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Wind Load Analysis of Roofing System in Luzon, Philippines

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Abstract: - The Philippines is one of the world's top disaster hotspots because of its vulnerability to numerous natural and man-made dangers. To create efficient risk reduction measures, a systematic vulnerability assessment of important building typologies should be carried out. The roof serves as more than just a covering for our heads; it also serves as the structure's spine or backbone, shielding the house's vital organs. The function of a structure and the roofing materials available determine a roof's features. Flat roof, Gable, Pyramid Hip, Skillion and Lean, Hip and Valley are a few examples of roofing types. The most popular type is long-span, pre-painted metal roofing made of GI sheets. You can also use other metals like copper, tin, and aluminum. The type of roofing system installed on low-rise residential buildings had little to no impact on the intensity of wind loads. The building's location and the roof angle are the only factors that can change the wind pressure. Any roof system will react most strongly at a critical roof angle of 20° where uplift pressure is present.

Key Words— ***Wind Load, Roof, Roofing System.***

I. INTRODUCTION

The Philippines is among the top global disaster hotspots, being exposed to a wide range of natural and man-made hazards. This represents a limiting factor to the country's sustainable development. In the recent *Germanwatch Global Climate Risk Index 2020* [1], the Philippines ranked 4th among the most affected countries by disasters (in the period 1999–2018), with a significant percentage of gross domestic product (GDP) in areas at risk.

Being frequented by typhoons—with an annual average of 20 tropical cyclones entering the Philippine Area of Responsibility (PAR), the Philippines is heavily exposed to strong winds. These strong typhoons cause a great deal of building damage, especially on non-engineered residential houses. A systematic vulnerability assessment of key building typologies should be performed to develop effective risk reduction measures for non-engineered residential homes.

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A roof is a part of a building envelope, both the covering on the uppermost part of a building or shelter that provides protection from the weather, notably rain, but also heat, wind and sunlight, and the framing or structure that supports the covering. The roof is not just a structure over our heads but it is also known as the spine, or the backbone of the structure – the one that protects or shields the home's vital organs.

The characteristics of a roof are dependent upon the purpose of the building, the available roofing materials, the local traditions of construction and wider concepts of architectural design and practice, and may also be governed by local or national legislation. Some types of roofing systems include Flat roof, Gable, Pyramid Hip, Skillion and Lean, Hip and Valley.

Several roofing materials available locally are pre-painted long-span metal roofing, corrugated GI (galvanized iron) sheets, clay or ceramic roof tiles, fiber cement shingles, asphalt and wood shingles. Some buildings necessitate the use of another material, the concrete roof deck.

The most used roofing material by rank and type of application would be the unpainted corrugated G.I. roofing for the low-end markets. It is the cheapest, but would also corrode and deteriorate the fastest if not painted properly. Once corrosion sets in, it is very difficult to stop the deterioration, and the best way to arrest the problem is to replace the whole sheet. GI roof sheets are economical and practical. It is the most economical in terms of cost per square meter, and the required support structure is also most economical. It is also the easiest to patch up, since these can be easily performed by a homeowner. Pre-painted long-span metal roofing is also practical and economical. Less joints mean less chances of leaks being cut according to the length required, thus avoiding horizontal overlapping, which is one of the causes of leaks. They are also installed using a special type of screw called the 'tekscrew' with rubber washer that is watertight. It would be better to use long-span metal roofing than commercial-length roofing sheets to eliminate overlapping joints and minimize the potential for leaks. Pre-painted long-span metal roofing made of GI sheets is the most preferred. Other metals such as aluminum, tin, and copper, can also be used to produce pre-painted long-span roofing sheets, but they are more expensive.

Because the purpose of a roof is to protect people and their possessions from climatic elements, the insulating properties of a roof are a consideration in its structure. Also, drainage should be considered when designing the roofing system. It is the primary job of most roofs to keep out water. The large area of a roof repels a lot of water, which must be directed in some suitable way, so that it does not cause damage or inconvenience.

The construction of a roof is determined by its method of support, how the space underneath is bridged, and whether the roof is pitched. The pitch is the angle at which the roof rises from its lowest to highest point. Also, in the design and construction of a roof, wind and rain loads are governed by provisions that are based in the latest edition of National Structural Code of the Philippines, Volume 1 (NSCP 2010).

The problem with figuring out wind loads is the wind. In the realm of things near the ground, the wind is very erratic due to interaction with ground features. This can make it difficult to really know what speed is effectively acting on a structure near the ground. Preventing wind damage involves strengthening areas where things could come apart. The walls, roof, and foundation must be strong, and the attachments between them must be strong and secure. For a home to resist a hurricane and weak tornadic winds, it must have a continuous load path from the roof to the foundation -- connections that tie all structural parts together and can resist types of wind loads that could push and pull on the house in a storm.

