Windstorm Risk Engineering

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Overcoming the wind forces on buildings and structures has proven to be an age-old problem for engineers. As a result, significant time has been devoted to developing building standards in an effort to limit damage caused by wind. However, damage from wind continues. Therefore, wind engineering is an area of ongoing interest for the insurance industry and for those businesses with a keen interest in managing risk at their facilities. This paper will discuss the business engineering approach of FM Global, the main hazards associated with wind, a brief scope of FM Global's wind engineering standards and how we apply them, and finally how they compare to Australian standards.

Background

FM Global is the communicative name for Factory Mutual Insurance Company, a company whose original charter dates back to 1835. FM Global is a global, engineering-driven property insurance and risk management organisation that specialises in commercial and industrial property insurance and loss control. The customer base represents a variety of manufacturing and service industries, as well as public entities and educational institutions. FM Global customers include a healthy proportion of the Fortune 500 $_{TM}$.

Interestingly for an insurance company is that of the 4,000+ employees of FM Global, more than 1,600 are engineers. This reflects FM Global's commitment to understanding and mitigating the hazards for FM Global customers.

Evolution of Wind Insurance for FM Global

Wind has been one of the most significant contributors to FM Global Customer losses. Over the last 25 years, 11% of all the damage sustained by FM Global customers was related to wind. Approximately 70% of these losses were related to damage during severe tropical storms (hurricanes, typhoons, and cyclones). In fact, an analysis of our loss history indicates that loss due to wind and other natural hazards (such as earthquakes, floods and snowstorms) are increasing as a percentage of overall losses. This is an important trend as fire losses have traditionally been the core of the concern in industrial/commercial insurance.

Part of this trend can be attributed to the evolution of the insurance coverages. Like all industries, the quest is to offer customers more attractive products. Providing broad, all encompassing coverage is clearly attractive to an insurance buyer. Obviously, as the coverage expands, more losses will be paid. Wind coverage was added to policies near the start of the 20th century.

Secondly, there has been a migration of population. To use the United States as an example, population centres were historically concentrated in the northeastern regions, where exposure to perils such as wind and earthquake were relatively benign. With improved transportation and communications, the population centres have moved to better climates like Texas, California, and Florida. This shift in demographics means that a larger proportion of customers would be exposed to areas with major hurricane and earthquake exposures. Similar trends can be seen here in Australia as Queensland continues to grow and the mining industry continues to develop along the Northwest coast of Western Australia. Similarly, on a world scale more of the world's base production is moving to Asia – an area exposed to severe typhoon activity (China, Philippines, Japan and Korea are examples).

Finally, there has been the economic drive to more efficient designs. The mantra of builders early this century was "built to last" – many of their buildings still stand. The mantra today is "on time, under budget". Building Standards for wind have evolved immensely in the past few decades to support this drive for efficiency. However, as we sharpen the pencil to get closer to the line, the safety factors historically relied on to absorb errors in installation no longer exist. This is a terrific result for building owners, as it has improved the economics of buildings greatly. However, it does mean that because things are designed "closer to the line". Any mistakes in construction are less likely to be resisted. By doing this, the cost of this increased risk has been passed from the building owner to the insurance company who is now responsible for bearing that risk.

With these changes going on we saw losses but on a large scale, they were manageable from an underwriting perspective. Losses would slowly rise, so underwriters would make incremental increases in rates to accrue for the losses.

Hurricane Andrew: Birthplace of Wind Retrofits

This was true until Hurricane Andrew that hit South Florida in August 1992. This was an event that devastated many insurers (some never re-opened their doors). For FM Global it remains the largest single catastrophic event to affect the company. In 1992, wind related losses overwhelmed the results such that only 20% of losses for the year were attributed to traditional fire events. Never had this been seen before. This was a wake up call for the entire insurance industry.

Touted as the "Big One" by many, Hurricane Andrew may well have been far from it. This storm raced across a relatively thinly populated stretch south of the major urban centre of Miami, Florida and it still resulted in some $US 16 Billion in damages. If it were a direct hit on the Miami City area, the damage toll would have been much higher. Also, it needs to be understood that Andrew, although possessing extremely powerful winds, was a tightly packed storm with relatively low rainfall. It is interesting to look at the history of hurricane activity in the region in the years prior to the storm. There were only three major storms (Category 3 or higher) to hit Florida from 1950 to 1980 – one in each decade. There were actually no major storms affecting Florida in the decade preceding Andrew. However, if the clock is turned back another two decades, a different trend altogether is seen. In the period between 1941 and 1950, there were four major storms and similarly in the period between 1931 and 1940, there were another 4 major storms.

