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A parametric analysis of wind effects on tall buildings according to European, American, and Australian standards

Abstract:

As the construction industry is booming day by day all around the world and different codes are followed in different countries. There is a need in the construction industry to compare the various effects of wind loads on tall buildings by using different codes and different approaches. A parametric analysis of the wind effects will be done on tall buildings using different international codes and standards. The results will then be compared using Excel computer programs to find out the similarities and differences in various approaches. Wind load estimation is a lengthy process due to this reason various institutions publish their own research and standard procedures for wind load applications on various structures. Wind load calculations consider various factors include i.e., wind speed, effective wind speed, orography factors, dynamic factors, gust loading factors, and shape factors. These all factors are different in various design codes. A comparative study was published in 2013 (Kareemb, 2013) which compared these factors given in different international codes. After a detailed literature review, a requirement for wind analysis on a full-scale model arises using different international codes to understand the wind loading effects in more detail and to make a comparison. The main objective of this research is to create a clear comparison of the various international wind codes after applying them to a common model to see the differences and similarities. As the UK is highly subjected to high winds so a lot of damage has been done each year due to storms and winds. Although BS and National Annex to Eurocodes (BS EN 1993-1-4) provide a sufficient level of safety against wind loads. But a comparison with other international codes may increase safety as well and minimize the costs of the projects.

Keywords:

Wind Loads, Leeward, Windward, Uplift, Sliding, International Codes, Eurocodes, ASCE, Tall Buildings

Contents

List of Figures	3
List of Tables	4
Abstract.....	Error! Bookmark not defined.
1. Introduction:	6
1.1 Wind Loads	6
1.2 Factors affects Wind Loadings:	6
1.1.1 Location of the site:	6
1.1.2 Distance from the sea:	6
1.1.3 Obstructions near the site:	6
1.1.4 Topography:	6
1.1.5 Direction:	6
1.1.6 Exposure:	7
1.1.7 Geometry of structure:	7
1.3 International Codes:	7
1.3.1 Australian Code (AS /NZS 1170.2:2011):	7
1.3.2 European Code (BS EN 1991-1-4):	7
1.3.3 American Code (ASCE 7-10):	7
1.4 Parametric Data Analysis:	7
1.5 Excel for Analysis:	8
1.6 Research Problem:	8
1.7 Objectives:	8
1.8 Thesis Outline:	9
1.8.1 Introduction:	9
1.8.2 Literature Review:	9
1.8.3 Methodology:	9
1.8.4 Results and discussions:	9
1.8.5 Conclusions:	10
1.8.6 Appendices:	10
2. Literature Review:	11
2.1 The Motive of research:	11
2.2 Types of natural wind:	11
2.2.1 Cyclones:	11
2.2.2 Tornados:	11
2.2.3 Straight-line winds:	13
2.2.4 Downdraft:	14
2.2.5 Microburst:	14

2.2.6	Macro-burst:.....	14
2.3	Damages due to the wind:	14
2.3.1	Water Seepage:.....	14
2.3.2	Sliding Failure:.....	14
2.3.3	Overturning:.....	14
2.3.4	Vibrations:.....	14
2.3.5	Corner wind:	14
2.3.6	Turbulence:.....	14
2.3.7	Funneling Effect:	15
2.3.8	Uplift:.....	16
2.3.9	Downward Pressure:	16
2.4	Pressures:.....	16
2.4.1	Internal Pressure:	16
2.4.2	External Pressure:	17
2.4.3	Net Pressure:	18
2.5	Wind Codes and their role in Industry:	19
2.6	Previous Research:	20
3.	Methodology:	21
3.1	Characteristics of the site:.....	22
3.2	Wind Loadings as per Eurocode 1:	22
3.2.1	Limitation:	22
3.2.2	Procedure and factors:	22
3.2.3	Probability Factor:	22
3.2.4	Application of Wind load to buildings:.....	24
3.3	Wind Loading as per ASCE 7-10:	26
3.3.1	Basic Wind Speed:	26
3.3.2	Pressure:.....	26
3.3.3	Other factors:.....	27
3.4	Wind Loading as per AS / NZS 1170:.....	30
3.4.1	Minimum Design Wind Speed:.....	31
3.4.2	Conservative Approach:	31
3.5	Data Handling in Excel sheets and Calculations:.....	32
4.	Results and Discussion:	33
4.1	Wind Loads with Eurocodes:.....	33
4.2	Wind Loads with Australian Codes:	33
4.3	Wind Loads with American:.....	34
4.4	Comparison:	35

5. Conclusion and Recommendation:	39
6. References	40
Appendix A	41

List of Figures

Figure 2.1:Probability (%) of a tornado occurring in a 10-km grid box across the British Isles per year, using a 15-day temporal and 50-km spatial smoothing parameter (Source: Mulder and Schultz, 2015).....	13
Figure 2.2:Wind pattern when wind attacks the tall urban building (Source: https://www.windcrane.com/blog/construction/wind-speed-patterns-city-buildings)	15
Figure 2.3:Wind forces acting on the buildings (Source: https://www.tremcocpg-asiapacific.com/).....	16
Figure 2.4:Wind Pressures in buildings(Source: https://www.dlsweb.rmit.edu.au/)	18
Figure 2.5: Wind Pressures acting on the buildings (Source: https://www.paramvisions.com/2022/10/what-is-wind-load-over-structurewhat-is.html)	19
Figure 2.6: Comparison of various storey shear forces from different codes (M. T. Cogurcu, 2019)	20
Figure 2.7Comparison of various storey moments from different codes (M. T. Cogurcu, 2019)	20
Figure 3.1: Flow Chart for methodology of research.....	21
Figure 3.2:Formula for probability factor as per Eurocode (Source: BS EN 1991-1-4:2005+A1:2010).....	23
Figure 3.3: Informative Flowchart as per BS EN 1991-1-4 (Source: National Annex to Eurocode 1).....	24
Figure 3.4: Pressure on the Surfaces as per BS EN 1991-1-4 (Source: Eurocode 1)	25
Figure 3.5 External Pressure Coefficients as per (BS EN 1991-1-4:2005+A1:2010) (Source: Eurocode 1).....	25
Figure 3.6Key for vertical walls (Source: BS EN 1991-1-4:2005+A1:2010).....	26
Figure 3.7:Velocity exposure factor coefficients are given in table 27.3.1 of ASCE.....	28
Figure 3.8: External pressure coefficient for walls can be obtained from 27.4-1 of ASCE. ...	28
Figure 3.9: Flow Chart for Wind load estimation as per American Wind Code (Source: ASCE 7-10)	29

Figure 3.10: The figure of orthogonal axes from the Australian Wind Code (Source: AS / NZS 1170).....	30
Figure 3.11: Site Wind speed definition from the Australian Wind Code (Source: AS / NZS 1170).....	31
Figure 3.12: Wind Pressure definition from the Australian Wind Code (Source: AS / NZS 1170).....	31
Figure 3.13: $M_{d\ Cat}$ for Ultimate Limit state (Source: AS / NZS 1170).....	32
Figure 4.1: Excel Sheet for calculations as per Eurocode	33
Figure 4.2: Excel Sheet for calculations as per Australian Wind Code.....	34
Figure 4.3: Excel Sheet for calculations as per American Wind Code.....	34
Figure 4.4: Graph for Base Shear Against height for various codes.....	35
Figure 4.5: Graph for Bending Moment Against height for various codes	36
Figure 4.6: Comparison table of various codes from study (Dae Kun Kwon, 2013).....	38
Figure 4.7: Base shear forces in a building against various codes (M. T. Cogurcu, 2019) ..	38

List of Tables

Table 4-1: Table for the comparison of results achieved in the research for base shear and bending moments.....	37
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1. Introduction:

1.1 Wind Loads

Wind loads are the types of loads that act on the surface of the buildings when a strong wind blows. As a civil and structural engineer, one should consider the effects of these loadings while designing the structure.

1.2 Factors affects Wind Loadings:

There are multiple factors that affect the wind loads acting on the structures. Below is the discussion on the different factors affecting wind loads.

1.1.1 Location of the site:

Site location is an important factor as it will decide the intensity and direction of the wind loads acting on the structure. The following geographic factors must be considered while doing wind load analysis:

1.1.2 Distance from the sea:

The wind blows at a very high speed if there is no obstruction in the way and in the sea, there is no obstruction to stop the wind or to reduce the speed of the wind. Due to this reason, the beaches are always subjected to very high wind speeds.

Due to this reason distance from the sea plays an important role when describing the wind speed acting on the structure. The more the site is located the sea more will be the wind speed and wind pressures acting on the structure.

1.1.3 Obstructions near the site:

Obstructions always cause the wind speed to get lower. The area with high obstruction will have less wind speed while those areas where the obstructions are not as high wind speed will be high there.

1.1.4 Topography:

Topography or orography is a geographical feature of the ground surrounding the site, for example, a hill or a valley. These geographical features impact wind speed a lot. They can increase or reduce the wind speed acting on the structure. In order to consider these effects various international codes, use the orography or topography coefficient.

1.1.5 Direction:

The direction of the wind also plays an important role while calculating the wind loads on the structure. Different directions receive different wind speeds, and the maximum wind speed is acting on one of the faces of the structure.

1.1.6 Exposure:

Exposure is a very important aspect in calculating the wind loads on the structure. The more the height of the structure more it will be subjected to wind loads. Wind loads become high as building goes higher.

The wind loads calculated in codes are mostly measured at 10 meters in height. Considering the effect of height on the structure's exposure factor is applied to the wind loads.

1.1.7 Geometry of structure:

The geometry of the structure also plays an important role in determining the wind loads on the structure i.e., the tall building will experience more wind loads as compared to the small building. Similar structures such as with mono-pitched or duo-pitched roofs are subjected to different types of wind loadings.

1.3 International Codes:

In the world, there are various codes used for designing structures and calculating the loadings on the structure. A few of the codes used in this project are given below:

1.3.1 Australian Code (AS /NZS 1170.2:2011):

Australian design code is developed by Australian / New Zealand Standards.

The latest version of these codes is published in 2021 which supersedes the one published in 2011 and its addendum which was published in 2016. This code is widely used in Australia and New Zealand to estimate wind loads.

1.3.2 European Code (BS EN 1991-1-4):

Eurocodes were first developed in 1980 and later, various other sections were added to the codes. Also, the UK developed its own national annex to read in conjunction with the relevant Eurocodes. Eurocode 1 deals with the loadings on the structures and parts 1-4 deal with wind actions on the structures. Before Eurocode, British Standards were used in the UK to estimate the loadings on structures. The British Standards used were BS 6399 for load actions and the wind loading part is BS 6399 part 2. These codes are widely used in various parts of the world as well i.e. United Arab Emirates and other Gulf States.

1.3.3 American Code (ASCE 7-10):

ASCE 7-10 are developed by the American Society of Civil Engineers to provide the different loading effects and conditions on the structures. Chapters 26 to 29 have been used in this research project. This code is widely used all over the United States and various other countries i.e., Pakistan and sometimes in the Middle East.

1.4 Parametric Data Analysis:

Data is considered a new oil for the next generation. Data also plays an important role these days in finding out the various results. Also, data plays an important role in future predictions and Artificial Intelligence. Parametric Analysis is a separate branch of Statistics that deals with the change of the response of the model with the change of parameters.

1.5 Excel for Analysis:

Although a lot of tools are available these days to carry out data analysis and to represent the data in the form of graphs or visuals excel is easy to use of them. Due to these reasons excel is used in this research project.

1.6 Research Problem:

Most of the questions will be answered in this research report but a few of the questions listed below are aimed to be answered by the end of the report.

- Which wind design code is safer?
- Which Wind design code is more economical?
- If I got chosen as a Structural Engineer which code, should I adopt?
- Which code provides the maximum bending moment in structure?
- Which code will give the maximum base shear in the structure?

Although a lot of codes are available as mentioned above around the world, still there is a need to find a code that can be safer and more economical. Also, there is not any research already available which considers the effect of heights as well. Experimental testing is very expensive, and a lot of costs are involved to get the best results for wind load analysis, but the comparison of different codes can be useful in selecting the best option among the available ones.

Parametric data analysis will also provide the trends of the data and fluctuations of data with respect to the variation in heights for various codes.

1.7 Aims and Objectives:

The aim is to compare how the wind loads according to BS EN 1991, ASCE 7-10 and AS / ANZ 1170 affect the response of the buildings in terms of base shear and base moment for different building heights.

The main objective of this research project is to analyze the effects of height changes on wind loads, bending moments, and base shear on structures for various codes used internationally i.e. Eurocodes and ASCE codes. The following are the objectives of this research project:

- To study Australian, American, and European codes for wind loads on structures and appreciate the provisions adopted in each case.
- Build a program in excel software to calculate wind loads in accordance with these codes.
- Perform a parametric analysis for different building heights and compare the wind loads produced based on the different codes
- Thorough study of wind loadings and their effects on the structures.
- Study of factors affecting wind loads.
- Perform a deep and detailed study of international wind codes.
- Provide the side-by-side comparison of three international codes I.e., Australian, American, and European.
- Study the variations in wind load effects provided by each code against the changing heights of the structure.

1.8 Thesis Outline:

This research report comprises the following chapters:

1.8.1 Introduction:

In this chapter, the research basis and basic methodology are provided also this topic provides information about the various codes used in this research. Also, this chapter provides the basic idea of the technique which will be used in the project. It also outlines the objectives of the project.

1.8.2 Literature Review:

In this section the comparison carried out by various researchers and their findings has been included. Various coefficients and equations compared by various researchers in their papers have been discussed in this section.

1.8.3 Methodology:

In this section, the overall methodology has been discussed. A complete and thorough study of various international codes has been carried out in this section. The method of each code to find the wind loads on the buildings is discussed in detail along with a flow chart where possible. Also, this section contains the various coefficient values which are used in the calculations.

1.8.4 Results and discussions:

In this section, the results are discussed in detail. The graphs are discussed in detail which are created with the data obtained through the calculations in excel for all codes and various heights.

1.8.5 Conclusions:

This section summarizes the research work and provides suggestions for future work.

1.8.6 Appendices:

This section includes all data generated through the excel sheets

2. Literature Review:

A lot of research has been carried out on the comparison of the different wind codes. Many research papers have been reviewed to get the required knowledge to proceed with the research.

A comparison of calculations of wind loads on low, medium and high rise buildings, using fifteen different codes, including Australian, Canadian, Eurocode, American, Taiwanese and Japanese codes, has shown that “The coefficient of variation for the results for the low-rise (5.85m tall) building is somewhat large, considering its comparative simplicity as opposed to the complexities in the Buildings 2 and 3. For the medium-rise, 48m tall building (Building 2), no significant correlation was observed between the along-wind load effects, i.e. base shears and base bending moments, and dynamic response factors or gust loading factors. The mean values and coefficients of variation of the fifteen codes/standards in the Asia-Pacific region were calculated, and the coefficients of variation were estimated at around 22% - 23% for both: along-wind overall load effects and cladding pressures. And the coefficients of variation for both along-wind and crosswind responses were relatively small – in the range of 14 to 18% for the high-rise (183m tall) building.” (John Holmes, 2009)

The following are the reviews obtained with the previously done research and books written on wind loading and code comparison topics.

2.1 The Motive of research:

As already explained, the research is carried out due to the importance of the economy and safety of the structures.

“As buildings become taller their sensitivity to wind loads increases. Therefore, an accurate determination of the wind-induced building response is necessary to ensure safe and economical designs.” (H. M.A.D. Jayasundara, 2018)

2.2 Types of natural wind:

Following are the wind types which can do deadly damages to the structures:

2.2.1 Cyclones:

Cyclones are the winds rotating around the zones of low pressures.

