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A STATE OF THE ART REVIEW, IMPACT OF WINDSTORM ON STEEL STRUCTURE IN EAST ASIA

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Abstract- Damages, losses and social problems occurs every year due to the natural disaster in all over the world. The range of the damages caused by the windstorm on the build environment increase gradually. A number of the commercial and residential steel structure are collapse just because these building are not design to resist the high speed wind. In this work, more than 35 papers of different authors are reviewed on the windstorm related disasters. Although, the literature related to steel structure, which are collapse or partially damages due to the windstorm are very limited. Numerous authors focus on the design parameters and some of them studied the effects of high speed wind on the structure and their losses when the event happened. In results, it is found that due to extreme wind pressure roof and wall cladding of the structure damages, and it is observed that numerous buildings are not designed against the high speed wind load, design engineer should be consider the impact of high speed wind load, surrounding trees, anchoring, outdoor equipment and the direction of wind during design phase to mitigate or minimize the losses due to windstorm.

Keywords- Windstorm, steel structure, wind load, Natural disaster

1 Introduction

Damages, losses and social problems occurs every year due to the natural disaster in all over the world. The range of the damages caused by the windstorm on the build environment increases [1]. The most dangerous natural disaster on the earth surface are severe rainstorms, tornadoes, and also the hurricanes, and destructive damages and disturbance of societies are due to the tropical windstorm were reported. A number of the commercial and residential steel structure are collapse just because these building are not design to resist the high speed wind that many accrue particularly in the extreme events and the wind loading starting point on any structure is basically measure near surface wind speed [2]. Mehrshad Amini et al, [3] review the coastal domestic building performance w.r.t the direct and indirect damages, and discussed the mitigation techniques by considering the hurricanes and flood related hazards and concluded that the wood structure system shows weaker resistance as compared to other building system against the windstorm. N. Kishore et al, [4] studied that in the Atlantic, Indian and pacific ocean windstorm damages and discussed that the windstorm play vital role in the damages, losses, settlement of the build environment and the human live are also on high risk. The losses in the public and private properties and death rate lead to increase due to windstorm events. Damages and losses due to the storm event increase in 2017 as compared to the previous year according to the Centre for Research on the Epidemiology of Disasters (CRED) in Emergency Events Database (EM-DAT).

N. H. Zakaria et al, [5] used the NCEP FNL Operational Model Global Tropospheric Analyses and Meteorological Operational (MeTOP) datasets to regain the direction and the wind speed by analyzing the pattern of the wind speed in

Peninsular Malaysia, and concluded that the southeast monsoon were the highest wind speed event and finds that the 5.96 m/s to 6.23 m/s were the highest wind speed from norhtsouth. A.C. Khanduri et al, [6] discussed the building vulnerability to windstorm and the property losses due to the hurricane hazards. It is very important to consider the wind load during the design phase of structure [7]. The cold rolled steel structure are also very common in these day in all over the world and Na Yang et al, studied that in recent years many of the modern cold formed steel structure are damages ranging from the roof, wall cladding to complete collapse, because of the light weight and other components. The cold rolled formed steel structure are more vulnerable to windstorm as compare the hot-rolled steel structure [8].

Seonwoong Kim et al, [9] discussed that in the summer season typhoons with the strong wind are frequent in the Korean peninsula and the Maximum wind speed measured in the korea is about 63.7 m/s due to which the design of the elastic seismic of some of the building structure may be acceptable based on the slenderness ratios in all wind exposures. The risk of the wind pressure increase as we increase the height of the structure [10]. As the wind act on the building surface, it creates the inward and outward pressure, which depends upon the orientation and location of the building and the pressure which act on the building try to uplift that building and if the building is week to resist the wind pressure, then the pressure forcing the building part [11].

