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Effects of Wind in the Construction Activities at High-rise Buildings

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Abstract
Wind is one of the determinant factors of outdoor human comfort. In this respect, wind negatively affects the productivity of the workers working outdoors. Thus wind conditions can hamper the construction site activities and unless carefully planned for beforehand major delays can be faced. There are various studies made by the researchers regarding the effects of wind on productivity at construction sites. In high-rise construction, especially during the structural works, wind affects several functions on site. In cases of reinforced concrete buildings, these can be named as the workers' productivity, formwork manipulation, crane operations, concreting activities including curing of concrete and workers safety. The objective of this study is to demonstrate analytically the effects of wind on the construction schedules in the reinforced concrete high-rise constructions in Istanbul taking into the probabilistic wind conditions. The study is conducted using the commercial software code ANSYS-FLUENT. The necessary long term meteorological data is obtained from the Turkish State Meteorological Service. Through the study it is intended to form a guideline for the contractors for selecting the best probable scheduling scheme in high rise construction.

Keywords
Wind, Labor productivity, safety, scheduling

1. Introduction

Increasing populations and urbanization forces the cities continuously grow in size. Depending on the real estate market conditions and the physical limitations of the city, this growth is usually in both horizontal and vertical directions. Consequently, due to numerous reasons, especially in the central business areas of the cities the demand for built space increases which then forces the city administrations permit the construction of taller buildings in these areas. Yet on the other hand, with the aid of the new technologies being developed, every day we see new taller buildings being built.

Istanbul is a good example for the topic explained above. Being the most populous city in Turkey and inhabited by over 12 million residents, Istanbul produces about 50% of the gross national product. Parallel to Turkey's economic development in the several decades, the demand for new dwellings and office space have grown considerably in the city. Yet the city is separated into 2 sections, namely the Eastern and the Western sections separated by the Bosporus straits, and bound by the sea on the North and the South sides. Also a considerable part of its geographical area is covered by forests. Hence, land for new development is rapidly becoming scarce within the city and forcing the city to grow further to the East and West from its current setting, thus making the distance from the residential areas to the business districts increase.

As a natural consequence of this fact, to accommodate more building space, older buildings are being replaced by new high rises in the city (See Fig. 1). Typical examples for this case are the sections of the city districts Gayrettepe, Esentepe, 4^{th} Levent and Maslak / Ayazaga areas which host the headquarters of major banks and companies. Though there are many more tall buildings in the city, a considerable amount of tall buildings rise on the Buyukdere Avenue which runs through these districts.

Figure 1: Tall Buildings around Istanbul

A project, regardless of its sector is generally thought to be successful, if its defined scope is completed within its estimated cost, scheduled duration and desired quality. Yet, unlike the projects in most of the other sector, in the construction sector projects are almost always conducted in the open area. Due to this fact, construction sites are subject to the variations in the weather conditions. Indeed the weather conditions quite often constitute the basis for time extensions and / or disputes in the construction projects. Among the adverse climatic conditions, heavy rains, heavy snow fall, extreme temperatures and high speed winds can be named (Khan, 2005). The high speed winds not only affect the operation of the construction equipment such as cranes but also affect the productivity and the safety of the workers who work outdoors.

The objective of this study is to investigate the effects of wind velocities on the productivity rate and safety of the labor working in the structural construction of a typical tall building under the prevailing wind conditions in Istanbul. Some of the early findings achieved in the study will be presented in this paper.

2. Earlier Studies

Human comfort can be defined as conditions that hinder human beings' performance in some way or another. Outdoor human comfort depends on various factors such as temperature, humidity, precipitation, wind and noise levels. Regarding the human comfort in windy conditions, namely the human wind comfort, valuable studies have been conducted and published by various researchers. Through use of either wind tunnel tests and / or actual field measurements various researchers developed criteria for pedestrian wind comfort (ASCE, 2003; NOAA, 2010).

As a simple guide the Beaufort scale, which was developed for seaman can be used for the determination of the wind effects on humans (NOAA, 2010). The scale is designed to have 12 levels covering from calm to hurricane. In Table 1, the first 7 levels of the scale are presented. As can be seen from the table, the wind conditions at and above Beaufort Scale 7 are considered very dangerous for the people outdoors.

