Journal of Engineering
journal homepage: www.jcoeng.edu.iq
Number 5 Volume 24 May 2018

Civil and Architectural Engineering

Wind Interference Effect for Overall Design Load on Mid-Rise Building

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ABSTRACT

The constructed building in the urban area is subject to wind characteristics due to the influence of surrounding buildings. The residential complexes currently being built in Iraq represent a case study for the subject of this research. Therefore, the objective of this study is to identify the interference effect because of adjacent buildings effects on the mid-rise building. The speed and pressure of the wind have been numerically simulated as well as wind load has been simulated by using a virtual wind tunnel which is available in Autodesk Robot Structural Analysis, RSA, software. Two identical adjacent buildings have been simulated and many coefficients were included in this study such as the spacing, directionality, and elevation of adjacent building coefficients. The results of the study showed that the neighboring building could increase or decrease the wind pressure significantly so that it cannot be neglected.

Key Words: virtual wind tunnel, interference effect, CFD, CWE.

تأثير تداخل الرياح على تصميم الحمل التصميمي لبناية متوسطة الارتفاع

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الخلاصة

يخضع المبنى المنشأ في المنطقة الحضرية لخصائص الرياح بسبب تأثير المباني المحيطة به. إن المجمعات السكنية التي تبنى حاليا في العراق تمثل حالة دراسية لموضوع هذا البحث. لذا فأن الهدف من هذه الدراسة هو التعرف على تأثير التداخل بسبب تاثيرات الابنية المجاورة على مبنى متوسط الارتفاع. ان سرعة وضغط الرياح تم محاكتها عدديا وكذلك محاكاة حمل الرياح عن طريق عمل نفق رياح افتراضي والمتوفر في برنامج حاسوبي لتحليل العناصر المحددة لشركة اوتودسك (RSA). تم عمل محاكاة لبنايتين متماثلتين متجاورتين وتضمين العديد من المعاملات خلال هذه الدراسة مثل معامل المسافة ومعامل زاوية الدوران للبناية المجاورة ومعامل تأثير ارتفاع البناية المجاورة نسبة الى البناية الرئيسية. أظهرت نتائج الدراسة أن المبنى المسبب للتداخل يؤدي إلى زيادة ضغط الرياح بشكل كبير ومؤثر على المبنى الرئيسي بحيث لايمكن اهماله.

الكلمات الرئيسية: نفق الرياح الافتراضي، تأثير التداخل، ديناميكا الموائع الحسابية، هندسة الرياح الحسابية.

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Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2018.05.07

1 INTRODUCTION

Wind is the motion of air with respect to the surface of the earth is basically caused by changing solar heating of the earth's atmosphere. It is introduced in a more immediate sense by variances of pressure between point equal elevation **Simiu** and **Scanlan, 1996.** Wind is normally applied to the natural horizontal motion of the atmosphere and the motion in a nearly vertical direction is called a current **Taranath, 2004**. Movement of air close the surface of the earth is three dimensional with horizontal motion much larger than the vertical motion. Vertical motion is importance in meteorology. However, it is of less importance near the ground surface **Taranath, 2012.**

Wind-induced structure motion can basically be divided into three categories: across-wind, along-wind, and torsional motion. Structure sway parallel to the wind direction is called along-wind motion, this motion is made by fluctuations in wind, and the differences in wind pressure faces between the windward and leeward faces of the building, as shown in **Fig. 1, Günel** and **Ilgin, 2014**.

A typical application is the prediction of wind loading on buildings. The loading is the outcome of the pressure distribution on the building. The variation of the pressure is calculated by the flow field around the building that itself depends on the shape of the building and its surrounding buildings, and on the flow characteristics **Stathopoulos** and **Baniotopoulos, 2007**.

1.1 Computational Wind Engineer

Applications of computational fluid dynamics, CFD, in wind engineering, called Computational Wind Engineering, CWE, have significantly increased in the last two decades. Despite its widespread use, the general evaluation of the approach for quantitative, and sometimes even qualitative predictions. The main objection against practical application of the CWE are the many physical and numerical parameters in the approach, which should be chosen by the user without precise criteria **Franke, et al., 2004.**

Computational Fluid Dynamics is basically a numerical method for simulating or predicting phenomena and quantities of a fluid flow by solving the equations of motion of the fluid at a discrete set of points. CFD has significantly improved recently. CFD has become an application tool for wind engineering problems **Tamura** and **Kareem, 2013**. CFD is describing the fluid flow equations by solving it on a super-computer. In wind engineering, the air flow is normally the atmospheric boundary layer flow. Turbulent flows are defined by the well-known continuity, momentum, and energy equations, named after Navier and Stokes equations, NS equation **Anderson** and **Wendt 1995.**

1.2 Finite Volume Method

Finite Volume Method, FVM, is a numerical method started for the simulation of flow, it transforms the set of partial differential equations, PDE, into integral equations as a system of linear algebraic form. But, the discretization process used in the FVM is special and includes two fundamental stages. In the first stage, the PDE is transformed into equilibrium equations and integrated over an element besides this includes changing the volume and surface integrals for separate algebraic relations through elements in addition to their surfaces utilizing an integration quadrature of a particular order of accuracy. In the second stage, interpolation function is selected to estimate the differences of the variables within the element plus relate the variables surface values to their values of the cell. Therefore, transform the algebraic relationships to algebraic equations **Moukalled, et al., 2016**.

The conception behind the FVM, the fluid flow field is divided into several small volumes. In the proper development of the approach, the Navier and Stokes equations are integrated over a volume besides an accurate expression named the Gauss divergence theorem is operated to convert the volume integrals of shear stress and momentum into integrals of the surface. The resulting equations are like those that obtained by NS equations using the control volume **Mansun, et al., 2013**.

1.3 Previous Studies

The interference effect due to the adjacent structure has been studied by many researchers with several methods, thus the most important researches have been reviewed in below.