With this in mind, the insurance industry had to take another look at what they were doing with locations in these areas. The first option was to combat the trend by reconstructing pricing to accrue for future catastrophic events. The other option was to limit coverage and no longer write business in windstorm prone areas. Most insurance companies, including FM Global, re-evaluated their pricing structures for the area and made changes. Many also took the option of no longer writing business in the area. However, this was not considered as an option for FM Global. Our customers are made up primarily of large mutlinational companies that require consistent coverage worldwide, whether their factory is built in Miami, Madrid, Manila or Melbourne.

More importantly, the approach of limiting coverage does not harmonise with FM Global's core values. Since our inception in 1835, the principles of the company have been based on engineering and the belief that the majority of all losses are preventable. Therefore, our business engineering approach to wind was restructured. We set out to utilise our existing standards to aggressively identify, quantify, and improve wind-related deficiencies at our customer's sites. In a study of the losses following Hurricane Andrew, it became evident that locations engineered to our standards of the time fared much better than those that did not. Also, we learned that 80% of the losses were as a result of loss of the building envelope (roof, walls, and windows) with resultant interior water damage. Framing was seen to rarely be a factor in the losses. As a result of the study, FM Global developed standards to addressing building deficiencies retroactively, focusing on the deficiencies that were driving losses. The retroactive solutions were simple and required minimal cost. In most cases it required driving some additional fasteners in the corners or perimeter of the roof.

With this approach, we set about re-evaluating existing facilities and more proactively addressing wind issues in the planning stages of new construction. These principles were applied at locations world wide from February 1993 onwards. This was done with a belief that we were indeed reducing the hazard and the risk to FM Global customer's facilities. In 1998, Hurricane Georges put the program to the test.

Hurricane Georges: Putting the us to the test

Hurricane Georges was a Category 3 storm with 185 km/h-sustained winds and gust recorded as high as 225 km/h. The storm had its largest impact on the island of Puerto Rico; a region where the design wind speed being used was between 177 km/h and 193 km/h. The concentration of insured values in this region is very high – largely as a result of the large amount of pharmaceutical manufacturing in the region. FM Global alone had over 500 insured locations in the region. To put it into context the total dollars insured on the island of Puerto Rico is approximately the same as that insured in all of Australia. This is an island with a lot of high value industry. After the dust had settled, this storm ended up being the third most costly hurricane on record with losses of between US$2.5 and 5 billion to the insurance industry. However, when FM Global analysed their losses, it became clear that the engineering work had paid off. Customers that had completed recommendations made by FM Global had significantly smaller losses and these businesses returned to production must faster than locations that sustained major losses. Figure 1 shows the differences. In losses for customers that implemented FM Global wind solutions to those that did not. Customers that had implemented FM Global solutions were up and running their plants the next day, while those that did not were madly repairing damage and watching competitors produce.

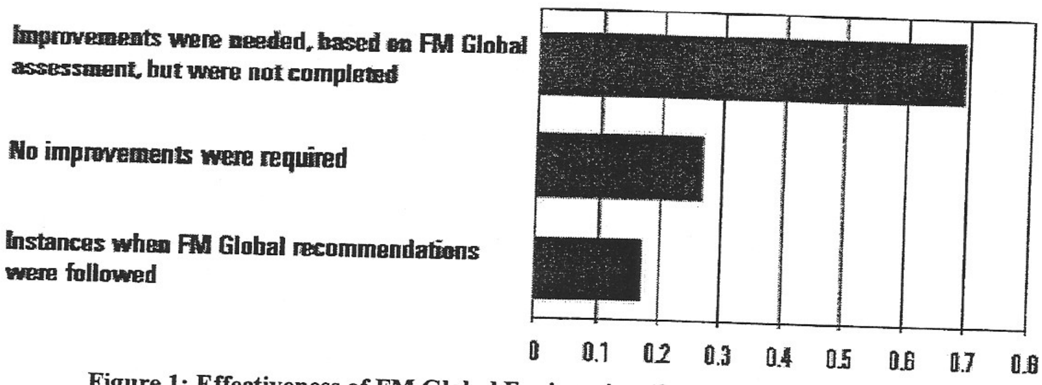

Figure 1: Effectiveness of FM Global Engineering (Scale indicates relative loss)

In addition, 35 large losses (individual events with more than $1million damage) were analysed in detail. 75% of those events had been predicted by FM engineers prior to the event. From this, it was concluded that our core engineering value that the majority of all losses are preventable was upheld with the engineering efforts put towards wind.