2.2.2 Tornados:

A tornado is a violently rotating air column which rotates at high speed. It's more likely a vortex of air. They can spin in clockwise as well as anticlockwise direction. In the northern

hemisphere they spin in anticlockwise fashion but in southern hemisphere they spin clockwise direction. The rotation wind speed can vary from 110mph to 300mph, and diameter can be up to 2 miles. Mostly the debris and dust are the major of the tornado. The Northwest to East Anglia of England is more subjected to tornadoes. Also, the UK is surrounded by the sea from all sides. When a tornado forms near the coast of the UK they can easily indulge water sprouts in it which start rotating at the violent speed and causing way more damages in the coastal area extending up to several villages. (Abbey, 1976)

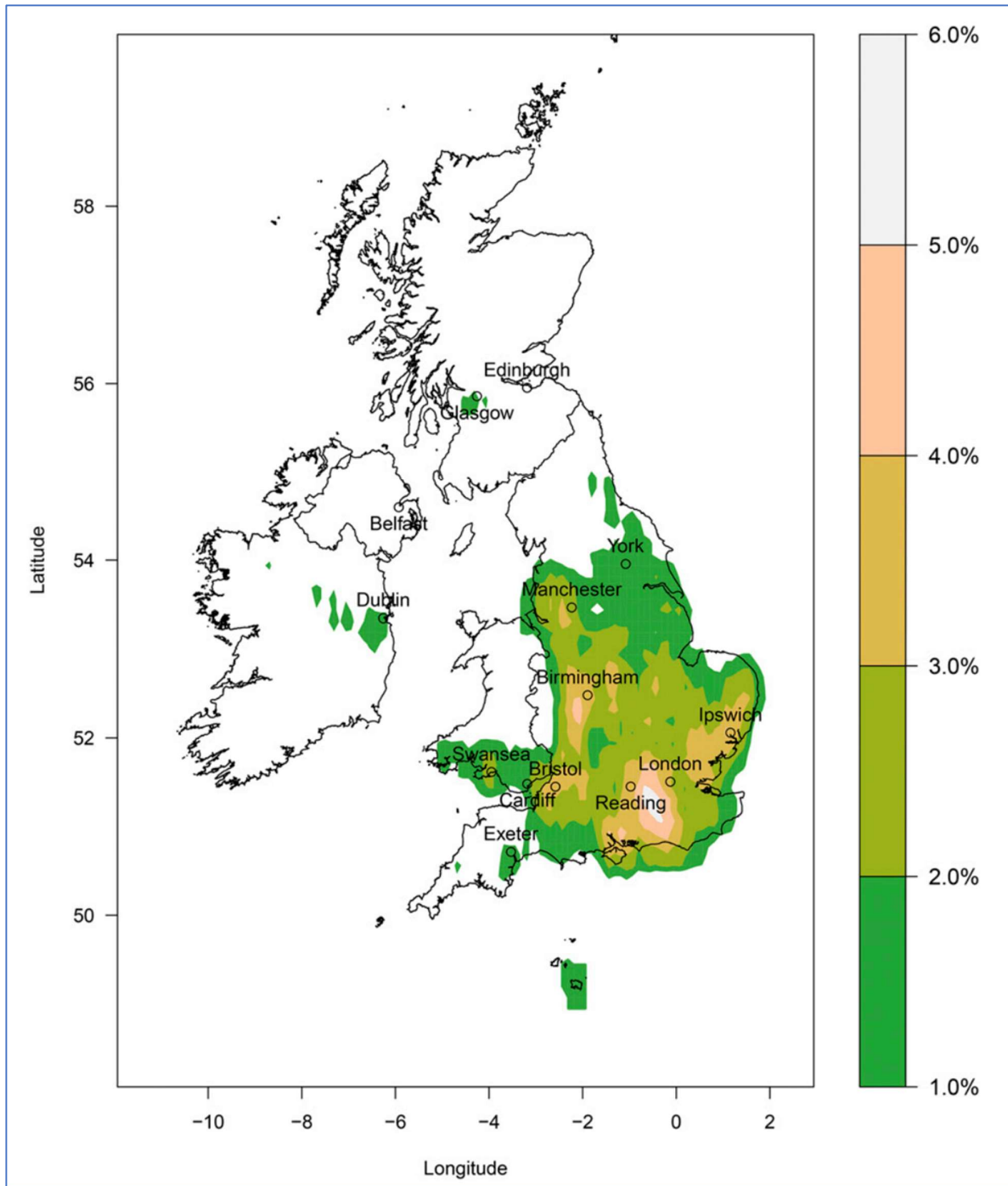


Figure 2.1: Probability (%) of a tornado occurring in a 10-km grid box across the British Isles per year, using a 15-day temporal and 50-km spatial smoothing parameter (Source: Mulder and Schultz, 2015)

The occurrence probability of tornados in UK is given in figure 2.1 as per Mudler. (Mulder and Schultz, 2015)

2.2.3 Straight-line winds:

These winds usually travel in the straight line, and they don't have any rotation in them. And they are different from the tornado.

2.2.4 Downdraft:

Downdraft is the motion of the wind in the downward direction rapidly. Although its not the large amount of wind it's only the small portion of wind.

2.2.5 Microburst:

Microburst is a small, concentrated downdraft for small interval of time.

2.2.6 Macro-burst:

Macro Burst is the motion of the wind in outward direction near the earth surface with horizontal dimension more than 2.5 miles.

2.3 Damages due to the wind:

There are incidents and catastrophes that happen each year around the world due to wind loads. The main reason for the damage is non-safe buildings which are not designed as per the correct international wind design code or standards.

2.3.1 Water Seepage:

Most of the damage happens when the structural components are not strong enough to resist the wind and broken down due to wind due to which the water from rain seeps inside the building causing damages further.

2.3.2 Sliding Failure:

High winds can cause structures to slide and move away from their original position.

2.3.3 Overturning:

Overturning is the phenomenon which happens when the disturbing forces are greater than the stabilizing forces. So due to high wind the equilibrium of the structure can be at risk of failing and shifting toward the disturbing forces.

2.3.4 Vibrations:

Any force which is acting in the lateral direction can cause disturbance in tall structure. These disturbances can cause vibrations in the structure which can be dangerous for the overall integrity of the structure and structure might fail due to these vibrations. Due to these effects various codes have a separate provision to encounter the vibrations in the structure.

2.3.5 Corner wind:

When wind acts at the corner of the free-standing wall it's the worst case which can be observed for these types of walls or even in tall buildings.

2.3.6 Turbulence:

Turbulence is caused when wind is not blowing in streamline fashion. This phenomenon mostly happens on the ground floor of buildings. When wind hits the building, it deflects in various directions including upward, downward or sides. The wind which is deflected in the downward direction acts as downdraft which cause the turbulence at the lower floor levels.

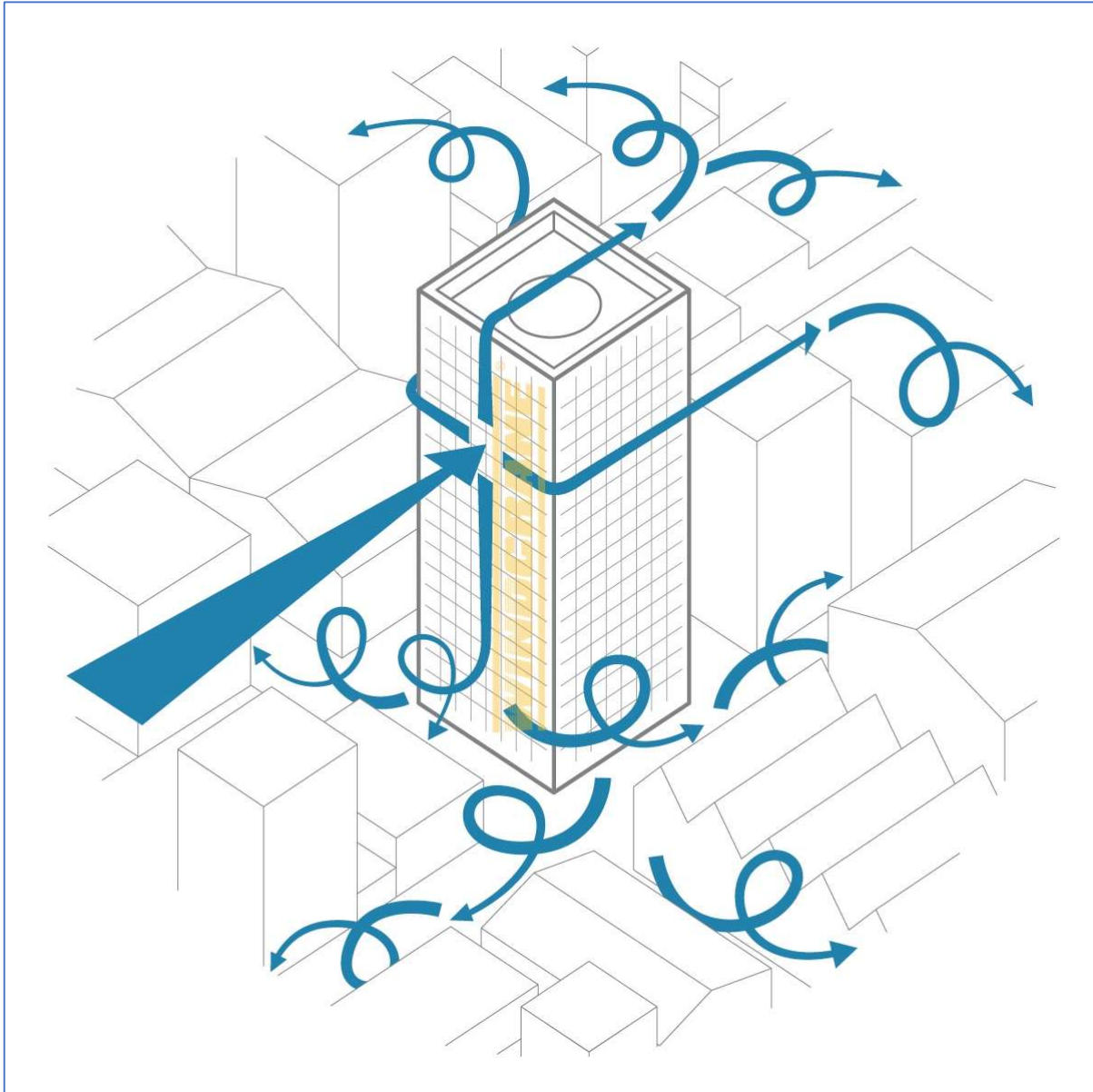


Figure 2.2: Wind pattern when wind attacks the tall urban building (Source: <https://www.windcrane.com/blog/construction/wind-speed-patterns-city-buildings>)

2.3.7 Funneling Effect:

The funneling effect of wind is a phenomenon which happens in the area where there are a lot of tall buildings. As per Bernoulli's principle where the area of passage for fluid is reduced the speed fluid will increase. Similar effects happen between the tall buildings where the area of passage for wind is reduced due to the reduction of area the speed of wind increase by some factor and this can cause damage to small structure present on the roads or sideways.

2.3.8 Uplift:

Uplift is usually caused when the external pressure acts on the roof of the building and try to lift the roof also internal pressure also acts on the internal face of the roof and try to push the roof towards upward direction.

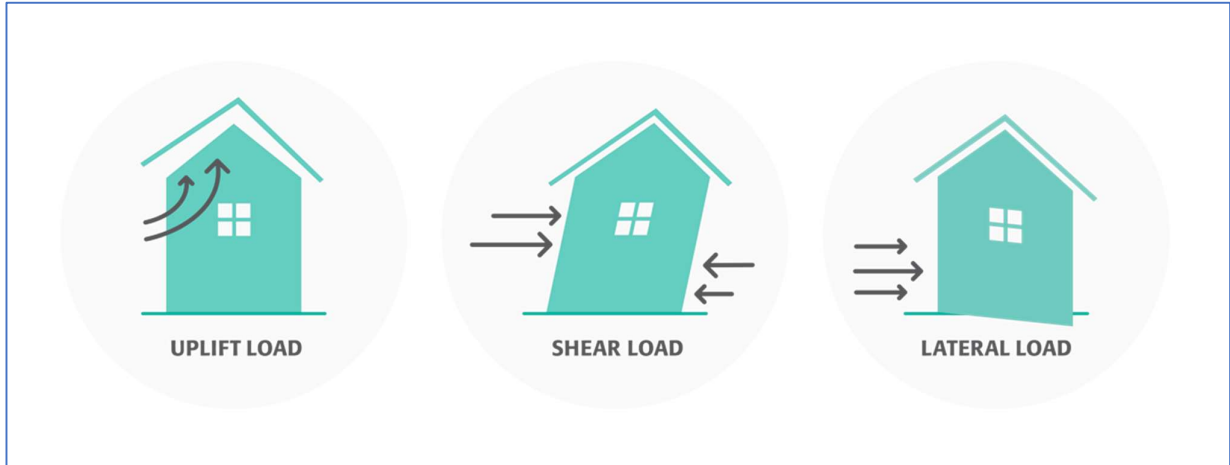


Figure 2.3: Wind forces acting on the buildings (Source: <https://www.tremcocpg-asiapacific.com/>)

2.3.9 Downward Pressure:

Sometimes when the wind act on the roof of the building another opposite load case to uplift can be possible which will be the worst downward force and it will push the roof in downward side causing additional reaction force to gravity loads.

2.4 Pressures:

When the wind hits the structure or surface of the structure it will exert some force on the structure and when this force is divided by the area of the building it will be considered wind pressure. To convert wind speed in pressure in kN/m^2 various equations are considered in different codes considering wind density into effect as well. Wind pressure acts on the building faces. It can push the building face and other faces can be in suction. Also, wind pressures have two types, one of them is called internal pressure and the other one is known as external pressure.

2.4.1 Internal Pressure:

Internal pressure is the pressure which is applied from inside the building, and it can be directed away from the wall or towards the walls. Mostly codes follow the same convention signs positive or negative. The positives ones are those which have the direction towards the surface and negative are those which are directed away from the surface. Following are the factors effecting the internal pressure:

- **Opening in the faces:** Internal pressures are highly dependent on the openings in the building. As more the opening will be, the more wind will penetrate the building which could build up more and more internal pressure on the walls. If the openings are fewer then there would be less internal pressure which could be buildup inside the building due to wind. This effect is also considered in various codes for calculating the internal pressures and special coefficients are used in codes to consider this effect as well.
- **Porosity of the walls:** Internal pressure also depends on the porosity of the walls of the building if the walls are more than 90% porous than they are considered as rigid from the wind to penetrate directly into them. On the other hand, if this value is less than 90% then wind has more chances to penetrate the building easily and build up the internal pressures on the walls.

2.4.2 External Pressure:

External pressures are the pressure which is applied from outside the building. It also has both dimensions towards the surface and away from the surface. Similar types of conventions are applied to external pressures as the internal pressures. These pressures are generated due to wind speed which hits the structure from outside.

- **Wind Speed:** External wind pressure depends upon the wind speed which acts on the external faces of the building from the sides or from the top of the building.
- **Angle of Attack:** External wind pressure also depends upon the angle of attack of the wind to the building. If angle between the wind and building surface is 90 degree than the impact will be more high and pressure will also be high.
- **Geographical Features:** As the structure will be more closer to the sea or at height of cliff than it will be more subjected to the winds and external pressures would be higher in that case.

