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Comparison of Wind Pressures Using Wind Tunnel Test (WTT), the Prescriptive Approach (NSCP 2015), and Computational Fluid Dynamics (CFD) in the Case of Cooling Towers for Geothermal Power Plants

Ernesto Q. Malicad, Jr., Martin Jude V. Lacambra, Virgilio G. Lapuz, Jr.

Energy Development Corporation, Pasig City, Philippines

malicad.eq@energy.com.ph, lacambra@energy.com.ph, lapuz.vg@energy.com.ph

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ABSTRACT

Energy Development Corporation (EDC) is a global geothermal energy industry pioneer and the recognized world leader in wet steam field technology. EDC is the Philippines' largest vertically-integrated geothermal developer, delivering 1,457.8 MW of clean and renewable energy to the country. EDC continues to diversify its renewable energy portfolio through investments in solar, hydropower and wind power projects in the Philippines. EDC has four (4) geothermal business units located in Leyte, Albay-Sorsogon, Kidapawan and Southern Negros, Philippines with a combined geothermal capacity of 1,169 MW.

EDC's geothermal sites, especially Leyte and Albay-Sorsogon are located along the path of the country's strongest typhoons. Its Leyte and Albay-Sorsogon sites have been hit by recent super typhoons like Typhoon "Haiyan" (Yolanda) in 2013 with one-minute sustained winds of 315kph and Typhoon "Glenda" in 2013 with one-minute sustained winds of 260kph, respectively, that caused widespread damage to its power plant facilities particularly the cooling towers. Cooling towers are an essential integral part of the geothermal power plants the damage of which can result to extended shut down of operations. This prompted EDC to enhance and strengthen major structures such as cooling towers, control buildings, power plant buildings, and warehouses for a basic wind speed of 300kph.

To further enhance engineering judgment, wind modeling studies for cooling towers in the abovementioned sites Tongonan Power Plant in Leyte and Palayan Power Plant in Albay-Sorsogon – Palayan were commissioned in mid-2016 with objectives (1) to determine the localized wind forces taking into consideration the topography, geometrical features of the structures, regional wind climate analysis; (2) to confirm the adequacy of enhancements made like the new resin transfer molding (RTM) fan stacks and additional reinforcements installed on the cooling tower structures; and (3) to determine the effectiveness of proposed wind fences in reducing wind speeds. The study involved major steps and scopes such as the conduct of a regional wind climate analysis, wind tunnel test (WTT), computational fluid dynamics (CFD) and analytical method referring to the provisions of the National Structural Code of the Philippines (NSCP 2015).

This paper discusses the results of the wind modeling studies considering the three (3) methods in determining wind pressures using non-directional wind speeds including their limitations and advantages. The results were interpolated to come up with general results and conclusions. Such initiative is geared towards long term savings and preventing extended forced outages of power plants due to the potential damage caused by super typhoons.

1. INTRODUCTION

Cooling Towers have historically been the most vulnerable and at highest risk during strong typhoons. Cooling towers usually sustained loss of cladding, sheeting failures and torn-off or broken fan stacks when subjected to uplift and fluctuating or spatially varying wind pressures during extreme typhoons. This consequently resulted to damaged blades and motors. This mechanism is sometimes aggravated by wind-borne debris such as broken tree branches and blown-off materials that could trigger progressive damage to the structure's façade or cladding due to impact or collision of flying debris. These were observed during past typhoons that landed particularly in Leyte and Bicol damaging several cooling towers of the Leyte Geothermal Production Field (LGPF) and Bacman Geothermal Production Field (BGPF) of Energy Development Corporation (EDC), see Figure 1 and Figure 2.

The cooling towers were designed using basic wind speeds of 161 to 200kph that were based on previous versions of the National Structural Code of the Philippines (NSCP pre-2001 editions). Also, basic wind speeds were previously based on "fastest-kilometer wind speed" as compared to the three-second gust being applied by the current editions of the codes.

Aside from the use of the "fastest-kilometer wind speed", the cooling towers may have been designed using codes that did not account for the effects of topographic factors, directional factors, gust to account for along-wind dynamic and wind gust buffeting that provide significant effect on the results of wind pressures.