Alzaidee and **Kasim, 2017,** studied the validation of CFD simulation for flow around the building. This paper is evaluated by direct comparison in wind pressure coefficient between CFD simulations in three dimensions with experimental wind tunnel data. The simulation was carried out using virtual wind tunnel that found in Autodesk Robot Structural Analysis software. The study results show the CFD simulation results tend to overestimate the pressure distribution in the faces of buildings.

The paper of **Pallab** and **Sujit, 2015,** is based on a case study of the effect of the adjacent building due to wind load over a high-rise building by using CFD technique. This analytical study is carried out by modeling of the single building, interfering structures, main building and the surface boundary with different wind circumstances angles (directionality effects). The interference effect anticipates the several shapes and sizes of the primary building and the surrounding interference structure and their angle, numerous terrain conditions (upstream surface roughness) and directionality condition. The paper found that surrounding interfering structures may increase or decrease the wind pressure response on the major building and it is depending on the arrangement of surrounding structures and the direction of flow.

The main purpose of this present work **Kim** and **Tamura, 2013**, was to realize the characteristics of wind load correlations and quasi-static wind pressure combinations of a target model in a group of surrounding structures. Fluctuating pressures were integrated over the cladding and results were found along, across, uplift, wind force and along and across wind overturning moment and torsional moment. The main results of this study found the peak normal stresses in columns were practically 27% underestimated on average for the single low-rise building if only along wind force was considered in the structural design.

Dayang, et al., 2012, discussed in details wind load characteristics of a twin-tower tall building disturbed by surrounding structures were examined using large eddy simulation. The study has been performed for the mean and fluctuating pressure coefficients and detail explanations of each analysis results were assumed. The numerical results which obtained in this study are anticipated to provide engineers a well understanding of wind field flow around structures.

2 CASE STUDY

2.1 General Remark

Overall design load means that the total wind force for lateral analysis contains combined negative and positive pressures around the structure. The total load is the sum of negative and positive pressures revolving instantaneously over the whole structure surface and it is assumed to have a precise direction and intensity. Even though appropriate evaluation of total wind load is vital, for any structures have been collapsed by winds. **ASCE 7, 2010**, design code reflect the overall design load as Main Wind Force Resisting systems**,** MWFRS**,** and state it as an accumulation of structural elements assigned to afford stability and support for the global structure. The structure usually takes wind loading from further than one surface. The sign convention for overall design load, **Fig. 2** shows force components a three-dimensional structure that adopted by default in RSA software.

For all case below, the term of “response without interaction” is adapted to the results of a single building whereas the term of “response with interaction” is referring to the results of two identical buildings. The objective is to find the ratio of response with interaction per response without interaction for across and along-wind directions. It has been expressed in a normalized form as indicated in

Table 1.

2.2 Numerical Modeling

Numerical modeling was carried out using RSA software. Structural system for the case study has been assumed as Moment Frame System (flat slab system) with 15 stories. A multi-story concrete building consisting of 15 floors each floor with $3m$ height (total building height equal to $45m$) with square layout equal to $30 \times 30\ m$ with grid spacing equal to $5m$. Mean wind speed has been assumed to be $40\ \mathrm{m/sec}$. Topographic factor, $\mathrm{K_{zt}}$, is assumed to 0.85 that adopted from ASCE/SEI 7-10. Exposure C for upstream Atmosphere Boundary Layer, ABL, is adopted from ASCE/SEI 7-10. All columns have been modeled with $3\ m$ in height with $0.6 \times 0.6\ m$ cross section. Slab depth for roofs, and floors has been supposed to be $0.2m$ Moment frame system physical model, which was created by Revit software that will be adopted for all cases. **Fig. 3** shows the two identical buildings model.

2.3 Virtual Wind Tunnel Size

The dimensions of the Virtual wind tunnel were set to be large enough (compared to the model) to avoid edge effects at all wind directions. Tunnel size is established automatically and is large in relation to the building, typically 4 x width, 4 x length, and 2.5 x height of the structure. For the case of the effect of adjacent building spacing, **Fig. 4** illustrates the virtual tunnel size where b, l, and h donate width, length, and height building size and B, L, and H donate the tunnel size besides s donates the spacing between two identical building. In case of directionality effect, the spacing is assumed constant and equal to main buildings width. Wind direction is perpendicular to buildings width as shown in **Fig. 5**. Finally, **Fig. 6** displays the virtual wind tunnel size for the case of elevation of the adjacent building.

2.4 Effect of Spacing of Adjacent Building

The aim of this study is to find the amount of variation for overall design load along and across wind direction. Location of adjacent building is considered as the main predicting parameter and it is implicit in normalized form relative to principle building width. Results that extracted from software are illustrated in **Table 2.** Normalization technique that adopted, in this case, is presented in **Table 2. Fig. 7** shows the pressure distribution that extracted from software. The results below show the wind effects on overall design load is shown in **Fig. 8 and 9**. Normalizations form for base shear and moments and total deformation is shown in

Table 1.

2.5 Directionality Effect

Aerodynamic behavior depends upon direction for most structural members. Thus, another parameter is considered in this study which is the effect of directionality for two identical buildings. **Table 4** displays the calculations of overall design load that extracted from software. **Fig. 10** presented the wind load simulation that extracted from software. Normalization technique that adopted, in this case, is presented in **Table 2. Fig. 11 and 12** show the effect of directionality on along and across wind direction for overall design load. The spacing between two identical building is assumed constant and equal to half of the main building width (15m). Note that the term of response with interaction that shown in figures below means that the simulation was done for two building including the directionality effect. Normalizations form for base shear and moments and total deformation is shown in

Table 1**.**

2.6 Effect of Elevation of Adjacent Building

The purpose of this study is to find the effect of the height of the adjacent building. The height of the adjacent building is assumed the main predicting parameter for this study. It has been expressed in a normalized form relative to main building width. The spacing between two building is assumed constant and equal to main building width (30m). Note that, for this study, the parameter (h) is assumed the elevation of the adjacent building and (b) is equal to main building width. **Fig. 13** shows the form of this study. **Table 6** presents the results of overall design load that extracted from software. Normalization technique that adopted, in this case, is presented in **Table 2**. **Fig. 14 and 15** display the variation in overall design load for along and across the wind. Normalizations form for base shear and moments and total deformation is shown in

Table 1.