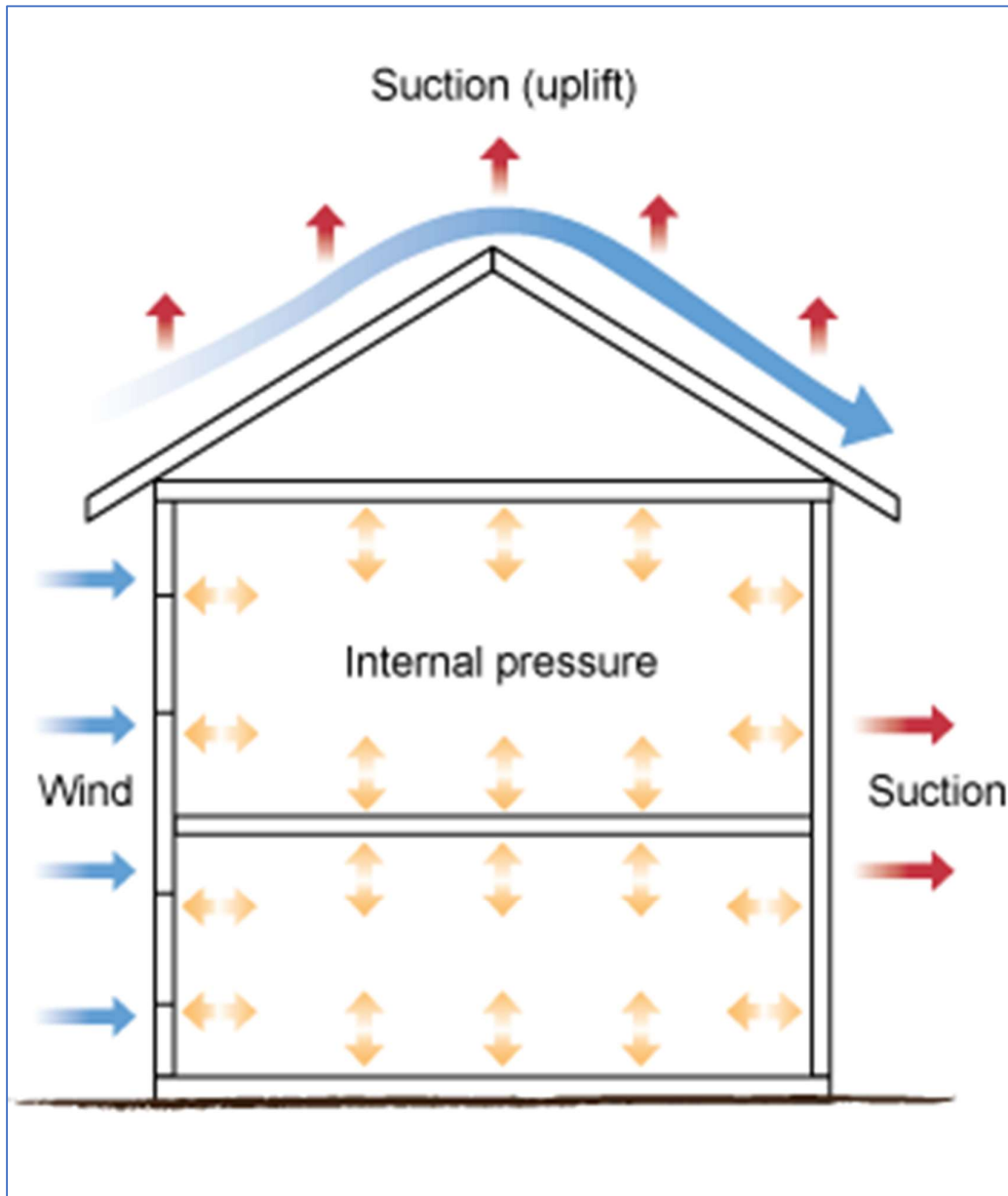


Figure 2.4: Wind Pressures in buildings (Source: <https://www.dlsweb.rmit.edu.au/>)

2.4.3 Net Pressure:

Net pressures are the pressure which are resultant pressures acting on the wall of the building. These pressures are the sum of the total internal and external pressure on the wall and this vector addition in which the direction of the internal and external pressure is considered while calculating the net pressures.

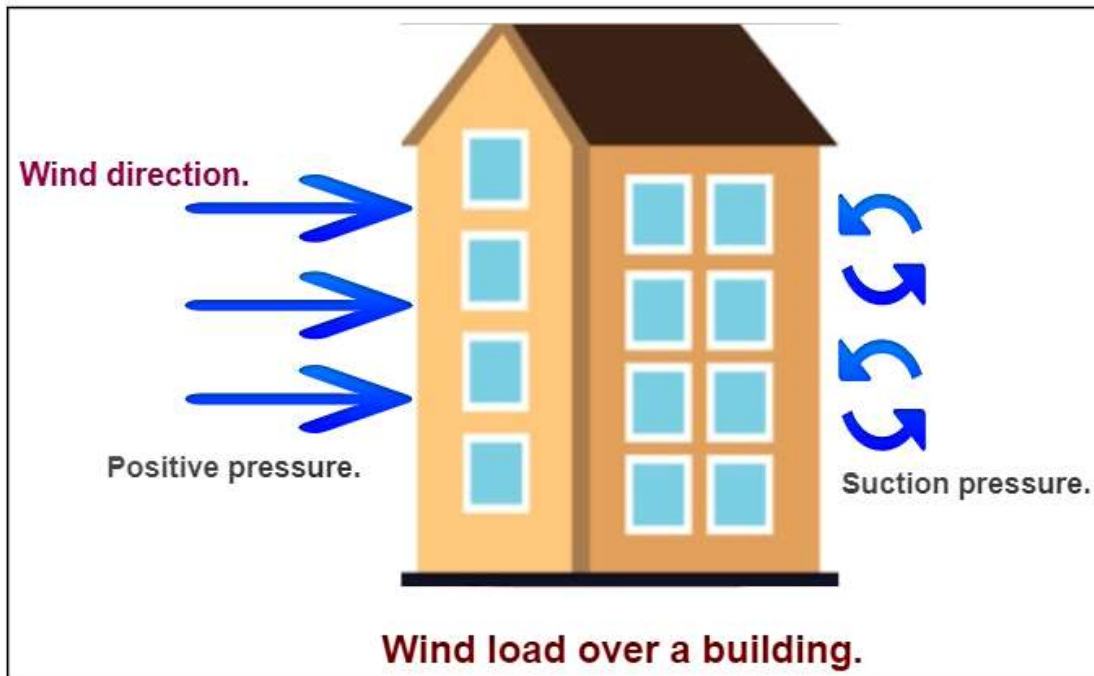


Figure 2.5: Wind Pressures acting on the buildings (Source: <https://www.paramvisions.com/2022/10/what-is-wind-load-over-structurewhat-is.html>)

2.5 Wind Codes and their role in Industry:

A lot of standards and codes are still in use all around the world in different countries. The role of codes is to help the engineers to calculate the wind forces and effects on structures accurately and keeping them more towards the reality. Codes are based on the experiments carried out by the group of scientists and cross checked and after cross verification after series of experiments. Mostly wind tunnel experiments are used to carry out the standard calculations and creating the standard methods and tables / charts for the coefficients and loadings for various building shapes and conditions. Most common shapes of the building covered by codes are rectangular, mono pitched, duo pitched etc. But mostly all codes recommend that for irregular shapes and high buildings one should go for wind tunnel testing for the calculations of loads and observation of the effects of the wind effects on the buildings and some codes also describe the procedure of wind tunnel testing such as the ASCE 49-12 code explains the wind tunnel testing procedure. So wind codes have mostly all the data required to apply the wind loads to the common shapes of the building and they possess the required information about the area, wind exposure, terrains and common wind speeds in specific country.

2.6 Previous Research:

A lot of research papers have been published for comparison of the international codes. One of the papers published in June 2019 provides the following results form (M. T. Cogurcu, 2019):

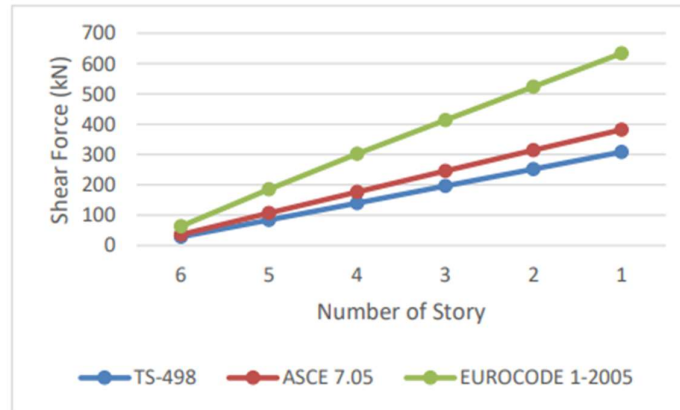


Figure 2.6: Comparison of various storey shear forces from different codes (M. T. Cogurcu, 2019)

It can be clearly seen that the shear force is increase at the base story for Eurocode 1 and its increasing for ASCE 7.05 but the increase in Eurocode is quite higher than the ASCE code. Similarly, below is the graphs shown for bending moment which also show the similar results that the bending moment at the 1st storey is higher than the ASCE design codes. (M. T. Cogurcu, 2019)

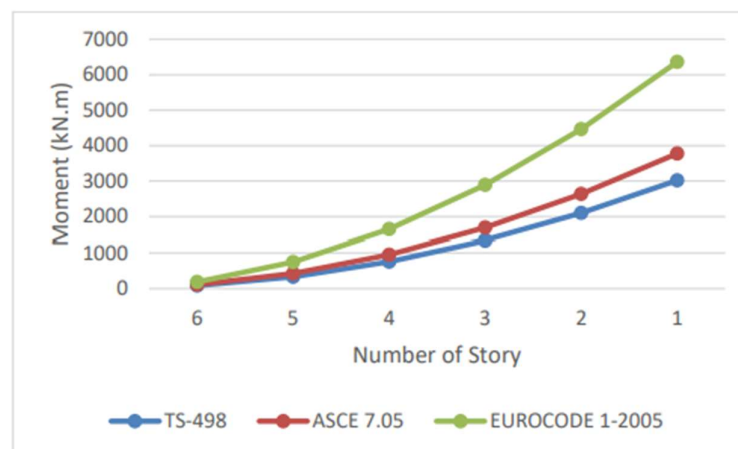


Figure 2.7 Comparison of various storey moments from different codes (M. T. Cogurcu, 2019)

This research project can be related with the above-mentioned research results as the codes used in the research above are Eurocode and American code which are also used in this research as well.

3. Methodology:

An excel program will be created which can compute base shear and bending moments in buildings. The initial height of the building will be 3 meters and will gradually increase to 150 meters considering other geometric and geographic conditions constant. Base shear and bending moments will be recorded for all buildings and the process will be repeated with different codes to find out base shear and bending moments. Once all data is recorded in excel then a thorough comparison of the collected data will be created to find out the variation of the various parameters with respect to the height of the building and with respect to different design codes. In the end, graphs will be created of the obtained results data to find out the trends of the fluctuations in base shear and bending moments in the structure against various codes and heights.

The following Codes and standards will be used to apply wind loadings on buildings:

- Eurocodes 1 (BS EN 1991: Actions on structures)
- American Codes (ASCE 7-10)
- Australian Standards (AS /Nzs 1170.2:2011)

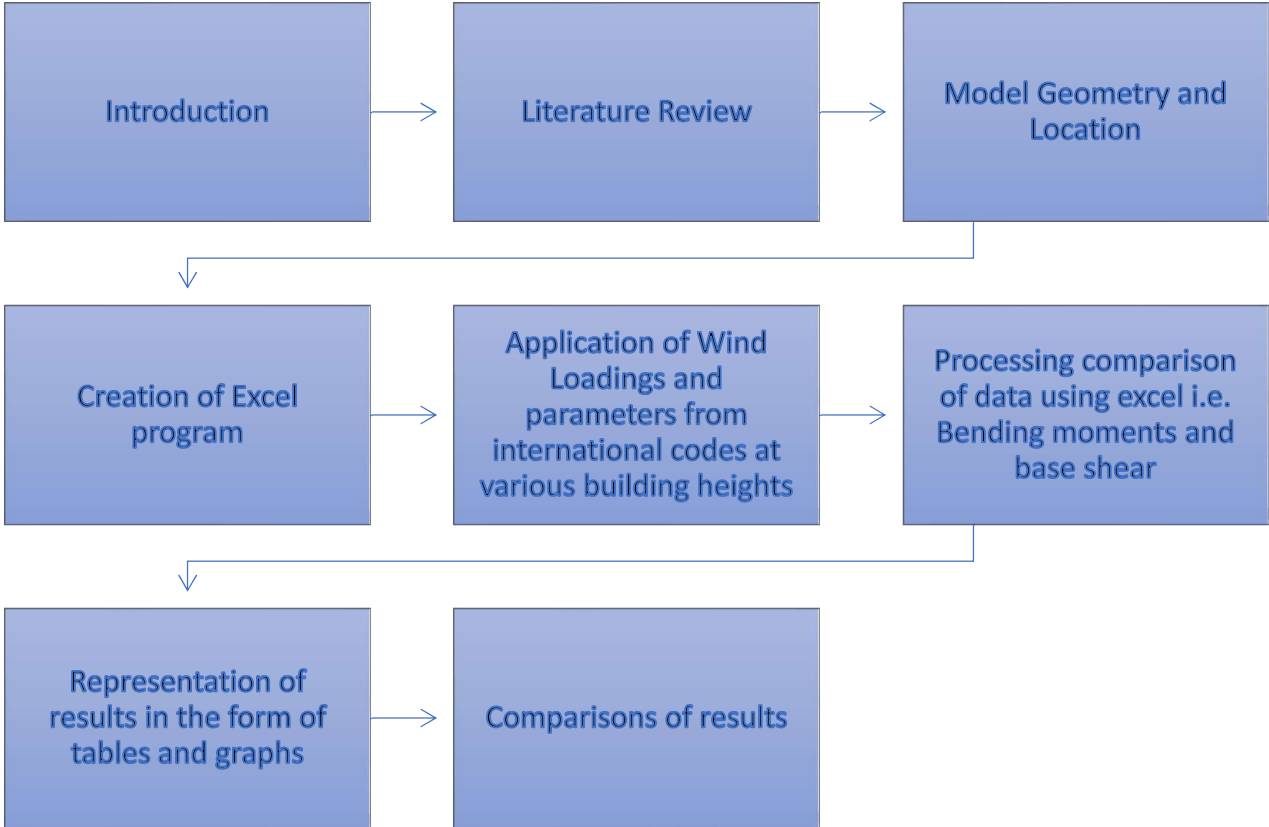


Figure 3.1: Flow Chart for methodology of research

3.1 Characteristics of the site:

Sub Urban or Town Terrain

Dimension of building = 30x30x30m to 30x30x150m with an increase of 3m in height.

Distance from Sea = 100+ km

Distance inside town = 3 km

Exposure category = Town

Orography = Not Significant

Basic Wind Speed = 21 m/s

Return = 10 years (To make probability factor = 1)

3.2 Wind Loadings as per Eurocode 1:

Eurocode was developed by the European Committee for Standardization upon the request of the European Commission after carrying out a lot of research work. And Eurocodes have 10 different standards for various civil and structural engineering works. The standard used for wind calculations is BS EN 1991-1-4 which describes the wind actions carried out on structures.

3.2.1 Limitation:

Eurocode 1 (BS EN 1991-1-4) is only applicable to buildings with heights up to 200 meters. Although various codes share a common theoretical basis, but the results obtained from using these different wind codes have observable differences. Furthermore, in general, the applicability of wind codes is limited to regular-shaped structures with a height not exceeding 200 meters. (H. M.A.D. Jayasundara, 2018)

3.2.2 Procedure and factors:

Along with Eurocodes, the National Annex of each country is also available which provides additional information on the use of various variables and values according to each country's terrain and climate conditions. In this report, the UK National Annex has been used along with Eurocodes.

Eurocode considers direction, season, probability, and altitude factors to predict the wind speed to predict the pressure acting on the structure at specific locations.

An important factor which is known as the exposure factor is applied to basic pressure to consider the wind pressure and height of the building.

3.2.3 Probability Factor:

The probability factor is determined by the following expression from Eurocode:

$$c_{\text{prob}} = \left(\frac{1 - K \cdot \ln(-\ln(1 - p))}{1 - K \cdot \ln(-\ln(0,98))} \right)^n \quad (4.2)$$

where:

K is the shape parameter depending on the coefficient of variation of the extreme-value distribution.

n is the exponent.

NOTE 5 The values for K and n may be given in the National Annex. The recommended values are 0,2 for K and 0,5 for n .

Figure 3.2: Formula for probability factor as per Eurocode (Source: BS EN 1991-1-4:2005+A1:2010)

The probability factor is taken as 1 for 10 years of return. The values of K and n are taken as per UK national Annex provisions. Formula for probability factor is given in figure 3.2 (BS EN 1991:2010)

The flowchart for calculating wind pressure is given in figure 3.3 (BS EN 1991:2010).