Wind in an Australian Context

Prior to concluding this section, it is worthwhile to review some facts about Australia. In cyclone prone areas, Australia is sparsely populated compared to many other areas of the world. However, because of the mining and agricultural industries, there are many very important assets located in cyclone prone areas that are important to Australia's economy. Mining alone accounts for 19% of the value of Australia's fixed assets and natural capital. Because of the remote nature of many of these operations, they often use ocean transport and thus have large processing and port infrastructure development in cyclone prone areas.

In the waters surrounding Australia (Southeast Indian and SW Pacific), it is estimated that 19% of world's severe tropical storms occur (i.e. cyclones, typhoons, and hurricanes). The North Atlantic accounts for 11%. In the waters surrounding Australia, there are an average of 7.7 severe cyclones per season (winds above 120 kph). In the North Atlantic, there are 5.4. (Source Neumann 1993). In the average cyclone season, 10 tropical cyclones develop over Australian waters, of which six cross the coast, mostly over northwestern Australia (between Exmouth and Broome), and Northeast Queensland (between about Mossman and Maryborough). Cyclones vary in number from 0 to 16 per year (1963). Cyclone history exists back to the early 1800's in Australia.

As noted, the cyclone exposure is obvious in Australia. Similar to the United States from 1950 to 1990, there have not been many severe storms that have made land fall in populated areas since Cyclone Tracy in 1974, which devastated Darwin. It should be noted that since 1993, we have conducted several windstorm evaluations at insured properties. The findings have been relatively favourable, with few recommendations resulting. This can be attributed to Australia's good wind engineering standards and construction techniques. However, because of the inherent exposure, the importance of maintaining prudent engineering and construction standards in Australia is as important as it is in the United States.

FM Global Wind Engineering Standards

The focus of FM Global's wind engineering efforts is on the building envelope (cladding), not the main frame structure. This damage occurs mostly at the perimeter of the roof structure. This is what drives our loss experience. Our experience has shown that the structural frame, when designed to a recognised code, will likely be adequate. Hence, our focus is the cladding.

In developing our standards, we have relied heavily on our loss-analysis database to gain subtle insights into the underlying causes for structural damage and resulting property losses. We also employ researchers from a wide variety of backgrounds. We also have well-developed approval protocols. Roofing systems are subjected to our large scale testing regimes and if they pass are listed in our Approval Guide. These tests are carefully designed to emulate the conditions expected in the real world. The testing protocols are recognised by many authorities and have proven to be world class. Similar roofs that are pass other approval protocols are not always able to pass the Factory Mutual Research (FMR) protocol. This has had great benefit to our customers as the FMR approved roofs have stayed in place during severe winds, while roofs passing less stringent protocols have failed. These listings are common in the United States, however, not common in Australia. Currently, efforts are under way to work with local manufacturers to extend this program into Australia.

In looking at our loss history, we have determined that the most frequent and damaging ways that the building envelope can be opened are:

- Roofing cover and/or insulation tear up and off from supporting members.
- Lightweight wall covers such as exterior insulating finishing systems (EIFS) or aluminium panels tear away from the structure.
- Windows are broken by windblown debris, such as surrounding trees.
- The pressures exerted on the building envelope blow in windows.

When working with designers on a new roof, we would specify pressures per our data sheets. A safety factor of 2.0 is recommended for all new designs. A safety factor as low as 1.5 can be employed when evaluating existing structures.

Typically with new construction, FM Global will provide recommended design pressures for the roof (with the safety factor). Then the designer can is able to design the roof, walls, and windows based on these pressures. Where possible, FMR approved products are encouraged. Once appropriate pressures are chosen in the design, the focus of attention shifts to the actual construction. The reason – the human factor is at the root of most roofing losses. We estimate that approximately 60% of the losses we have evaluated, the error was not in design, but application.

With existing structures, FM Global consultants visit a site and evaluate it in accordance with special standards for existing structures. The most common recommendations that would result from an FM Global evaluation are:

- Secure roof flashing with additional fasteners.
- Install a few more fasteners to secure the roof/walls (primarily in the perimeter and corners).
- Utilise window shutters or look at alternative window material (e.g. impact resistant glass and frames, window films).
- Develop/improve a windstorm emergency/contingency plan. This is probably one of the most effective ways to mitigate the hazards associated with windstorms. Securing doors, removing debris, ensuring the back-up power supply is functional at the time of the storm, securing heavy/critical equipment (e.g. cranes), and knowing where to go for resources following a storm are critical items in limiting possible damage and interruption to business.