3 CONCLUSIONS

Reviewing the achieved results, the following conclusions have been drawn:

1. For case of interference effect due to spacing of adjacent building, for along wind action, it shows at distance *0.25* of the main building width (adjacent building at 7.5m from main building) that the amounts of base moment and shear and total deformation of the wind are 45% higher than for a single building due to the impact of the adjacent building. At distance of 0.5 of the main building width (adjacent building at 15m from the main building), the effect starts to decrease as the adjacent building move away from the principle building until reach twice the width of the main building (adjacent building at 30m from the main building). For across wind action, the results showed that there is a significant impact because of the influence of the neighboring building, which cannot be neglected, especially for base shear and moment. However, there is no significant effect for twisting moment and total deformation because of the difference less than *5%*.
2. For the case of interference effect due to directionality effect, it showed that the wind direction has a significant impact, which may lead to increase or decrease the values of base shear and bending moment and total deformation in along and across wind direction. The results showed that the highest effect of wind at an angle 0^{o}. However, the wind action tends to decrease at an angle 45^{o}. At angle 90^{o}, the results show decreases for over-all design load and may be neglected.
3. For the case of elevation of the adjacent building, the results show that in a long wind direction the base shear and moment and total deformation increases by increasing the height

of the adjacent building. The increase was 35% compared to an isolated building. In across wind action, the results of overall design load increases about 10% compared to a single building and it is increased by increasing neighbor building height.

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5 NOMENCLATURE

b= building width, m.
l= building length, m.
h= building height, m.
B= virtual wind tunnel width, m.
L= virtual wind tunnel length, m.
H= virtual wind tunnel height, m.

F= base shear, kN.
M= base moment, kN.m.
U= total deformation, cm.

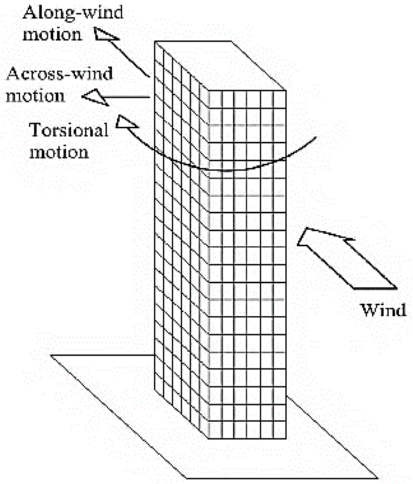


Figure 1. Building under the effect of wind loads.

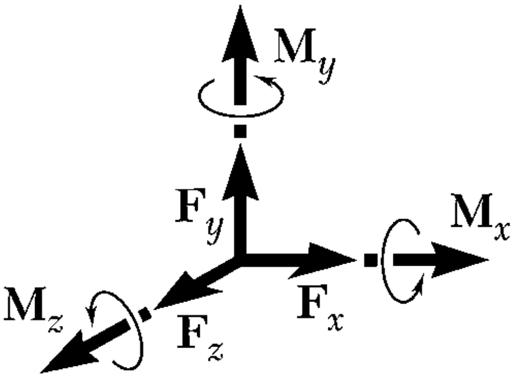


Figure 2. Three force components and three couples.

Table 1. Normalization technique which adopted in this study.

Case	Load Direction	Base Shear	Base Moment	Deformation	Twisting Moment
Single Building	Along Wind	F_{x1}	M_{y1}	U_{x1}	-
	Across Wind	F_{y1}	M_{x1}	U_{y1}	-
Two Identical Buildings	Along Wind	F_{x2}	M_{y2}	U_{x2}	-
	Across Wind	F_{y2}	M_{x2}	U_{y2}	M_{z2}

Normalization (along wind)	$\frac{F_{x2}}{F_{x1}}$	$\frac{M_{y2}}{M_{y1}}$	$\frac{U_{x2}}{U_{x1}}$	-
Normalization (across wind)	$\frac{F_{y2}}{F_{x1}}$	$\frac{M_{y2}}{M_{y1}}$	$\frac{U_{y2}}{U_{x1}}$	$\frac{M_{z2}}{M_{y1}}$

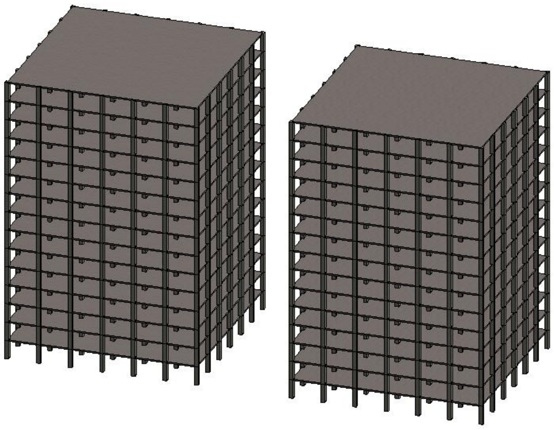


Figure 3. Moment Frame System 3D Modeling.