Annex A (informative) Flowcharts for obtaining q_p

Figure A.NA.1 Flowchart for obtaining q_p for sites in country

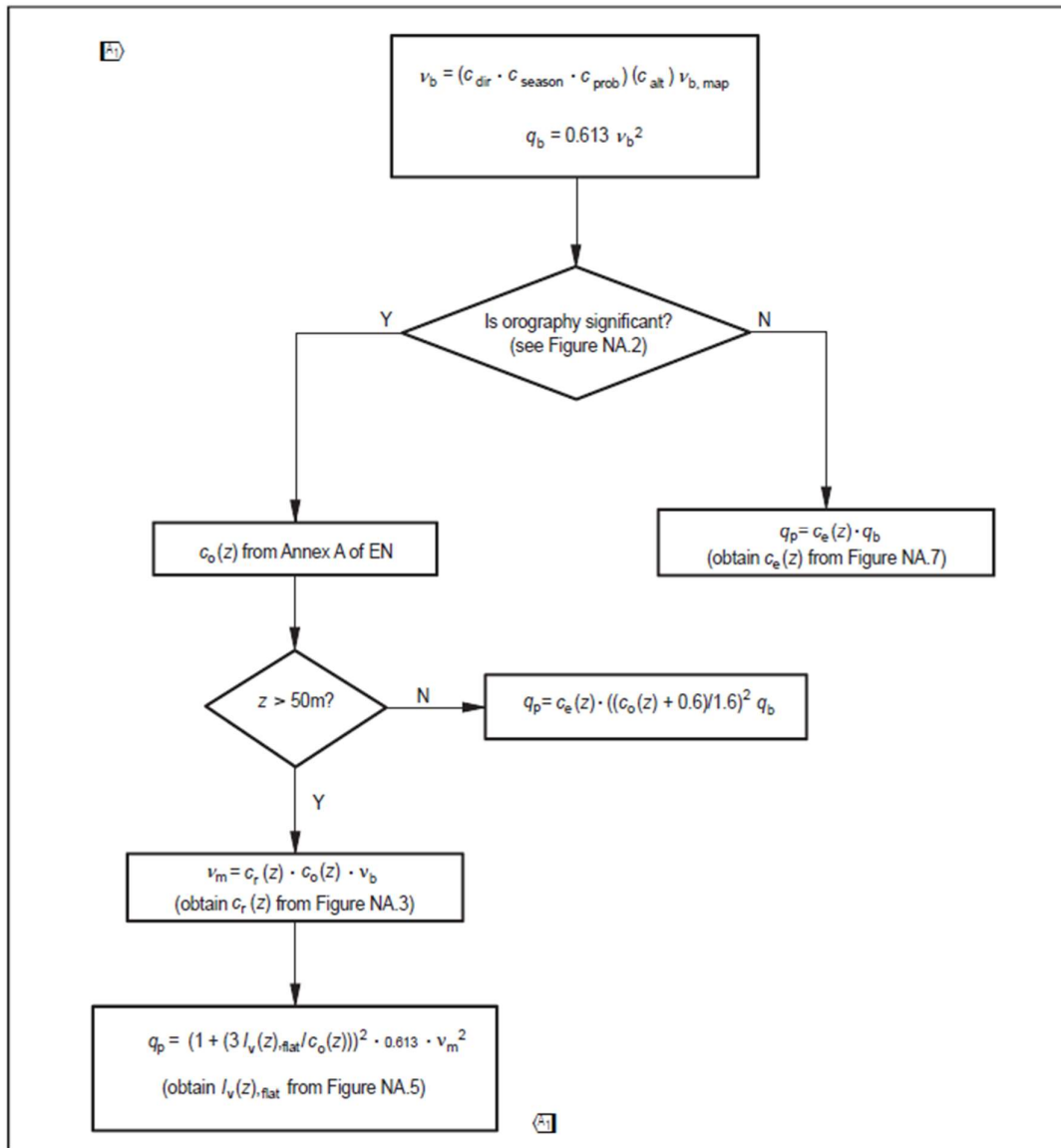


Figure 3.3: Informative Flowchart as per BS EN 1991-1-4 (Source: National Annex to Eurocode 1)

3.2.4 Application of Wind load to buildings:

Pressures on surfaces are taken as positive and negative as per Eurocodes any pressure directed towards the surface is taken as positive and pressure directed away from the surface is taken as negative.

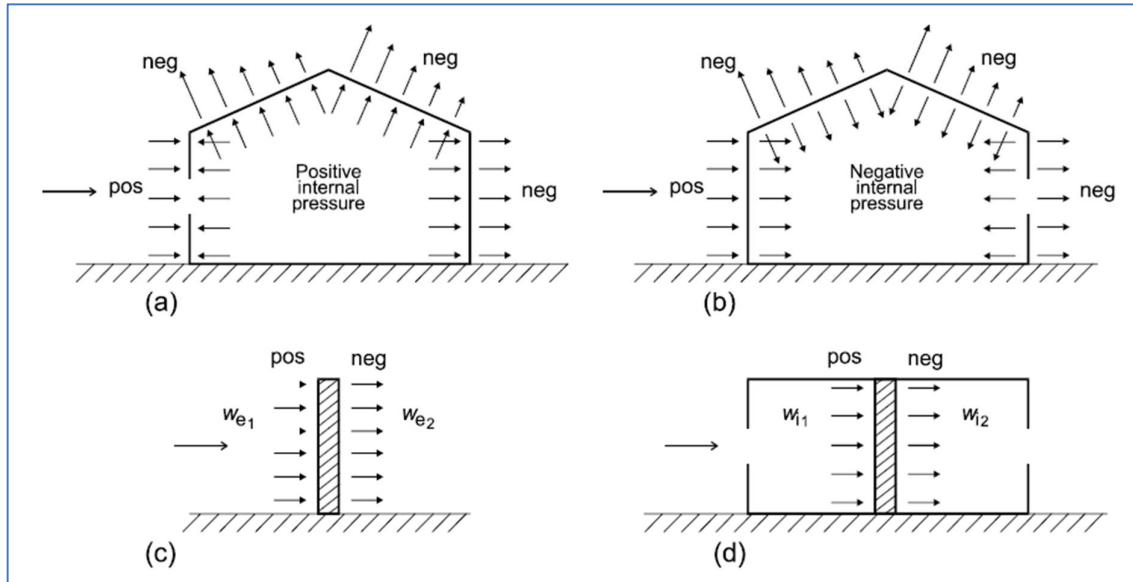


Figure 3.4: Pressure on the Surfaces as per BS EN 1991-1-4 (Source: Eurocode 1)

The pressure considered is the net pressure which is the difference between internal and external pressure on the surface acting on both sides of the surface. External and internal pressure explained in figure 3.4 (BS EN 1991:2010)

Net Pressure = External Pressure – Internal Pressure (BS EN 1991-1-4:2010)

The formula for getting pressure from Wind Speed:

$$q_b = 0.613 \times v_b^2 \text{ (BS EN 1991-1-4)}$$

The procedure for applying wind loads to the buildings is given in section 7.2 of BS EN 1991-1-4. The external pressure coefficient is taken from table 7.1 against the h/b ratio and the table is only valid up to h/b = 5. External pressure coefficients are given in figure 3.5 (Table 7.1, BS EN 1991:2010)

Table 7.1 — Recommended values of external pressure coefficients for vertical walls of rectangular plan buildings

Zone	A		B		C		D		E	
	$C_{pe,10}$	$C_{pe,1}$	$C_{pe,10}$	$C_{pe,1}$	$C_{pe,10}$	$C_{pe,1}$	$C_{pe,10}$	$C_{pe,1}$	$C_{pe,10}$	$C_{pe,1}$
5	-1,2	-1,4	-0,8	-1,1	-0,5		+0,8	+1,0	-0,7	
1	-1,2	-1,4	-0,8	-1,1	-0,5		+0,8	+1,0	-0,5	
≤ 0,25	-1,2	-1,4	-0,8	-1,1	-0,5		+0,7	+1,0	-0,3	

Figure 3.5 External Pressure Coefficients as per (BS EN 1991-1-4:2005+A1:2010) (Source: Eurocode 1)

- The most critical case is the wind on the front face D of the building which is accompanied by the negative force on the other side E of the building.

Ce(z) is the exposure factor. Exposure factor will be taken by using figure NA 7 (NA to BS EN 1991-1-4)

In case the site is located inside the town then the exposure correction factor Ce(T) should be applied along with the exposure factor using figure NA 8 (NA to BS EN 1991-1-4). Key for vertical walls is given in figure 3.6 (BS EN 1991:2010)

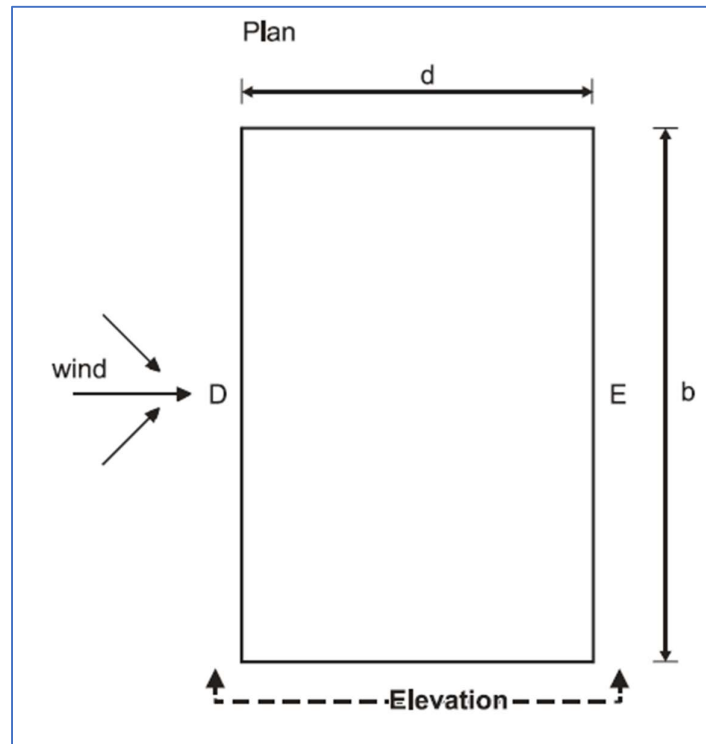


Figure 3.6 Key for vertical walls (Source: BS EN 1991-1-4:2005+A1:2010)

3.3 Wind Loading as per ASCE 7-10:

3.3.1 Basic Wind Speed:

Basic wind speed is calculated using a 3-second gust height of 33 ft compared to your record in which the 10 minutes mean speed is considered at a 10-meter height from the ground.

3.3.2 Pressure:

As per ASCE recommendations, the following formula can be used to find out wind pressures:

$$q_z = 0.613 \times K_z \times K_{zt} \times K_d \times V^2 \text{ (N/m}^2\text{)} \text{ (ASCE 7-10:2010)}$$

Wind directionality factor = $K_d = 0.85$ As per (Table 26.6-1 of ASCE 7-10:2010)

Topographic effects are not considered so $K_{zT} = 1$

The surface roughness category is B.

The exposure category is also B.

$GC_{pi} = 0.55$ and -0.55 (Partially Open Building) (ASCE 7-10:2010)

3.3.3 Other factors:

The exposure factor K_z Will be taken from the ASCE code for the above formula. The topographies factor will be considered as 1 as orography considered not significant.

The directional factor will be taken from the relevant ASCE codes. For applying all the factors from ASCE and the basic wind speed which were used for calculations as per Eurocode the wind pressure as per ask codes will be obtained.

Internal wind pressures will be taken from the codes and well and net wind pressure will be applied to the buildings.

Design wind pressure will be calculated as per the formula below:

$$p = qGC_p - q_i(GC_{pi}) \text{ (lb/ft}^2\text{) (N/m}^2\text{) (ASCE 7-10:2010)}$$

The wind directionality factor is taken as 0.85 in (Table 26.6.1 in ASCE 7-10:2010)

Internal wind pressure given in 26.11.1 of (ASCE 7-10:2010).

Height above ground level, z		Exposure		
		B	C	D
ft	(m)			
0-15	(0-4.6)	0.57	0.85	1.03
20	(6.1)	0.62	0.90	1.08
25	(7.6)	0.66	0.94	1.12
30	(9.1)	0.70	0.98	1.16
40	(12.2)	0.76	1.04	1.22
50	(15.2)	0.81	1.09	1.27
60	(18)	0.85	1.13	1.31
70	(21.3)	0.89	1.17	1.34
80	(24.4)	0.93	1.21	1.38
90	(27.4)	0.96	1.24	1.40
100	(30.5)	0.99	1.26	1.43
120	(36.6)	1.04	1.31	1.48
140	(42.7)	1.09	1.36	1.52
160	(48.8)	1.13	1.39	1.55
180	(54.9)	1.17	1.43	1.58
200	(61.0)	1.20	1.46	1.61
250	(76.2)	1.28	1.53	1.68
300	(91.4)	1.35	1.59	1.73
350	(106.7)	1.41	1.64	1.78
400	(121.9)	1.47	1.69	1.82
450	(137.2)	1.52	1.73	1.86
500	(152.4)	1.56	1.77	1.89

Figure 3.7: Velocity exposure factor coefficients are given in table 27.3.1 of ASCE (ASCE 7-10)

Wall Pressure Coefficients, C_p			
Surface	L/B	C_p	Use With
Windward Wall	All values	0.8	q_z
Leeward Wall	0-1	-0.5	q_h
	2	-0.3	
	≥ 4	-0.2	
Side Wall	All values	-0.7	q_h

Figure 3.8: External pressure coefficient for walls can be obtained from 27.4-1 of ASCE (ASCE 7-10)

Step-by-step wind load calculations as per ASCE 7-10 are given below in figure 3.9. (ASCE 7-10:2010)

Table 27.2-1 Steps to Determine MWFRS Wind Loads for Enclosed, Partially Enclosed and Open Buildings of All Heights

- Step 1:** Determine risk category of building or other structure, see Table 1.4-1
- Step 2:** Determine the basic wind speed, V , for the applicable risk category, see Figure 26.5-1A, B or C
- Step 3:** Determine wind load parameters:
- Wind directionality factor, K_d , see Section 26.6 and Table 26.6-1
 - Exposure category, see Section 26.7
 - Topographic factor, K_{zt} , see Section 26.8 and Table 26.8-1
 - Gust Effect Factor, G , see Section 26.9
 - Enclosure classification, see Section 26.10
 - Internal pressure coefficient, (GC_{pi}) , see Section 26.11 and Table 26.11-1
- Step 4:** Determine velocity pressure exposure coefficient, K_z or K_h , see Table 27.3-1
- Step 5:** Determine velocity pressure q_z or q_h Eq. 27.3-1
- Step 6:** Determine external pressure coefficient, C_p or C_N
- Fig. 27.4-1 for walls and flat, gable, hip, monoslope or mansard roofs
 - Fig. 27.4-2 for domed roofs
 - Fig. 27.4-3 for arched roofs
 - Fig. 27.4-4 for monoslope roof, open building
 - Fig. 27.4-5 for pitched roof, open building
 - Fig. 27.4-6 for troughed roof, open building
 - Fig. 27.4-7 for along-ridge/valley wind load case for monoslope, pitched or troughed roof, open building
- Step 7:** Calculate wind pressure, p , on each building surface
- Eq. 27.4-1 for rigid buildings
 - Eq. 27.4-2 for flexible buildings
 - Eq. 27.4-3 for open buildings

Figure 3.9: Flow Chart for Wind load estimation as per American Wind Code (Source: ASCE 7-10)

3.4 Wind Loading as per AS / NZS 1170:

The Australian code method for estimating the wind load is like the method of Eurocodes and American codes. Australian code is also only valid for buildings are to 200 meters.

This site's wind speed is calculated based on the wind coming from 8 directions. Regional wind speed, topography, terrain, and direction factors are considered while calculating the site wind speed.

