and humid along the coast; hot and dry in interior; and strong southwest summer monsoon (June to September) in far south.

The climate varies from region to region. In the coastal areas it is hot and humid in summer. In the interior it is hot and dry, with the exception of some higher places, where moderate temperature occurs all year round. In the southern region, the climate is more benign. The country's rainfall is generally low and irregular, although heavy local rains are sometimes experienced, with the exception of the southern region, where heavy monsoon rains regularly occur between June and September.

Oman is a hot country and during summer between the end of April and the beginning of November; the daily high temperatures average around 38°C. In May, the temperature is 45°C, and temperatures of 48°C and 49°C are not uncommon.

In winter from the middle of November until middle of March, the climate is moderate and sometimes cold. Along the coast, the highs are generally between 20°C and 25°C and the lowest temperatures virtually never go below 13°C, except in Aljabal Al-Akhder (the highest mountain in Oman, around 3,000m above sea level). The climate there is comfortable in summer and cold in winter.

1.5 Oman Topography

As shown in Figure 1.3, Oman consists of 5 main geographic regions namely, Al-Batinah coastal strip, the Hajar mountainous range which contains Aljabal Al-Akdar, the desert plateau which is extending to the empty Quarter (Al- Ruba Al-Khali), Musandam Peninsula in the north and Dhofar in the south which contains Salalah coast and Al-Qara mountains.