After the onslaught of Typhoon "Haiyan" (Yolanda) which caused widespread damage and structural failure to EDC's power plants in Leyte, particularly to the cooling towers (refer to Figure 3), EDC decided to enhance and strengthen major structures such as control buildings, power plant buildings, cooling towers and warehouses for a basic wind speed of 300kph with the NSCP2010 as the referral code.

In general, the enhancements identified for the cooling towers include the replacement of old wood members with FRP pultrusion tubes, existing fan stacks were replaced with new fan stacks designed to withstand 300kph basic wind speed further strengthened with an enhanced support system.

Figure 1: Cooling tower in Leyte Geothermal Production Field (LGPF).

Figure 2. Typical cooling tower of EDC.

Figure 3. A damaged cooling tower in Leyte after Typhoon Yolanda.

The enhanced support system consists of stainless circular rings where the base of the fan stack is attached to the cooling tower deck. Moreover, an outer ring secured to the cooling tower deck supports diagonal FRP struts attached to another circular band at about two-thirds the height of the fan stack, see Figure 4.

Figure 4. The "enhanced support system" includes a steel support ring at about two-thirds the height of the fan stack and a stainless lower ring spread out from the base of the fan cylinder. The struts are square FRP pultrusion tubes connecting to the SS ring.

The objective of this scheme is to prevent the fan stacks from being blown off which would take several months to replace resulting to longer plant outage. Moreover, damaged fan stacks expose the fans and motors to further damage. On the other hand, cladding can be replaced immediately as compared to the fan stacks.

As additional protection, a wind fence system (as shown in Figure 5) was also considered to reduce and dissipate the wind speed before it hits the structures and decrease possible occurrence of large turbulence thereby preventing serious damage to the cooling towers particularly blown off fan stacks.

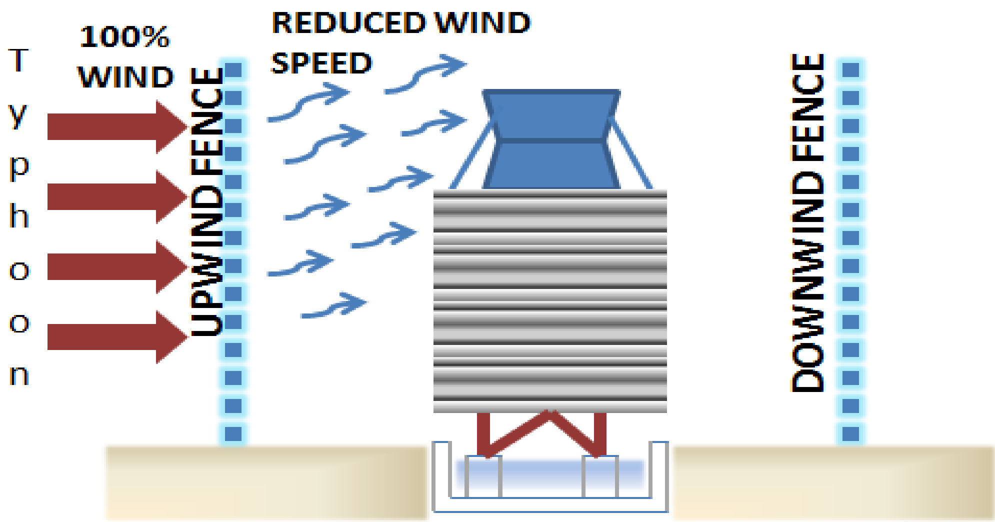

Figure 5: The wind fence aims to reduce and dissipate the wind speed before it hits the structures and decrease possible occurrence of large turbulence thereby preventing serious damage particularly blown off fan stacks.

In order to ensure a more objective analysis on the need and layout for a possible wind fence, decision was made to engage a third party to conduct the wind modeling and analysis. This was necessary considering the very high cost of installing wind fences. However, the results of the wind fence study will not be discussed in this paper. This paper focused on the comparison of wind pressures derived from the three methods such as the wind tunnel test (WTT), code-based approach using the NSC2015 and computational fluid dynamics (CFD).

Figure 6: Wind dust control in Oman 30m (100ft) x 3150m (10,300ft). (http://weathersolve.com).