To find the wind pressure acting on the building Australian code requires the design wind speed which is the maximum side wind speed obtained by considering all eight directions around the building at the angle of 45 degrees. This means that the max direction factor will be considered while calculating the design wind speed. Figure 3.10 and 3.11 shows the orthogonal directions and definitions of various factors as per Australian Wind code. (AS/NZS 1170:2011)

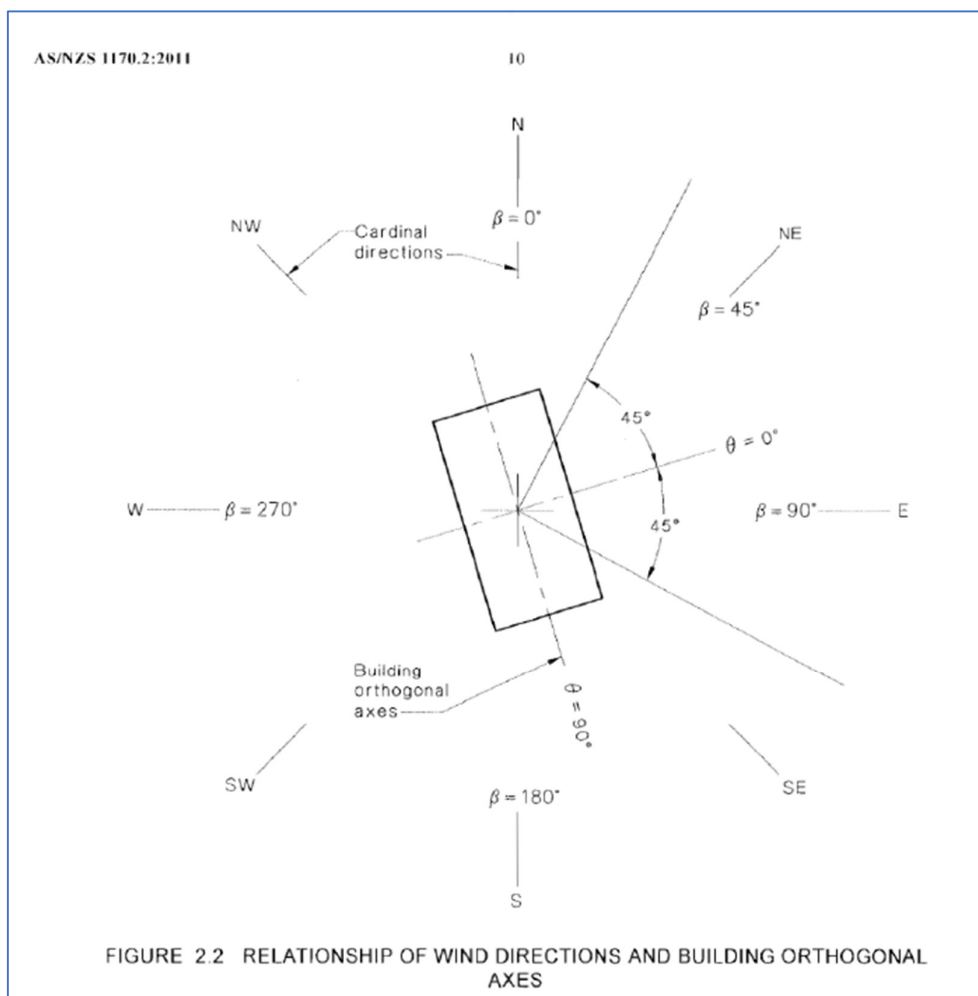


Figure 3.10: The figure of orthogonal axes from the Australian Wind Code (Source: AS / NZS 1170)

The site wind speeds ($V_{sit,\beta}$) defined for the 8 cardinal directions (β) at the reference height (z) above ground (see Figure 2.1) shall be as follows:

$$V_{sit,\beta} = V_R M_d (M_{z,cat} M_s M_t) \quad \dots 2.2$$

where

V_R = regional 3 s gust wind speed, in metres per second, for annual probability of exceedence of 1/R, as given in Section 3

M_d = wind directional multipliers for the 8 cardinal directions (β) as given in Section 3

$M_{z,cat}$ = terrain/height multiplier, as given in Section 4

M_s = shielding multiplier, as given in Section 4

M_t = topographic multiplier, as given in Section 4

Generally, the wind speed is determined at the average roof height (h). In some cases this varies, as given in the appropriate sections, according to the structure.

Figure 3.11: Site Wind speed definition from the Australian Wind Code (Source: AS / NZS 1170)

3.4.1 Minimum Design Wind Speed:

The minimum design wind speed for those structures having a design life of more than 5 years should be at least 30 m/s and for those with a design life of fewer than 5 years should be at least 25 m/s.

3.4.2 Conservative Approach:

The conservative approach is to use the maximum site wind speed for all directions. End this maximum site wind speed will be used as the design wind speed in all directions. Figure 3.12 provides wind pressure definition. (AS/NZS 1170:2011)

2.4.1 Design wind pressures

The design wind pressures (p), in pascals, shall be determined for structures and parts of structures as follows:

$$p = (0.5 \rho_{air}) [V_{des,0}]^2 C_{fig} C_{dyn} \quad \dots 2.4(1)$$

where

p = design wind pressure in pascals

= p_e, p_i or p_n where the sign is given by the C_p values used to evaluate C_{fig}

NOTE: Pressures are taken as positive, indicating pressures above ambient and negative, indicating pressures below ambient.

ρ_{air} = density of air, which shall be taken as 1.2 kg/m³

$V_{des,0}$ = building orthogonal design wind speeds (usually, $\theta = 0^\circ, 90^\circ, 180^\circ$ and 270°), as given in Clause 2.3

NOTE: For some applications, $V_{des,\theta}$ may be a single value or may be expressed as a function of height (z), e.g. windward walls of tall buildings (>25m).

C_{fig} = aerodynamic shape factor, as given in Section 5

C_{dyn} = dynamic response factor, as given in Section 6 [the value is 1.0 except where the structure is dynamically wind sensitive (see Section 6)]

Figure 3.12: Wind Pressure definition from the Australian Wind Code (Source: AS / NZS 1170)

Dynamic Response Factor = 1 (AS / NZS 1170:2011)

Category 4 = Town Terrain or Urban Terrain

Direction factor $M_d = 1$ (AS/NZS 1170:2011)

TABLE 4.1(B)
TERRAIN/HEIGHT MULTIPLIERS FOR GUST WIND SPEEDS
IN FULLY DEVELOPED TERRAINS—ULTIMATE LIMIT
STATE DESIGN—REGIONS C AND D ONLY

Height (z) m	Multiplier ($M_{z,cat}$)	
	Terrain categories 1 and 2	Terrain categories 3 and 4
≤3	0.90	0.80
5	0.95	0.80
10	1.00	0.89
15	1.07	0.95
20	1.13	1.05
30	1.20	1.15
40	1.25	1.25
50	1.29	1.29
75	1.35	1.35
≥100	1.40	1.40

NOTE: For intermediate values of height z and terrain category, use linear interpolation.

Figure 3.13: $M_{d,cat}$ for Ultimate Limit state (Source: AS / NZS 1170)

Once the pressure is calculated, it will be applied to the faces of the building to find out the building's base shear and bending moments. Figure 3.13 provides terrain or height factor. (AS/NZS 1170:2011)

C_{pi} is taken from table 5.1 (A) of (AS / NZS 1170:2011)

C_{pe} is taken from table 5.2 (A) of (AS / NZS 1170:2011)

Action combination factor K_{ce} will be used with C_{pe} and C_{pi} as both windward and leeward forces are used to calculate the bending moment and shear force in the structure. As per section 5.4.3 of (AS / NZS 1170:2011).

$K_{ce} = 0.9$ (AS/NZS 1170)

The area reduction factor K_a is taken as 0.8 as per Table 5.4 of (AS / NZS 1170:2011)

3.5 Data Handling in Excel sheets and Calculations:

All the data and coefficients were generated through the excel sheets and all calculations has been done by using excel sheets. Overall, 4 excel sheets are created. One for each code and the 4th one is created to create a comparison of the data.

4. Results and Discussion:

In this section, the discussion is carried out for the results received after the analysis of data generated through excel sheets and the graphs plotted with the help of data.

4.1 Wind Loads with Eurocodes:

All coefficients from Eurocodes are added directly to the columns. The dimensions are fixed in all the codes for the buildings. They are added in the columns and the heights are increased with the interval of 3m. And the pressures and forces are calculated accordingly.

The below sheet is created for Eurocode and BS National Annex to find out the bending moment and base shear.

Obtaining qp in Town Terrain										Dimensions			Cpe			Cpl		Pressures kN/m ²		Areas		FORCES (kN)		Base Shear	Bending Moment
Cdir	Cseason	Cprob	Calt	Vb,map	Vb	qb	Ce(z)	H	D	B	H/D	D	E	D	E	D	E	m ²	D	E	kN	kN	kN	kNm	
1	1	1	1	21	21	0.27	1.5	3	30	30	0.1	0.68	-0.26	-0.30	0.20	0.40	-0.19	90	35.8	-16.8	52.6	78.8			
1	1	1	1	21	21	0.27	2	6	30	30	0.2	0.69	-0.29	-0.30	0.20	0.54	-0.26	180	96.7	-47.4	144.0	432.1			
1	1	1	1	21	21	0.27	2.3	9	30	30	0.3	0.71	-0.31	-0.30	0.20	0.63	-0.32	270	169.0	-86.2	255.2	1148.3			
1	1	1	1	21	21	0.27	2.4	12	30	30	0.4	0.72	-0.34	-0.30	0.20	0.66	-0.35	360	238.2	-126.1	364.4	2186.2			
1	1	1	1	21	21	0.27	2.6	15	30	30	0.5	0.73	-0.37	-0.30	0.20	0.73	-0.40	450	326.8	-179.2	506.1	3795.5			
1	1	1	1	21	21	0.27	2.7	18	30	30	0.6	0.75	-0.39	-0.30	0.20	0.76	-0.43	540	412.5	-233.9	646.4	5817.6			
1	1	1	1	21	21	0.27	2.8	21	30	30	0.7	0.76	-0.42	-0.30	0.20	0.80	-0.47	630	505.5	-295.7	801.1	8411.9			
1	1	1	1	21	21	0.27	2.9	24	30	30	0.8	0.77	-0.45	-0.30	0.20	0.84	-0.51	720	605.8	-365.0	970.9	11650.4			
1	1	1	1	21	21	0.27	3	27	30	30	0.9	0.79	-0.47	-0.30	0.20	0.88	-0.55	810	713.8	-442.3	1156.2	15608.2			
1	1	1	1	21	21	0.27	3.1	30	30	30	1	0.80	-0.50	-0.30	0.20	0.92	-0.59	900	829.7	-528.0	1357.6	20564.2			
1	1	1	1	21	21	0.27	3.1	33	30	30	1.1	0.80	-0.51	-0.30	0.20	0.92	-0.59	990	912.6	-584.9	1497.5	24709.1			
1	1	1	1	21	21	0.27	3.2	36	30	30	1.2	0.80	-0.51	-0.30	0.20	0.95	-0.61	1080	1027.7	-663.3	1691.0	30438.5			
1	1	1	1	21	21	0.27	3.3	39	30	30	1.3	0.80	-0.52	-0.30	0.20	0.98	-0.64	1170	1148.1	-746.3	1894.4	36941.1			
1	1	1	1	21	21	0.27	3.3	42	30	30	1.4	0.80	-0.52	-0.30	0.20	0.98	-0.64	1260	1236.4	-809.3	2045.8	42961.0			
1	1	1	1	21	21	0.27	3.3	45	30	30	1.5	0.80	-0.53	-0.30	0.20	0.98	-0.65	1350	1324.8	-873.1	2197.9	49452.9			
1	1	1	1	21	21	0.27	3.35	48	30	30	1.6	0.80	-0.53	-0.30	0.20	1.00	-0.66	1440	1434.5	-952.0	2386.5	57275.5			
1	1	1	1	21	21	0.27	3.35	51	30	30	1.7	0.80	-0.54	-0.30	0.20	1.00	-0.67	1530	1524.2	-1018.4	2542.6	64835.3			
1	1	1	1	21	21	0.27	3.4	54	30	30	1.8	0.80	-0.54	-0.30	0.20	1.01	-0.68	1620	1637.9	-1101.9	2739.7	73973.2			
1	1	1	1	21	21	0.27	3.45	57	30	30	1.9	0.80	-0.55	-0.30	0.20	1.03	-0.69	1710	1754.3	-1188.1	2942.5	83860.1			
1	1	1	1	21	21	0.27	3.5	60	30	30	2	0.80	-0.55	-0.30	0.20	1.04	-0.71	1800	1873.4	-1277.3	3150.7	94521.9			
1	1	1	1	21	21	0.27	3.55	63	30	30	2.1	0.80	-0.56	-0.30	0.20	1.06	-0.72	1890	1995.2	-1369.4	3364.6	105984.8			
1	1	1	1	21	21	0.27	3.6	66	30	30	2.2	0.80	-0.56	-0.30	0.20	1.07	-0.74	1980	2119.6	-1464.5	3584.1	118275.2			
1	1	1	1	21	21	0.27	3.6	69	30	30	2.3	0.80	-0.57	-0.30	0.20	1.07	-0.74	2070	2216.0	-1541.1	3757.1	129619.4			
1	1	1	1	21	21	0.27	3.6	72	30	30	2.4	0.80	-0.57	-0.30	0.20	1.07	-0.75	2160	2312.3	-1618.6	3930.9	141514.0			
1	1	1	1	21	21	0.27	3.6	75	30	30	2.5	0.80	-0.58	-0.30	0.20	1.07	-0.75	2250	2408.7	-1697.0	4105.7	153963.1			
1	1	1	1	21	21	0.27	3.6	78	30	30	2.6	0.80	-0.58	-0.30	0.20	1.07	-0.76	2340	2505.0	-1776.3	4281.3	166970.6			
1	1	1	1	21	21	0.27	3.6	81	30	30	2.7	0.80	-0.59	-0.30	0.20	1.07	-0.76	2430	2601.4	-1856.4	4457.8	180540.3			
1	1	1	1	21	21	0.27	3.7	84	30	30	2.8	0.80	-0.59	-0.30	0.20	1.10	-0.79	2520	2772.6	-1991.3	4763.9	200084.0			
1	1	1	1	21	21	0.27	3.7	87	30	30	2.9	0.80	-0.60	-0.30	0.20	1.10	-0.80	2610	2871.7	-2075.4	4947.1	215198.8			
1	1	1	1	21	21	0.27	3.7	90	30	30	3	0.80	-0.60	-0.30	0.20	1.10	-0.80	2700	2970.7	-2160.5	5316.2	230903.6			
1	1	1	1	21	21	0.27	3.7	93	30	30	3.1	0.80	-0.61	-0.30	0.20	1.10	-0.81	2790	3069.7	-2246.5	5742.2	247202.5			
1	1	1	1	21	21	0.27	3.7	96	30	30	3.2	0.80	-0.61	-0.30	0.20	1.10	-0.81	2880	3168.7	-2333.3	5502.1	264099.7			
1	1	1	1	21	21	0.27	3.8	99	30	30	3.3	0.80	-0.62	-0.30	0.20	1.13	-0.84	2970	3356.1	-2486.5	5842.6	289209.9			
1	1	1	1	21	21	0.27	3.8	102	30	30	3.4	0.80	-0.62	-0.30	0.20	1.13	-0.84	3060	3457.8	-2577.6	6035.4	307804.9			

Figure 4.1: Excel Sheet for calculations as per Eurocode

Almost all factors remain the same as compared to the height except the exposure factor which goes up with the increase in the height of the building. Similarly, as the height is increasing the wind loading or wind force is also increasing. The base shear and bending moment will be increased with the increase in height of the building.

4.2 Wind Loads with Australian Codes:

Similarly, all coefficients are applied by using the Australian code, and formulas are also applied to the columns to find out the wind loads as per the Australian code procedure. The same effect can be seen in the Australian codes for wind loads. The base shear and bending moment is increasing with the increase in the height of the building. All coefficients remain

same except the one for category exposure factor Mz CAT which increase with the increase in the height of the structure.

