DESIGN AND PROTECTION OF BUILDINGS AND STRUCTURES FROM WINDSTORMS

INTRODUCTION

Severe damage to a building or structure could be caused by a minor windstorm if the building or structure is under-designed or unprotected. The damage could be caused by several different phenomena. The most common phenomenon is the force of the wind acting directly on the walls or vertical supports causing them to buckle. Another phenomenon is when wind blows over and around a building, creating a negative pressure on the roof and the leeward (downwind) and side walls, causing the roof to lift or walls to fail. In some instances internal positive pressure in the building, caused by broken windows and doors, will combine with the negative pressure on the leeward and side walls to cause the structure to fail. A well-designed and protected building or structure could effectively resist these forces from all except winds of tornado velocity.

Serious property damage could also be caused by unsecured objects that are hurled through the air by the wind, striking and damaging other property. In buildings or structures of unusual length or shape, it is possible for wind to generate vibrations or "flutter" which can lead to structural failure.

Many countries have local building design standards that cover wind loads on buildings and structures[1]. Many local governments establish local building codes to address specific local problems. It is important to remember that such codes are *minimum* requirements. Often, prudence or experience dictate using a more stringent design to minimize losses. Properly designed and adequately maintained buildings and structures should survive thunderstorms, local winds and most hurricanes or typhoons with minimal damage. In geographical areas that infrequently experience very high winds, miscellaneous structures, such as signs, cooling towers, ventilators, antennas, conveyor systems and silos, may be erected without proper regard for the winds associated with major storms.

This Property Risk Consulting Guideline covers the design of buildings and structures, whether completed or under construction against windstorm damage. Structures include outdoor process equipment, pipe racks, cranes, antenna towers, cooling towers, signs, silos and storage tanks.

POSITION

Building And Structure Design

General

When using any of the design standards, use the highest Risk Category, Working Life, or equivalent when designing essential buildings or structures. Buildings and structures that are considered important use a medium Risk Category, Working Life, or equivalent when designing the buildings or structures. Buildings and structures that are not in the highest or medium category use a low Risk Category, Working Life, or equivalent when designing the building or structure.

The following occupancies are considered highest Risk Category (IV) occupancy:

- Buildings and other structures designated as essential facilities such as hospitals and other health care facilities, power generating stations, public utilities, aviation control towers and centers, emergency aircraft hangers, and buildings that have critical national defense functions.
- Structures such as communication towers, fuel storage tanks, cooling towers, electrical substation structures, and water storage for fire-suppression equipment.
- Buildings and other structures, which would cause a substantial economic impact or disruption.
- Buildings and other structures, the failure of which could pose a substantial hazard to the community.
- Buildings and other structures that manufacture, process, handle, store, or use hazardous substances such as hazardous fuels, hazardous chemicals, or hazardous waste.
- Buildings and other structures that contain sufficient quantities of highly toxic substances.
- Building and structures that are critical to production or where there is interdependency with other facilities.
- Buildings and other structures required to maintain the functionality of the facility (boiler plants, water treatment facilities, warehouses storing dies and spare parts, etc.).
- Buildings and structures with high occupancy loads.

The following occupancies are considered medium Risk Category (II) occupancies:

- Building and structures that, if damaged, will not disrupt production.
- Office buildings where the occupants could work remotely if the building is damaged AND production is not disrupted.
- Warehouse buildings that store noncritical products.

The following occupancies are considered low Risk Category (I) occupancies:

- Temporary facilities (erected for less than 60 days).
- Minor storage facilities.

Where the design standards do not have a Risk Category or Working Life coefficient or factor, calculate the design pressure based on the wind speeds given then multiply the calculated design pressure by the correction factor (c) from Equation 1.