2. METHODOLOGY

After the Typhoon Yolanda, the level of subjective interpretation is high and disagreements have always been noted in attempting to assume if there is already a need to increase the basic wind speeds as indicated on the codes. Designers and owners suggested choosing for much higher wind speeds, but this would correspond to an increase of cost of installation or construction. Due to the damaged caused by the recent typhoons, structures have been strengthen to basic wind speed of 300kph.

Prior to the release of the NSCP2015, EDC was able to conduct a wind modeling study through the partnership with Windtech Consultants Pty Ltd. that involves the conduct of a regional wind climate analysis for selected geothermal sites (Bacman-Palayan and Leyte-Tongonan).

Also, boundary layer wind tunnel tests and CFD analysis were performed by Windtech's laboratory in Sydney, Australia. Measurements were made in the wind tunnel from 36 wind directions at 20 degree increments using a 1:70 scale model. Likewise, the study model was installed on a proximity model which included all significant surrounding buildings and topographical effects for a radius of approximately 100m centered on the development sites.

The testing was performed in Windtech's blockage tolerant boundary layer wind tunnel facility. The good agreement between Windtech's wind tunnel cladding pressure results and full-scale data from the Texas Tech Experimental Building provides some indication of the accuracy of Windtech's wind tunnel results (Rofail, 1995, as cited by Windtech 2016). Due to the effective design of Windtech's blockage tolerant wind tunnel facility, no corrections for blockage generated by the model were required for this study.

Both CFD and wind tunnel tests (WTT) have been performed in the study. However, WTT, being the only method permissible in the NSCP in determining the wind pressures to be applied for structures not meeting the criteria set for the Analytical Method which can only be applied for a regular-shaped structures having no unusual geometric irregularity in spatial form, does not have response characteristics making it subject to across-wind loading, vortex shedding, instability due to fluttering or galloping and where the site location does not have the chance for channeling effects or buffeting in the wake of upwind obstructions. The results derived from WTT were applied on the analysis to determine the mode of failure, behavior, displacements and deflections of the structural members and fan stacks when subjected to a unidirectional wind speed of 300 and 350kph, respectively.

The topographic study was conducted to accurately account for the significant variations in the local terrain surrounding the site using a 1:2000 scale model of the local land topography, these data was used in conjunction with a detailed regional wind climate analysis to produce the wind models. The topographic effects beyond 6km diameter of the topographic study have been calculated in a desktop study. The recent LiDAR maps for LGPF and BGPF were very useful in the topographic modeling of the sites.

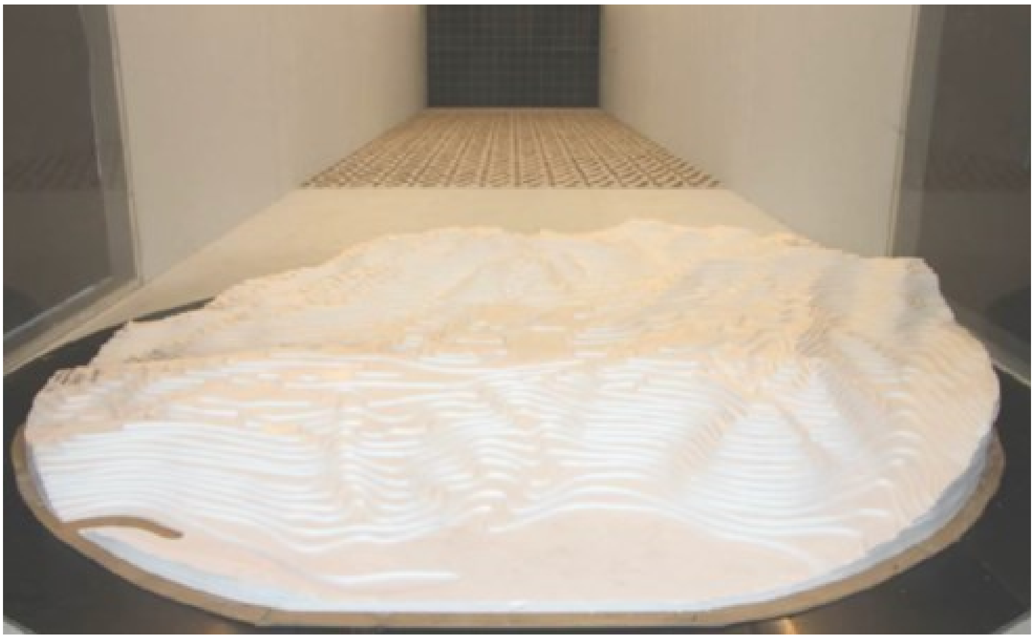

Figure 7: One of the topographic models used in the study taken from the LiDAR data.