Obtaining qp in Town Terrain						Cpe x Kce x Ka						Cpi x Kci		Net Pressure		Dimensions			Areas		FORCES (kN)		Base Shear	Bending Moment	
Mz	Mz Cat	Md	VR	Vsit	Mt	Ka	d/b	W	L	W	L	p Air	Cdyn	P, W	P, L	H	D	B	m2	W	L	kN	kN	kN	kNm
			m/s	m/s								kg/m3		kN/m2	kN/m2	m	m	m							
1	0.8	1	21	16.8	1	0.85	1	0.61	-0.38	-0.27	0.54	1.2	1	0.15	-0.16	3	30	30	90	13.4	-14.1	27.5	41.3		
1	0.8	1	21	16.8	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.14	-0.15	6	30	30	180	25.8	-27.4	53.2	159.7		
1	0.89	1	21	18.69	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.18	-0.19	9	30	30	270	47.9	-50.9	98.8	444.6		
1	0.95	1	21	19.95	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.20	-0.21	12	30	30	360	72.7	-77.4	150.1	900.6		
1	0.95	1	21	19.95	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.20	-0.21	15	30	30	450	90.9	-96.7	187.6	1407.2		
1	1	1	21	21	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.22	-0.24	18	30	30	540	120.9	-128.6	249.5	2245.3		
1	1.05	1	21	22.05	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.25	-0.26	21	30	30	630	155.5	-165.4	320.9	3369.3		
1	1.1	1	21	23.1	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.27	-0.29	24	30	30	720	195.0	-207.5	402.5	4829.8		
1	1.12	1	21	23.52	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.28	-0.30	27	30	30	810	227.4	-242.0	469.4	6337.1		
1	1.15	1	21	24.15	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.30	-0.31	30	30	30	900	266.4	-283.4	549.9	8248.3		
1	1.22	1	21	25.62	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.33	-0.35	33	30	30	990	329.8	-350.9	680.8	11232.4		
1	1.23	1	21	25.83	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.34	-0.36	36	30	30	1080	365.8	-389.1	754.9	13587.5		
1	1.25	1	21	26.25	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.35	-0.37	39	30	30	1170	409.2	-435.3	844.6	16469.3		
1	1.26	1	21	26.46	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.36	-0.38	42	30	30	1260	447.8	-476.4	924.2	19407.3		
1	1.27	1	21	26.67	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.36	-0.38	45	30	30	1350	487.4	-518.5	1005.9	22633.8		
1	1.28	1	21	26.88	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.37	-0.39	48	30	30	1440	528.1	-561.8	1092.0	26159.4		
1	1.3	1	21	27.3	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.38	-0.40	51	30	30	1530	578.8	-615.8	1194.6	30461.6		
1	1.31	1	21	27.51	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.38	-0.41	54	30	30	1620	622.3	-662.0	1284.4	34678.1		
1	1.32	1	21	27.72	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.39	-0.41	57	30	30	1710	667.0	-709.5	1376.5	39230.4		
1	1.33	1	21	27.93	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.40	-0.42	60	30	30	1800	712.7	-758.2	1471.0	44129.7		
1	1.34	1	21	28.14	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.40	-0.43	63	30	30	1890	759.7	-808.2	1567.9	49387.4		
1	1.34	1	21	28.14	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.40	-0.43	66	30	30	1980	795.9	-846.7	1657.5	54202.9		
1	1.34	1	21	28.14	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.40	-0.43	69	30	30	2070	832.0	-885.1	1717.2	59242.5		
1	1.35	1	21	28.35	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.41	-0.43	72	30	30	2160	881.2	-937.5	1818.7	65472.3		
1	1.35	1	21	28.35	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.41	-0.43	75	30	30	2250	917.9	-976.5	1894.5	71042.0		
1	1.36	1	21	28.56	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.41	-0.44	78	30	30	2340	968.8	-1030.7	1999.5	77981.6		
1	1.36	1	21	28.56	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.41	-0.44	81	30	30	2430	1006.1	-1070.3	2076.4	84095.6		
1	1.37	1	21	28.77	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.42	-0.45	84	30	30	2520	1058.8	-1126.4	2185.1	91775.1		
1	1.38	1	21	28.98	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.43	-0.45	87	30	30	2610	1112.7	-1183.7	2296.3	99890.0		
1	1.38	1	21	28.98	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.43	-0.45	90	30	30	2700	1151.0	-1224.5	2375.5	106897.7		
1	1.38	1	21	28.98	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.43	-0.45	93	30	30	2790	1189.4	-1265.3	2454.7	114143.0		
1	1.38	1	21	28.98	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.43	-0.45	96	30	30	2880	1227.8	-1306.1	2533.9	121625.9		
1	1.4	1	21	29.4	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.44	-0.47	99	30	30	2970	1303.1	-1386.3	2689.3	133122.6		
1	1.4	1	21	29.4	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.44	-0.47	102	30	30	3060	1342.6	-1428.3	2770.8	141312.9		

Figure 4.2: Excel Sheet for calculations as per Australian Wind Code

4.3 Wind Loads with American:

All coefficients are applied in the columns as per American Code and formulas are applied for wind load calculations as per the American code. Kz is the exposure factor which is increasing with the increase in the height of the structure.

Obtaining qp in Town Terrain					Dimensions			GCp e		GCp i		Pressure		Areas		FORCES (kN)		Base Shear	Bending Moment		
Kd	Kz	KzT	Vb,map	qz	H	D	B	L/B	Windward	Leeward	Windward	Leeward	Windward	Leeward	m2	Windward	Leeward	kN	kN	kN	kNm
			m/s	kN/m2	m	m	m						kN/m2	kN/m2							
0.85	0.57	1	21	0.13	3	30	30	1	0.80	-0.50	-0.55	0.55	0.18	-0.14	90	15.9	-12.4	28.3	42.4		
0.85	0.62	1	21	0.14	6	30	30	1	0.80	-0.50	-0.55	0.55	0.19	-0.15	180	34.6	-26.9	61.5	184.6		
0.85	0.7	1	21	0.16	9	30	30	1	0.80	-0.50	-0.55	0.55	0.22	-0.17	270	58.6	-45.6	104.2	469.0		
0.85	0.76	1	21	0.17	12	30	30	1	0.80	-0.50	-0.55	0.55	0.24	-0.18	360	84.9	-66.0	150.9	905.3		
0.85	0.81	1	21	0.19	15	30	30	1	0.80	-0.50	-0.55	0.55	0.25	-0.20	450	113.1	-87.9	201.0	1507.6		
0.85	0.85	1	21	0.20	18	30	30	1	0.80	-0.50	-0.55	0.55	0.26	-0.21	540	142.4	-110.7	253.1	2278.2		
0.85	0.89	1	21	0.20	21	30	30	1	0.80	-0.50	-0.55	0.55	0.28	-0.21	630	173.9	-135.3	309.2	3246.8		
0.85	0.93	1	21	0.21	24	30	30	1	0.80	-0.50	-0.55	0.55	0.29	-0.22	720	207.7	-161.6	369.3	4431.2		
0.85	0.96	1	21	0.22	27	30	30	1	0.80	-0.50	-0.55	0.55	0.30	-0.23	810	241.2	-187.6	428.8	5789.2		
0.85	0.99	1	21	0.23	30	30	30	1	0.80	-0.50	-0.55	0.55	0.31	-0.24	900	276.4	-215.0	491.4	7370.5		
0.85	1.02	1	21	0.23	33	30	30	1	0.80	-0.50	-0.55	0.55	0.32	-0.25	990	313.2	-243.6	556.9	9188.6		
0.85	1.04	1	21	0.24	36	30	30	1	0.80	-0.50	-0.55	0.55	0.32	-0.25	1080	348.4	-271.0	619.4	11149.6		
0.85	1.07	1	21	0.25	39	30	30	1	0.80	-0.50	-0.55	0.55	0.33	-0.26	1170	388.3	-302.0	690.4	13462.7		
0.85	1.09	1	21	0.25	42	30	30	1	0.80	-0.50	-0.55	0.55	0.34	-0.26	1260	426.0	-331.4	757.4	15905.4		
0.85	1.11	1	21	0.26	45	30	30	1	0.80	-0.50	-0.55	0.55	0.34	-0.27	1350	464.8	-361.5	826.4	18593.8		
0.85	1.13	1	21	0.26	48	30	30	1	0.80	-0.50	-0.55	0.55	0.35	-0.27	1440	504.8	-392.6	897.4	21536.8		
0.85	1.15	1	21	0.26	51	30	30	1	0.80	-0.50	-0.55	0.55	0.36	-0.28	1530	545.8	-424.5	970.3	24743.4		
0.85	1.17	1	21	0.27	54	30	30	1	0.80	-0.50	-0.55	0.55	0.36	-0.28	1620	588.0	-457.3	1045.3	28222.4		
0.85	1.18	1	21	0.27	57	30	30	1	0.80	-0.50	-0.55	0.55	0.37	-0.28	1710	625.9	-486.8	1112.8	31714.1		
0.85	1.2	1	21	0.28	60	30	30	1	0.80	-0.50	-0.55	0.55	0.37	-0.29	1800	670.0	-521.1	1191.2	35735.9		
0.85	1.2	1	21	0.28	63	30	30	1	0.80	-0.50	-0.55	0.55	0.37	-0.29	1890	703.5	-547.2	1250.8	39398.8		
0.85	1.22	1	21	0.28	66	30	30	1	0.80	-0.50	-0.55	0.55	0.38	-0.29	1980	749.3	-582.8	1332.2	43961.1		
0.85	1.23	1	21	0.28	69	30	30	1	0.80	-0.50	-0.55	0.55	0.38	-0.30	2070	789.8	-614.3	1404.1	48442.2		
0.85	1.24	1	21	0.28	72	30	30	1	0.80	-0.50	-0.55	0.55	0.38	-0.30	2160	830.9	-646.2	1477.1	53175.0		

Figure 4.3: Excel Sheet for calculations as per American Wind Code

And similarly, the base shear and bending moment are also increasing with the increase in the height of the structure.

4.4 Comparison:

A comparison of the bending moment and base shear has been created against the increasing height of the structure.

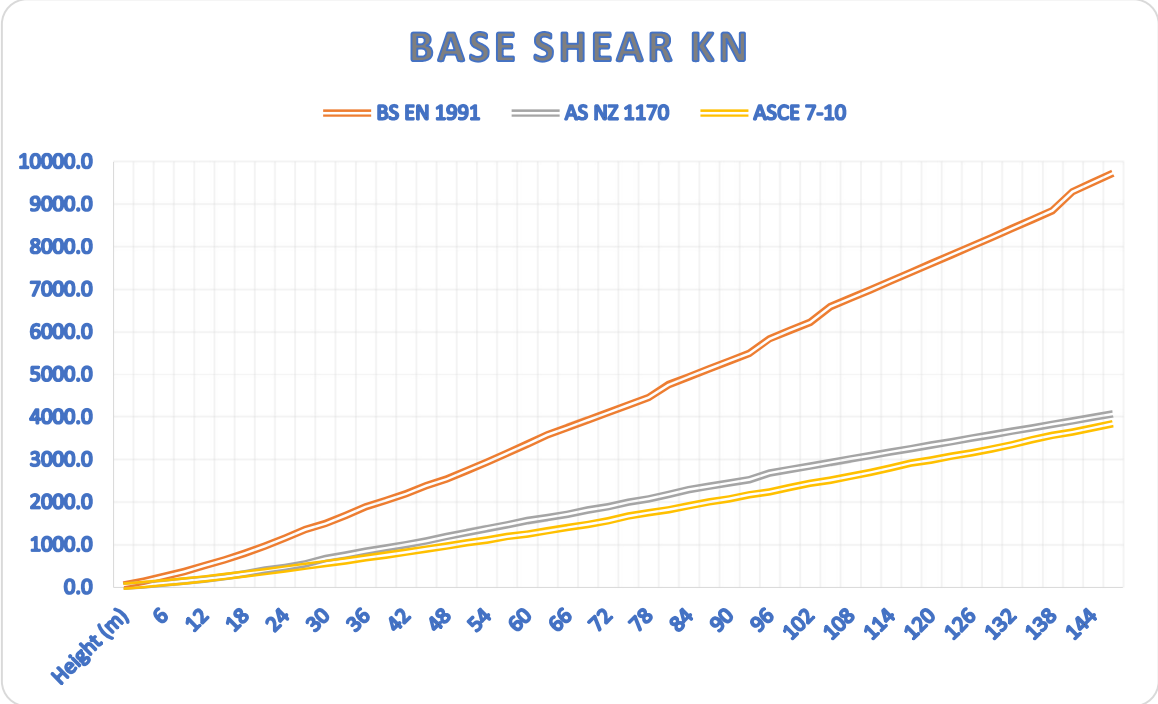


Figure 4.4: Graph for Base Shear Against height for various codes

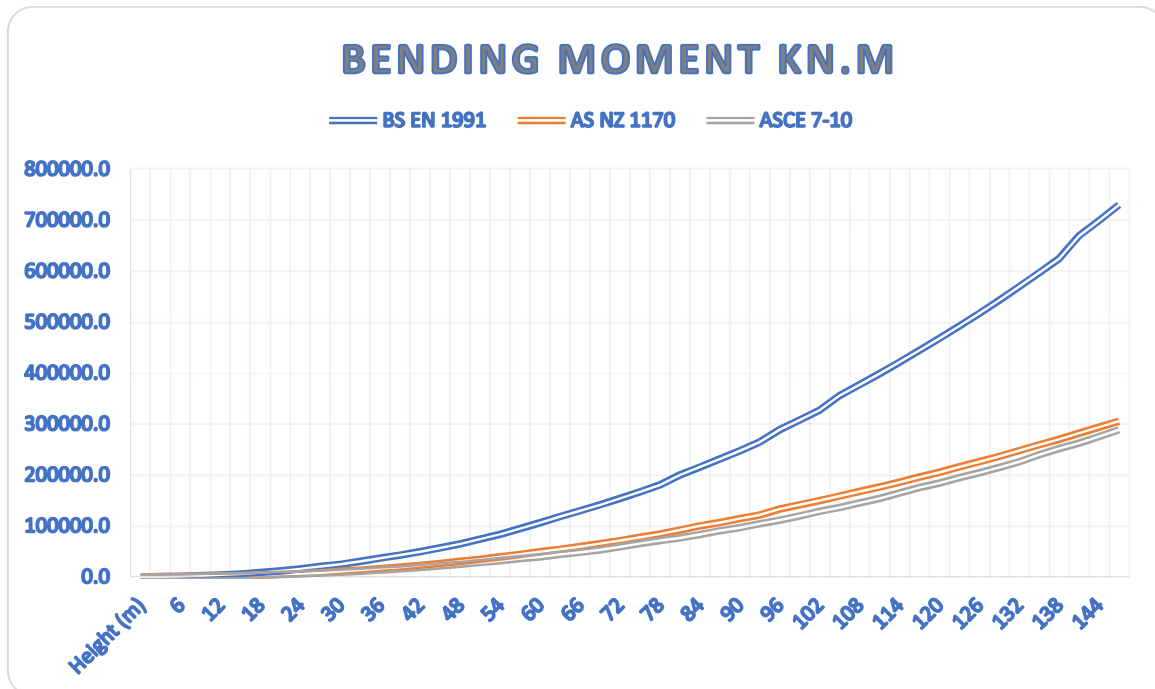


Figure 4.5: Graph for Bending Moment Against height for various codes

The following observations have been extracted from the comparison graphs:

- Eurocodes give the highest base shear force as compared to all codes.
- Australian and American codes give almost the same values, but the Australian code provides slightly higher values of base shear.
- All values of base shear increase with the increase in heights.
- Eurocodes give the highest base Bending Moment as compared to all codes.
- Australian and American codes give almost the same values, but the Australian code provides slightly higher values of bending moment.
- All values of bending moment increase with the increase in heights in a parabolic curve.

Following is the comparison table created through all the calculations.

Height (m)	Base Shear kN			Height (m)	Bending Moment kN m		
	BS EN 1991	AS NZ 1170	ASCE 7-10		BS EN 1991	AS NZ 1170	ASCE 7-10
3	52.6	27.5	28.3	3	78.8	41.3	42.4
6	144.0	53.2	61.5	6	432.1	159.7	184.6
9	255.2	98.8	104.2	9	1148.3	444.6	469.0
12	364.4	150.1	150.9	12	2186.2	900.6	905.3
15	506.1	187.6	201.0	15	3795.5	1407.2	1507.6
18	646.4	249.5	253.1	18	5817.6	2245.3	2278.2
21	801.1	320.9	309.2	21	8411.9	3369.3	3246.8
24	970.9	402.5	369.3	24	11650.4	4829.8	4431.2

27	1156.2	469.4	428.8	27	15608.2	6337.1	5789.2
30	1357.6	549.9	491.4	30	20364.2	8248.3	7370.5
33	1497.5	680.8	556.9	33	24709.1	11232.4	9188.6
36	1691.0	754.9	619.4	36	30438.5	13587.5	11149.6
39	1894.4	844.6	690.4	39	36941.1	16469.3	13462.7
42	2045.8	924.2	757.4	42	42961.0	19407.3	15905.4
45	2197.9	1005.9	826.4	45	49452.9	22633.8	18593.8
48	2386.5	1090.0	897.4	48	57275.5	26159.4	21536.8
51	2542.6	1194.6	970.3	51	64835.3	30461.6	24743.4
54	2739.7	1284.4	1045.3	54	73973.2	34678.1	28222.4
57	2942.5	1376.5	1112.8	57	83860.1	39230.4	31714.1
60	3150.7	1471.0	1191.2	60	94521.9	44129.7	35735.9
63	3364.6	1567.9	1250.8	63	105984.8	49387.4	39398.8
66	3584.1	1642.5	1332.2	66	118275.2	54202.9	43961.1
69	3757.1	1717.2	1404.1	69	129619.4	59242.5	48442.2
72	3930.9	1818.7	1477.1	72	141514.0	65472.3	53175.0
75	4105.7	1894.5	1563.4	75	153963.1	71042.0	58629.1
78	4281.3	1999.5	1677.6	78	166970.6	77981.6	65426.4
81	4457.8	2076.4	1755.5	81	180540.3	84095.6	71098.7
84	4763.9	2185.1	1820.5	84	200084.0	91775.1	76462.8
87	4947.1	2296.3	1914.4	87	215198.8	99890.0	83274.2
90	5131.2	2375.5	2010.1	90	230903.6	106897.7	90456.4
93	5316.2	2454.7	2077.1	93	247202.5	114143.0	96587.3
96	5502.1	2533.9	2175.9	96	264099.7	121625.9	104444.0
99	5842.6	2689.3	2243.9	99	289209.9	133122.6	111073.8
102	6035.4	2770.8	2345.7	102	307804.9	141312.9	119628.8
105	6229.1	2852.3	2449.4	105	327026.7	149747.6	128593.3
108	6592.7	2933.8	2519.4	108	356008.0	158426.9	136046.4
111	6793.4	3015.3	2607.7	111	377035.2	167350.6	144728.7
114	6995.1	3096.8	2697.1	114	398718.5	176518.9	153732.7
117	7197.6	3178.3	2806.8	117	421062.2	185931.6	164195.1
120	7401.2	3259.8	2918.4	120	444070.6	195588.8	175105.7
123	7605.7	3341.3	2991.4	123	467748.0	205490.4	183970.4
126	7811.1	3422.8	3085.2	126	492098.6	215636.6	194367.3
129	8017.5	3504.3	3158.7	129	517126.6	226027.3	203733.1
132	8224.8	3585.8	3253.9	132	542836.5	236662.4	214760.6
135	8433.1	3667.3	3350.2	135	569232.3	247542.0	226141.0
138	8642.3	3748.8	3470.3	138	596318.5	258666.1	239454.1
141	8852.5	3830.3	3569.1	141	624099.3	270034.7	251622.9
144	9296.0	3911.8	3645.1	144	669311.6	281647.8	262444.2
147	9513.5	3993.3	3745.3	147	699242.6	293505.4	275280.8
150	9732.0	4074.8	3846.6	150	729899.1	305607.4	288492.6

Table 4-1: Table for the comparison of results achieved in the research for base shear and bending moments

If results are compared with the literature review which was studied before starting this project, similarities can be found in the results achieved in this report and the literature review as well. Below is the table from another study

Table 20
Alongwind survivability results for Example 3 (EC3).