As for the steel building structure are very common now a days, so many of the bridges are also constructed in the steel. Yan Han et al, [12] studied the typical long span steel-truss suspension bridges which is under the combine loading of the random traffic and wind and present an effective framework for fatigue reliability assessment and observed that the fatigue reliability have certain effect of random traffic and wind load. Most of the cases in the urban area tall and highest buildings are constructed which are highly vulnerable for windstorm, but now a days many rural areas are also subjected the extreme loads and the natural hazards such as earthquake, hurricanes, and tornados [13]. Just like the commercial and residential steel structure the steel towers can also affects from windstorm. M. Pavan Kumar et al, [14] compared the monopole and self-support type towers against the for basic wind speeds of 33m/s, 47m/s and 55m/s for the different height of the towers like 30m, 40m and 50m and concluded that under same height and same amount of loading monopole towers have higher lateral displacements compared to the self-support towers. Windstorm caused damages and collapse of the structure, because of which financial and human live losses are found all around the world [15]. N. O. Nawari, [16] observed that most of the cases build environment and their occupancies threaten by the windstorm/high speed wind, airborne projectiles, wind-driven water, sea surges, and flooding.

2 Limitations

The available literature related to steel structures, which were collapsed or partially damages due to the windstorm are very limited. Many authors focus on the design parameters and some of them studied the effects of high speed wind on the structure and their losses when the event happened.

3 Steel Structure and Windstorm Anatomy

Windstorm is the combination of air and water in turbulent flow, although the windstorm is complicated phenomenon, the combine form of wind and air means that the individual particle of either air or water have very erratic motion which is studying storm and one of them must be concerned with the statistical direction and the speed distraction expect of physical quantity. The storm forces are must be combination of wind pressure, Windborne debris, falling objects, flood pressure and maybe in the form of rain forces when analytical model are concerned. Windstorms, hurricanes, and sandstorms are basically the wind related disaster, these are very critical and dangerous for the local citizens. Due to the failure of structural members, number of tragedies have been observed in the previous decade. Structural design engineer and the wind engineer play a vital role to save the live and economy of any country by adopting and following the building design codes during design phase of tall buildings [17] basically wind is a process which occur uncertainty without warns, and various facts are responsible for this uncertainty and this uncertainty is the core and basic components while assessing the impact of wind on the buildings [18].

On the surface of the building wind load act as a lateral load in the direction of flow of wind. Wind load changes frequently when compared with the dead load and live load, if the same magnitude of wind load was applied gradually on the built in environment, different effect of the wind load are created in this case [19]. In contrast, very rough distribution of the tornados is observed, uneven distribution of vortices were acquired just because of the alternative [20] generation of the low pressure zones on the built environment cross wind sides under the crucial condition of the high wind speed as shown in (Figure 1).