Table 1: Analyzed Model Definitions

Beaufort Force	Hourly-Average Wind Speed (m/s)	Hourly-Average Wind Speed (km/s)	Description of Wind	Noticeable Wind Effect
0	< 0.45	<1.6	Calm	Smoke rises vertically
1	0.45 - 1.55	1.60 – 5.60	Light	Air Direction shown by smoke drift but not by vanes
2	1.55 - 3.35	5.60 -12.10	Gentle Breeze	Wind felt on face; leaves rustle; wind vane moves
3	3.35 - 5.60	12.10 – 20.20	Light Breeze	Leaves & twigs in motion; wind extends a flag
4	5.60 - 8.25	20.20 – 29.70	Moderate Breeze	Raises dust and loose paper; small branches move
5	8.25 – 10.95	29.70 – 39.40	Fresh Breeze	Small trees, in leaf, sway
6	10.95 - 14.10	39.40 – 50.80	Strong Breeze	Large branches begin to move; telephone wires whistle
7	14.10 - 17.20	50.80 – 61.90	Near Gale	Whole trees in motion

There are numerous publications available in the technical literature on the effects of the climatic conditions on the performance and productivity of construction labor. In the study published by Moselhi and Kahn (2010), wind velocity was stated as one of the climatic conditions that seems to have a noteworthy effect on the labor productivity of formwork labor. It was reported that an increase in wind speed negatively affects productivity and that wind speeds exceeding 15.0 km/hr (4.2 m/sec) affect the labor productivity adversely by 20% or above. The relationship between the productivity of formwork labor and the wind speed developed by Moselhi and Khan (2010) is presented graphically in Figure 2. While developing this curve, Moselhi and Khan used the data monitored from two major building construction sites in early the 2000's in downtown Montreal, Canada.

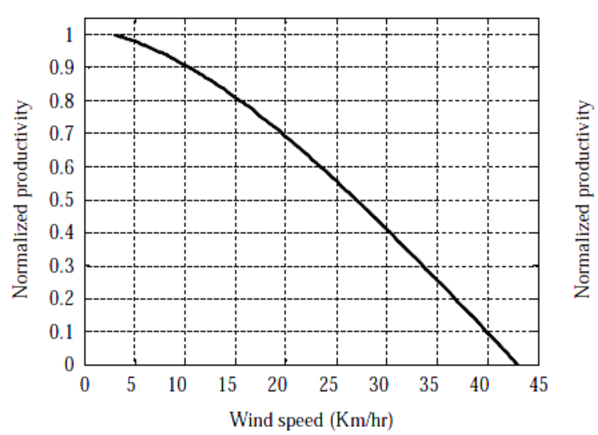


Figure 2: Wind – Productivity (Moselhi and Khan, 2010)

Another climatic condition that can have adverse effects on productivity is the outside temperature. To be more specific, both cold weather and hot weather affect men both psychologically and physiologically. Psychologically, people may merely wish not to be exposed to unpleasant working conditions. Physiologically, individuals may suffer loss of an extremity due to exposure during cold temperatures (Koehn and Brown, 1985). At this point, it is worth bearing in mind that the temperature felt by the humans is a function of the relative humidity and the wind speed.

In addition to impacts on productivity, the wind speed also has negative effects on laborers occupational health and safety. According to a study conducted by Jensen (Jensen Roger C., 1983), injuries due to the effect of a combination of low temperature and wind velocity may occur whenever personnel are required to work in cold climates. Workers' compensation data from USA indicate that over three-fourths of the claims for cold weather injuries are for frostbite involving the fingers, hands, toes, feet, ears and nose (Koehn and Brown, 1985).

3. Method of Analysis

To investigate the effects of the wind on the working environment of tall building constructions, a parametric computational fluid dynamics (CFD) analysis has been performed. The analyses have been performed on a building that was built in the late 80's of the past century. The building is 100.0 m's tall and is surrounded by buildings of relatively short sizes, namely 12.0 to 30.0 m's. The building has a reinforced concrete structural system with the elevator and staircase shafts placed in the center of the floor plan to form a core. The columns are placed on the periphery at about every 4.0 m's. The slabs are waffle slabs. The building site is located at the south end of the Buyukdere Avenue mentioned above, which is about 30.0 m's wide at this location.

The CFD analysis was performed by FLUENT which is a part of ANSYS Workbench Products (ANSYS, 2006). The main reason for selecting ANSYS FLUENT is the program's capability to perform 3 dimensional CFD analyses. At each step of the analysis, grid generation, selection of turbulence model, discretization scheme etc. was done and special attention was given to follow the Best Practice Guideline for the CFD Simulation of Flows in the Urban Environment developed in the COST (Franke et al. 2007).

3.1 Analysis Model

To simulate the urban environment a numerical model representing 600 x 350 x 400 m urban model volume is developed as presented in Fig. 3. The locations and dimensions of the other buildings including their heights have been obtained from the urban plans and maps of the Istanbul Metropolitan Municipality.