	ASCE	NALD ^a	AS/NZ	AII	CNS ^b	NBCC	EU		ISO		IWC
							B	C	Peak	Mean	
V_0 (m/s)	60.0	60	62.8	39.3	40.3	39.1	38.6		58.8	42.3	61.3
h_{ref} (m)	108	180	180	180	180	180	108		180	180	180
$V_{h_{ref}}$ (m/s)	48.9	-	77.1	55.6	55.5	53.7	50.0		77.1	55.6	77.1
q_h (kN/m ²)	3.622	-	3.622	1.887	1.887	1.758	3.622		3.622	1.887	3.622
g_R	3.845	3.845	3.166	3.270	2.5 (3.348)	3.810	3.265		3.348	3.348	3.688
$r_{h_{ref}}$	0.343	-	0.287	0.283	0.244	0.262	0.340		0.323	0.323	0.287
$L_{h_{ref}}$ (m)	216	-	175	245	1200	1220	206		245	245	206
B	0.617	-	0.651	0.519	-	0.625	0.523	0.427	0.660	0.660	0.521
E	0.159	-	0.124	0.106	-	0.302	0.118	0.118	0.105	0.107	0.090
S	0.085	-	0.152	0.177	-	0.135	0.137	0.178	0.218	0.224	0.140
R	0.530	-	0.740	0.741	-	2.036	0.637	0.825	0.902	0.937	0.793
GLF	2.153	-	2.159	1.923	1.97 (2.29)	2.433	2.195	2.241	2.361	2.377	1.988
G	0.994	-	1.047	1.923	1.97 (2.29)	2.433	1.003	1.024	1.125	2.377	0.992
C_{fs}	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
V_{base} (MN)	18.07	15.09	17.74	18.31	13.79 (15.76)	17.49	18.85	19.25	18.72	18.43	18.10
M_{base} (MN-m)	1792	1637	1742	1853	1528 (1758)	1819	1835	1873	1938	2065	1807

^a Averaging values obtained from EC2 and EC4 using NALD.
^b Values in parentheses are obtained using ISO peak factors.

Figure 4.6: Comparison table of various codes from study (Dae Kun Kwon, 2013)

From the highlighted values in the figure above, it can be easily seen that the values of base shear V_0 and the base moment for Eurocode are quite higher than the one which are achieved against the Australian codes and American codes which can also be seen in the trends of graphs in figure 4.4 and figure 4.5 in this section above this shows that the work done during this project has successfully achieved the expected results.

Also, the results received are like the results shown in figure 2.6 and figure 2.7 of this report. The same trend is shown in those graphs which is shown in the above-mentioned figures which can be seen in our results as well.

Base shear from the same studies is shown below:

Table 4. Base shear forces

Code	Base Shear Force (kN)
TS-498	307.93
ASCE 7.05	73.75
EUROCODE 1-2005	252.12

Figure 4.7: Base shear forces in a building against various codes (M. T. Cogurcu, 2019)

As it's clearly shown in figure 4.7 that the base shear for Eurocode is 252.12kN for the same building as compared to the ASCE 7.05 design code which is 73.75 kN. Which means that the Eurocode is more conservative and safer in other terms. (M. T. Cogurcu, 2019)

Detailed discussion of this report can be seen in the Appendix A of this report which includes the full excel sheet calculations for the Eurocode, Australian and American codes as well.

5. Conclusion and Recommendation:

The results achieved in this research project are almost similar as expected in the literature review section of this report.

The research concludes that the Eurocodes have a very high level of safety due to high values of the exposure factor as compared to the Australian and American codes which provide the almost same level of safety and economy.

The exposure factor in Eurocodes provides conservative values of the wind pressure applied on the building. The value of this coefficient increases with the increase in the height and with the closeness to the sea as well. But on the other hand, the exposure factors in ASCE code and Australian codes are not increasing in the same fashion as the factors for Eurocode increase. Also, ASCE and Australian codes are not much conservative in exposure factor as the Eurocodes.

As the side winds are not considered because they cancel the effect of each side also, orography has not been significant. But in the author's opinion future studies should consider the orographic effect also to prepare a healthy comparison between the codes. Also, various other factors which are considered as unity in this research project should also be considered to make comparison between the codes.

Also, the use of finite element software can be useful in comparison of codes as it will give the resultants more accurately for the various models.

This study is based on hypothetical location of the building with same basic wind speed considered for all codes, but a complete and more realistic conditions should be considered for future studies as it can give more deep and detailed comparisons for the codes.

Also, it is recommended that the dynamic prospect of the building should be considered in future research to study effects in more detail.

One more this which has been observed in this study is the gust factor which is 3 seconds considered for Australian and American codes for basic wind speed on the other hand Eurocodes uses 10 mins means wind speed for calculating basic wind speed although ASCE and Australian codes provides a high wind speeds but the exposure factors of these codes have less values than the Eurocodes.

6. References

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Appendix A

Calculations as per BS EN 1991-1-4

Obtaining qp in Town Terrain								Dimensions			Cpe			Cpi		Pressures kN/m2		Areas	FORCES (kN)		Base Shear	Bending Moment
Cdir	C.season	C. prob	C. alt	Vb,map	Vb	qb	Ce(z)	H	D	B	H/D	D	E	D	E	D	E	m2	D	E		
				m/s	m/s	kN/m2		m	m	m						kN/m2	kN/m2		kN	kN	kN	kNm
1	1	1	1	21	21	0.27	1.5	3	30	30	0.1	0.68	-0.26	-0.30	0.20	0.40	-0.19	90	35.8	-16.8	52.6	78.8
1	1	1	1	21	21	0.27	2	6	30	30	0.2	0.69	-0.29	-0.30	0.20	0.54	-0.26	180	96.7	-47.4	144.0	432.1
1	1	1	1	21	21	0.27	2.3	9	30	30	0.3	0.71	-0.31	-0.30	0.20	0.63	-0.32	270	169.0	-86.2	255.2	1148.3
1	1	1	1	21	21	0.27	2.4	12	30	30	0.4	0.72	-0.34	-0.30	0.20	0.66	-0.35	360	238.2	-126.1	364.4	2186.2
1	1	1	1	21	21	0.27	2.6	15	30	30	0.5	0.73	-0.37	-0.30	0.20	0.73	-0.40	450	326.8	-179.2	506.1	3795.5
1	1	1	1	21	21	0.27	2.7	18	30	30	0.6	0.75	-0.39	-0.30	0.20	0.76	-0.43	540	412.5	-233.9	646.4	5817.6
1	1	1	1	21	21	0.27	2.8	21	30	30	0.7	0.76	-0.42	-0.30	0.20	0.80	-0.47	630	505.5	-295.7	801.1	8411.9
1	1	1	1	21	21	0.27	2.9	24	30	30	0.8	0.77	-0.45	-0.30	0.20	0.84	-0.51	720	605.8	-365.0	970.9	11650.4
1	1	1	1	21	21	0.27	3	27	30	30	0.9	0.79	-0.47	-0.30	0.20	0.88	-0.55	810	713.8	-442.3	1156.2	15608.2
1	1	1	1	21	21	0.27	3.1	30	30	30	1	0.80	-0.50	-0.30	0.20	0.92	-0.59	900	829.7	-528.0	1357.6	20364.2
1	1	1	1	21	21	0.27	3.1	33	30	30	1.1	0.80	-0.51	-0.30	0.20	0.92	-0.59	990	912.6	-584.9	1497.5	24709.1
1	1	1	1	21	21	0.27	3.2	36	30	30	1.2	0.80	-0.51	-0.30	0.20	0.95	-0.61	1080	1027.7	-663.3	1691.0	30438.5
1	1	1	1	21	21	0.27	3.3	39	30	30	1.3	0.80	-0.52	-0.30	0.20	0.98	-0.64	1170	1148.1	-746.3	1894.4	36941.1
1	1	1	1	21	21	0.27	3.3	42	30	30	1.4	0.80	-0.52	-0.30	0.20	0.98	-0.64	1260	1236.4	-809.3	2045.8	42961.0
1	1	1	1	21	21	0.27	3.3	45	30	30	1.5	0.80	-0.53	-0.30	0.20	0.98	-0.65	1350	1324.8	-873.1	2197.9	49452.9
1	1	1	1	21	21	0.27	3.35	48	30	30	1.6	0.80	-0.53	-0.30	0.20	1.00	-0.66	1440	1434.5	-952.0	2386.5	57275.5
1	1	1	1	21	21	0.27	3.35	51	30	30	1.7	0.80	-0.54	-0.30	0.20	1.00	-0.67	1530	1524.2	-1018.4	2542.6	64835.3
1	1	1	1	21	21	0.27	3.4	54	30	30	1.8	0.80	-0.54	-0.30	0.20	1.01	-0.68	1620	1637.9	-1101.9	2739.7	73973.2
1	1	1	1	21	21	0.27	3.45	57	30	30	1.9	0.80	-0.55	-0.30	0.20	1.03	-0.69	1710	1754.3	-1188.1	2942.5	83860.1
1	1	1	1	21	21	0.27	3.5	60	30	30	2	0.80	-0.55	-0.30	0.20	1.04	-0.71	1800	1873.4	-1277.3	3150.7	94521.9
1	1	1	1	21	21	0.27	3.55	63	30	30	2.1	0.80	-0.56	-0.30	0.20	1.06	-0.72	1890	1995.2	-1369.4	3364.6	105984.8
1	1	1	1	21	21	0.27	3.6	66	30	30	2.2	0.80	-0.56	-0.30	0.20	1.07	-0.74	1980	2119.6	-1464.5	3584.1	118275.2
1	1	1	1	21	21	0.27	3.6	69	30	30	2.3	0.80	-0.57	-0.30	0.20	1.07	-0.74	2070	2216.0	-1541.1	3757.1	129619.4
1	1	1	1	21	21	0.27	3.6	72	30	30	2.4	0.80	-0.57	-0.30	0.20	1.07	-0.75	2160	2312.3	-1618.6	3930.9	141514.0
1	1	1	1	21	21	0.27	3.6	75	30	30	2.5	0.80	-0.58	-0.30	0.20	1.07	-0.75	2250	2408.7	-1697.0	4105.7	153963.1
1	1	1	1	21	21	0.27	3.6	78	30	30	2.6	0.80	-0.58	-0.30	0.20	1.07	-0.76	2340	2505.0	-1776.3	4281.3	166970.6
1	1	1	1	21	21	0.27	3.6	81	30	30	2.7	0.80	-0.59	-0.30	0.20	1.07	-0.76	2430	2601.4	-1856.4	4457.8	180540.3
1	1	1	1	21	21	0.27	3.7	84	30	30	2.8	0.80	-0.59	-0.30	0.20	1.10	-0.79	2520	2772.6	-1991.3	4763.9	200084.0
1	1	1	1	21	21	0.27	3.7	87	30	30	2.9	0.80	-0.60	-0.30	0.20	1.10	-0.80	2610	2871.7	-2075.4	4947.1	215198.8
1	1	1	1	21	21	0.27	3.7	90	30	30	3	0.80	-0.60	-0.30	0.20	1.10	-0.80	2700	2970.7	-2160.5	5131.2	230903.6
1	1	1	1	21	21	0.27	3.7	93	30	30	3.1	0.80	-0.61	-0.30	0.20	1.10	-0.81	2790	3069.7	-2246.5	5316.2	247202.5
1	1	1	1	21	21	0.27	3.7	96	30	30	3.2	0.80	-0.61	-0.30	0.20	1.10	-0.81	2880	3168.7	-2333.3	5502.1	264099.7
1	1	1	1	21	21	0.27	3.8	99	30	30	3.3	0.80	-0.62	-0.30	0.20	1.13	-0.84	2970	3356.1	-2486.5	5842.6	289209.9
1	1	1	1	21	21	0.27	3.8	102	30	30	3.4	0.80	-0.62	-0.30	0.20	1.13	-0.84	3060	3457.8	-2577.6	6035.4	307804.9
1	1	1	1	21	21	0.27	3.8	105	30	30	3.5	0.80	-0.63	-0.30	0.20	1.13	-0.85	3150	3559.5	-2669.6	6229.1	327026.7
1	1	1	1	21	21	0.27	3.9	108	30	30	3.6	0.80	-0.63	-0.30	0.20	1.16	-0.88	3240	3757.5	-2835.2	6592.7	356008.0
1	1	1	1	21	21	0.27	3.9	111	30	30	3.7	0.80	-0.64	-0.30	0.20	1.16	-0.88	3330	3861.9	-2931.5	6793.4	377035.2
1	1	1	1	21	21	0.27	3.9	114	30	30	3.8	0.80	-0.64	-0.30	0.20	1.16	-0.89	3420	3966.3	-3028.8	6995.1	398718.5
1	1	1	1	21	21	0.27	3.9	117	30	30	3.9	0.80	-0.65	-0.30	0.20	1.16	-0.89	3510	4070.6	-3127.0	7197.6	421062.2
1	1	1	1	21	21	0.27	3.9	120	30	30	4	0.80	-0.65	-0.30	0.20	1.16	-0.90	3600	4175.0	-3226.2	7401.2	444070.6
1	1	1	1	21	21	0.27	3.9	123	30	30	4.1	0.80	-0.66	-0.30	0.20	1.16	-0.90	3690	4279.4	-3326.3	7605.7	467748.0
1	1	1	1	21	21	0.27	3.9	126	30	30	4.2	0.80	-0.66	-0.30	0.20	1.16	-0.91	3780	4383.8	-3427.3	7811.1	492098.6
1	1	1	1	21	21	0.27	3.9	129	30	30	4.3	0.80	-0.67	-0.30	0.20	1.16	-0.91	3870	4488.1	-3529.3	8017.5	517126.6
1	1	1	1	21	21	0.27	3.9	132	30	30	4.4	0.80	-0.67	-0.30	0.20	1.16	-0.92	3960	4592.5	-3632.3	8224.8	542836.5
1	1	1	1	21	21	0.27	3.9	135	30	30	4.5	0.80	-0.68	-0.30	0.20	1.16	-0.92	4050	4696.9	-3736.2	8433.1	569232.3
1	1	1	1	21	21	0.27	3.9	138	30	30	4.6	0.80	-0.68	-0.30	0.20	1.16	-0.93	4140	4801.3	-3841.0	8642.3	596318.5
1	1	1	1	21	21	0.27	3.9	141	30	30	4.7	0.80	-0.69	-0.30	0.20	1.16	-0.93	4230	4905.7	-3946.8	8852.5	624099.3
1	1	1	1	21	21	0.27	4	144	30	30	4.8	0.80	-0.69	-0.30	0.20	1.19	-0.96	4320	5138.5	-4157.5	9296.0	669311.6
1	1	1	1	21	21	0.27	4	147	30	30	4.9	0.80	-0.70	-0.30	0.20	1.19	-0.97	4410	5245.5	-4268.0	9513.5	699242.6
1	1	1	1	21	21	0.27	4	150	30	30	5	0.80	-0.70	-0.30	0.20	1.19	-0.97	4500	5352.6	-4379.4	9732.0	729899.1