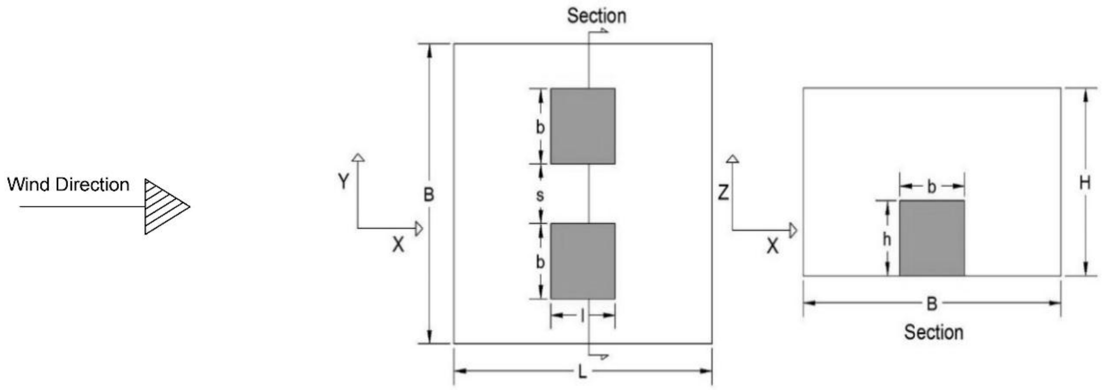
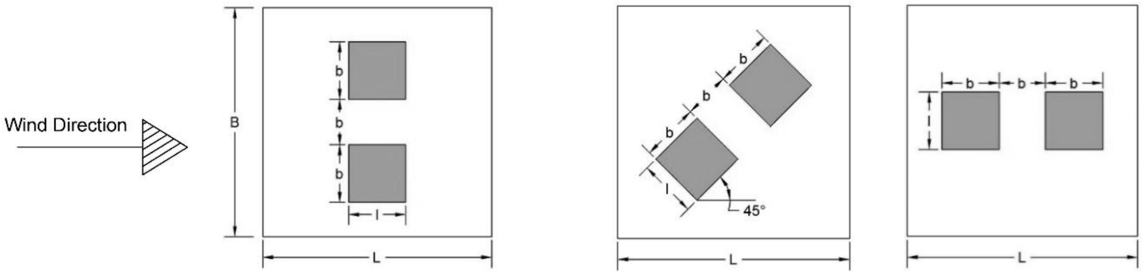


Figure 4. Virtual Wind Tunnel Size. In case of the effect of spacing of adjacent building.



(a) (b) (c)

Figure 5. Plan view for virtual wind tunnel, in case of directionality effect; (a) angle = 0^o; (b) angle = 45^o; (c) angle = 90^o.

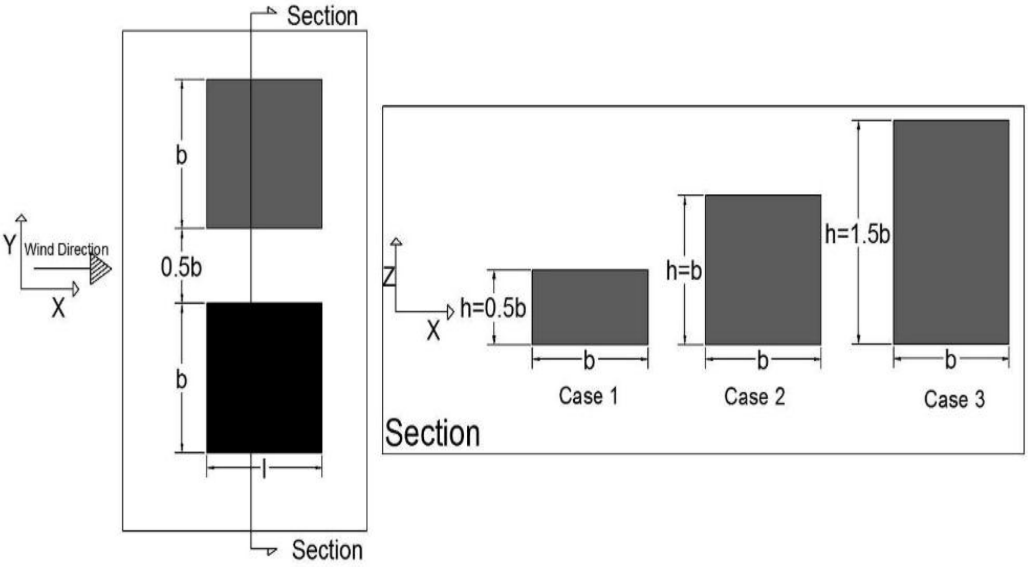


Figure 6. Virtual wind tunnel size, elevation of adjacent building case.

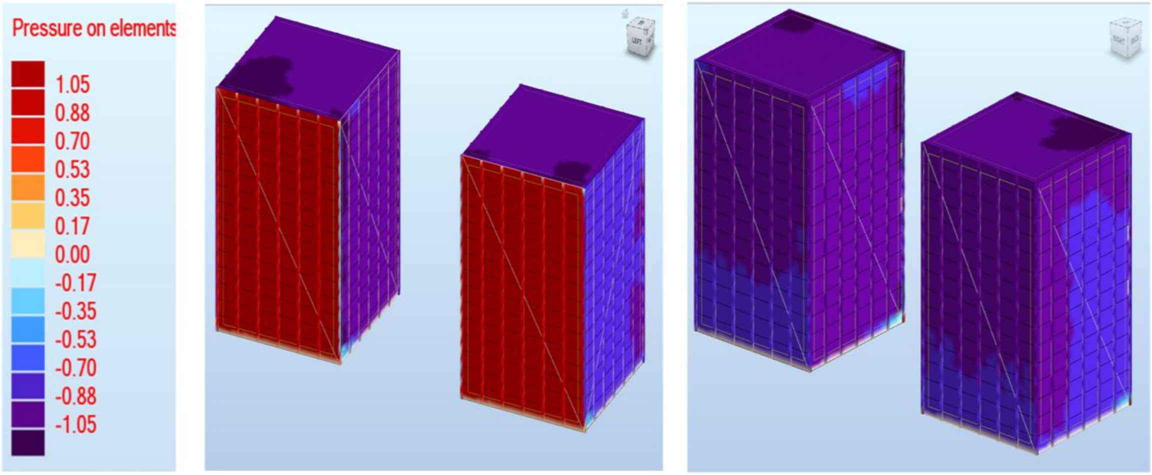


Figure 7. Pressure distribution for all faces of building at b/s=1.

Table 2. Results of base shear, moment, and total deformations in along and across wind directions. Note that b/s=0 means a single building.

