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# Wind Load on Chimney Study at Difference Wind Direction by Considering Surrounding Buildings by using Wind Tunnel Test

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**Abstract:** *The paper is present wind load on chimney regarding the effect of upstream chimney and considering surrounding building in open terrain. The static model of the chimney has been studied in a simulated atmospheric boundary layer in the Boundary Layer Wind Tunnel at LAGG Industrial and Wind Engineering Tunnel which has test section 2.0 m wide, 1.5 m high, and 10 m length. The chimney model has been fabricated with aluminium at a geometric scale of 1:250 representing a chimney with height of 150 m in prototype. Measurements were conducted in the wind tunnel with 37 wind directions by using six–component balance measures three forces (Fx,Fy,Fz) and three moments (Mx,My,Mz). The non-dimensional aerodynamics force has been tested as independent due to Reynolds number effect and constant at difference Reynolds number particularly above Reynolds Number 15,000. The maximum wind load is occurring when the wind come from 210 degrees which is the condition while the wind is blocked by the high building in front of the chimney. Surrounding building can effect larger wind load to the chimney compared to without surrounding building, the force and moment with surrounding building is 5% and 13% larger than without the surrounding building. Therefore, the wind tunnel testing with considering surrounding gives the safe result compare to without surrounding building.*

***Keywords:*** *Wind load, Chimney, Wind Tunnel test, Surrounding buildings*

## 1. Introduction

Wind load on building is an important role in structure design to ensure the building is safety from the wind load. Wind can exert a force (load) on the structure. There are some ways to predict wind load on structure. Wind load can be quantified analytically and experimentally. Calculation of wind load analytically shall be determined using building code. Building code is a guidance in the design and construction of building structures. Some countries have their own national building code, for example, United States has ASCE 7 as a code for specifying load on structures, Canada has Canadian code NBC 1995. Both of it have become recognized as code of practice in determining wind load. However, the code analytical methods have limitations, one of them is, it's poorly suited to provide loads for building with complex surroundings. For structure with configuration outside the scope of building codes, wind tunnel experiments can be used to determine the wind load. Besides the experimental determination of the interference effect, no analytical approach or mathematical model is available to quantitatively predict the extent of interference, except for some work towards the application of neural network in some cases [1]. Another limitations of the analytical methods are the load obtained from analytical procedure are often conservative, hence wind tunnel is an alternative to get the wind loading more precisely. Several empirical formulas for estimating the across-wind forces and torsional moments have been proposed based on wind tunnel experimental results, although there are various limitations of the existing empirical models [2].

The effect of wind load on surrounding building have been done for scaffolding building and neighbouring building by Feng Wang et al which the result is when the neighbouring building is located on the left or right side of the measured scaffolding, the positive mean panel force coefficients are greater than those for the isolated case [3]. Different surrounding building is different wind load effect, that is important to studies the effect of surrounding building and difference wind direction for precisely result. In this study, the wind tunnel test was carried out to obtain static wind load at the base of chimney as expressed in terms of aerodynamic forces and bending moment. The measurements were conducted with two configurations, isolated chimney and chimney with surrounding buildings.

## 2. Wind Tunnel Test for Chimney

The total height of the chimney is 150 m, the diameter at the outer top is 3.42 m, and the diameter at outer bottom is 12 m. Wind tunnel testing which used for identifying wind load on chimney is LIWET (LAGG industrial and wind engineering tunnel), operates by National Laboratory of Aerodynamics, Aero elastics, and Aero Acoustics – BPPT (Indonesian agency for Assessment and Application of Technology).

Wind tunnel test section is 1.5 m high, 2 m wide, 10 m long, with 1.6 m turntable diameter. The scale of the model is 1:250. The chimney under investigation (Measured chimney) was positioned at the centre of turntable, which is equipped with the surrounding buildings with a radius of 225 m in the true scale. Measurements were made in the wind tunnel with 37 wind directions, with 5-degrees increment for angle under ± 20 degrees, and 10-degrees increments for angle between 20 degrees and 34 degrees. Turbulent generator and appropriate roughness element was placed at the upstream to simulate the planetary boundary layer.