The effects of storm surge also play an important role in evaluating the exposure to a site. Addressing this hazard in the emergency plan is critical. For new construction, all efforts should be made to avoid constructing new structures in these areas. However, a detailed discussion on storm surge lies outside the scope of this paper.

FM Global Standards vs. Australian Standards

The scope of the comparison is in relation to wind loading on cladding. Therefore, the comparison will focus on the key items from AS1170.2, Section 3, "Detailed Procedure: Static Analysis".

<u>Derivation of Wind Speed:</u>

In the past, FM Global utilised the fastest mile wind speed. However, we are currently in the process of adapting American Society of Civil Engineers (ASCE) standard 7-98 as the basis for wind load calculations. Therefore, our standards have changed to adopt the 3-sec gust wind speed that is utilised in AS 1170.2 as well. Our wind standards are also based on a 100-year return period. As a result our design wind speeds are the same as the V_p values given in AS 1170.2.

<u>Wind Direction</u>

Similar to AS 1170.2, FM Global standards do not consider wind direction in cyclonic areas. This is primarily because of the ability for the wind direction to change as a cyclone passes. FM Global do not consider wind direction in non-cyclonic areas either. However, this usually has little impact on the cladding, as we are still concerned with "freak" weather patterns that may deliver winds in an unusual direction. Also, the minimum installation requirements for most cladding systems usually provide for a suitable safety factor in non-cyclonic areas.

Terrain

The terminology is different. Adopting ASCE 7-98, FM Global use the ground roughness A (Category 4), B (Category 3), C (Category 2) and D (Category 1). Ground Roughness A is not applied by FM Global. This is because structures in inner city centres can be subject to unique localised wind conditions. Specific models or full-scale studies are really necessary to determine these wind forces. This is also noted in Appendix E of AS 1170.2. FM Global consider ground roughness based on the scenario governed by the worst case 30 degree window when surveying the property from all angles extending more than 180 m from the building. In cyclonic areas, it is unlikely that Ground Roughness D would be used as the wave action created by the cyclone would act to make this a Ground Roughness C terrain (also noted in Appendix E of AS 1170.2).

Structure Importance Multiplier

For new construction, FM Global utilise a structural importance factor of 1.15. This is in line with the factors in ASCE 7-98 for buildings of special importance. Because most of FM Global's customers are multinational manufacturing companies, and our goal is to assist them in protecting their business continuity, it follows that we would adopt this.

Velocity Pressures

FM Global calculate velocity pressures to be used for design in a similar manner (i.e. based upon the formula $p=0.0006V^2$). However, the tables in FM Global Standards already contain the field of roof external and internal pressures. Local pressure factors for cladding are also provided in tables (normalised to field of roof pressures). This is similar to the methodology in Section 3.4.5 of AS 1170.2, however, FM Global consider larger pressures in the corners. Most wall/roofing damage starts at the corner of the building where pressures are highest. Because we are primarily concerned with cladding, some of the multipliers are not factored into our calculations.

Roofing Systems

This is not part of the standards, but is worth commenting on. In North America and Europe, the use of specialised built-up insulation systems on steel deck is common. The number of available products and possible combinations is very large. Many roofing systems in the United States hold FM Approval and these are the roofs that we commonly recommend. These roofing combinations have all passed approval requirements for various uplift pressures and therefore, once pressures are determined, a suitable roof can be selected.

In Australia, these roofing systems are not very common. Most building cladding systems are either lap seam (screwed down deck) or concealed clip types. With screwed down decks, the calculations for uplift resistance can be done easily if the screw size, screw spacing, purlin spacing, and deck parameters (e.g. thickness, metal type, yield strength) are known. Concealed clip systems in Australia are of a unique design. Therefore, we rely on the manufacturers test results in combination with applied safety factors to determine the adequacy of the roof per FM Global standards.

Evaluation of impact and pressure resistance of windows is done on a case by case basis.

Conclusion

No peril can match the wind of a severe tropical storm in its ability to cause widespread devastation. Damage in these storms is predominantly a result of the failure of the building envelope. As a result, special engineering techniques are applied by FM Global engineers to assist in reducing the risk of major losses to insured customers. History has shown that the results of these evaluations (and subsequent improvements) have resulted in the reduction of damage at FM Global's customer facilities and consequently less downtime following a storm. Although our standards differ slightly from the approach in the Australian Standards, there is generally harmony between the standards. The application of slightly larger safety factors and multipliers on building cladding has proved to be a benefit to the businesses that apply them.