Spacing	b/s	0	$^1/_4$	$^1/_2$	$^3/_4$	1	$^3/_2$	2
F_x	kN	5284	7600	7028	6984	6955	5996	4265
F_y	kN	0	-1000	529	307	300	84	0
M_x	$kN.m$	0	15000	-11300	-6150	-6100	-1436	0

M_y	$kN.m$	106794	155000	142025	141250	140100	121575	86776
M_z	$kN.m$	0	-339	-3100	-5322	-2362	-1396	0
U_x	cm	12.5	18	16.6	16.5	16.3	14.1	10.2
U_y	cm	0	-3	1.2	0.69	0.68	0.1	0

Table 3. Normalization technique that adopted for this case for along and across wind. Note that the procedure of normalization is presented in Table 1.

b/s	0	$^{1}/_{4}$	$^{1}/_{2}$	0.75	1.00	1.50	2.00
Fx	1	1.44	1.33	1.32	1.32	1.13	1.00
My	1	1.45	1.33	1.32	1.31	1.14	1.00
Ux	1	1.44	1.33	1.32	1.30	1.13	1.00
Continued							
Continued							
Fy	0.00	-0.19	0.10	0.06	0.06	0.02	0.00
Mx	0.00	0.14	-0.11	-0.06	-0.06	-0.01	0.00
Mz	0.00	0.00	-0.03	-0.05	-0.02	-0.01	0.00
Uy	0.00	-0.10	0.10	0.06	0.05	0.01	0.00

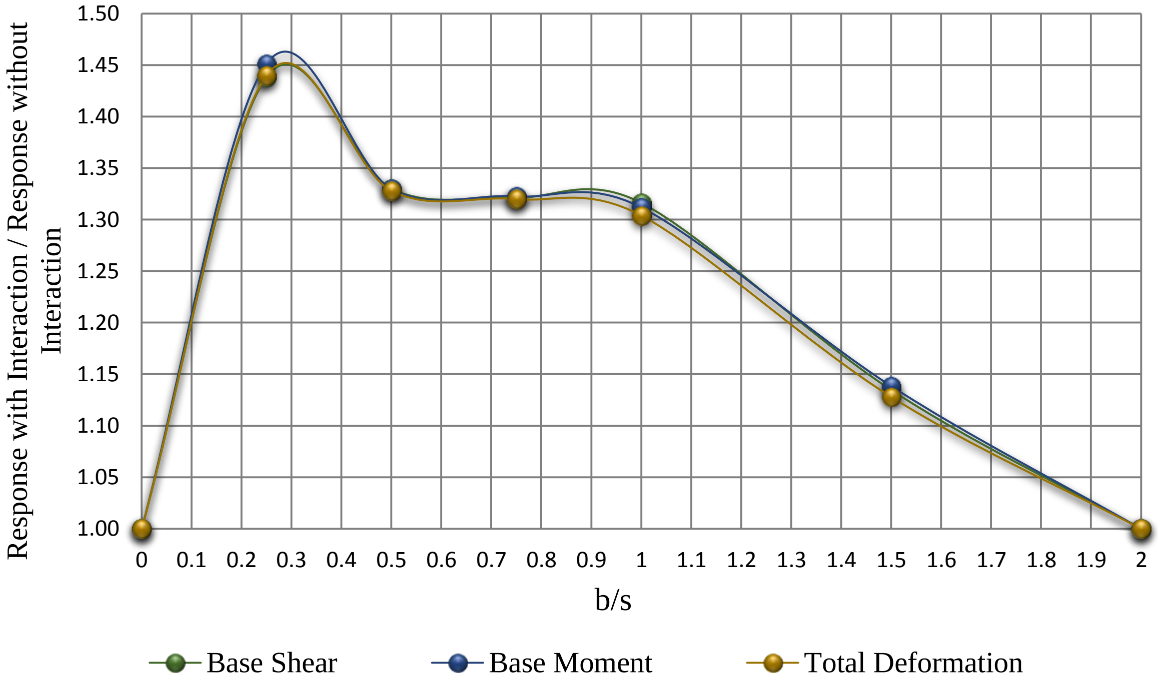


Figure 8. The amount of variation in the base shear and moments and total deformation with respect to the spacing of adjacent building in along wind direction.

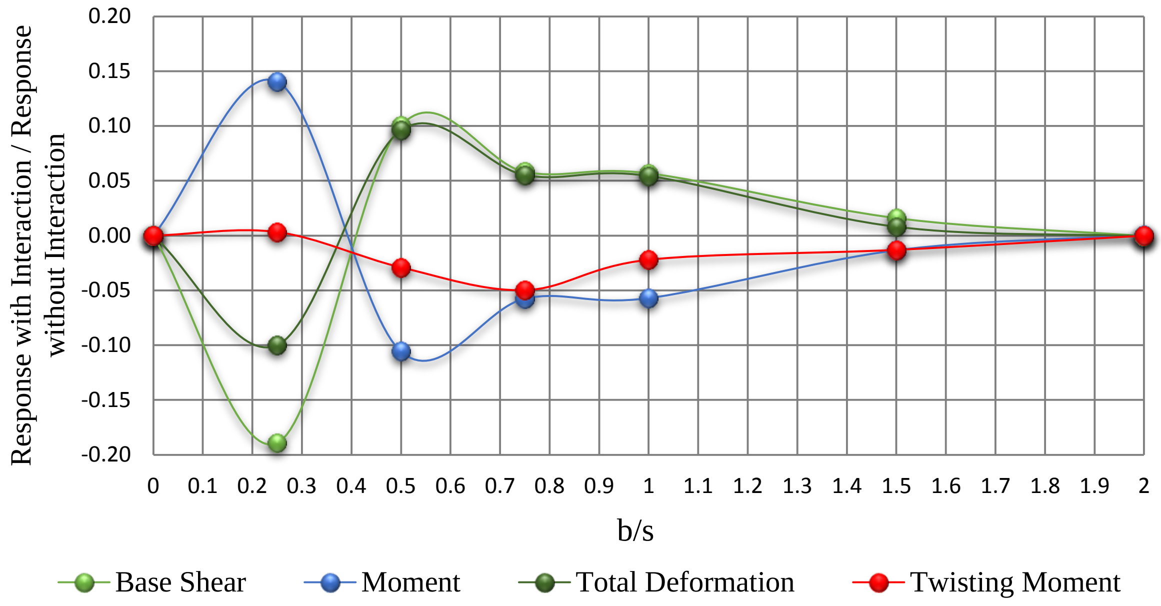


Figure 9. The amount of variation in the base shear and moments and total deformation with respect to building width in across wind direction.