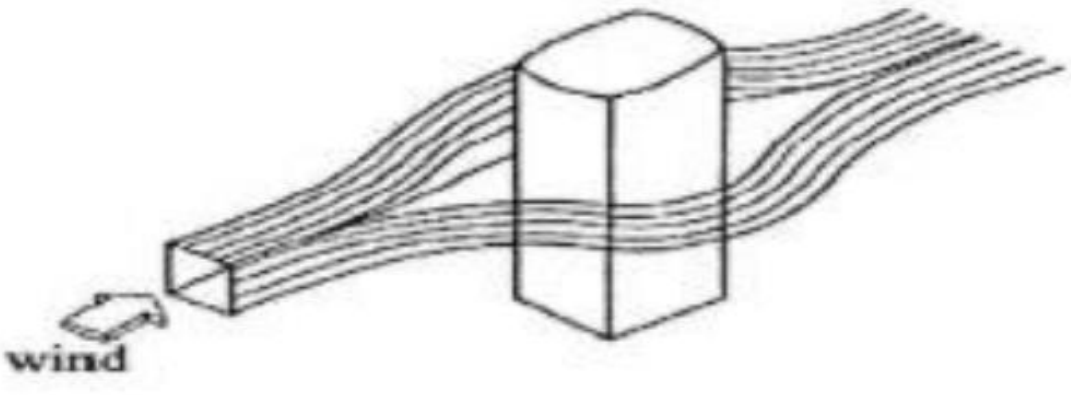


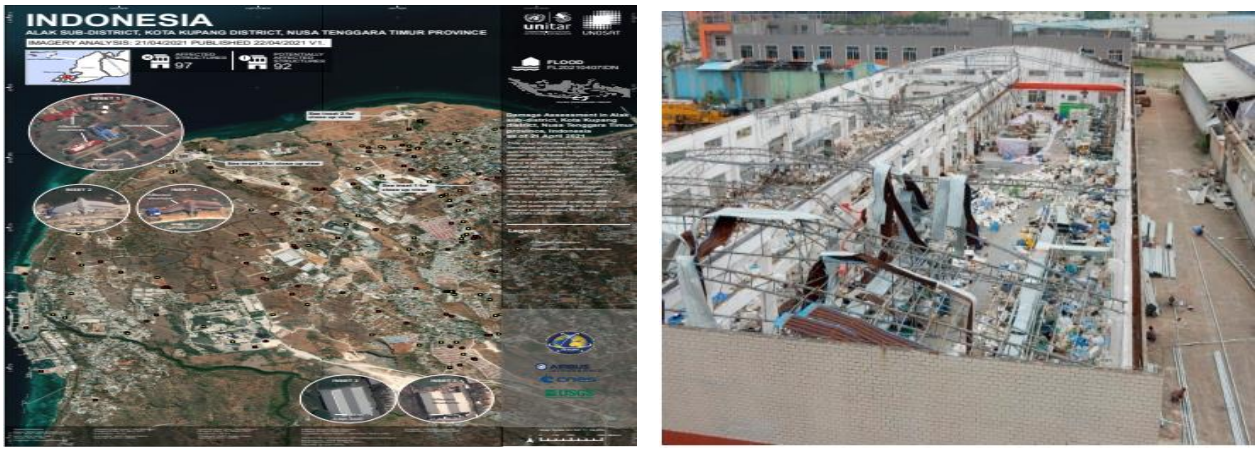
Figure 1: Built environment cross wind sides under the crucial condition of the high wind speed [20]

Windstorm, hurricanes, and tornadoes are basically wind related natural disaster which are the responsible for wind loading on the building structure significantly. Wind load impact on the building structure must be taken into under consideration during the designing of the building to control and minimize the failure of the structure and losses of the human lives [21] whenever the flow direction of the wind towards the building wind flow is separated and during the turbulent flow tornados are generated in the wake section [22].

4 Damage to buildings and structures due to windstorm in East Asia

In April 2021, in eastern Indonesia, bordering Timor-Leste tropical cyclone SEROJA formed dover the Savu Sea, as shown in Figure 2, and moving towards the Western Australia. During this event around 128 fatalities, 72 people reported missing and 8,424 people displaced according to the Indonesian national board for disaster management [23] as shown in (Figure 2a).

In 2019, a windstorm surge [23] effects the sixty seven communities of Gambia, and specifically hit the five region Jimara, Tumanna, Wuli East, Wuli West and Sandu districts and also it effects the two districts of central riven region. About 900 families are effected during this event and four deaths are reported. The wind storm surge were effected around 15,000 people and about 1,425 people were displaced. It was reported that 4 people are dead due to flying iron sheets and falling walls of the buildings. 101 people have been injured, and over 900 houses have been damaged or destroyed during this event. In china [24] during the typhoon the main resisting frame steel structures was collapsed as shown in (Figure 2b).



a) b)

Figure 2: a. *In eastern Indonesia, bordering Timor-Leste tropical cyclone Gurney [23] and b. Main resisting frame steel structures collapsed [25]*

As reported by Tan, during the event of hurricane in southeast of china, steel structure beams buckled while the purine, girts and the connection plats remain safe [17]. In 2019, Cappucci M, reported that due to the high speed of wind a sandstorm event happened at Gurney, Penang as shown in (Figure 3a). In the nearby the toppling over of trees and tearing off of zinc roofs of houses happened, and the approximated reported speed of the wind are 80m/h. due to high wind speed debris are scattered into the air a few hundreds of meters, and approximately 50 buildings were damaged on that event [25].