The wind exerts three types of forces on your home. Uplift load, in which the wind flow pressures create a strong lifting effect. Wind flow under a roof push upward; wind flow over a roof pull upward. Shear load, in which horizontal wind pressure could cause racking of walls, making a house tilt. And the Lateral load, in which the horizontal pushing and pulling pressure on walls that could make a house slide off the foundation or overturn.

The actual effects of these wind forces on houses depend on their design, construction, and surroundings. Among other things, high wind pressures tend to collapse doors, window units, and doors, rip off roofing and roof decking and destroy walls. Roof overhangs, porches and other features that tend to trap air beneath them, resulting in high uplift forces, are particularly susceptible to damage. In addition, broken windows, doors, and roofs can expose your home to serious damage from internal wind pressures and water entry.

II. OBJECTIVE OF THE RESEARCH

The research aimed to determine and analyze the existing roofing systems in the Luzon region of the Philippines in terms of wind loads. Acquire existing wind variables in the selected locations in Central Luzon. Determine the intensity of the uplift pressures provided by wind loads between the three (3) roofing systems (flat roof, gable roof, and hip roof). Determine the critical roof angle where the wind pressure is at its maximum.

III. STATEMENT OF THE PROBLEM

This research undertaking sought to determine and analyze the existing roofing systems in the Central Luzon region of the Philippines in terms of wind loads.

Thus, this research was designed to answer the following:

- What are the existing wind variables in the selected locations in Central Luzon?
- What is the intensity of the uplift pressures provided by wind loads between the three (3) roofing systems (flat roof, gable roof, and hip roof)?
- What is the critical roof angle where the wind pressure is at maximum?

IV. REVIEW OF RELATED LITERATURE

4.1 Lateral Loads

According to Jong Soo Kim et.al (2016), The roof size of Philippine Arena [5-7] is approximately 227 m × 179 m. Roof shape was drawn from the torus shape and span-rise ratios were 0.096 for major axis and 0.055 for minor axis (Fig. 5). Because the roof does not have enough rise height to expect arch action, deriving reasonable system for roof was quite challenging issue for structural engineer.

Lateral Load Resistance System—Wind Load Wind loads on roof structure can be categorized into positive and negative pressure. As long as it is out of plane pressure, the behavior of wind load is similar to that of gravity load. Philippine is in a region which experiences typhoon, so it is recommended that wind tunnel test (Fig. 10) should be performed to estimate design wind pressure. To evaluate more accurate wind pressure, wind tunnel test was conducted. The dome had been divided into 42 tributary areas and panels. The net pressure on a panel was obtained by combining the external pressure coefficients acting on the tributary area by simultaneously differencing the external and back pressure acting on the area. The external pressure was determined based on the area weighting of the pressure sensors monitoring the pressures of the tributary area. Wind tunnel test result showed that most part of the roof wind pressure is similar or little below than wind load from code except cantilevered roof area. This result was considered reasonable and applied to roof structure design. For the area that result of wind tunnel test was much smaller than code, the 80% of code value was applied.

4.2 Wind Loads

According to Joshua Joseph C.Gumaro et.al, (2022), Tropical cyclones have caused significant damage to low-rise buildings in the Philippines, with severe to complete damages observed in non-engineered houses. As a response, vulnerability assessments need to be conducted to identify strategies that will improve the resilience of buildings against the severe wind.

This paper presents a methodology for identifying critical key building components and building typologies that can be used for a component-based vulnerability assessment against extreme wind loads. The paper discusses the recommended survey preparations, survey proper and post-survey activities needed to produce vulnerability and fragility curves. The paper focuses on collecting data wherein buildings can be classified into key building typologies based on their key critical components. Furthermore, a discussion on the application of the methodology in the province of Cebu is presented, wherein four new building classifications are proposed in addition to the existing key building typologies identified in previous research for the Philippines. The new classifications are as follows: Reinforced concrete moment frame, open/without walls (C1o), Steel moment frame, open/without walls (S1o), Wood frame with CHB walls (W4), and wall: bottom half concrete and upper half wood (W5). The amended key building types for the Philippines can then be used for risk assessments initiatives wherein the results can be implemented in disaster risk reduction mitigation strategies (DRRM).