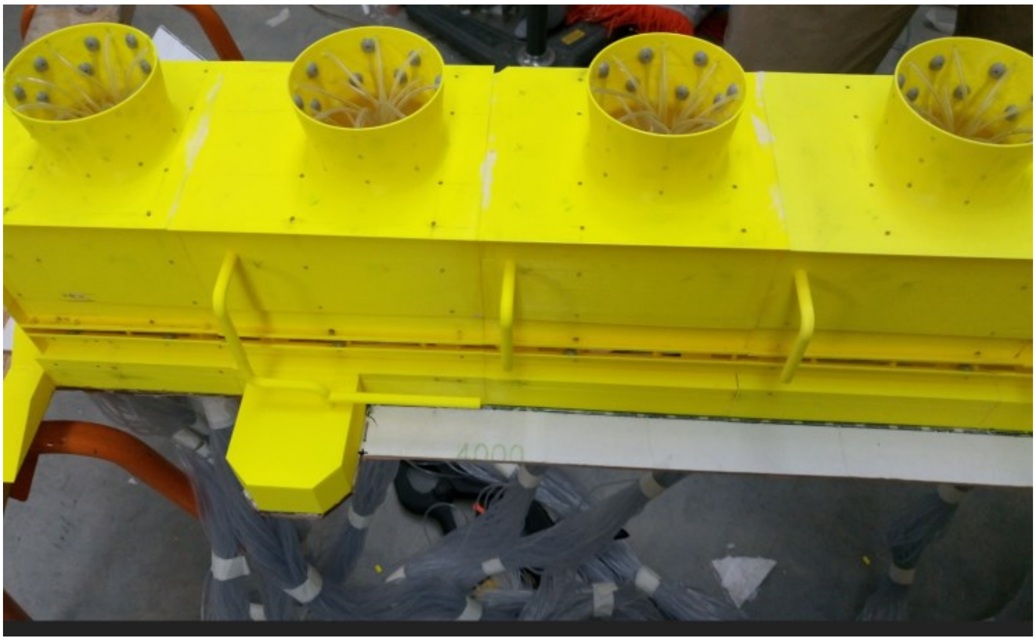

Figure 8: The study models were fitted with individual pressure sensors spread across the facades of the cooling towers and wind fences.