The mega losses of the human societies and extreme damages of the buildings and other structure caused by the extreme wind events such as typhoons and tornadoes. Qingshan Yang et al, [26] studied the wind related disaster in East Asia, including disasters in Japan, the Philippines and China, from 2013 to 2016. They observed that the in 2008 disaster happened due to tropical cyclones was the most serious disaster in the Asian region. In this disaster about 138,000 fatalities and missing numbered happened and estimated 10 billion USD economical losses were noted. In Poland, windstorm considered most costly natural hazard. In 2017 a very strong and destructive thunderstorm happened in Poland, which caused disastrous damages in the 3 major provinces like Wielkopolskie, Kujawsko-Pomorskie and Pomorskie because of this disaster around 6 person are dead, dozens of peoples were injured and huge loss of property and buildings were noted, [27].

In 2007, inside a matter of seconds the I-35W steel Bridge over the Mississippi Stream in Minneapolis, Minnesota, collapsed as appeared in (Figure 3b).These extraordinary occasions, in any case, this occasion caused an enormous extent of wind-induced misfortunes. The later 2017 storms that affected the joined together States (Harvey, Irma, and Maria), caused $250 billion in harms to the joined together states and its domain [28]. Tropical storms Ike in 2008 and Sandy in 2012 caused almost US$29.5 billion and US$71.4 billion in harm, separately. In 2013, super storm Yolanda, too known as Storm Haiyan-caused comparable levels of harm in Southeast Asia, which were esteemed at about US$2.9 billion [29]. Kamil MuhammadKafi et al, [30] considers the harm seriousness of a windstorm that demolished more than 30 lives and thousand buildings and other basic structures inside the 2-h of its damaging span in Bauchi city in northern Nigeria. Lam, F.S. at al, [31] detailed that in 2019 alone, Temerloh area found in central Peninsular Malaysia has been hit by eccentric wind storms in restricted ranges which harmed more than 185 provincial homes.

a) b)

Figure 3: a. wind and sandstorm event happened at Gurney [25] and b. collapsed bridge center section [28]

Mehrshad Amini et al, [32] reported that during hurricane Irma and Maria (2017) residential building having the, steel roof frames faced extreme wind induced damages as shown in (Figure 4a). As the steel frame structure are light in weight so these type of structure are more vulnerable to windborne debris, and successive pressure induced due to high wind speed can also increase the chances of damage to the structure. Due to the failure of the connections between roof members and base plate for the gable end wall column complete structure as shown in (Figure 4b) collapsed during the Hurricane Charley (2004). Boback Bob Torkian et al, [33] studied the losses during the last fifty years and reported that losses due to the hurricane gradually increase of $1.3 billion US dollars per year from 1949 to1989, $10.1 billion US dollars per year from 1990 to 1995, and $35.8 billion US dollars per year from 2001 to 2006.

a) b)

Figure 4:a. Wind induces damage to steel frame structure, a. collapse of steel roof frame during hurricane Irma and Maria, 2017 [32] and b. roof frame failure and gable end wall collapse due to insufficient latera support during hurricane Hurricane Charley, 2004. [33]

From 2010 to 2021 around 7 time storm hit within the Asia region at different location or origins, due to which around 153 people are dead, 1,377 injured, 1,18,884 effected, 70,490 are homeless and 5,21,251 US dollar losses are reported in EM-DAT [34] as shown in Table 1 .

Table 1- Effects of Storm hit Asia from 2010 to 2021 [34]

Year	Disaster type	Death	No. injured	No. homeless	Total damages (US$)
2010	Storm	29	190	70000	70190
2012	Storm	05	-	490	490
2013	Storm	02	-	-	25020
2013	Storm	09	-	-	0
2103	Storm	00	67	-	3931
2016	Storm	102	1000	-	46000
2019	Storm	06	120	-	45120

5 Conclusion

Following conclusions can be drawn from the conducted study:

- This paper briefly reviewed the actual causes and evidence of damages of steel structure due to the windstorm.
- Most common failure and the mitigation techniques also discussed in connection with the windstorm related hazards and the conclusions can be drawn from the conducted study is that numerous structure are not designed against the wind load.
- Most of the structure collapse or damages due to windstorm are old or week due to rusting and due to extreme wind pressure roof and wall cladding of the structure damaged.
- It is observed that the steel structure without bracing wire suffer damages of roof and walls. During the design phase wind direction and wind load are not considered due to which most of the structure collapse from the connection point.
- Sever damage of the structure observed because of increasing the internal pressure due to pressurization. While studying the number of windstorm hit the Asia in last decade, it is observed that from 2010 to 2021 around 7 time storm hit within the Asia region at different location or origins, due to which around 153 people are dead, 1,377 injured, 1, 18,884 effected, 70,490 are homeless and 5,21,251 US dollar losses are reported.
- The wind induced damages significantly reduce by following the standardized installation methods, providing constant load-path, adopting passable connection systems and by proving the adequate wind load resisting materials for structural roofing and wall systems.
- It is observed that the structure which are designed according to the modem system and code have effective resistance against wind storm as compared to others, although they are still vulnerable, due to wind induced damages .
- Structural design engineer and the wind engineer play a vital role to save the live and economy of any country by adopting and following the building design codes during design phase of tall steel structure or buildings.

6 Recommendations

- It is very important to consider the win load during the design phase of structure
- Structure design engineer must be follow the wind design code and other relevant parameters
- During design of the building, surrounding trees, bracing, anchoring and outdoor equipment must be take into under consideration to mitigate or minimize the losses.

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References

[1] Yum, Sang-Guk, Ji-Myong Kim, and Hsi-Hsien Wei, "Development of vulnerability curves of buildings to windstorms using insurance data: An empirical study in South Korea," *Journal of Building Engineering*, vol. 34, pp. 101932, 2019.

[2] Chmielewski, T., J. Szer, and P. Bobra, "Derecho wind storm in Poland on August 11-12, 2017: Results of the postdisaster investigation," *Environmental Hazard, Published online*, vol. 20, 2020.

[3] Amini, Mehrshad, and Ali M. Memari, "Review of literature on performance of coastal residential buildings under hurricane conditions and lessons learned," *Journal of performance of constructed facilities* vol. 34, pp. 04020102, 2020

[4] Kishore, Nishant, et al, "Mortality in puerto rico after hurricane maria," *New England journal of medicine* vol. 379.2, pp. 162-170, 2018.

[5] Zakaria, N. H., et al, "Seasonal Windstorm Pattern and Damages in Peninsular Malaysia 2018," *IOP Conference Series: Earth and Environmental Science*, vol. 385, 2019.

[6] Khanduri, A. C., and G. C. Morrow, "Vulnerability of buildings to windstorms and insurance loss estimation," *Journal of wind engineering and industrial aerodynamics*, *vol.* 91.4, pp.455-467, 2003.

[7] Bharvase, Shruti, and Priyanka Patil, "comparative study of vertically regular and irregular steel structure", 2019.

[8] Yang, Na, and Fan Bai, "Damage analysis and evaluation of light steel structures exposed to wind hazards," *Applied Sciences*, vol. 7.3, pp. 239, 2017.

[9] Kim, Seonwoong, "Seismic performance evaluation of high-rise steel buildings dependent on wind exposures," *Advances in Mechanical Engineering*, vol. 11.3, pp. 1687814019835111, 2019.

[10] Hatim Saleem et al, "A Comparative Study on High Rise Building for various Geometrical Shapes Subjected to Wind Load of RCC & Composite Structure using ETABS, "*International Research Journal of Engineering and Technology*, Vol. 6, pp. 2395-0056, 2019.

[11] Ahmed Sada Dheeb and Rafaa M. Abbas, "Deterministic Wind Load Dynamic Analysis of High Rise Steel Buildings Including P-Delta Effects, "*Association of Arab Universities Journal of Engineering Sciences*, vol. 26.1, pp. 129-135, 2019.

[12] Yan Han, Aff.M et al, "Fatigue Reliability Assessment of Long-Span Steel-Truss Suspension Bridges under the Combined Action of Random Traffic and Wind Loads Y J. Bridge Eng., vol. 25(3), 2020.

[13] Brito, Lianne, and Christine Wittich, "Performance of Steel Grain Silos and Rural Communities to Windstorms," *Structures Congress 2019: Blast, Impact Loading, and Research and Education*. Reston, VA: American Society of Civil Engineers, 2019.