4.3 Extreme Wind Effects on Low Rise Buildings

According to Timothy Acosta (2021), This paper investigates the prominent failure modes of educational facilities by using field observations. Specifically, damage to the roof covering, roof structure and exterior windows were quantified. An archetype of these structures is modeled in a Monte Carlo Simulation wherein the probabilistic resistance capacities of the building envelope components are compared to their corresponding probabilistic wind loads. The probability of exceedance is then evaluated at three levels of damage state per 3-s gust wind speeds. For the vulnerability curve, the results were fitted into a cumulative probability density function with a mean of 4.7314 and a standard deviation of 0.4061. The results of the model are then evaluated through a case study of Typhoon Nina 2016. The model generally underpredicts the mean damage ratio per municipality by about 13.17% for wind speeds of 40.225 m/s and by about 3–6% for wind speeds between 49 m/s to 71 m/s. The reported damage by the respective government authorities was aggregated on a municipality level and compared to the performance of the model. A statistical analysis between the reported and mean predicted damage was also done by using the Spearman rank correlation coefficient. The results yielded a positive correlation of 0.856.

4.4 Typical Terrain Exposures

According to Ahmed Musa et. Al (2016), Steel liquid storage tanks in the form of truncated cones are commonly used as containment vessels for water supply or storing chemicals. A number of failures have been recorded in the past few decades for steel liquid tanks and silos under wind loading. A steel conical tank vessel will have a relatively small thickness making it susceptible to buckling under wind loads especially when they are not fully-filled. In this study, a wind tunnel pressure test is performed on an elevated conical tank in order to estimate the external wind pressures when immersed into a boundary layer. The tested tank configuration represents combined conical tanks where the cone is capped with a cylinder. In addition, the effect of terrain exposure and wind speed on the pressure values and wind forces is assessed. The mean and rms pressure coefficients are presented for different test cases in addition to the mean and rms total drag forces that are obtained by integrating the pressure coefficient over the tank model's surface. It is found that the total mean and rms drag forces are highly-dependent on Reynolds number which is a function of wind speed and they have a maximum value at mid-height for the lower cylinder, at top for the conical part, and at bottom for the upper cylindrical part. Keywords: conical steel tanks, wind pressure, wind tunnel pressure test, Reynolds number, terrain exposure

4.5 Wind Loads on Low-Rise Buildings

According to Garciano, L.; Alvarez et.al, (2013), Every year about fifteen to twenty typhoons enter the Philippine Area of Responsibility, causing devastating effects to residential structures in many parts of the country. The strong uplift force of the wind and the inadequate uplift resistance of the roof are the main reasons of roof failure during extreme wind speeds (typhoons). In this regard the authors investigated the probability of pullout and pullover failures of roof panels in low-rise residential structures when subjected to extreme wind speeds. The area studied is part of Malate Manila, Philippines, where many structures appear to be non-engineered or not designed according to applicable national structural codes. The extreme wind speeds were modeled using the generalized extreme value distribution (GEV) using 50 years of annual wind speed maxima from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA).

A survey was conducted on 42 residential houses in the study area. Galvanized iron roofs similar (rusted roofs) to the ones used in the study area were also tested for tensile strength. The roof panel resistance was obtained using the wind load provisions of the National Structural Code of the Philippines (NSCP 2010) while the wind uplift pressures for different typhoon return periods were obtained using NSCP 2010 and the GEV model. Finally, the probability of failure for each roof was obtained by Monte Carlo simulation of the performance function, resistance minus load. The results obtained show that pullout failure is the main mode of failure attaining a maximum of 27.2% for a 150-year wind return period (200 km/h wind speed).

A risk curve was also obtained using the annualized expected loss and the average annual exceedance probability of the wind speeds. Finally, a map in Geographic Information System (GIS) format was developed that can help local authorities identify house roofs that are vulnerable to strong typhoons. This hazard map may also help residents strengthen their roofs to lessen damage during typhoons.

4.6 Types of Roofing System

Gable roof is a triangular section of wall at the end of a pitched roof, extending from the eaves to the peak. The gables in Classical Greek temples are called pediments. The architectural treatment of a gable results from the effort to find an aesthetically pleasing solution to the problem of keeping water out of the intersection of walls and roof. This is accomplished either by carrying the roof out over the top of the end walls, or by carrying the end walls up above the roof level and capping them with a waterproof coping. The former method is in general use in wooden and other small buildings with pitched roofs, while the latter method is used in larger and more monumental masonry structures, particularly those in the Gothic style.

A flat roof is not just defined by its lack of or very slight inclination of less than 10°. All roofs which require waterproofing are classed as flat roofs. This includes domed roofs, sawtooth roofs, design-based suspended roofs, VT gabled roofs, “butterfly roofs”, HP shell roofs. The supporting substructure is usually identical to the upper ceiling. Long-term waterproofing is imperative for flat roofs which are permanently subjected to climatic and temperature extremes and various mechanical stresses.