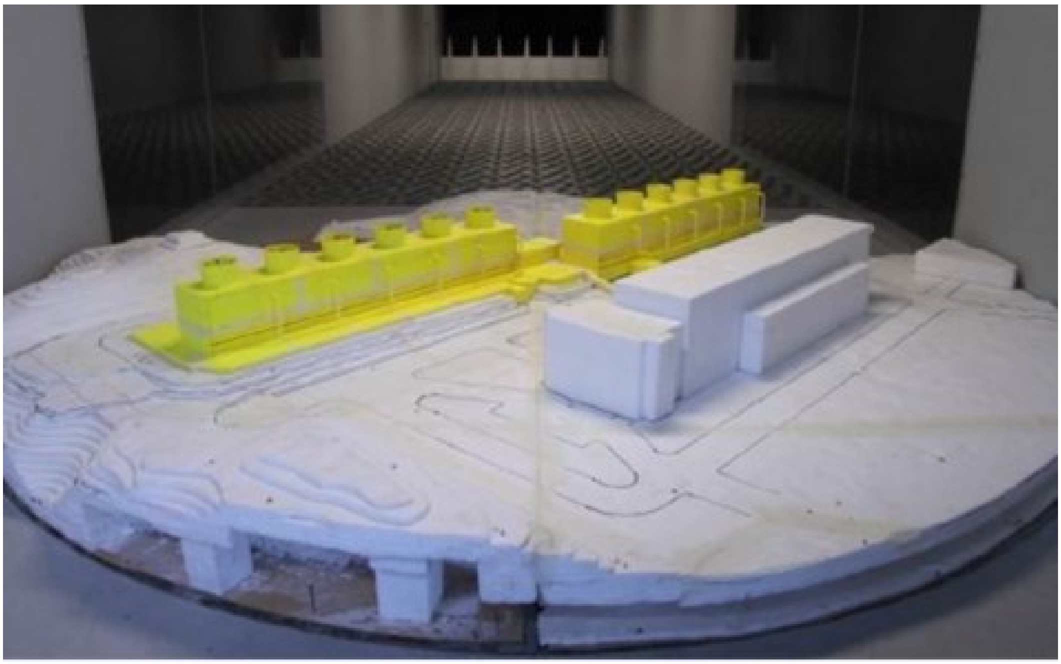

Figure 6: Wind Tunnel Model fence of Bacman-Palayan viewed at North, without wind fences.

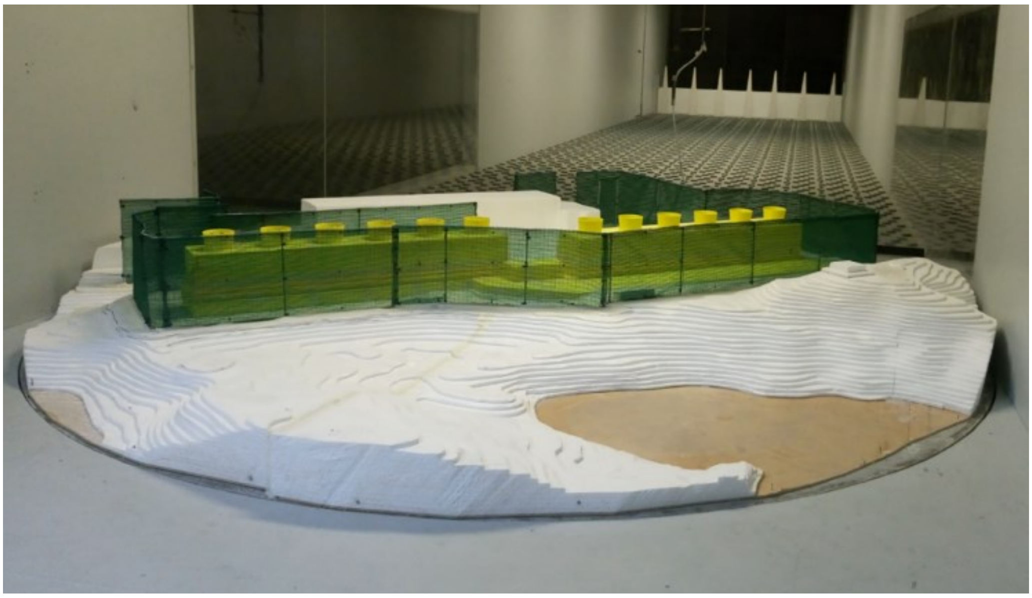

Figure 10: Wind Tunnel Model of Bacman-Palayan Cooling Tower with Wind Fence.

3. ANALYSIS

3.1 Wind Climate Analysis

The results of the regional wind climate analysis for the two sites (Bacman-Palayan and Leyte-Tongonan, Figure 11) have been undertaken and compared to the old and new basic wind speeds including the two (2) unidirectional wind speeds identified by EDC to be used on the study. The analysis was determined using the published literature of P.J. Vickery (2009) which is consistent to the method used by the ASCE 7-10 and NSCP2015 in formulating the new wind contour maps.

The regional climate analysis showed that the non-directional basic wind speeds of 300kph and 350kph correspond to about 1,700 and 10,000 year return periods, respectively.

Under the latest edition of the NSCP, buildings under Category I Structures (essential structures) are classified with mean recurrence interval (MRI) period of 1,700 where cooling towers are classified due to its importance in the power plant operations.

3.2 Mean External Pressure

It is apparent that the wind tunnel results and computational model agree quite closely with one another in detecting these localized regions this was observed in qualitatively analyzing the localized hotspots. This holds true for areas of both high mean positive and negative external pressures.

Additionally, localized regions of high mean negative pressures are also detected in similar locations across both analysis types.

However, the maximum and minimum values obtained from the wind tunnel and computational model on the mean external pressures for both cooling towers have significant variations.