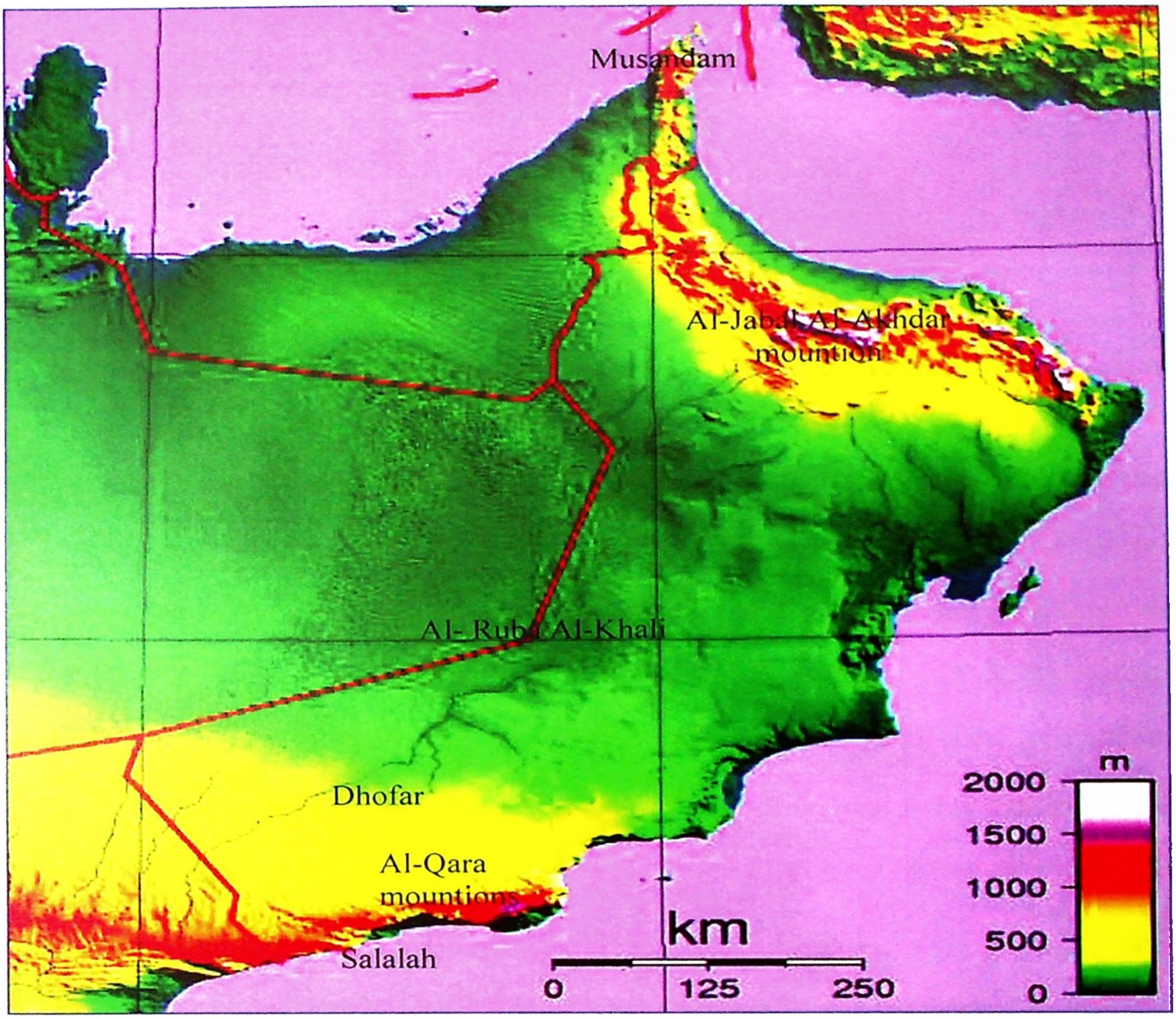

Figure 1.3: Oman Topographic Map (Wikipedia, 2012)

1.6 Cyclones in Oman

Cyclones are typical wind phenomenon in Oman. One such cyclone (Gonu Cyclone) hit the coastal areas of the country in 6th June 2007 causing extensive damage. Another tropical cyclone called Phet occured in June 2010. Cyclone Gonu is one such example of the wretched nature of cyclonic trends in Oman. The cyclone had the top gust speed of about 185-205 km/h, and the centre of the cyclonic storm was located just about 480 km from Oman Beach as shown in Figure 1.5. It approached Oman's coast at very high speed of about 18 km per hour and resulted in death of 50 people and severe damage to several infrastructures in Oman. The initial estimate of the damage incurred as a result of this cyclone was between 1.25 to 1.5 billion Omani Riyals (US$3.25 to US$3.9 billion) according to the Omani Ministry for National Economy. Figures 1.4 and 1.6 show the extent of damage on account of this cyclone.

These terrible events put additional pressure on the decision makers in Oman, particularly those related to building planning and design. Therefore, the existing regulations and strategies need to be revised to take into account all possible effects and loads influencing building structures. This gap calls our attention towards design and development of safer infrastructure which can withstand the extreme loads on account of these recurring natural disasters and thereby prevent loss of property and life in general. Considering this unpredictable nature of the environment, the research Centres and universities are asked to establish an Omani Code of Practice for Building Design based on the climatic and geographic conditions of Oman.

Figure 1.4: Damages in some houses caused by Cyclone Gonu (Roohoman, 2010)