A hip roof is a little more complex to frame than a gable roof. Besides a ridge board, a gable roof has only common rafters (all rafters the same length) as its only components. The components of a hip roof are the ridge board, common rafters, hip rafters, and jack rafters.

If the building is a square with all four walls being the same length, there will be no ridge and the roof will resemble a pyramid. Pyramid roof is a roof with four slopes terminating at a peak. It is a type of roof where all sides slope downwards to the walls, usually with a fairly gentle slope. Thus, it is a house with no gables or other vertical sides to the roof. A square hip roof is shaped like a pyramid. Hip roofs on houses could have two triangular sides and two trapezoidal ones. A hip roof on a rectangular plan has four faces. They are almost always at the same pitch or slope, which makes them symmetrical about the centerlines.

A skillion roof is a sloping roof surface, often not attached to another roof surface. Skillion roofs are sometimes called a shed, flat, or lean-to roof. The term skillion can also be used for a smaller addition to an existing roof, where keeping to the same slope (roof pitch) puts the skillion roof lower than the ceiling height of the main structure. In this case even though the main roof has a flat ceiling, the skillion part will have a sloping, or raked, ceiling line to maximise the ceiling height. Skillion roofs can also be used to provide clerestory windows for a hallway or similar room where a row of windows is placed below the edge of the skillion section reaching above the other roof below.

Hip roofs and gabled roofs have at least two sloping sides which meet towards the centre of a building in a ridge or peak. The skillion roof is somewhat different, in that it only has one single flat surface. A skillion roof is different from a standard flat roof though - it has a steeper and more noticeable pitch. In Australia, a skillion roof is also commonly called a 'shed roof'. Skillion roofs are often installed because they are cheap, easy and fast to construct. Another reason they are installed is that they do not suffer from the drainage problems encountered by less steeply pitched roofs.

The skillion roof was once consigned mainly to shed. It is also common to see building extensions finished with skillion roofs. More recently, the skillion roof has gained popularity in Australia as a design feature in its own right, evoking rural and industrial themes. Variations on the skillion roof include circular or oval-shaped designs, and the butterfly roof. A butterfly roof has two skillions which angle down towards the centre. This design is a particularly effective way to trap water, which is a big advantage for houses where collecting rainwater is a priority. Skillion roofs tend to be fairly steeply pitched, which allows water to run off more effectively than on flatter roofs. Roofs with good drainage require a less tightly sealed building envelope. For this reason, the rubber skins or roofing membranes that are necessary on flat or low-pitched roofs may be done away with. Skillion roofs generally have an industrial/minimalist look, which often leads to a choice of more streamlined roofing materials. Such finishes might include metal rather than tiles; for example, which have a more traditional and elaborately decorative look. Skillion roofs, if positioned correctly, may also offer a large surface for solar panel installations.

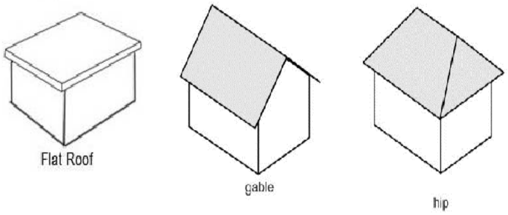

Fig.1. Common Types of Roofing System from NSCP 2010

4.7 Uplift Pressure on Roofs

According to Carmine Galasso et.al, (2020), recent catastrophic events in the Philippines (e.g., the 2013 Typhoon Haiyan) have highlighted that ageing cultural heritage (CH) assets are especially vulnerable to typhoon-induced extreme wind. Non-engineered CH roofs have been recognized as the most vulnerable component in the building envelope due to wind uplift, often resulting in large economic losses and disruption for those assets. Effective prioritization of high-vulnerable structures is a key to effective risk mitigation and resilience-increasing strategies.

This paper introduces a simulation-based approach for non-engineered CH roof fragility analysis (i.e., to assess the likelihood of different levels of roof damage over a range of wind hazard intensities) and risk assessment. In the proposed approach, two common failure modes are considered, corresponding to (first) roof-fastener pullout and roof-panel pullover. The overall aim is to identify the highest-risk candidate assets and prioritize more detailed data collection campaigns and structural assessment procedures (e.g., properly accounting for load redistribution and fastener failure progression), and ultimately to plan further repair/strengthening measures.