For example, the global maximum mean external pressure from the computational model is seen to be approximately 1.9kPa as opposed to a global maximum of 0.9kPa from the wind tunnel results. Similarly, the computational results yield a global minimum mean external pressure of -5.7kPa as opposed to -2.9kPa from the wind tunnel results.

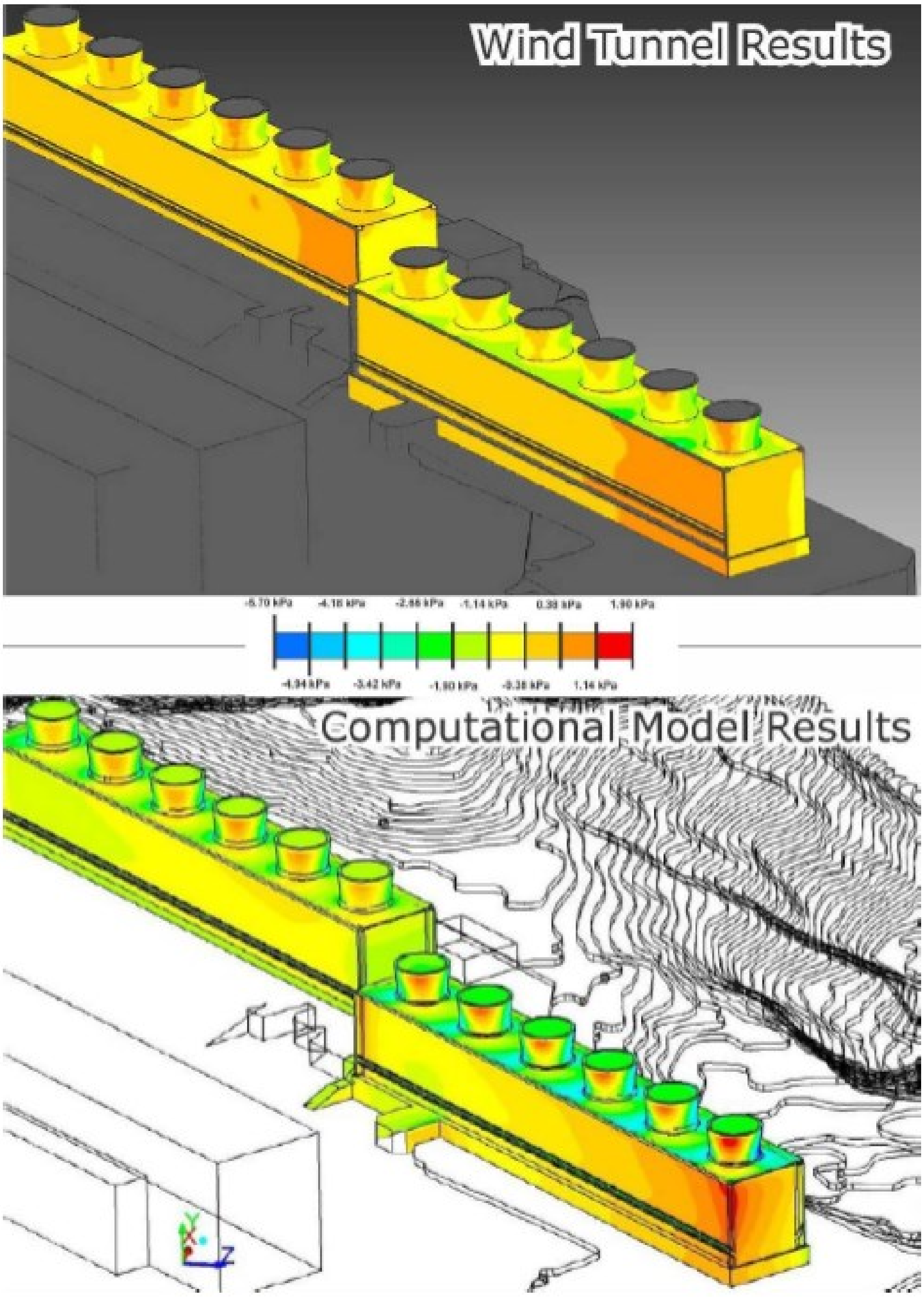

Figure 71: Mean External Pressure Comparison for the Westerly Winds for the Bacman-Palayan Cooling Towers.