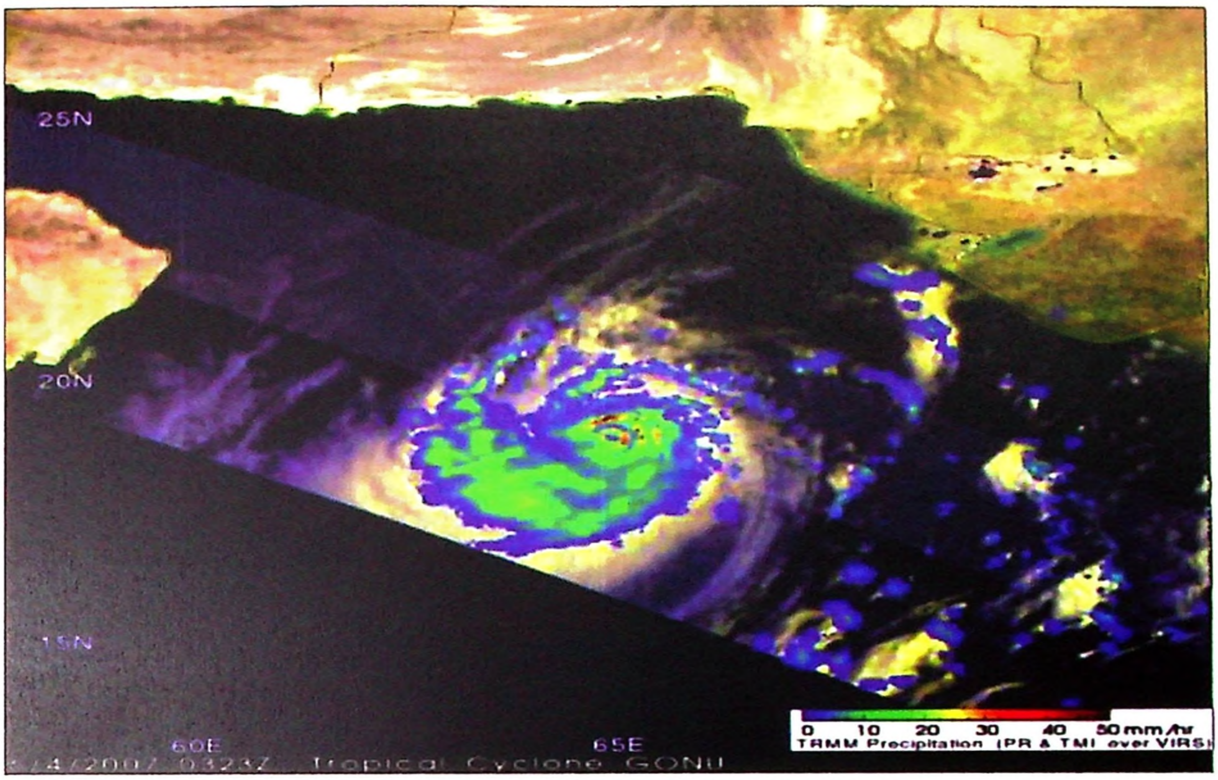

Figure 1.5: Centre of Cyclone Gonu (Omanya, 2009)

Figure 1.6: Damages in Oman's infrastructures caused by Cyclone Gonu (Roohoman, 2010)

Cyclone Phet was the second strongest tropical cyclone ever recorded in the Arabian Sea, which devastated Oman in June 2010. Phet spread heavy rains with winds reaching up to 120 km (75 miles) per hour over the heavily populated northern regions of Oman, which caused extreme flooding. It accounted for 24 deaths and an estimated 300 million Rials ($780 million) loss from the damages incurred due to this cyclone. Cyclone Phet damaged bridges, roads, desalination plants, electricity and water pipes across the country, with the bulk of destruction along the eastern coast. Many Omani residents found their homes and shopping areas submerged under water on Saturday 5th of June 2010 from flooding caused by Phet's heavy rains, and hundreds of cars were swept away (Reuters, 2010). Figure 1.6 shows a view of the damages caused by Cyclone Phet.

Figure 1.7: Damages caused by Cyclone Phet (Roohoman, 2010)

1.7 General Effects of Wind on Structures

Structural design process previously utilized simplistic assumptions while estimating live loads. However, factors such as wind, snow, earthquake, and floor loads are recently considered in the estimation of live loads on buildings, in order to arrive at more accurate analysis of the structure under construction.

The importance of wind loads in recent times can be attributed to significant growth in the high rise buildings worldwide. Also, the need for light weight low-slope roofs, structures of aerodynamic shapes and curtain wall constructions have contributed to the need for estimating correct wind loads. In the context of high rise structures, high velocity winds that strike the outward extensions can cause swaging of these structures. In certain structures, strong winds have blown off improperly anchored lightweight roofs, and roofing materials have experienced unexpected lifts due to high local suctions, which eventually blow away large areas of roofs (Dalgliesh and Boyd, 1962).

These examples thus call for renewed understanding of the effect of wind and its effects while designing tall structures. Earlier, the uniform lateral pressure on windward side of the structure and suction on leeward wall together represented the total effect imposed by wind, which were further simplified to estimate the suction or pressures on roofs. These simplifications might be sufficient for low or medium height constructions; however, the taller the structure the more significant is the effect of wind. Wind is a very complicated phenomenon, and it does not blow constantly. The complication of wind flow is that it involves turbulence wherein it would require statistical estimation of speeds associated with individual particles, rather than simple averages.