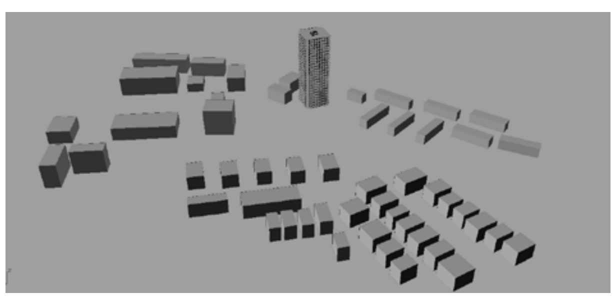


Figure 3: Model Used In Analysis

The CFD simulation has been performed for the structural works phase of the construction only. For this purpose, the reinforced concrete frame of the building is modeled for 4 different heights, namely 5, 10, 15 and 20 floors above ground level. These floors correspond to 18.0, 36.0, 54.0 and 72.0 m's of height above ground. By this, it was intended to observe the effect of the wind at different heights of the construction. The models have been coded as R1H05, R1H10, R1H15 and R1H20 to represent 5, 10, 15 and 20 storey models respectively.

3.2 Wind Data

It is known from the basic laws of fluid mechanics that wind speeds start at zero km/h and increase parabolically / exponentially by height. In this study the power law equation was implemented to acquire a vertical wind profile which is used as input data for the CFD software FLUENT. The power law equation is a simple and useful method to predict the vertical wind profile. The method was first proposed by Hellman (1916) according to Spera and Richards (1979). The general form of this equation is as follows,

$$V_2 = V_1 \left({}^{Z_2}\!/_{Z_1} \right)^{\alpha} \qquad (1)$$

where, V_1 and V_2 are simultaneous steady wind speeds at elevations Z_1 and Z_2 respectively. Though the accurate value for exponent α is recommended to be obtained experimentally, values tabulated in Table 2 can be utilized for most of the studies.

Table 2: Typical values for exponent a

Terrain	A
Sea, mudflats, snow covered flat land, etc.	0.10 – 0.13
Flat open countryside, fields with crops, fences and few trees etc.	0.14 – 0.20
Dense woodland, domestic housing, suburban area	0.20 – 0.25
City	0.25 – 0.30
Large city center	0.30 – 0.50

The long term wind speed data (for years 1974 through 2010) for the Istanbul area have been obtained by the Turkish State Meteorological Service (TSMS) in Ankara, Turkey. In Istanbul the prevailing wind direction is from the N, NE and NNE directions. About 60 to 65% of the time of the year wind blows from these directions. In the remaining periods wind blows from the S, SW and SSW directions. Then, using this data set the probabilities of wind speeds, namely the Weibull diagram, for NNE direction has been developed (See Fig. 3). The wind speeds given in this figure represent the wind speeds at 10.0 m height.

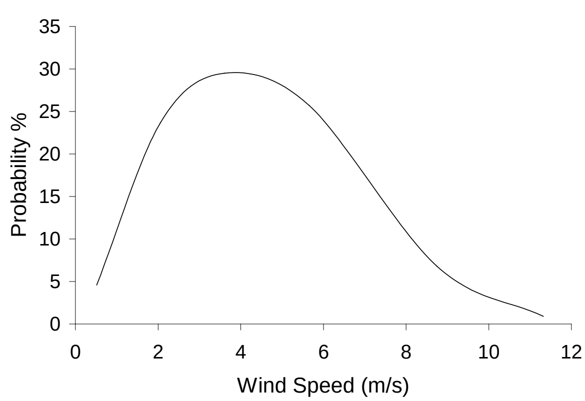
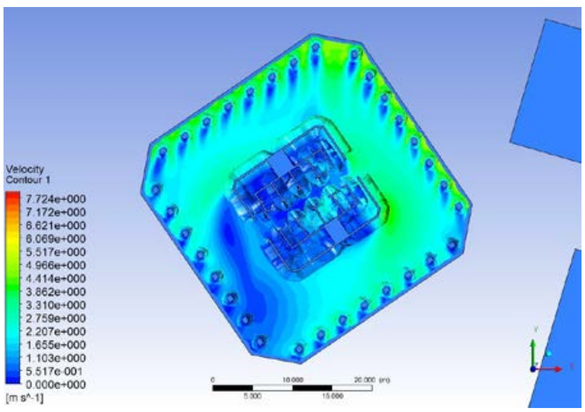


Figure 4: Annual wind probability data for Istanbul (courtesy TSMS, 2011)

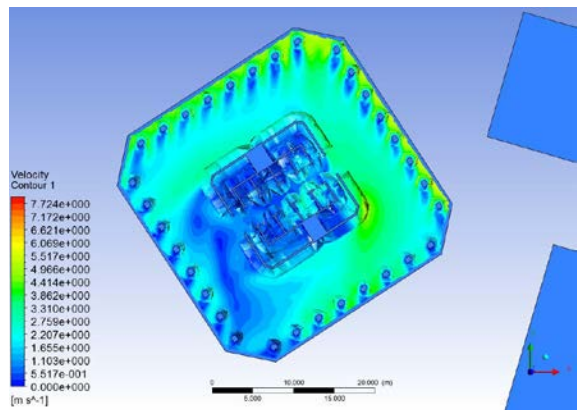
From the diagram it can be seen that, the most probable wind speed at the height of 10.0 m is about 3.6 m/s (See Fig. 3). Using Equation 1, the corresponding 100.0 m velocity can be calculated as 6.4 m/s. Furthermore, from the figure it can be seen that the 10.0 m wind speed exceeding 4.0 m/sec has a probability of more than 50% for the Istanbul area.