Below is a comparison between the mean pressures obtained from both methods.

Table 1: Mean Pressures obtained from CFD and WTT

	Cooling Tower A (Bacman-Palayan)		Cooling Tower B (Leyte-Tongonan)	
	WTT (kPa)	CFD (kPa)	WTT (kPa)	CFD (kPa)
Net Positive Pressure	0.90	1.90	0.80	2.00
Net Negative Pressure	-2.90	-5.70	-2.20	-3.3

In a similar manner to the Bacman-Palayan Cooling Towers, the global maximum mean external pressure from the computational model is seen to be approximately 2.0kPa as opposed to a global maximum of 0.8kPa from the wind tunnel results. Similarly, the computational results yield a global minimum mean external pressure of -3.3kPa as opposed to -2.2kPa from the wind tunnel results.

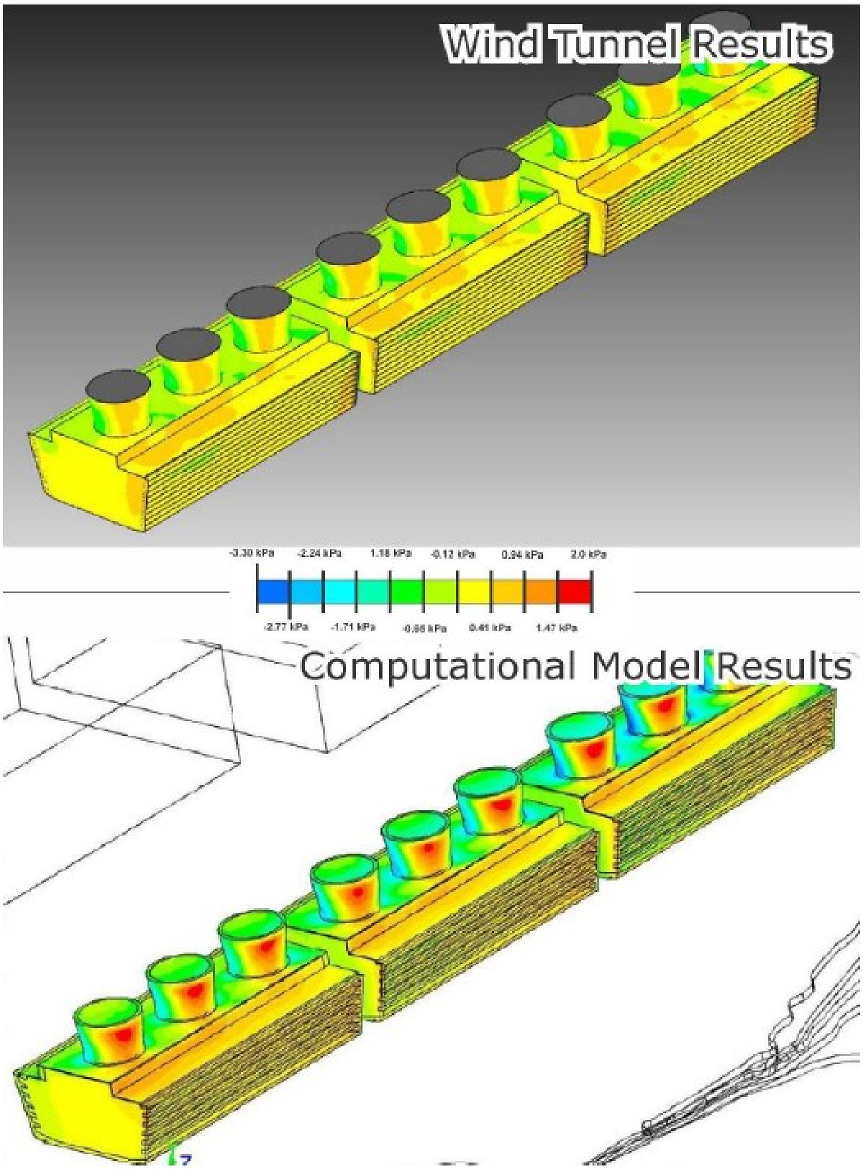

Figure 12: Mean External Pressure Comparison for the North-Westerly Winds for the Leyte-Tongonan Cooling Towers.