In designing any structure, architects and engineers are concerned not only with the design, but also other aspects such as the exterior cladding materials and components, operation of mechanical services such as heating and ventilating equipment, etc. Thus, it is clear that other than these factors on which wind has important effects, some other ambiguous manifestations of nature also need to be taken into account. Figure 1.8 illustrates the effects of wind on building structures (Dalgliesh and Boyd, 1962).

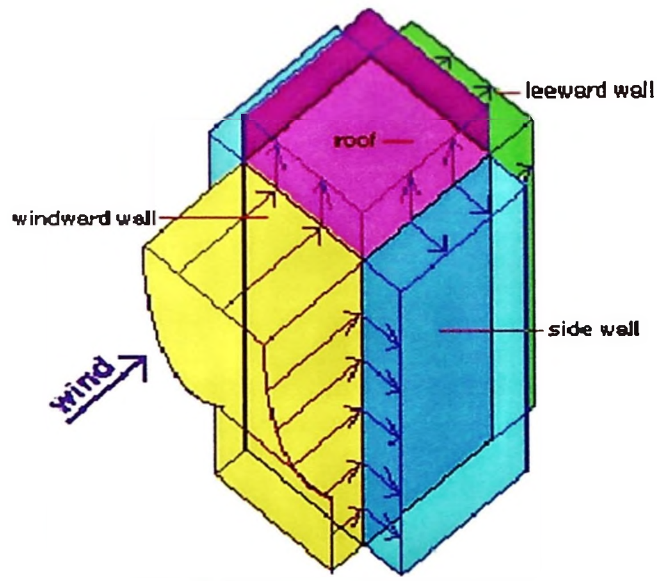

Figure 1.8: Wind effects on structures (Dalgliesh and Boyd, 1962).

The type and magnitude of the applied load and the structural strength and stiffness have a big influence on an engineering structure responding to various loading conditions. There are several requirements that need to be heeded in order to consider if the response is satisfactory or not. Some of the precautionary conditions that should be met include primarily the safety of the structure against collapse, other than limitations imposed on damage, or on deflections or other criteria. Although these design requirements are considered important over many years, it is generally overlooked at the hindsight.

Therefore structural engineers should ensure reliability and safety of any building by able to forecast and assess the risk factors. Although the notion of risk assessment is practiced to large extent in other professions, but the need for a more stringent life risk assessment is required particularly in the design of safe structures.

This risk management approach will have shorter and familiar exercise for structures demonstrating established behaviour and robustness. It is only in case of structures which are relatively larger or having complex architectures, other aspects like fire strategy, possible deterioration, risk associated with the degree of redundancy, decommissioning and similar extreme events would play major roles.

In order to estimate the extent of safety check, the ratio of the section strength to the section force is compared with the safety factor. The section strength is calculated by using an appropriate physical equation using the design material strength; whereas the section force is calculated by using appropriate structural analysis by taking into account the design load. The following steps are followed while determining the safety check, considering the margin of the safety:

- The design material strength is determined
- Section strength is calculated
- Design load is estimated
- Section force is calculated
- Finally the safety factor is determined

The inclusion of these partial safety margins ensures the safety of the structural section at the ultimate limit state (Melchers, 1999)

1.8 Definition of Basic Wind Speed

According to Gibbs et al. (1981) the definition of the basic wind speed (Vs) is the 3-second gust speed estimated to be exceeded on the average only once in 50 years at a height of 10 m above the ground in an open situation. Table 1.1 shows the values of basic wind speed for some countries around the world including some Arab countries such as Saudi Arabia and Dubai. These values are obtained from different codes of practices and from previous researches. The value of Oman basic wind speed was taken from Almaawali (2007) who conducted analysis for annual and monthly wind speed data from 10 stations. The accuracy of these values for Oman basic wind speed requires verification to use it in building design process. An indication of the less accuracy of these values is the big difference between the highest value (52.6 m/s) and the lowest value (36.5 m/s) since Oman climate is almost the same for all regions; so it is quite irrelevant to have this much difference in basic wind speed. The analysis of more data such as daily or hourly wind data and more techniques may improve the accuracy of the basic wind speed value.