Calculations as per ASCE 7-10

Obtaining qp in Town Terrain					Dimensions			GCp e			GCp i		Pressure		Areas	FORCES (kN)		Base Shear	Bending Moment
Kd	Kz	KzT	Vb,map	qz	H	D	B	L/B	Windward	Leeward	Windward	Leeward	Windward	Leeward	m2	Windward	Leeward		
			m/s	kN/m2	m	m	m						kN/m2	kN/m2		kN	kN	kN	
0.85	0.57	1	21	0.13	3	30	30	1	0.80	-0.50	-0.55	0.55	0.18	-0.14	90	15.9	-12.4	28.3	42.4
0.85	0.62	1	21	0.14	6	30	30	1	0.80	-0.50	-0.55	0.55	0.19	-0.15	180	34.6	-26.9	61.5	184.6
0.85	0.7	1	21	0.16	9	30	30	1	0.80	-0.50	-0.55	0.55	0.22	-0.17	270	58.6	-45.6	104.2	469.0
0.85	0.76	1	21	0.17	12	30	30	1	0.80	-0.50	-0.55	0.55	0.24	-0.18	360	84.9	-66.0	150.9	905.3
0.85	0.81	1	21	0.19	15	30	30	1	0.80	-0.50	-0.55	0.55	0.25	-0.20	450	113.1	-87.9	201.0	1507.6
0.85	0.85	1	21	0.20	18	30	30	1	0.80	-0.50	-0.55	0.55	0.26	-0.21	540	142.4	-110.7	253.1	2278.2
0.85	0.89	1	21	0.20	21	30	30	1	0.80	-0.50	-0.55	0.55	0.28	-0.21	630	173.9	-135.3	309.2	3246.8
0.85	0.93	1	21	0.21	24	30	30	1	0.80	-0.50	-0.55	0.55	0.29	-0.22	720	207.7	-161.6	369.3	4431.2
0.85	0.96	1	21	0.22	27	30	30	1	0.80	-0.50	-0.55	0.55	0.30	-0.23	810	241.2	-187.6	428.8	5789.2
0.85	0.99	1	21	0.23	30	30	30	1	0.80	-0.50	-0.55	0.55	0.31	-0.24	900	276.4	-215.0	491.4	7370.5
0.85	1.02	1	21	0.23	33	30	30	1	0.80	-0.50	-0.55	0.55	0.32	-0.25	990	313.2	-243.6	556.9	9188.6
0.85	1.04	1	21	0.24	36	30	30	1	0.80	-0.50	-0.55	0.55	0.32	-0.25	1080	348.4	-271.0	619.4	11149.6
0.85	1.07	1	21	0.25	39	30	30	1	0.80	-0.50	-0.55	0.55	0.33	-0.26	1170	388.3	-302.0	690.4	13462.7
0.85	1.09	1	21	0.25	42	30	30	1	0.80	-0.50	-0.55	0.55	0.34	-0.26	1260	426.0	-331.4	757.4	15905.4
0.85	1.11	1	21	0.26	45	30	30	1	0.80	-0.50	-0.55	0.55	0.34	-0.27	1350	464.8	-361.5	826.4	18593.8
0.85	1.13	1	21	0.26	48	30	30	1	0.80	-0.50	-0.55	0.55	0.35	-0.27	1440	504.8	-392.6	897.4	21536.8
0.85	1.15	1	21	0.26	51	30	30	1	0.80	-0.50	-0.55	0.55	0.36	-0.28	1530	545.8	-424.5	970.3	24743.4
0.85	1.17	1	21	0.27	54	30	30	1	0.80	-0.50	-0.55	0.55	0.36	-0.28	1620	588.0	-457.3	1045.3	28222.4
0.85	1.18	1	21	0.27	57	30	30	1	0.80	-0.50	-0.55	0.55	0.37	-0.28	1710	625.9	-486.8	1112.8	31714.1
0.85	1.2	1	21	0.28	60	30	30	1	0.80	-0.50	-0.55	0.55	0.37	-0.29	1800	670.0	-521.1	1191.2	35735.9
0.85	1.2	1	21	0.28	63	30	30	1	0.80	-0.50	-0.55	0.55	0.37	-0.29	1890	703.5	-547.2	1250.8	39398.8
0.85	1.22	1	21	0.28	66	30	30	1	0.80	-0.50	-0.55	0.55	0.38	-0.29	1980	749.3	-582.8	1332.2	43961.1
0.85	1.23	1	21	0.28	69	30	30	1	0.80	-0.50	-0.55	0.55	0.38	-0.30	2070	789.8	-614.3	1404.1	48442.2
0.85	1.24	1	21	0.28	72	30	30	1	0.80	-0.50	-0.55	0.55	0.38	-0.30	2160	830.9	-646.2	1477.1	53175.0
0.85	1.26	1	21	0.29	75	30	30	1	0.80	-0.50	-0.55	0.55	0.39	-0.30	2250	879.4	-684.0	1563.4	58629.1
0.85	1.3	1	21	0.30	78	30	30	1	0.80	-0.50	-0.55	0.55	0.40	-0.31	2340	943.7	-734.0	1677.6	65426.4
0.85	1.31	1	21	0.30	81	30	30	1	0.80	-0.50	-0.55	0.55	0.41	-0.32	2430	987.5	-768.0	1755.5	71098.7
0.85	1.31	1	21	0.30	84	30	30	1	0.80	-0.50	-0.55	0.55	0.41	-0.32	2520	1024.1	-796.5	1820.5	76462.8
0.85	1.33	1	21	0.31	87	30	30	1	0.80	-0.50	-0.55	0.55	0.41	-0.32	2610	1076.8	-837.5	1914.4	83274.2
0.85	1.35	1	21	0.31	90	30	30	1	0.80	-0.50	-0.55	0.55	0.42	-0.33	2700	1130.7	-879.4	2010.1	90456.4
0.85	1.35	1	21	0.31	93	30	30	1	0.80	-0.50	-0.55	0.55	0.42	-0.33	2790	1168.4	-908.8	2077.1	96587.3
0.85	1.37	1	21	0.31	96	30	30	1	0.80	-0.50	-0.55	0.55	0.42	-0.33	2880	1224.0	-952.0	2175.9	104444.0
0.85	1.37	1	21	0.31	99	30	30	1	0.80	-0.50	-0.55	0.55	0.42	-0.33	2970	1262.2	-981.7	2243.9	111073.8
0.85	1.39	1	21	0.32	102	30	30	1	0.80	-0.50	-0.55	0.55	0.43	-0.34	3060	1319.4	-1026.2	2345.7	119628.8
0.85	1.41	1	21	0.32	105	30	30	1	0.80	-0.50	-0.55	0.55	0.44	-0.34	3150	1377.8	-1071.6	2449.4	128593.3
0.85	1.41	1	21	0.32	108	30	30	1	0.80	-0.50	-0.55	0.55	0.44	-0.34	3240	1417.2	-1102.2	2519.4	136046.4
0.85	1.42	1	21	0.33	111	30	30	1	0.80	-0.50	-0.55	0.55	0.44	-0.34	3330	1466.8	-1140.9	2607.7	144728.7
0.85	1.43	1	21	0.33	114	30	30	1	0.80	-0.50	-0.55	0.55	0.44	-0.35	3420	1517.1	-1180.0	2697.1	153732.7
0.85	1.45	1	21	0.33	117	30	30	1	0.80	-0.50	-0.55	0.55	0.45	-0.35	3510	1578.8	-1228.0	2806.8	164195.1
0.85	1.47	1	21	0.34	120	30	30	1	0.80	-0.50	-0.55	0.55	0.46	-0.35	3600	1641.6	-1276.8	2918.4	175105.7
0.85	1.47	1	21	0.34	123	30	30	1	0.80	-0.50	-0.55	0.55	0.46	-0.35	3690	1682.7	-1308.7	2991.4	183970.4
0.85	1.48	1	21	0.34	126	30	30	1	0.80	-0.50	-0.55	0.55	0.46	-0.36	3780	1735.4	-1349.8	3085.2	194367.3
0.85	1.48	1	21	0.34	129	30	30	1	0.80	-0.50	-0.55	0.55	0.46	-0.36	3870	1776.7	-1381.9	3158.7	203733.1
0.85	1.49	1	21	0.34	132	30	30	1	0.80	-0.50	-0.55	0.55	0.46	-0.36	3960	1830.3	-1423.6	3253.9	214760.6
0.85	1.5	1	21	0.34	135	30	30	1	0.80	-0.50	-0.55	0.55	0.47	-0.36	4050	1884.5	-1465.7	3350.2	226141.0
0.85	1.52	1	21	0.35	138	30	30	1	0.80	-0.50	-0.55	0.55	0.47	-0.37	4140	1952.1	-1518.3	3470.3	239454.1
0.85	1.53	1	21	0.35	141	30	30	1	0.80	-0.50	-0.55	0.55	0.47	-0.37	4230	2007.6	-1561.5	3569.1	251622.9
0.85	1.53	1	21	0.35	144	30	30	1	0.80	-0.50	-0.55	0.55	0.47	-0.37	4320	2050.3	-1594.7	3645.1	262444.2
0.85	1.54	1	21	0.35	147	30	30	1	0.80	-0.50	-0.55	0.55	0.48	-0.37	4410	2106.7	-1638.6	3745.3	275280.8
0.85	1.55	1	21	0.36	150	30	30	1	0.80	-0.50	-0.55	0.55	0.48	-0.37	4500	2163.7	-1682.9	3846.6	288492.6

Calculations as per AS NZ 1170

Obtaining qp in Town						Ka	Cpe x Kce x Ka			Cpi x Kci		p Air kg/m3	Cdyn	Net Pressure		Dimensions			Areas m2	FORCES (kN)		Base Shear kN	Bending Moment kNm
Ms	Mz Cat	Md	VR m/s	Vsit m/s	Mt		d/b	W	L	W	L			P, W kN/m2	P, L kN/m2	H m	D m	B m		W kN	L kN		
1	0.8	1	21	16.8	1	0.85	1	0.61	-0.38	-0.27	0.54	1.2	1	0.15	-0.16	3	30	30	90	13.4	-14.1	27.5	41.3
1	0.8	1	21	16.8	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.14	-0.15	6	30	30	180	25.8	-27.4	53.2	159.7
1	0.89	1	21	18.69	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.18	-0.19	9	30	30	270	47.9	-50.9	98.8	444.6
1	0.95	1	21	19.95	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.20	-0.21	12	30	30	360	72.7	-77.4	150.1	900.6
1	0.95	1	21	19.95	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.20	-0.21	15	30	30	450	90.9	-96.7	187.6	1407.2
1	1	1	21	21	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.22	-0.24	18	30	30	540	120.9	-128.6	249.5	2245.3
1	1.05	1	21	22.05	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.25	-0.26	21	30	30	630	155.5	-165.4	320.9	3369.3
1	1.1	1	21	23.1	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.27	-0.29	24	30	30	720	195.0	-207.5	402.5	4829.8
1	1.12	1	21	23.52	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.28	-0.30	27	30	30	810	227.4	-242.0	469.4	6337.1
1	1.15	1	21	24.15	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.30	-0.31	30	30	30	900	266.4	-283.4	549.9	8248.3
1	1.22	1	21	25.62	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.33	-0.35	33	30	30	990	329.8	-350.9	680.8	11232.4
1	1.23	1	21	25.83	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.34	-0.36	36	30	30	1080	365.8	-389.1	754.9	13587.5
1	1.25	1	21	26.25	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.35	-0.37	39	30	30	1170	409.2	-435.3	844.6	16469.3
1	1.26	1	21	26.46	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.36	-0.38	42	30	30	1260	447.8	-476.4	924.2	19407.3
1	1.27	1	21	26.67	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.36	-0.38	45	30	30	1350	487.4	-518.5	1005.9	22633.8
1	1.28	1	21	26.88	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.37	-0.39	48	30	30	1440	528.1	-561.8	1090.0	26159.4
1	1.3	1	21	27.3	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.38	-0.40	51	30	30	1530	578.8	-615.8	1194.6	30461.6
1	1.31	1	21	27.51	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.38	-0.41	54	30	30	1620	622.3	-662.0	1284.4	34678.1
1	1.32	1	21	27.72	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.39	-0.41	57	30	30	1710	667.0	-709.5	1376.5	39230.4
1	1.33	1	21	27.93	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.40	-0.42	60	30	30	1800	712.7	-758.2	1471.0	44129.7
1	1.34	1	21	28.14	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.40	-0.43	63	30	30	1890	759.7	-808.2	1567.9	49387.4
1	1.34	1	21	28.14	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.40	-0.43	66	30	30	1980	795.9	-846.7	1642.5	54202.9
1	1.34	1	21	28.14	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.40	-0.43	69	30	30	2070	832.0	-885.1	1717.2	59242.5
1	1.35	1	21	28.35	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.41	-0.43	72	30	30	2160	881.2	-937.5	1818.7	65472.3
1	1.35	1	21	28.35	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.41	-0.43	75	30	30	2250	917.9	-976.5	1894.5	71042.0
1	1.36	1	21	28.56	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.41	-0.44	78	30	30	2340	968.8	-1030.7	1999.5	77981.6
1	1.36	1	21	28.56	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.41	-0.44	81	30	30	2430	1006.1	-1070.3	2076.4	84095.6
1	1.37	1	21	28.77	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.42	-0.45	84	30	30	2520	1058.8	-1126.4	2185.1	91775.1
1	1.38	1	21	28.98	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.43	-0.45	87	30	30	2610	1112.7	-1183.7	2296.3	99890.0
1	1.38	1	21	28.98	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.43	-0.45	90	30	30	2700	1151.0	-1224.5	2375.5	106897.7
1	1.38	1	21	28.98	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.43	-0.45	93	30	30	2790	1189.4	-1265.3	2454.7	114143.0
1	1.38	1	21	28.98	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.43	-0.45	96	30	30	2880	1227.8	-1306.1	2533.9	121625.9
1	1.4	1	21	29.4	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.44	-0.47	99	30	30	2970	1303.1	-1386.3	2689.3	133122.6
1	1.4	1	21	29.4	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.44	-0.47	102	30	30	3060	1342.6	-1428.3	2770.8	141312.9
1	1.4	1	21	29.4	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.44	-0.47	105	30	30	3150	1382.1	-1470.3	2852.3	149747.6
1	1.4	1	21	29.4	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.44	-0.47	108	30	30	3240	1421.5	-1512.3	2933.8	158426.9
1	1.4	1	21	29.4	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.44	-0.47	111	30	30	3330	1461.0	-1554.3	3015.3	167350.6
1	1.4	1	21	29.4	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.44	-0.47	114	30	30	3420	1500.5	-1596.3	3096.8	176518.9
1	1.4	1	21	29.4	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.44	-0.47	117	30	30	3510	1540.0	-1638.3	3178.3	185931.6
1	1.4	1	21	29.4	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.44	-0.47	120	30	30	3600	1579.5	-1680.3	3259.8	195588.8
1	1.4	1	21	29.4	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.44	-0.47	123	30	30	3690	1619.0	-1722.3	3341.3	205490.4
1	1.4	1	21	29.4	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.44	-0.47	126	30	30	3780	1658.5	-1764.3	3422.8	215636.6
1	1.4	1	21	29.4	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.44	-0.47	129	30	30	3870	1698.0	-1806.3	3504.3	226027.3
1	1.4	1	21	29.4	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.44	-0.47	132	30	30	3960	1737.4	-1848.3	3585.8	236662.4
1	1.4	1	21	29.4	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.44	-0.47	135	30	30	4050	1776.9	-1890.4	3667.3	247542.0
1	1.4	1	21	29.4	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.44	-0.47	138	30	30	4140	1816.4	-1932.4	3748.8	258666.1
1	1.4	1	21	29.4	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.44	-0.47	141	30	30	4230	1855.9	-1974.4	3830.3	270034.7
1	1.4	1	21	29.4	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.44	-0.47	144	30	30	4320	1895.4	-2016.4	3911.8	281647.8
1	1.4	1	21	29.4	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.44	-0.47	147	30	30	4410	1934.9	-2058.4	3993.3	293505.4
1	1.4	1	21	29.4	1	0.8	1	0.58	-0.36	-0.27	0.54	1.2	1	0.44	-0.47	150	30	30	4500	1974.4	-2100.4	4074.8	305607.4