The building structural components were designed using structural analysis calculations, as required by the 2005 NBCC. However, the building also contained parts that were only prototype tested by the Underwriters Laboratories (UL); i.e. these parts and their components did not pass a diligent structural engineering analysis. Such building parts or assemblies are allowed to be designed by testing only if the parts (quote from Article 4.1.1.5, "Design Basis" of 2005 NBCC, Division B): "... are not amenable to analysis using a generally established theory..." (e.g. Strength/Resistance of Materials; Statics and Dynamics; Theory of Elasticity; and other structural sciences). We note that this Article of the 2005 NBCC differed from the corresponding articles of previous codes by giving a preference to the results obtained from theoretical structural analysis versus the results obtained through prototype testing. In previous codes such a preference was not explicitly stipulated. In this particular case, after reviewing and determining that there was a general Code compliance of all structural components designed with the use of structural calculations, we decided to apply structural analysis calculations on a component of a two-component part that was allowed in the hangar roof construction based only on the results of the Underwriters Laboratories (UL) testing. Our decision was also justified due to insufficient information in regards to the materials used for this particular project in the production of the subject components. We proved that the failed component of the subject part could have been analyzed (i.e. was amenable to analysis) using generally established theory and that the component was the "weak link" that caused the damage. It is important that a forensic structural engineer explores all possibilities to apply structural analysis calculations in order to assess the structural capabilities of building components. In the event of missing or incomplete information regarding components that are part of a group or assembly tested only through a prototype, one must be prepared to challenge established construction tables based on prototype testing. The engineer must explore all possibilities to identify a scientific method to apply academic knowledge to the structural engineering evaluation of a component within a building assembly or part. (Peytchev, 2012).

When wind hits a building, pressure is exerted against the building as the air pushes against the sides and moves up and around the building. Wind uplift is a force (pounds per square foot) that occurs when the pressure below a roof is greater than above it. This can happen from many different ways but is usually because pressure above the roof system decreases by high air flow (wind) or pressure increases inside a building from air pressure buildup. When wind uplift is greater than the system was designed for, the roof could potentially lift off the building.

There are many design considerations, but most codes (such as IBC 2012) and design professionals are using the 2010 edition of ASCE 7, or ASCE 7-10 to design a roof system (ASCE is the American Society of Civil Engineers). The old version of ASCE was ASCE 7-05, and with the new version of ASCE 7-10, some things remain the same with the new version, such as factors for design including building location, height and ground surface. However, with the new code, there have also been items that have changed such as the use of new wind speed maps based on risk categories and an expanded seismic area. In addition, there are tools such as www.roofwinddesigner.com that can help with the design.

Once a design professional understands the wind loads on the building, it is time to pick a roof system. For a rated system, most entities (such as IBC 2012) will look to Factory Mutual (FM) or Underwriter's Laboratories (UL) for guidance. Because there are differences in how the systems are tested, designers should always compare products using the same test agency numbers. (USGWeb, 2012).

A flat roof surface is known to be subjected to unusually high suction induced by a pair of "horseshoe" vortices caused by the wind coming diagonally facing a corner of the building (Kind et al., 1979). This phenomenon can cause very serious damage to the roofing system, such as dislocation of concrete "pavers" or insulation boards. It is also known that some architectural features of the building, such as parapets, varying in height, have some influence on these phenomena (Baskaran, 1986). At the same time, wind tunnel testing of this situation is a challenging task because the extent of damage depends a lot on the structural details, which can hardly be modeled properly in a reduced scale. Since the early 1970's, several wind tunnels studies have focused on this issue, and there are commonly observed difficulties in modeling the structural details (Kind, Savage & Wardlaw 1988). Wind tunnel testing of a full-scale building, on the other hand, would be nearly impossible. By taking advantage of a very large test section of the 9m x 9m wind tunnel at the National Research Council of Canada (NRCC), Kind and Wardlaw carried out a series of comprehensive studies of the wind effects on a variety of roof assemblies during the period of 1975-1990. These formed the basis for several roofing standards internationally. Baskaran, (2003) also stated that in wind tunnel studies, models had rigid roofs, and their deformation due to wind suction was assumed negligible. However, in a mechanically attached single ply roof, the membrane may oscillate once high suction is applied, which in turn may give a different wind-induced pressure distribution. Another engineering concern is the structural detail of how the roofing system is installed on the building. In order to examine these points, a pilot study was carried out. This paper reports benefits of the use of full-scale roof component materials for the wind tunnel tests of such roof sections.