An important factor affecting the basic wind speed is the return period which is an estimate of the interval of time between events of certain intensity. It is the inverse of probability of exceedance. For example a 50 year return period equals 0.02 or 2% probability of exceedance.

This proves that the prediction of basic wind speed must be done through statistical analysis as mentioned in many text books (Holmes, 2001; Ambrose and vergun, 1987) and works of (Harris, 2000; Cook, 2011) and not just by adapting the raw data wind speed.

Table 1.1: Basic wind speed in some countries

Country	Basic wind speed (m/s)	Recorded data used	Reference
Malaysia	32.5-33.5	Hourly	MS1553, 2002
Oman	36.5 – 52.6	Annual and Monthly	Almaawali, 2007
Saudi Arabia	33-44	Annual	Arafah et al, 1987
Sudan	31-43	Annual	Wahab et al, 2001
UK	20-30	Hourly	BS6399, 1995
USA	38-67	Annual	Simiu et al, 2001
Brazil	30 – 50	Annual	Holmes, 2007
India	33-55	Annual	Krishna et al, 2004
Germany	22.5-32.5	Daily	Kasperski, 2002
UAE (Dubai)	35-39	Annual	Holmes, 2007
Denmark	22-25	Annual	Kristensena et al 2000
Singapore	24.8-26.8	Annual	Choi and Tanurdjaja, 2002

1.9 Problem Statement

With increasing trend observed all over the world to build higher and lighter buildings, the safety of such gigantic structures is a major concern. Since these high rise buildings are affected by wind loads, it must be taken into consideration while designing. The establishment of appropriate basic wind speed is a critical first step towards the appropriate calculation of design wind loads for structures. Therefore basic wind speed (V_s) must be determined based on the climatic condition of each country.

In Oman the usual practice is to adapt design wind speed of foreign codes of practice, which can be quite irrelevant due to differences in climatic and geographic conditions. The values adapted from other codes or taken from the raw data can be unsafe if the predicted value is higher. On the other hand, it is non-economical if the predicted value is extremely less than the basic wind speed for which it is designed.

A few studies have been conducted to estimate the basic wind speed in the context of Oman. For example Almaawali (2007) performed a preliminary study to determine the basic wind speed using data collected from only 10 stations in Oman. He used the annual and monthly wind data and estimated the wind speed using only two prediction methods namely, Gumbel and Gringorten. The results are based on only 10 stations; therefore, it might be inaccurate and differ from the actual practice. By contrast the use of more data (daily) and more prediction methods can give more reliable results and improve the confidence in the building design, such process is widely used by many countries in producing their own code of practice as listed previously in Table 1.1.

Even the countries with own codes of practice are required to perform regular revisions for the values after some period of time by adding new data in the analysis, or employing new methods to increase the accuracy in design values similar to those conducted by Kasperski (2002) and Franklin (2012).

Almaawali (2007) found that the values of basic wind speed range from 36.5 m/s to 52.6 m/s, based on annual and monthly wind speed data. These values are relatively high when compared to the neighbouring countries like Saudi Arabia (33-44 m/s) and Dubai (33-39 m/s). The high value of basic wind speed predicted by Almaawali (2007) may be uneconomical and can lead to overdesign. In any design project for large structures, safety considerations must be balanced against the additional cost of over-design. The survey conducted with some engineering design firms in Oman showed considerable variability in the values of basic wind speeds they used (26-55 m/s). Therefore more efforts to obtain a better estimate of extreme wind speeds must be focused on at-site modelling, which means that only the information at the site of interest should be used for statistical inference. Thus performing statistical analysis of recorded wind speed is necessary

1.10 Objectives of Research

The main aim of this research is to predict the basic wind speed for design of building structures in Oman by achieving the following objectives:

1) To determine the characteristics of daily wind speed data in Oman.
2) To predict the basic wind speed for 13 cities in Oman using three different prediction methods (Gumbel, Cunnane and Gringorten) and two probability distributions (Gumbel and Generalized Pareto distribution) with three different data types [all data, Peaks Over Threshold (POT) , and Method of Independent Storms (MIS)].
3) To propose basic wind speed map for designing building structures in Oman.