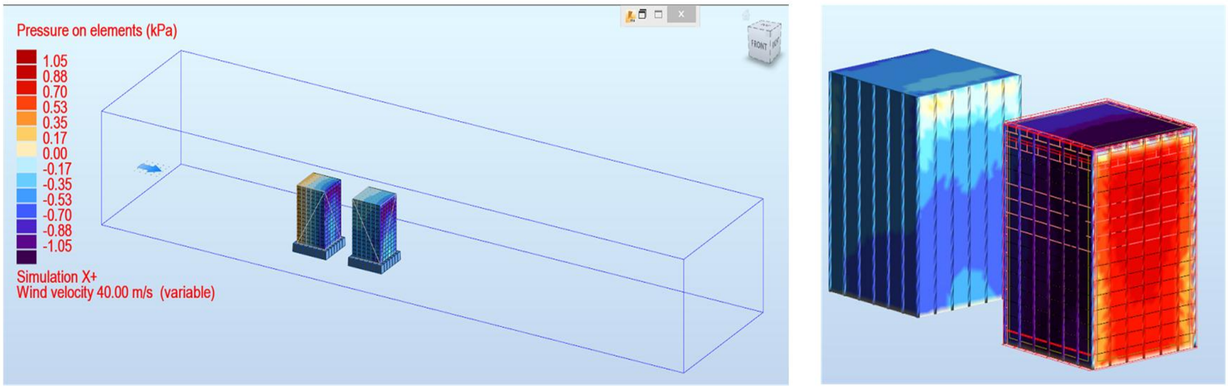


Figure 10. Wind load simulation for an angle = 90^0 with b/s=1.

Table 4. Results of base shear, moment, and total deformations in along and across wind.

Angle (θ)		0^o	45^o	90^o
Fx	KN	5285	2453	3785
Fy	KN	0	2530	0
Mx	$KN.m$	0	-50500	0
My	$KN.m$	106800	49000	79200
Mz	$KN.m$	0	-2700	0
Ux	cm	12.5	5.8	9.2
Uy	cm	0	6	0

Table 5. Normalization technique that adopted for this case for along and across wind direction. Note that the procedure of normalization is shown in Table 1.

Angle	0	45	90
Fx	1.39	0.46	0.72
Fy	0.06	0.48	0.00
Mx	-0.06	-0.47	0.00
My	1.39	0.46	0.74
Mz	-0.02	-0.03	0.00
Ux	1.35	0.45	0.71
Uy	0.05	0.46	0.00

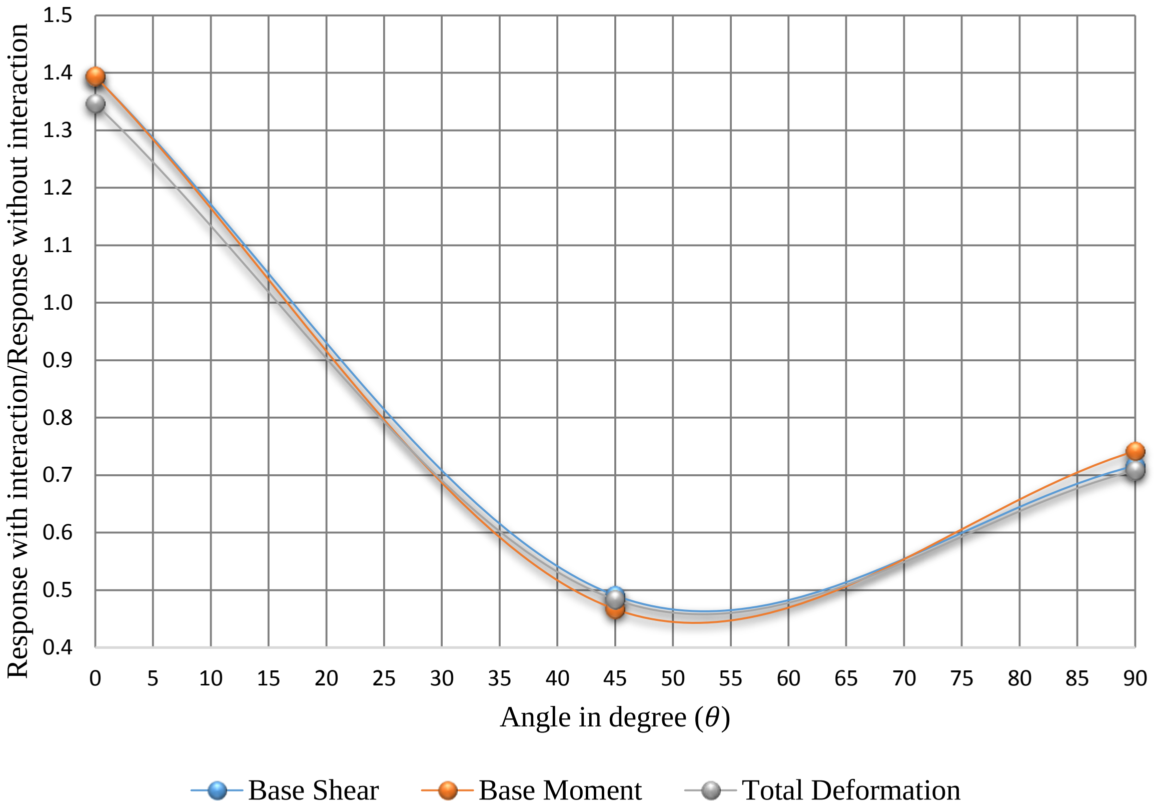


Figure 11. The amount of variation in the base shear and moments and total deformation with respect to building angle in along wind direction.