Use wind speed that are equal to a 0.06% chance of exceedance (1700 yr). If the wind speed is given in other than 0.06% chance of exceedance, first determine the design pressures then use Equation 1 to determine the correction factor (c) for the 0.2% chance of exceedance. Multiply the design pressure by the correction factor (c).

$$c=\left(\frac{5+\ln R}{5+\ln X}\right)^2 \qquad \textbf{Eq 1}$$

Where:

R = 1700 for building and structures in Risk Category IV
700 for building and structures in Risk Category II
300 for building and structures in Risk Category I

X = is the Return Period used for design pressure calculation

Roof Assemblies

Use roof assemblies and components that are listed by a nationally recognized testing laboratory for wind uplift. If a metal deck is being used, at a minimum, secure the deck to the structural support using ⅝ in. (16 mm) diameter welds spaced 12 in. (304 mm) on center or No. 12-24 by 7/8 in. long (M6 by 23 mm), self-drilling, self-tapping screws.

The Underwriters Laboratories *Online Certification Directory* has two sections that cover uplift classifications.

- "Roof Deck Construction" (TGKX) section which is based on UL 580 and covers roof systems that have been tested for wind uplift resistance with a classification of 15, 30, 60 or 90; correlating to a maximum uplift pressure.
- "Roofing System, Uplift Resistance" (TGIK) section is based on UL 1897 and lists assemblies that have been tested to a specified uplift pressure.

Use Table 1 to determine the appropriate uplift classification for UL listed assemblies in the TGKX section and FM Approved roof systems based on the uplift calculation.

When using the assemblies listed in the UL "Roofing System, Uplift Resistance" (TGIK) section, multiply the uplift resistance indicated in the listing by 0.50.

TABLE 1
Uplift Classification

Maximum Uplift Pressure (psf)	UL Classification	FM Class
	30	60
30	60	60
45	90	90
60	N/A	120
75	N/A	150
90	N/A	180

SI Units: 1 psf = 0.0479 kPa

FM *Approval Guide* refers to their RoofNav program and has lists for roof assemblies as 1-60, 1-90, 1-120, 1-150 or 1-180 correlating to a maximum uplift pressure.

Secure the first layer of insulation to the metal deck with mechanical fasteners. Never use asphalt as an adhesive to secure the first layer of insulation to the metal deck. (See Discussion.)

Secure fastening along the perimeter of the roof assembly properly. Use flashing that has been tested and listed to either FM 4435 or ANSI/SPRI ES-1.

For information on installations with single ply membrane roof systems, see also PRC.2.1.1. For installations involving built-up roof systems on metal decks, see also PRC.2.1.2.

Wall Assemblies

Design the exterior walls to withstand the calculated pressures. Use glazing material and windows that have been tested to ASTM E1886 and ASTM E1996. For locations in wind speed areas ≥ 100 mph (45 m/s), use windows and glazing materials tested for small missiles. For locations in wind speed areas ≥ 120 mph (53 m/s), use windows and glazing materials tested for large missiles. For locations in wind speed areas ≥ 100 mph (45 m/s), use exterior doors that have been tested to ASTM E1886 and ASTM E1996.

Cranes

Design crane anchorage points to resist the wind loads as determined by the design standards. When the wind load is 30 psf (1.4 kPa) or less, parking brakes may be considered acceptable securement.

Where the wind loads exceed the 30 psf (1.4 kPa), provide special anchors, such as tie-downs or latches at the home position or remotely operated rail clamps for all positions to supplement the braking system.

Where rail clamps are used for anchorages, secure the rails to withstand the resultant loads applied by the rail clamps.

Install all permanent foundations and anchors on footings below the frost line.

Provide a wind velocity-indicating device at the top of the crane with an alarm located in the operator's cab or house and at a remote location. Set the alarm to sound when the wind speed is within 5 mph (8 km/h) of the manufacturer's recommended maximum in-service wind speed.

Where there are several cranes in the yard, provide a remote wind velocity indicating device that would give an alarm to discontinue crane operations in the event the wind speed is within 5 mph (8 km/h) of the manufacturers recommended maximum in-service wind speed.