4. Analyses and Discussions of Results

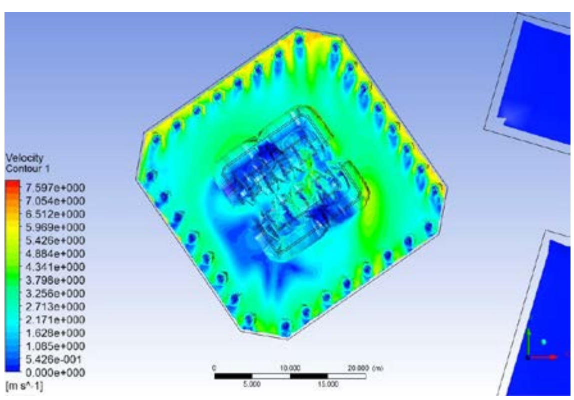
As mentioned above, to investigate the effects of the wind on the labor productivity, 4 different building heights have been studied, namely 5, 10, 15 and 20 story buildings. All the analyses were made for 4.0 m/sec wind speed at 10.0 m height from the North (N) direction. The results of the analysis are presented graphically for each model in figure 5a, 5b, 5c and 5d for 5, 10, 15 and 20 storey heights respectively. The wind speed results given correspond to 1.50 m from concrete floor height which is assumed to be the chest to head height of the workers.



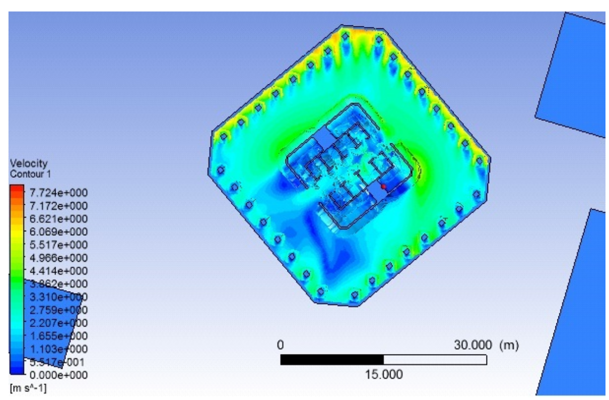
a. 5 Story Building (R1H05)



b. 10 Story Building (R1H10)



c. 15 Story Building (R1H15)



d. 20 Story Building (R1H20)

Figure 5. Results of the CFD analysis

The results for the 5 storey (Figure 5a) indicate a wind distribution varying between 2.0 km/h to 14.4 km/h. At areas sheltered by the core the speeds drop to 2.0 km/h, while reaching to 14.4 km/h on the periphery and the wind side of the core. The 5 story building's height is similar to the surrounding buildings, for this reason the wind speeds on a 5 story building is considerably lower compared to 10, 15 and 20 story buildings as presented below.

In case of the 10 storey model, the wind speeds observed from the analysis are in the range of 2.5 km/h to 15 km/h. Similarly for the 15 storey building, the minimum wind speed observed was 3.5 km/h while the maximum is 20.0 km/h. Finally for the 20 storey building the wind speed range calculated is between 3.6 and 21.0 km/h. In all cases the low wind speeds are in the areas sheltered by the core and the high wind speeds are at the periphery and the wind side of the core.

Obviously the wind speeds reaching 21.0 km/hr makes working difficult as well as dangerous. According to the curve developed by Moselhi and Khan (2010) at these speeds only about 70% productivity can be obtained for the formwork labor at the maximum wind speed areas. With the same token, if a weighted average of the wind speeds at the floor height is assumed to be the average of the maximum and the minimum speeds it can be foreseen that an average of 15% productivity loss will take place, which in turn will impact both the safety of the workers and the schedule of the works adversely.

5. Conclusion

A numerical parametric study by using commercial CFD software ANSYS has been conducted to demonstrate the effects of wind velocities on the working environment. As discussed above the height of the building has a significant impact on the working environment wind speeds creating even environments that can be dangerous for the laborers and decreases the productivity rate which causes higher costs. Hence, scheduling the order of the works in a large complex having structures of varying heights by taking into account the weather conditions may be one way of avoiding unexpected costs due to wind conditions. However, the most important point is that while estimating the costs one should take into account the potential idle times due to wind conditions.

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