1.11 Scope of Research

This research is an important step in determining the wind loads in Oman which will be able to utilize when structural experts decide to introduce Omani Code of Practice based on the geographic and climatic conditions of Oman. In this research daily wind gust data are analysed through nine different ways. The three methods used are Gumbel Method, Cunnane Method and Gringorten Method. The data types used are all data and part of data (Peaks over Threshold Method and Method of Independent Storms) with two common distribution methods, namely; Gumbel and Generalised Pareto Distribution for comparison and more reliable findings. Moreover this research aims to determine the basic wind speed for building structures in Oman by statistically analysing daily wind speed data measured in 13 stations in different regions of Oman. These stations were chosen among 23 meteorological stations available in Oman. These 13 stations are the oldest stations and having a continuous record of more than five years. The remaining stations were established recently (less than five years); therefore, the data from these stations cannot be considered. The data are used in the identification of the daily wind speed characteristics, which are used to estimate the basic wind speed for the 13 stations. Finally, a map for basic wind speed in Oman is developed for use by design firms in building design process.

1.12 Thesis Layout

This thesis is compiled in six chapters. A brief outline of each chapter is given below:

- Chapter 1 describes the general overview and background of the research, research objectives, problem statement, and scope of research and thesis layout.

- Chapter 2 presents the literature review on the subjects related to the research study such as the wind speed measuring instruments, Parameters for determining design wind speeds, wind velocity profile, turbulence in surface winds, dynamic effects, wind tunnel, different codes of practice for wind loads, building code requirements for wind, wind data in Oman, basic wind speeds in some countries, some previous studies in the field and a review of some statistical distributions commonly used in wind engineering.
- Chapter 3 shows the methodology of the research; a brief description of how the study is conducted starting from data collection, the statistical analysis procedures and the methods used in the research to obtain the main aim of the study.
- Chapter 4 illustrates the sample size of wind data and the characteristics of daily wind speed in Oman and a study about the present situation of basic wind speed in Oman by designing a questionnaire to some design firms and analyzing the outcomes.
- Chapter 5 presents the prediction of basic wind speed using three different methods with two probability distributions and three data types then comparison of these methods to overcome with the recommended basic wind speed for Oman in the form of table and map.
- Chapter 6 gives the conclusions and some recommendations for future studies in the field of wind engineering in Oman.

1.13 Thesis Contributions

The main contributions of this research are summarized as follows:

1. The characteristics of daily wind speed data for 13 stations in Oman have been identified for the first time.
2. New methods such as Cunnane Method, POT and MIS, have been used in this research for the analysis of Oman daily wind speed data.
3. Comprehensive comparison of different methods for extreme wind estimation in Oman has been conducted, which does not exist in literature before. A comparative extreme value analysis of wind speed data in Oman is performed in this research using different methods, namely, Gumbel Method, Gringorten Method, Cunnane Method, Peaks over Threshold (POT) and Method of Independent Storms (MIS). The analysis highlights the influence of methodological differences on the estimates of design wind speed corresponding to 50 years, 100 years, 500 years and 1000 years return periods. Besides the results demonstrate that the MIS Method is more stable than POT Method.
4. The basic wind speeds for designing structures in Oman have been determined for the main 13 cities in Oman. This useful information is presented in the form of Table and Map and is now available to all Engineers and designers.

CHAPTER 2

LITERATURE REVIEW

2.1 Preface

This chapter reviews many topics related to this study such as the wind speed measuring instruments, parameters for determining design wind speeds, wind velocity profile, turbulence in surface winds, dynamic effects, wind tunnel, different codes of practice for wind loads, building code requirements for wind, wind data in Oman, basic wind speeds in some countries, some previous studies in the field and a review of some statistical distributions commonly used in wind engineering.