When the alarm sounds, lower the boom of boom type cranes to the ground or fold the boom in such way that the center of gravity is lowered significantly. On climbing and tower type cranes, place the boom into a freewheeling mode so that it can turn with the wind. Anchor and secure gantry and large track cranes.

Antenna Towers

For towers under 100 ft (30 m), design the tower and anchor points for wind loads using the design standards. For towers 100 ft (30 m) or higher, design the tower and anchor points for wind loads using TIA/EIA 222

Chimneys

Design the chimney using the design standards as modified by Equation 1.

Storage Tanks

Design storage tanks using the design standards. Adequately brace and support aboveground storage tanks that are under construction or empty. Anchor and secure empty underground storage tanks that are above ground waiting to be installed.

Buildings And Structures Under Construction

Secure loose building material and other equipment before the onset of a storm. Brace all structural members (walls, flooring, roofs, storage tanks, etc.) until the final fasteners and coverings have been installed. Secure cranes when winds approach the high end of the safe operating conditions.

DISCUSSION

Building And Structure Design

AXA XL Risk Consulting considers most all buildings essential. There will be some exceptions. These exceptions must be agreed upon by the account consultant. When designing a building to withstand the force of wind, it is important to examine all elements of the building. These elements include the building structural framework, walls and roofs.

When using the design standards to design the pressures on the building roof and walls, there is some basic information needed to calculate the wind load (velocity pressure). The information is:

- Maximum sustained wind speed
- The topography
- The ground exposure
- Building height
- Roof geometry and slope

- Whether the building is fully enclosed.

Maximum sustained wind speed, how fast the winds are in the region of the building or structure. The higher the wind speed the higher the pressures will be.

Topography takes into account any ridge, hill or escarpment that causes the wind to speed up as it passes over them. Depending on where the building or structure is located, this will have an effect on the pressures on the building or structure.

Ground exposure is the terrain and openness of the area around the building or structure. Wind coming off of an open water surfaces such as large lakes and oceans will be at the maximum wind speed verses the wind coming going through an area built-up with buildings and trees which would slow the wind down.

Wind speed is usually measured 30 ft (10 m) above the ground. If the building is taller than the surrounding buildings and trees, the wind pressure would be higher.

The roof geometry and slope will play a role in the pressures applied to the roof system and where the pressures would be the highest.

Finally whether the building is enclosed or partially enclosed. Wind pass around an enclosed building while a building with one open wall can have the wind enter it and apply pressure on the inside as well as the outside of the building.

Roof Assemblies

Roof assemblies are one of most important and the most fragile parts of a building. They are continuously subjected to the outside elements, including extreme changes in temperature. At the same time they must maintain watertight integrity and the structural ability to deal with constantly changing loads. Attempts to create better and more economical roofing systems have resulted in a proliferation of new designs and materials. Each system may be made up of different kinds of roof decking, insulation, fasteners or adhesives, covering, ballast, waterproofing materials and flashing materials. Some of these components may be incompatible with others. Some may be sensitive to temperature and force for proper application.

In spite of good intentions and careful design, there are a disproportionate number of roof damage losses due to all types of windstorms. In some losses the damage is a result of the large uplift forces generated near the edge of a roof, which pull the top covering and insulation free of the roof decking. These were due to inadequate or lack of perimeter fastening. In most losses the cause is the adhesives were often applied improperly, too sparingly, or at the wrong ambient temperature. Reviewing losses involving wind damage to roof system over a 5 yr period, there were 410 losses. Of those losses, 409 were attributed to improper or inadequate application of adhesives, including asphalt. Excessive moisture in the materials or the atmosphere, low temperatures, improper pressures, contamination of the surfaces and many other problems can create poor fastening or bonding. The resulting weaknesses may not manifest themselves until the roofing system is stressed by storms. In many cases the extent of the loss was increased by the rain, snow or hail that accompany the wind and penetrate the damaged roof causing damage to the building contents.