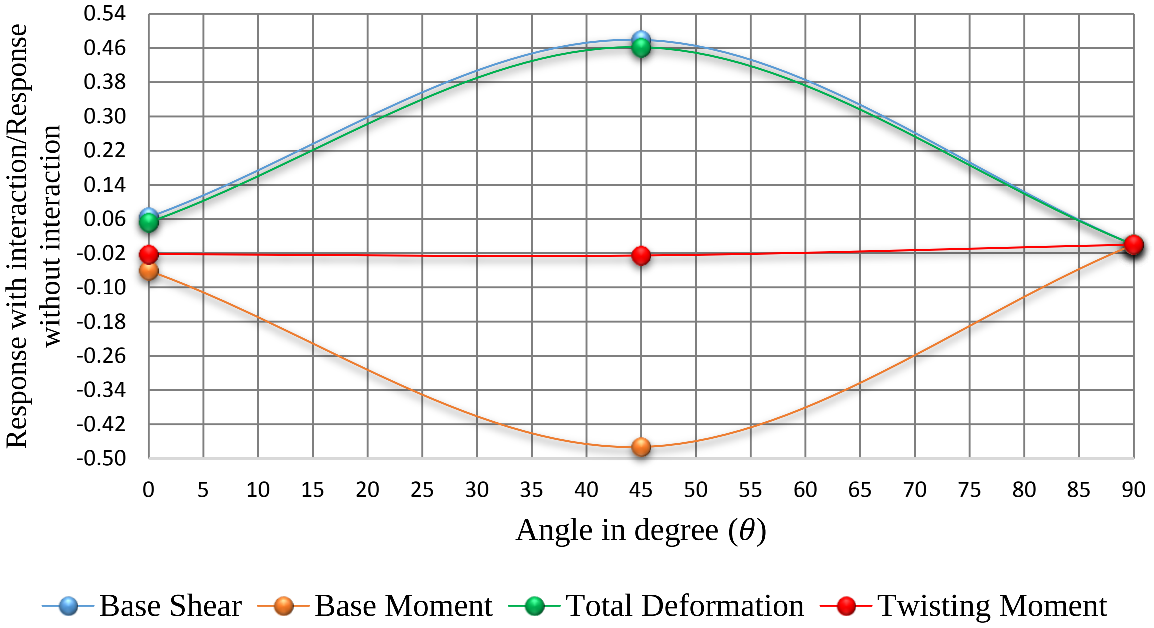


Figure 12. The amount of variation in the base shear and moments and total deformation with respect to building angle in across wind direction.

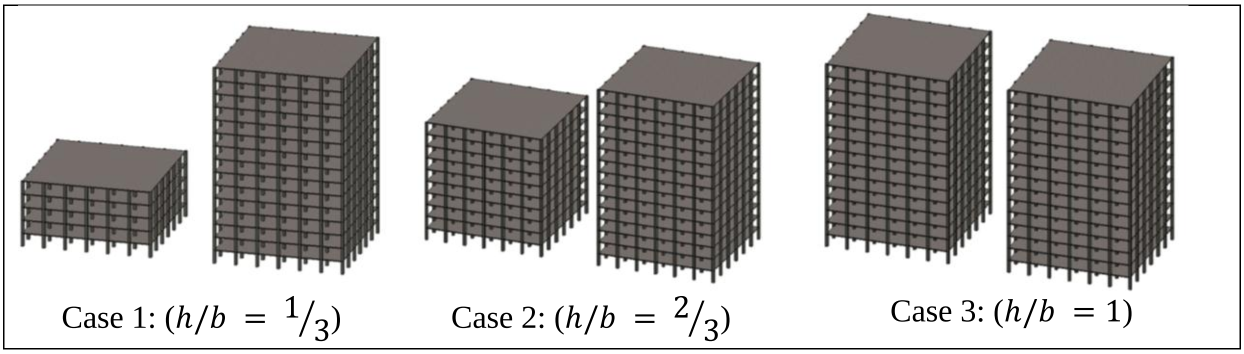

Case 1: ($h/b = {}^{1}/_{3}$)
Case 2: ($h/b = {}^{2}/_{3}$)
Case 3: ($h/b = 1$)

Figure 13. Case Study Forms, where ***h***: the elevation of the adjacent building; ***b***: the width of main building.

Table 6. Results of base shear, moment, and total deformations in along and across wind directions.

h/b		0	1/3	2/3	1
Fx	KN	5285	5940	6400	7028
Fy	KN	0	370	460	529
Mx	$KN.m$	0	-7300	-10000	-11300
My	$KN.m$	106800	121500	129000	142025
Mz	$KN.m$	0	-460	-1200	-3100
Ux	cm	12.5	14.2	15	16
Uy	cm	0	0.8	1.1	1.2

Table 7. Normalization technique that adopted for this case. Note that the procedure of normalization is shown in Table 1 and (h/b) means single building.

Along Wind				
h/b	0	0.333	0.667	1
Fx	1	1.12	1.21	1.33
Fy	0	0.07	0.09	0.10
Mx	0	-0.07	-0.11	-0.11
Across Wind				
My	1	1.14	1.21	1.33
Mz	0	0.00	-0.01	-0.03
Ux	1	1.14	1.20	1.28
Uy	0	0.06	0.09	0.10