2.2 Wind Speed Measuring Instruments

Weather conditions are measured by standard instruments. Wind vanes are the first instrument used by ancient Greeks to determine wind direction, and the use of anemometers became popular by the middle of fifteenth century (National Research Council, 1993). These anemometers were used in the measurement of surface wind speeds. It consists of three or four wind-driven cups mounted on a vertical axis whose rate of rotation varies with wind speed. Wind direction is indicated by a vane, a pointer that swings with the wind and is mounted on a vertical axis attached to a compass rose. For weather measurements, wind direction always refer to the direction from which the wind is blowing.

In Oman, cup anemometers are widely used in wind speed measurement whilst the wind vanes are used to determine wind direction. These instruments are installed at 10 m height and they use the 3 second gust as averaging period.

Figures 2.1 (a) and 2.1 (b) show the instruments used in wind speed measurement; the photo shown in Figure 2.1(a) is taken while the pole was tilted for maintenance so the instruments used where very clear, whereas Figure 2.3 shows the wind speed measuring station in Nizwa.

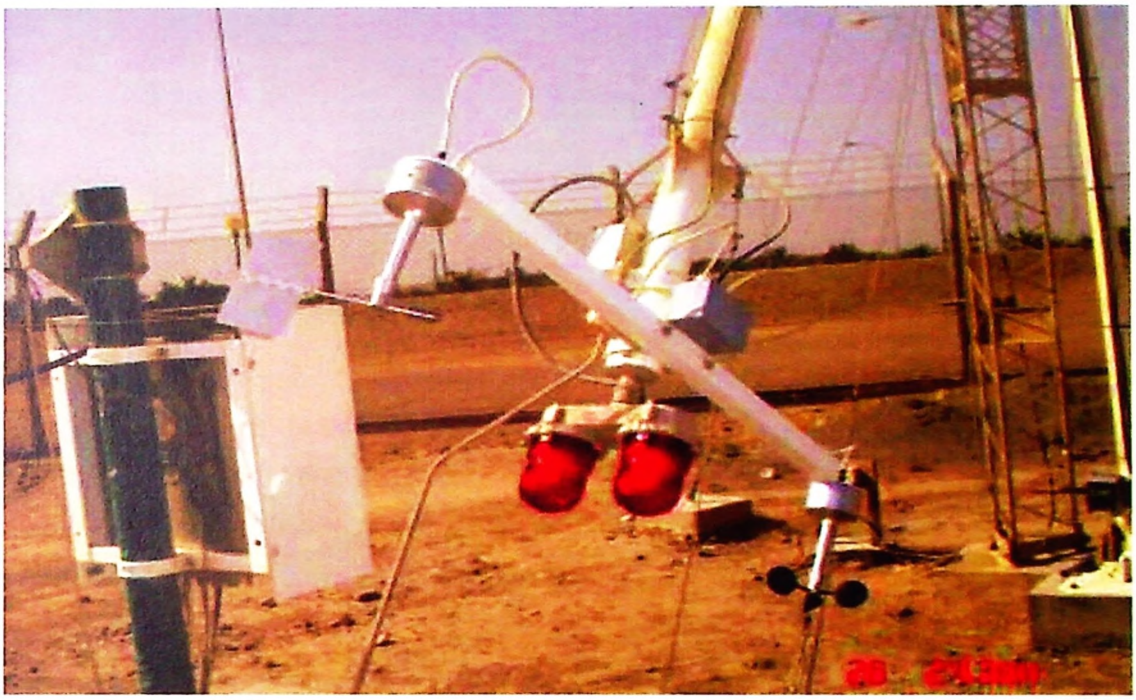

Figure 2.1 (a): Instruments used in wind speed measurement

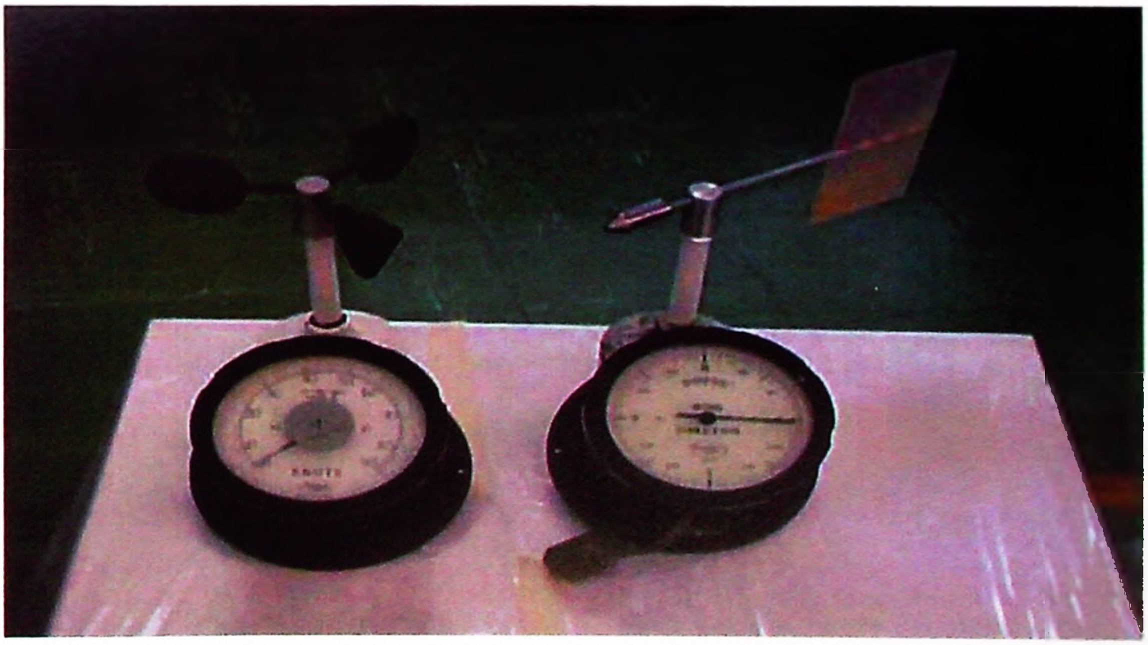

Figure 2.1 (b): Instruments used in wind speed measurement

Figure 2.2: Wind speed measuring station at Nizwa

2.3 Parameters for Determining Design Wind Speeds

Wind speed measured in meteorological stations with anemometers are then converted by structural engineers to wind loads in accordance with the codes and standards. Wind loading standards are very useful and provide procedures for determining the loads on specific structures, in specific locations and for specific conditions and needs. They begin with general (or neutral) conditions and then move towards the specific (Gibbs et al., 1981).