[14] Kumar, Pavan, et al, "Effect of wind speed on structural behaviour of Monopole and self-support telecommunication towers," *Asian Journal of Civil Engineering*, vol. 18.6, pp. 911-927, 2017.

[15] Kim, Ji-Myong, Taehui Kim, and Kiyoung Son, "Revealing building vulnerability to windstorms through an insurance claim payout prediction model: a case study in South Korea," *Geomatics, Natural Hazards and Risk*, vol.8.2, pp.1333-1341, 2017.

[16] Nawari, N. O, "Analysis and prediction of building damage due to windstorms," *WIT Transactions on The Built Environment*, vol. 119, pp. 25-33, 2011.

[17] Tan, Yee Jin. *Wind Load Effects On High-Rise Building*. Diss. UTAR, 2020.

[18] Lombardo, Franklin T, "Treatment of Uncertainty for Windstorm Risk Assessment," pp. 02019001, 2019.

[19] Rajmani, A. and Guha,"Analysis of Wind & Earthquake Load For Different Shapes of High Rise Building, "*International Journal of Civil Engineering & Technology (IJCIET)*, vol. 6(2), pp.38-45, 2015.

[20] Roy, A.K. et al, "Wind Load on High Rise Buildings with Different Configurations" : A Critical Review, "*lnternational Conference on Emerging Trends in Engineering lnnovations & Technology Management,*vol. 2, pp.372–379, 2017.
[21] Dagnew, Agerneh K., Girma T. Bitsuamalk, and Ryan Merrick, "Computational evaluation of wind pressures on tall buildings," *11th Americas Conference on Wind Engineering, San Juan, Puerto Rico*, 2009.
[22] Hallebrand, Erik, and Wilhelm Jakobsson. "Structural design of high-rise buildings." *TVSM-5000*, 2016.
[23] https://reliefweb.int/

[24] Fan, B.Y.et al, "Investigation and Analysis of Public and Industrial Building Damage Caused by Typhoon" "Mujigae", In Zhanjiang Guangdong Yearbook of Disaster Prevention; Zhanjiang Municipal People's Government: Zhanjiang, China, 2016.
[25] Cappucci, M., "Massive wrong-way waterspout makes landfall in Malaysia", damaging 50 buildings - The Washington Post 21 April 2020.
[26] Yang, Qingshan, et al, "Damage to buildings and structures due to recent devastating wind hazards in East Asia," *Natural hazards*, vol. 92.3, pp. 1321-1353, 2018.
[27] Chmielewski, T., J. Szer, and P. Bobra, "Derecho wind storm in Poland on August 11-12, 2017: Results of the postdisaster investigation," *Environmental Hazard, Published online*, vol.20, 2020.
[28] NOAA National Centers for Environmental Information (NCEI). "US billion-dollar weather and climate disasters", 2018.
[29] Kim, Ji-Myong, Taehui Kim, and Kiyoung Son, "Revealing building vulnerability to windstorms through an insurance claim payout prediction model: a case study in South Korea," *Geomatics, Natural Hazards and Risk*, vol. 8.2, pp. 1333-1341, 2017.
[30] Kamil MuhammadKafi et al, "damage severity of a windstorm that ruined more than 30 lives and thousand buildings and other essential structures within the 2-h of its destructive span in Bauchi city in northern Nigeria"
[31] Lam, F.S., et al. / 8th AcE-Bs2019LangkawiIsland, Malaysia 18-19 Dec 2019 / E-BPJ, 4(12), pp.279-285.2019.
[32] Amini, Mehrshad, and Ali M. Memari, "Review of literature on performance of coastal residential buildings under hurricane conditions and lessons learned," *Journal of performance of constructed facilities*, vol. 34.6, pp. 04020102, 2020.
[33] Torkian, Boback Bob, et al, "Cost-and-benefit evaluation of windstorm damage mitigation techniques in Florida," *Natural Hazards Review*, vol.15.2, pp. 150-157, 2014.
[34] https://public.emdat.be/