### 2.1. Experimental Setup

For measuring wind load on chimney, wind tunnel test shall meet the test conditions. The first test conditions are the natural atmospheric boundary layer has been modelled to account for the variation of wind speed with height. The vertical distribution of wind speed above earth surface forms a profile which is known as ABL profile. Physically, the profile can be approximated by power law equation,

$$\overline{V}_z = \overline{V}_{Zref}\left(\frac{z}{Zref}\right)^{\overline{\alpha}} \tag{1}$$

$\overline{V}_{Zref}$ : wind speed reference [m/s]
$\overline{V}_z$ : wind speed at z height [m/s]
z : height above earth surface [m]
$Z_{ref}$ : reference height above earth surface [m]
α : power law categories.

The measurement of overturning moment and aerodynamic force were conducted using six component balances. The six–component balance measures three forces ($F_x, F_y, F_z$) and three moments ($M_x, M_y, M_z$) as described in Fig. 1.

### 2.2. Atmospheric Boundary Layer and Reynolds Number Check

Atmospheric boundary layer will be depend on the condition of the area where will be obverse. The dept of boundary layer normally ranges in the case of neutrally satisfied flows form a few hundred meters to several kilometers, depending upon angle of latitude, wind intensity, roughness of terrain (obstacle around the area). The wind velocity increases with elevation and make some profile of wind velocity where the highest wind velocity is at the top of boundary layer. Outside the boundary layer the wind flows approximately with the gradient speed along the isobars and that is the free atmosphere. The vertical distribution of wind speed above earth surface forms a profile which is known as ABL profile. Small cubics at the floor wind tunnel and spire in front of the test section (Fig.1) have successful to models ABL which comply with the criteria for wind load on structure in open terrain condition. Velocity profile was recorded using ABL rake. By using ABL rake, mean wind speed at certain height can be obtained.The mean velocity profile were obtained in the wind tunnel (Fig.2).

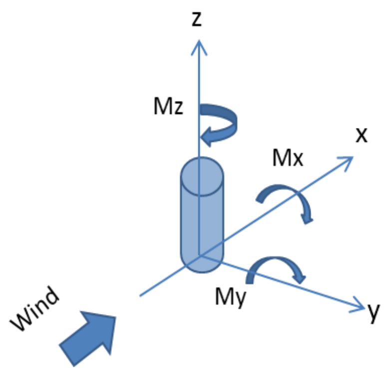


Fig. 1: Axis system of balance

Fig. 2: ABL Generator

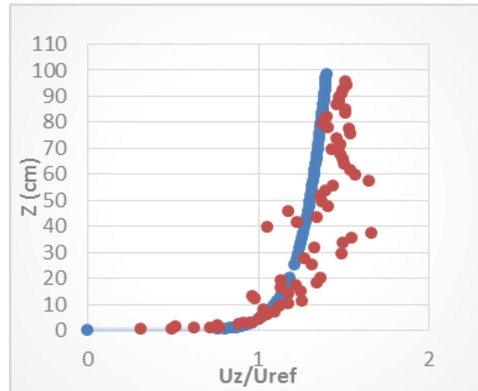


Fig. 3: Wind Velocity profile

The other test condition which should be meet at this testing is the longitudinal component of atmospheric turbulence are should be modelled. Instantaneous velocity fluctuations have been recorded using hot-wire probe at a sampling rate of 30000 samples for duration of approximately 3 second. The turbulence measurement can be seen at Fig. 3.