The roof assembly can consists of the structural support, the deck material, vapor barrier, insulation, and roof covering and ballast material. If the entire roof assembly is not properly secured, the uplift forces imposed by the wind passing over the roof could cause the assembly to come apart. Some of the key components that need to be addressed are:

- Securing the metal deck to the structural support.
- Securing the insulation to the metal deck.
- Securing the roof covering to the rest of the assembly.

The uplift pressures in the corners and along the perimeter are stronger than the pressures in the field or middle of the roof. Additional securement is needed in the corner and perimeter.

It is not always possible to determine the integrity of an existing roof through an inspection. There are, however, some signs of potential problems, which can be observed. Evidence of ponding, blistering, alligatoring, delamination, surface erosion and loose flashing indicates a potential problem. Any problem with the roof should be investigated by a roofing consultant and corrected or repaired.

Carefully examine roofs without aggregate or gravel, and directly exposed to the elements, for signs of cracking, alligatoring or other problems. This type of roof is particularly prone to deterioration, damage and failure.

It may be difficult to determine whether perimeter fastening was installed and if it is adequate. If fastening does not appear to be provided, determine whether a special adhesive system was substituted for more conventional roof fasteners. Note, however, that the usual roof adhesives used to secure the insulation are not an adequate substitute for mechanical fastenings.

Although the UL lists assemblies use asphalt or other adhesives to secure the first layer of insulation to the metal deck, loss experience shows this method of securement created many problems. If too much asphalt is used, the roof system will be considered combustible. If too little asphalt or adhesive is used, or they are applied improperly, the roof system will not withstand the wind loads.

Wall Assemblies

The other vulnerable part of the building to wind damage is the wall assembly. Depending on the type of construction, damage could happen in different manners. Lightweight metal panel walls (pre-engineered metal buildings) are vulnerable to damage at the corners. If the only method of securement is by fasteners, the fastener spacing must be decreased to allow more fasteners in the corners. Curtain walls constructed of Exterior Insulation Finishing Systems (EFIS) and Glazing are vulnerable to impact damage from flying debris.

Opening in the wall such as windows and doors are susceptible to damage from the direct wind pressure and flying debris. In regions where this is possible, provide impact resistant glazing or protection for the openings.

Cranes

Maximum safe operating wind speed is usually between 20 and 40 mph (32 and 64 km/h), depending upon the crane and the loads.

Most cranes are particularly vulnerable to windstorms. Many forms of construction cranes have exceptionally long booms, which make them susceptible to overturning in high winds, unless they are properly secured. The effects of the crane, rigging, and load, when operating above the safe wind speed, make it difficult to control and increase the risk of loss. Gantry cranes, which are common in shipyards, and marine cargo container cranes are subject to overturning during heavy winds unless they are properly secured with ground anchors. Many of the larger track mounted cranes have been found to have inadequate braking power and inadequate propulsive power to ensure control of the crane when wind speeds exceed 40 mph (65 km/h). If such cranes have not been secured to their ground anchors before the wind reaches these modest levels, it may be difficult to maneuver them into position for anchoring.

Storage Tanks

Large liquid tanks with extensive areas are particularly susceptible to windstorm loss, since large areas of the shell may not be adequately supported. Even when designed to generally accepted standards, they may be affected by major hurricanes and tornadoes. They are more susceptible to deformation and failure when empty.

Underground storage tanks that are being installed are susceptible to movement by high winds that could roll these rounded tanks around a site, damaging other structures or themselves.

Buildings And Structures Under Construction

Construction sites are highly vulnerable to windstorm losses. Structures are susceptible to damage when not completely braced or anchored. Masonry walls or prefabricated wall panels can blow down if they are not secured or braced. Steel frames are often erected using a few bolts or fasteners before the final alignment and plumbing of the structure. Once aligned, the remaining fasteners are installed. If high winds hit during the interim period, the structure could collapse.

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