The comparison between the wind pressures obtained from WTT and NSCP are shown on the Table 2 and Table 3. It is observed that the wind pressures obtained from WTT are slightly higher than the results from the analytical method specified on the NSCP2015 for the Bacman-Palayan Cooling Tower. This can be attributed by many factors such as topographical and directional factors, effects of wake and channeling and localized recirculation of wind, irregular or unusual geometric shapes of buildings and layout of the structures. These factors are vague or merely silent on the provisions on the code. Analytical method has been based on studies involving isolated structures and did not account on such factors.

Table 4: Comparison between generalized net pressure against NSCP 2015 derived pressures applied on the structure.

	Cooling Tower A (Bacman-Palayan)		Cooling Tower B (Leyte-Tongonan)	
	WTT (kPa)	NSCP (kPa)	WTT (kPa)	NSCP (kPa)
Net Positive Pressure	4.50	3.63	3.50	3.20
Net Negative Pressure	-5.90	-3.26	-4.50	-2.88

Table 5: Comparison between generalized net pressure against NSCP 2015 derived pressures applied on the fan stacks.

	Cooling Tower A (Bacman-Palayan)		Cooling Tower B (Leyte-Tongonan)	
	WTT (kPa)	NSCP (kPa)	WTT (kPa)	NSCP (kPa)
Net Positive Pressure	7.90	5.338	5.60	5.348
Net Negative Pressure	-7.00	-4.206	-5.80	-4.21

As cited by Chatten (2015), buildings with unusual or irregular geometry, wind loading is most accurately determined through wind tunnel testing which may be used in lieu of the analytical code method. For buildings with unusual or irregular geometry it is common that localized "aerodynamic hot spots" are identified by wind tunnel testing which may exceed analytical code predictions. If not identified, such a hotspot will mean the building will be constructed with an inherent localized weakness that may only be revealed years later when there is a typhoon event occurs leading to a small localized breach of the building envelope. This is especially concerning as a small localized breach of the building envelope can often cause a progressive/domino type failure of large areas of the façade as the interior wind pressures will increase as the inside the building becomes exposed to exterior wind pressures, leading to increased net wind pressures on adjacent façade panels.

4. CONCLUSION

The regional climate analysis showed that the non-directional basic wind speeds of 300kph and 350kph correspond to about 1,700 and 10,000 year return periods, respectively. Based on the latest edition of the NSCP, cooling towers which are classified under Essential Structures requires a MRI of 1,700 years.

Wind flow analysis showed that the effects of channeling or funneling in the sites are prevalent, with or without wind fences due to the orientation of the buildings and complex structures' surroundings. The effect of this phenomenon is vague in the NSCP2015. For buildings with unusual or irregular geometry it is common that localized "aerodynamic hot spots" are identified by wind tunnel testing which may exceed analytical code predictions. If not identified, such a hotspot will mean the building will be constructed with an inherent localized weakness that may only be revealed years later when there is a typhoon event occurs leading to a small localized breach of the building envelope. This has been observed considering the damages of the cooling towers during typhoons. The particular arrangements of buildings and other structures will also affect the derived pressures, in some cases, shielding will not act but can result to 'hotspots' in some areas of the façade creating larger wind pressures derived from the analytical method.

From previous projects undertaken by Windtech, it has been found that a good agreement between the CFD and wind tunnel results may be achieved for mean pressures. However, these studies were performed for conventional prismatic-type buildings that are situated within relatively flat terrain and with standard velocity profiles. The large variations between the computational model and wind tunnel results for this particular study may be attributed by the complex local topography of the sites. The structures of the cooling towers have been designed with relatively unconventional designs (non box-like buildings).

These factors are vague or merely silent on the provisions on the code. Analytical method has been based on studies involving isolated structures and did not account on such factors.

5. RECOMMENDATIONS

The conduct of a wind tunnel test is necessary for buildings with unusual or irregular geometry. Additionally, where many factors such as topographical and directional factors, effects of wake and channeling and localized recirculation of wind, irregular or unusual geometric shapes of buildings and layout of the structures are prevalent specially for power plants located in mountainous areas, the conduct of wind tunnel test is recommended. The study may provide a long term potential savings and could prevent failures due to extreme typhoons.

6. ACKNOWLEDGMENT

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