Wind uplift forces acting on a roof system can be the cause of severe roof damage. Irrespective of the roofing system, the wind dynamics introduce stresses within the roofing system, causing fatigue, which may result in catastrophic failure overtime. Depending on the magnitude and frequency of the wind events, this could lead to costly insurance losses. For this reason, wind uplift testing of roofing systems has become a critical design consideration for insurance-approval agencies, architects, engineers, roofing contractors, and manufacturers. Baskaran (2013) also added that this type of testing acts as a key performance indicator of the materials used and provides insight into the expected longevity of a particular roof system. Once the system successfully resists a desired level of wind uplift pressure for a particular roof, the wind load design requirements have been met and the system can be approved for use. Wind uplift testing in many cases also identities the mechanisms or weakest links in the roof system responsible for failure, and can help facilitate manufacturers in addressing those susceptible failure components directly.

4.8 Wind Load Computation

4.8.1 ASCE7

4.8.1.1 Using the Appropriate Load Standard

When designing a truss for wind, it is necessary to abide by the governing building code for the jurisdiction where the project is located. Each code references a version of ASCE7 in the design of a structure. Knowing which code has been adopted allows you to determine which version of ASCE7 to use. There are still jurisdictions that have not adopted the International Codes and use the Standard Building Code (SBCCI) or the Uniform Building Code (UBC). If the applicable code is not specified on the construction documents, check with the building designer or truss engineer to determine the code, and load standard applicable to your project.

4.8.1.2 Using the Appropriate Analysis Method

ASCE7 outlines two methods for calculating wind pressures – Main Wind Force Resisting System (MWFRS) and Components & Cladding (C&C). MWFRS pertains to a structural frame or an assemblage of structural elements working together to transfer wind loads acting on the entire structure to the ground. Cladding receives wind loads directly. Examples are roof coverings and wall coverings. Components receive wind loads either directly or from the cladding and then transfer the loads to the main wind force resisting system. Fasteners, purlins and girts are examples of components.

C&C elements are exposed to higher wind pressures than MWFRS elements and must be designed accordingly. Trusses have always fallen into a gray area regarding use of the appropriate analysis method. By definition, a truss is an assemblage of structural elements, which would put it into the MWFRS category. But a truss also receives wind load directly from the roof sheathing (i.e., cladding) and therefore acts as a component, which puts the truss into the C&C category. Roof trusses can be found in the Commentary for ASCE7 as examples of both MWFRS and C&C.

4.8.1.3 Using the Correct Wind Speed

ASCE7 and most building codes contain a wind speed map developed by ASCE's Task Committee on Wind Loads. The non-coastal areas in the United States use a 90-mph wind speed, although there are special wind regions within this area that require increased wind speeds due to topographical conditions such as mountainous terrain, valleys and gorges. Coastal regions in hurricane-prone areas, specifically the Gulf Coast and the Atlantic Coast, have higher wind speed requirements, while the Pacific Coast states use an 85-mph wind speed. When in doubt, check with the building designer or the local building department. Starting with ASCE7-95, the wind speeds shown on the wind map in ASCE7 and in the I-Codes are based on a three-second gust. Prior versions of ASCE7 and earlier codes used a fastest-mile wind speed, which is more of an average wind speed. When using ASCE7-95 or newer as the design load standard, you must use a wind speed based on a three-second gust.

4.8.1.4 Building Enclosure Type

The size and location of openings in a building determines whether it is considered a closed building, a partially enclosed building or an open building. This determination is used to calculate the wind pressure on the inside of the building that acts against the underside of the ceiling or roof sheathing. The greater the amount and size of openings in a structure (e.g., doors and windows), the greater the wind flows that enters the building, increasing the wind pressure that must be applied to the structure or, in this case, to the roof trusses.

An open building is defined as one with each wall at least 80% open. Examples are a park pavilion, an open-sided car shelter or a boat shelter. Because wind is allowed to flow through an open building with minimal or no resistance from walls, no internal pressure develops. ASCE7-05 takes into consideration that while there may be minimal or no walls, obstructions within the structure may affect the resulting wind pressure; for example, an open-sided lumber storage shed.

A partially enclosed building is defined as a structure where: the total area of openings in a wall receiving positive external pressure exceeds the sum of the areas of openings in the balance of the building envelope (walls and roof) by more than 10 percent; and the total area of openings in a wall receiving positive external pressure exceeds 4 square feet or 1 percent of the area of that wall (whichever is smaller) and the percentage of openings in the balance of the building envelope does not exceed 20 percent.