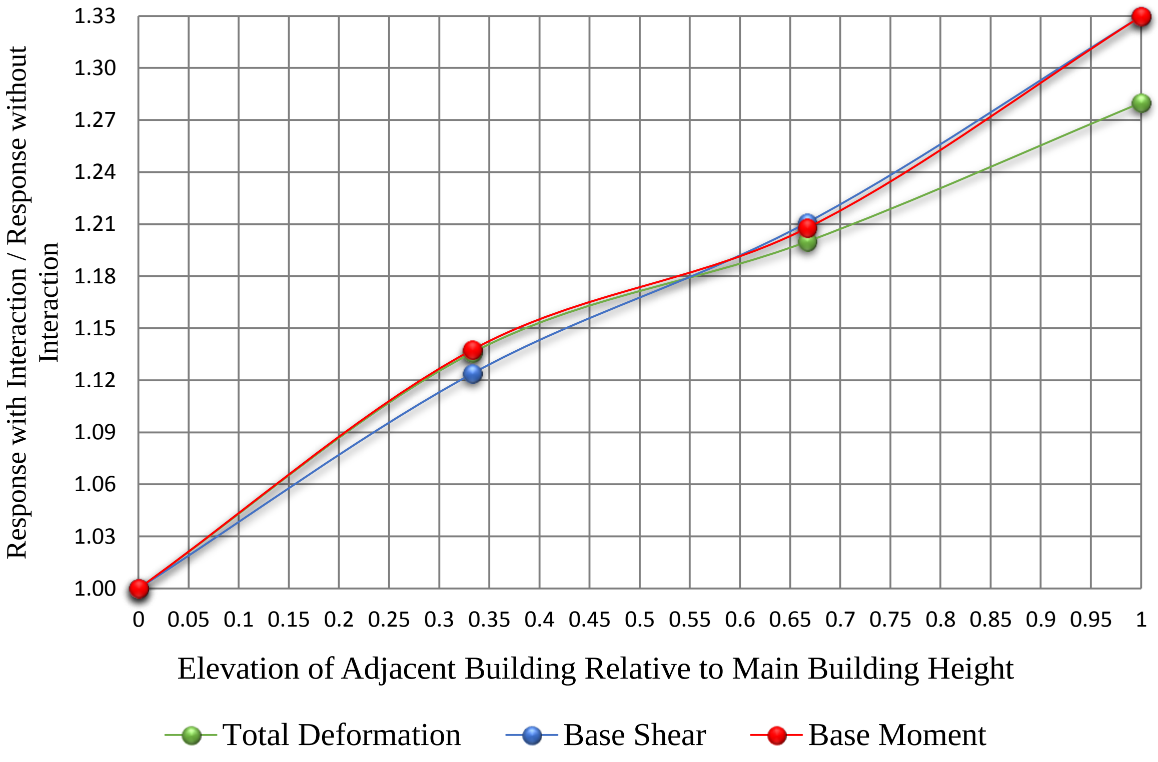


Figure 14. The amount of variation in the base shear and moments and total deformation with respect to elevation of the adjacent building relative to main building width in along wind direction.

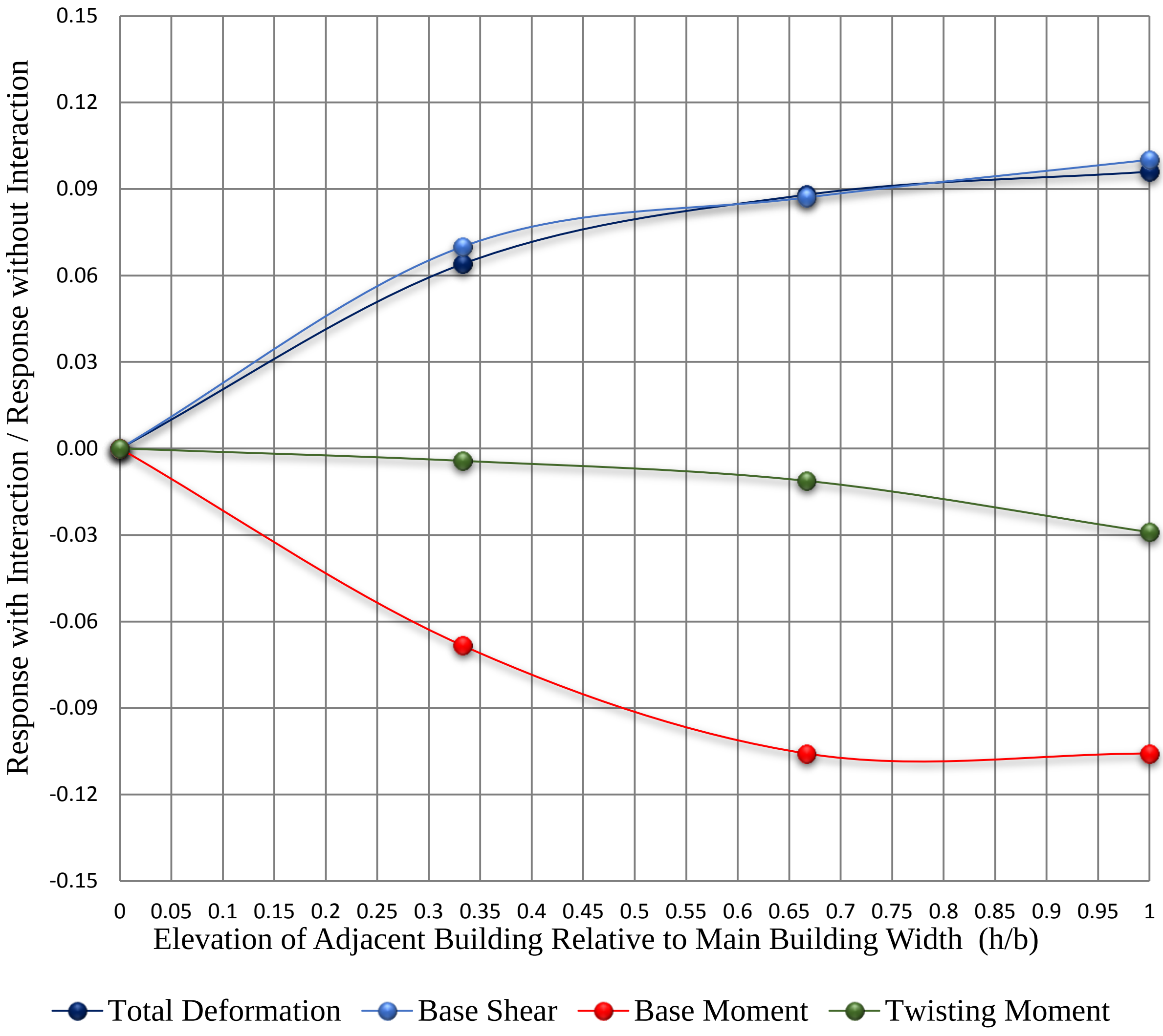


Figure 15. The amount of variation in the base shear and moments and total deformation with respect to elevation of the adjacent building relative to main building width in across wind direction.