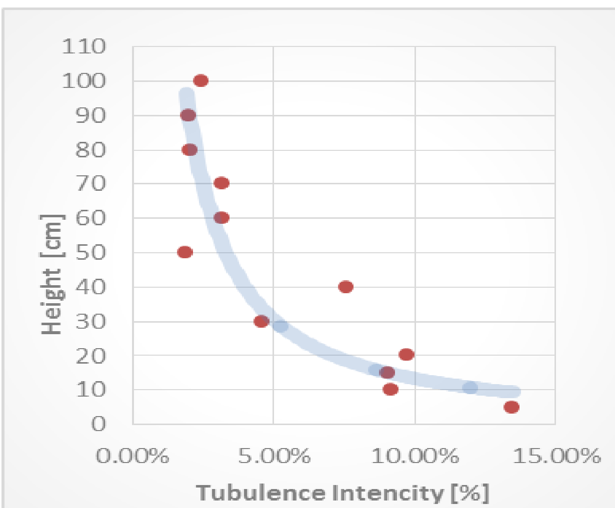


Fig. 4: Turbulence at different height at the test section

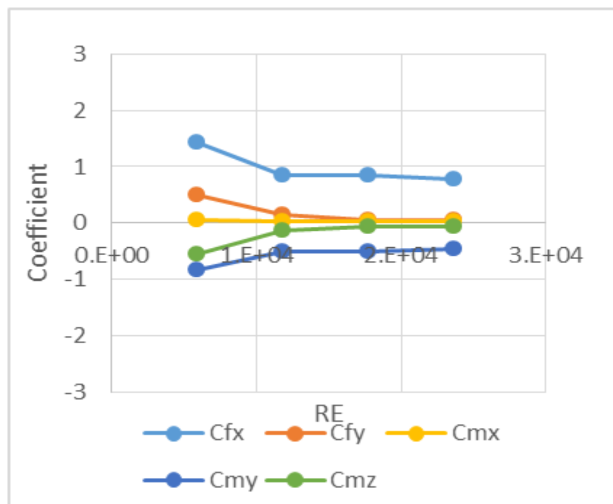


Fig. 5: Reynolds number check

The Reynolds Number (Re) Check is the other condition should be meet in wind tunnel testing. Re Check is to check at which Re the values of aerodynami coefficients become stable. Fig. 5. Show that Cfx ,Cfy , Cmx ,Cmy , and Cmz at each point are constant due to Reynolds number variation, so the value of Cfx ,Cfy , Cmx ,Cmy , and Cmz is similar with difference Reynolds number or wind velocity, particularly after RE 15000.

## 3. Result and Decision

The static model of the chimney has been studied in a simulated atmospheric boundary layer wind tunnel to measure wind load. The studied consist of wind load on isolated chimney and wind load on chimney with surrounding buildings. Chimney with the surrounding buildings is including the upstream chimney which have distance ratio (a/D) 34,2 (Fig.6). Where a is the distance between two chimney and D is chimney diameter. The chimney which measure is located in the middle of turn table wind tunnel.

Chimney has been tested with difference wind direction from 0 to 350 degree with 10-degree increment. Static model means no vibration measure at this wind tunnel test, the parameter which measure at this study are the mean forces and moment using base balanced. The comparison parameter between isolated chimney and chimney with surrounding building are the cross wind load, along wind load, and combination between cross and along wind load.

Fig. 7 shows that the along wind load with difference wind direction from isolated chimney and chimney with surrounding buildings. The value of along wind load at chimney with surrounding buildings has certain variation regarding wind direction. However, isolated chimney has the same value with different wind direction, because of the symmetric effect of the chimney shape. Isolated chimney has bigger along wind load than chimney with surrounding building. Nevertheless, the value of along wind load is both closely when wind direction 80 and 250 degree (Fig. 8 and 9). The minimum along wind load occur when the wind come from 0 and 180 degrees, that is happens because of the measured chimney is close to the building both upstream and downstream. Zhiwen Luo et al investigated that the effects of the surroundings significantly reduce the surface pressure coefficients, especially when the width of the street canyon is small [5].

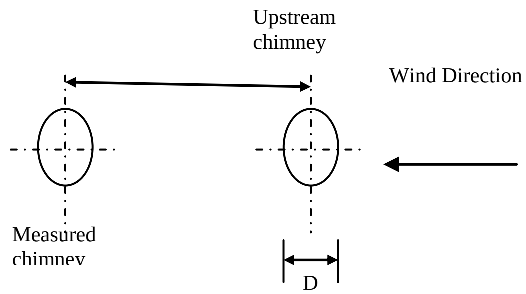


Fig. 6: Measured Chimney and upstream chimney distance ratio

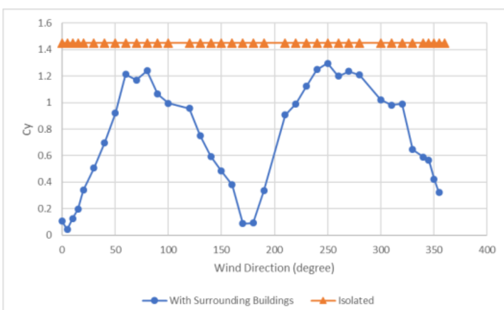


Fig. 7: Along wind load Coefficient (Cy)