Defining a closed building is easier. If the building does not meet the requirements of either an open building or a partially enclosed building, then it is a closed building. Defining what constitutes an opening determines which building type to use. General practice is to consider windows and doors as non-openings if the building is located outside of the wind-borne debris region defined by ASCE7. Within one mile of the coast, with wind speeds of 110 mph or greater or if the wind speed is 120 mph or greater regardless of the building's proximity to the coast, the structure is considered to be in the wind-borne debris region. All windows and doors must be constructed using code-approved impact-resistance materials to be considered non-openings. The concern is that flying debris may penetrate a window or door, allowing wind to flow

4.8.1.5 Building Usage

The intended usage of a building determines the importance factor used in the calculation of the wind pressures. The more people expected to occupy a building, the higher the importance factor, which results in higher wind pressures. There are four building classification categories, although Categories 3 and 4 use the same importance factor in wind pressure calculations. Category I - A building that represents a low hazard to human life in the event of a failure Category II - Any building that does not meet the requirements of Categories I, III or IV Categories III and IV - Buildings that represent substantial hazard to human life in the event of a failure, along with buildings that are considered essential facilities. Buildings used to store toxic and hazardous wastes also fall into this category. Residential construction falls into Category II. Commercial construction may fall into any of the four listed categories depending on the usage of the building. As always, refer to the building designer for the appropriate usage category.

4.8.1.6 Building Exposure

The surrounding area will affect the resulting wind pressures on the structure. Flat areas or adjacent large bodies of water increase wind pressures. Conversely, structures or trees surrounding the building result in decreased wind pressures because they tend to obstruct the wind. The exposure categories are as follows: Exposure A - Addressed structures in large city centers or downtown areas. This category has been dropped from ASCE7 and replaced with the recommendation that wind tunnel testing should be conducted to analyze the structure or to determine the appropriate wind pressures. Exposure B - A building in an urban or suburban location, having surrounding buildings and trees of sizes similar to the building under analysis. This is considered to be the default assumption for most structures. Exposure C - A building in an open area with scattered obstructions, or a building adjacent to shorelines in hurricane-prone regions. Exposure D - A building exposed to wind flowing over open water for a distance of at least one mile, excluding shorelines in hurricane-prone regions. This applies to shorelines of inland waterways, the Great Lakes, and the Pacific Coast.

The exposure category for a given building may change over time. A new residential subdivision built on farmland on the outskirts of a metropolitan area would probably fall under Exposure C. As additional development takes place, the exposure category may change to Exposure B. Similarly, surrounding trees that may result in an initial exposure classification of Exposure B may be cleared, changing the appropriate exposure category to Exposure C. When in doubt, it is always best to design for the worst-case situation.

4.8.1.7 Mean Roof Height

The distance from the ground to a point midway between the roof eave and roof peak is referred to as the mean roof height. If the roof slope is less than ten degrees (approximately a 2.1 / 12 pitch), the roof eave height is used as the mean roof height. This information is necessary because, as the elevation of the exposed roof surface increases, the calculated wind pressures increase.

4.8.1.8 Wind Dead Loads

Design dead loads used in the gravity load cases are typically increased due to the uncertainty of the materials used and their actual weight, and the possible addition of materials, such as the application of a second or third layer of roofing shingles. Since wind pressures are typically uplift pressures acting outward from the roof surface, excess dead loads lessen the impact of the wind analysis on the truss. (Feldmann, 2010)

4.8.2 NSCP 2010

Buildings, towers and other vertical structures, including the Main Wind-Force Resisting System (MWFRS) and all components and cladding thereof, shall be designed and constructed to resist wind loads as specified herein.

4.8.2.1 Allowed Procedures

The design wind load for building, towers and vertical structures, including the MWFRS and component and cladding element thereof, shall be determined using one of the following procedures: (1) Method 1 – Simplified Procedure as specified in Section 207.4 for building meeting the requirement specified therein; (2) Method 2 – Analytical Procedure as specified in Section 207.5 for buildings meeting the requirements specified therein; (3) Method 3 – Wind Tunnel Procedure as specified in Section 207.6.

Wind Pressure Acting on Opposite Faces of Each Building surface.

In the calculation of the design wind load for the MWFRS and for the components and cladding for buildings, the algebraic sum of the pressure acting on opposite faces of each building surface shall be considered.

4.8.2.2 Main Wind force Resisting System (MWFRS)

The wind load to be used in the design of the MWFRS for an enclosed or partially enclosed building or other structure shall not be less than 0.5 kPa multiplied by the area of the building or structure projected onto a vertical plane normal to the assumed wind direction. The design wind force for open buildings and other structures shall be not less than 0.5 kPa multiplied by the area Af as defined in Section 207.3.

Method 1 – Simplified Procedure:

A building whose design wind loads are determined in accordance with this section shall meet all the conditions of Section 207.4.1.1 or 207.4.1.2.

If a building qualifies only under Section 207.4.1.2 for design of its components and cladding, then its MWFRS shall be designed by Method 2 or Method 3.