The neutral data about the wind speed can be defined in terms of averaging period, return period, height above ground, topography and ground roughness. According to Gibbs et al. (1981) the definition of the basic wind speed, Vs is the 3-second gust speed estimated to be exceeded on the average only once in 50 years at a height of 10 m above the ground in an open situation.

The basic (or reference) wind speed is then adjusted for specific cases using various parameters such as averaging period, return period, ground roughness, height, topography and size of structure in order to obtain the design wind speeds for the particular cases.

2.3.1 Averaging Period

Anemometers are useful in making direct measurements of wind speeds. One of the characteristic features of a mechanical anemometer is its response time which in turn is a function of inertia of the system. Mechanical anemometers have been developed with response time as low as 1-3 seconds.

Some countries like Australia, USA and Barbados have adopted the 3-second gust as the averaging period for the basic wind speed. The UK used the 3-second gust up to 1995 and later adopted the 1-hour average. The wind speed data for any particular averaging period can be converted to a wind speed for any other averaging period using relationships determined experimentally and analytically. These relationships can be analysed using the semi-log S curve (Gibbs, 2000).

2.3.2 Return Period

Although, wind speeds are amenable to statistical analysis, the historical record is not sufficiently long for such analyses to be reliable. Despite this, it has been popularly adopted in common practice for statistical analyses by adjusting them on theoretical basis, for determining the relative wind-speeds expected to occur over different periods of time. The concept of probability is widely adopted in the design of