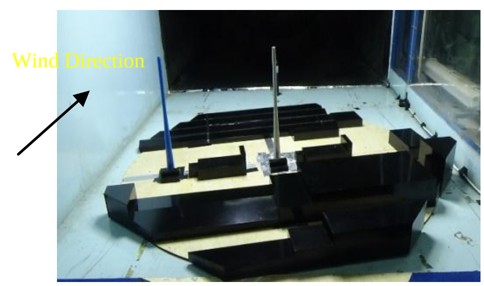


Fig. 8: Wind direction 80 Degree

Surrounding buildings is more effect across wind load than along wind load at many wind directions. Fig.10 shows that across wind load from isolated chimney and chimney with surrounding buildings with difference wind direction. Besides wind direction 90 and 270 degree, chimney with surrounding building have bigger across wind load than isolated chimney, particularly at 190 and 345-degree wind direction (Fig. 11 and 12) which have maximum across wind load compare to the other wind directions. Corner regions at upstream building generate vortex shedding to the downstream including measured chimney which can effect across wind load to the chimney.

Vortex shedding from the corner region are significantly influenced by eddies related to flow separation at the edge, Wind flow over the surface of building have a pressure changes. Negative pressure which goes to the surface upstream region will disturb boundary layer at the surface body. Disturbed flow will generate turbulence at the surface. Turbulence flow have many type of eddies depends on eddies size. Some point in turbulence flow is call separation point where eddies or vortex start release from surface, that phenomenon commonly call vortex shedding. Vortex shedding from the upstream building have large kinetic energy which can effect pressure difference between the right and the left side of the measured chimney. The large pressure difference between the right and the left of the measure chimney cause large across wind load at the chimney.

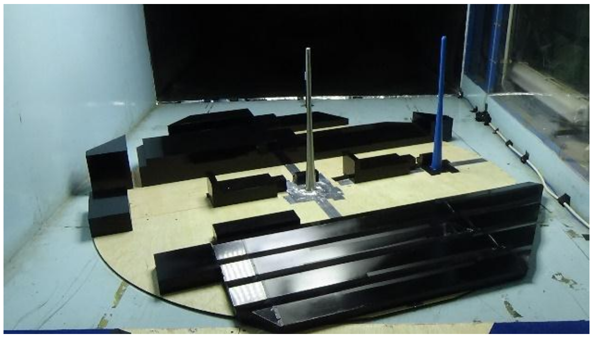

Fig. 9: Wind direction 250 Degree

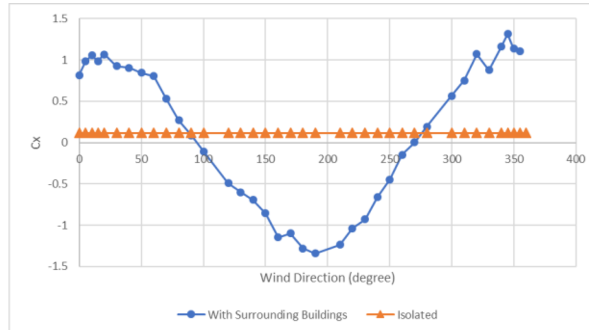


Fig. 10: Across wind load Coefficient (Cx)