4.8.2.3 Main Wind Force Resisting Systems

For the design of MWFRSs, the building must meet all of the following conditions: (1) The building is a simple diaphragm building as defined in Section 207.2. (2) The building is a low rise building as defined in Section 207.2. (3) The building is as defined in Section 207.2 and conforms to the wind-borne debris provisions of Section 207.5.9.3. (4) The building is a regular shaped building or structure as defined in Section 207.2. (5) The building is not classified as a flexible building as defined in Section 201.2. (6) The building does not have response characteristics making it subject to a cross wind loading, vortex shedding, instability due to galloping or flutter, and does not have a site location for which channeling effects or buffeting in the wake of upwind obstruction warrant special consideration. (7) The building has and approximately symmetrical cross-section in each direction with either a flat roof or a gable or hip roof with $\theta < 45^\circ$.

V. MATHEMATICAL MODEL

Simplified design wind procedure, ρ_s, shall be determined by the following equation:

$$\rho_s = \lambda K_{zt} I_w \rho_{s9}$$

ρ_s = Simplified Design Wind Procedure

λ = Height and Exposure Adjustment

K_{zt} = Topographic Factor

I_w = Importance Factor

ρ_{s9} = Simplified Wind Pressure

The simplified wind pressure will be then multiplied to the truss's spacing to get the windward and leeward wind loads. Taking summation of moment on the support will provide the reaction due to uplift pressure.

VI. RESULTS AND DISCUSSION

Station 1. Tuguegarao City, Cagayan

The PAGASA weather station in Cagayan is in the City of Tuguegarao. The maximum wind speed recorded in the station for the last two years was 54 kph, but in the NSCP, the design wind speed for Zone III where Cagayan belongs is 250 kph.

It is important to assign a constant mean height to be used in the computations in each roofing system for the consistency of results. Since the study focuses on low-rise residential buildings, the researchers applied the six (6) meters as the mean height of the roof. Also, the importance factor is equal to 1.0 since the building is having a standard occupancy. Topographic factor is 1.0 for all the locations assuming that there is no hill and ridge located near the area.

Station 2. Calapan City, Oriental Mindoro

Calapan City is where the PAGASA weather station in Mindoro resides. 101 kph is the at maximum wind speed recorded in the station for the last two years, therefore adopt the design wind speed for Zone II where Mindoro belongs which is 200 kph. Again, use the same mean height just like in the analysis in the roofing system in Tuguegarao which is six meters. Also, the importance factor is equal to 1.0 since the building has a standard occupancy. Topographic factor is 1.0 for all the locations assuming that there is no hill and ridge located near the area.

Station 3. Coron, Palawan

The next PAGASA weather station lies in the Municipality of Coron, Palawan. Because the recorded at maximum wind speed for the last two years was significantly lower than the basic wind speed for Zone III, use the design wind speed provided in NSCP 2010 which is 125 kph. Also, the importance factor is equal to 1.0 since the building is under category IV which is a standard occupancy. Still, topographic factor is 1.0. Use exposure D since it applies the conditions of the surface roughness D detailed in the NSCP.

VII. CONCLUSION

- The intensity of wind loads was not primarily affected by the kind of roofing system provided in low residential buildings. The computations showed that there are only small discrepancies in the uplift pressures in the different roofing systems. The only variables that affect the wind pressure are the roof angle and the wind speed on the location of the building. In case of this study, the wind speed that was used in each region is equal so the factor to be considered is the roof angle alone.
- For monoslope or flat roofs, the maximum uplift pressure is when the roof angle is from 0° to 20°. When the roof angle exceeds 20°, and the wind speed is significantly low, there is no uplift pressure and the wind loads path is downward. For hip and gable roofs, the reaction due to uplift pressure increases when the roof angle approaches 20°. In gable roofs, the minimum uplift pressure is when the roof angle is 30° to 45°.
- The critical roof angle for any roof system is 20° where the reaction due to uplift pressure will be maximal.

RECOMMENDATIONS:

The study limited its scope to the reactions to the uplift pressure provided by the wind loads in selected provinces in Luzon. Thus, the researchers would like to recommend the following:

- To focus on the roof angle is recommended in terms of roof design. One has to consider that for monoslope or flat roofs, the maximum uplift pressure is when the roof angle is from 0° to 20°. For hip and gable roofs, the reaction due to uplift pressure increases when the roof angle approaches 20°. In gable roofs, the minimum uplift pressure is when the roof angle is 30° to 45°.

- Avoid designing roof angle less than or equal to 20° where the reaction due to uplift pressure is at maximum.
- Continue the study with the analysis of the connections of the roofing systems to the main structure which is the anteceding step in wind load analysis.

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