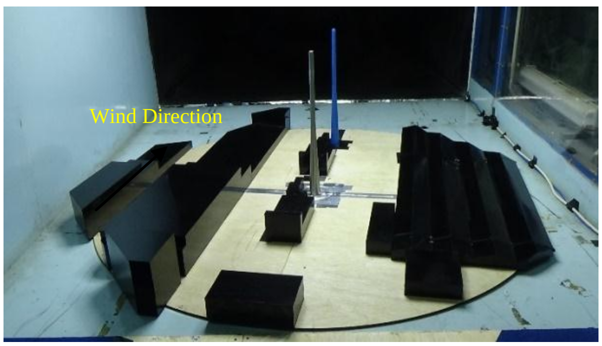


Fig. 11: Wind direction 190 Degree

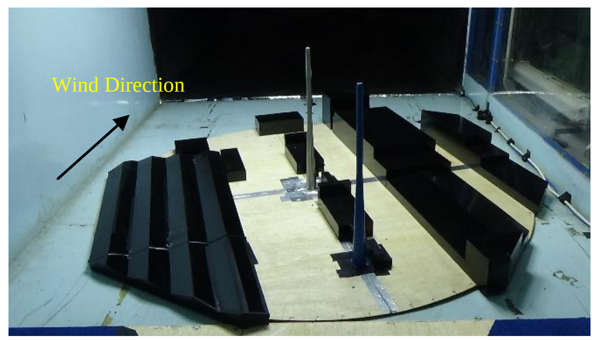


Fig. 12: Wind direction 345 Degree

For comprehensive wind load studies, the combination between along wind and across wind load and also overturning moment should be analysis. Fig. 13 and 14 shows that the combination wind load and overturning moment with difference wind direction from isolated chimney and chimney with surrounding buildings. Both combination wind load and overturning moment give a larger result for chimney with surrounding building compare to isolated chimney particularly at wind direction 210 degree (Fig.15). The combination force and overturning moment with surrounding building is 5% and 13% larger than isolated chimney.

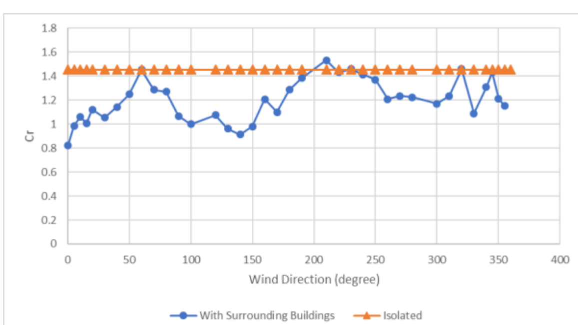


Fig. 13: Combination wind load Coefficient (Cr)

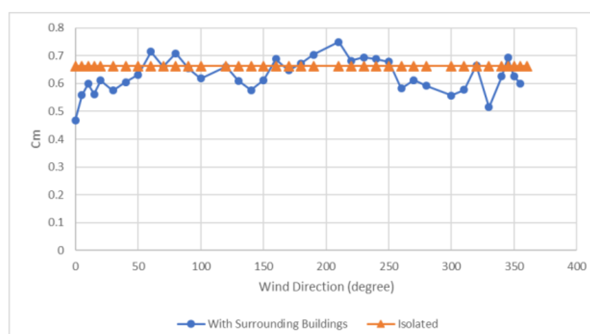


Fig. 14: Overturning moment Coefficient (Cm)

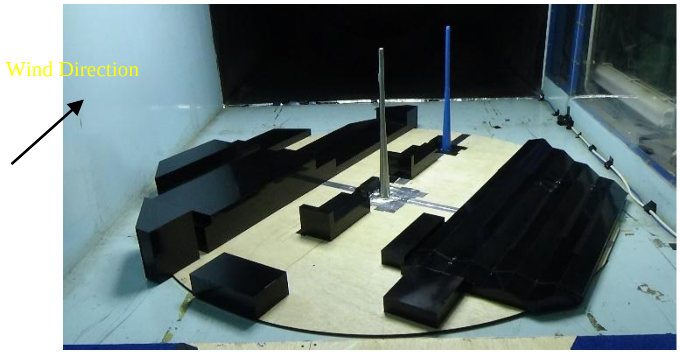


Fig. 15: Wind direction 210 Degree

## 4. Conclusion

Wind load studies on isolated chimney and chimney with surrounding buildings have been done with experimental method by using wind tunnel test. Wind tunnel test for wind load studies is a method to get the wind loading on building more precisely compare to analytical or numerical method. Conducting wind tunnel test in the building construction phase design is a good way for building owner. If the wind load by using wind tunnel is higher than the wind code, then the building is more safe so the building owner can save the money for repair the building because of wind load. If the wind load from wind code is higher than by using wind tunnel, then the structure building can be optimizing to reduce total cost construction. Surrounding building make wind load on chimney more complex because of the wind flow effect from the surrounding buildings. In addition to wind effect from surrounding building, wind direction also important to know the maximum wind load. From this research we can know that at some wind direction the wind load from isolated chimney is higher than the chimney with surrounding building but at some direction wind load on chimney with surrounding building is higher than isolated chimney. That is depend on the configuration of surrounding buildings, because the upstream building can generate vortex to the downstream particularly the vortex shedding form the corner of upstream building. Further studies should be made if we want to make some construction of a new building on area which previously conducted a study of wind loads on building, because it can be effect to the buildings that have been built before.

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