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Development of a Rapid Visual Assessment Tool (RVAT) for 1-Storey Classrooms Subjected to Severe Wind Loading

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Abstract

In recent years, three category V tropical cyclones have struck the Philippines, causing catastrophic damages. In the occurrence of typhoons with wind speeds greater than 250 kph, evacuation shelters such as school buildings are one of the important facilities in post-disaster recovery. Pre-disaster assessment of the resilience of classrooms is important not only for the educational sector but for post disaster recovery programs. This paper presents a tool, in the form of a user-friendly android application, that is able to give a level 1 assessment of the resilience of existing classrooms exposed to severe wind loadings. Resilience of the buildings is expressed as grades and is derived from the damage ratio from available simulated vulnerability curves. The grade is then compared to a threshold value to determine if a detailed investigation is recommended for retrofits to occur. The grade will also serve as a prioritization index for the urgency of the need of retrofits to prevent major damage. A post disaster module was also added to assist local engineers in the assessment of damage and making of the Program of Works (POW) for repairs.

Introduction

In the Asia-Pacific region, the Philippines is a typical pathway for tropical typhoons. On average, 20 cyclones make landfall in the country per year [8]. The Typhoon Haiyan which made landfall on November 7, 2013 was the strongest land falling tropical cyclone ever recorded. It is the deadliest Philippine typhoon on record killing at least 6,300 people in the country alone. Estimates of the storm's maximum ten-minute sustained winds were at 290 km/h (180 mph) prior to landfall in the central Philippines [1].

The Department of Education (DepEd) reported that a total of 3,171 schools were damaged by super typhoon Haiyan. The damage incurred in these areas were of varying degrees. With the damage assessment of the schools, DepEd has issued a new standard design for schools which hopes to cater to the increase of wind speeds. Schools are important as they do not only serve as educational facilities but as temporary evacuation centers during natural disasters. The new school building designs were released last 2014 as part of the Build Back Better program which was proposed by the government. However, Typhoon Nock-Ten, which made landfall last December 26, 2016 with reported maximum local wind speed of 245 kph (150 mph), was noted to have damaged some of the schools constructed in 2014. The Department of Education reported that an estimate of P1.1 billion of damage was attributed to infrastructure. A total of 625 schools reported classrooms to be totally damage, 1,082 schools reported classrooms to be partially damaged with needing major repairs and 988 schools reported classrooms to be partially damaged with needing minor repairs. Non-infrastructure damage such as damages to furniture, learning materials, computer units were estimated to be at P34.8 million [4]. This shows that previous repairs and retrofits were insufficient and these classrooms would still sustain damage in subsequent typhoons.

The ability to predict wind-induced damage is a prior requirement to pre-disaster mitigation strategies. However, the prediction of damage to buildings due to typhoons is not a simple task. There are a lot of uncertainties and parameters to be considered. Computational methods that involve detailed structural analysis and computational fluid dynamics are time consuming and sometimes not practical when considering various configurations of structures. Although predicting the damage of typhoons to buildings is complex, we can simplify the analysis by limiting it to a component-based approach. Here, we assume that majority of the wind-induced damage to a building is due to the failure of certain critical building envelope components [10]. Therefore, the assessment of the resilience of buildings can then be categorized according to the specification and material of certain components. Level 1 assessments are preliminary assessments that involve visual inspections of the building envelope while level 2 assessments involve performing field uplift tests and non-destructive evaluation [2].

The development of a rapid visual assessment tool will serve as a wind hazard assessment tool which will help authorities in disaster risk reduction strategies such as coming up with a prioritization index database for school buildings. The user interface of the tool will be in the form of an android application. The integration of android technology will allow the assessment to be accessible, user friendly, and time efficient as compared to the use of traditional paper forms for assessment. This would also allow any person, regardless of technical background in wind engineering, to be able to give a level 1 assessment of the resilience of a school building.

Vulnerability Model

The grades of the tool are based on vulnerability curves of classroom buildings in the Philippines. These curves were developed by a reliability based model and a building relative resistivity index model (*BRRI*) proposed by Unanwa [10]. The model makes use of the assumption that a damage ratio exists if there is a probability of failure of at least one of its building components at extreme wind speeds. This damage ratio, $DD(I)$, is stated mathematically as:

$$DD(I) = \sum_{i=1}^{n} p_{fi} \times CCF_i \times \alpha_i \qquad (1)$$

Where P_{fi} is the component fragility function, CCF_i is the component cost factor and α_i is the component location parameter. The various component fragility functions were derived using a tree-fault analysis coupled with experimental and heuristic data. In classic reliability analysis, fragility functions only dictate if components are damaged or not. The extent of damage is not measured. This is where the CLP_i comes into play. This parameter takes into account the degree of damage each component experiences as a function of their location on the building and as a function of wind speed. The *CCF* was then used to objectively aggregate the damage ratios of the different components into one damage ratio for the entire building. This parameter was computed based on the bill of quantities provided by the DepEd and is defined as the ratio of the repair cost of the component to the total construction cost of the building. The variable *I* corresponds to the wind speed intensity.

Once preliminary vulnerability curves were developed, a *BRRI* was used to account for parameters such as the building age, building maintenance, etc. An upper and lower limit is then defined based on configurations that correspond to the most vulnerable and resilient configuration respectively. The building relative resistivity index is then derived by multiplying a relative resistivity index (*RRI*) to the difference of the upper (DD_{UL}) and lower limit (DD_{LL}) and adding this to the lower limit. The values of the *RRI* were derived by local DepEd engineers providing values for the relative strength of parameters to the parameters specified in the upper and lower limit.

$$BRRI\left(I\right)=DD_{LL}\left(I\right)+RRI\times\left(DD_{UL}\left(I\right)-DD_{LL}\left(I\right)\right) \quad (2)$$

This led to a total of 103,680 vulnerability curves that considered different configurations. The critical components and attributes included in the model were limited to the roof covering, roof to column connection, exterior wall material, window material, beam/column system, roof geometry, total roof span, roof structure material & percent occupied by exterior windows These critical components were identified based on commonly observed damages in school buildings during Post-Haiyan surveys [4,5]. The building age and building maintenance were also considered as parameters that affect the resilience of classroom buildings.

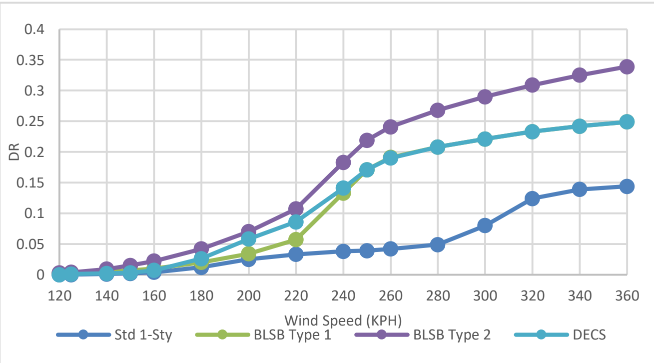

Figure 1. Example of Vulnerability Curves for different classroom building designs

Grading System

The grades are then computed by taking the corresponding predicted damage ratio of the desired wind speed and dividing it by the total CCF of the components considered for failure. The values will range from a value of 0-10. This is expressed as the following equation:

$$Grade=10-\left(\frac{DR}{\sum_{i=1}^{n}CCF_i}\times 10\right) \quad (3)$$

The grades with a value of 10.0 correspond to a typhoon-resilient classroom building while a value of 0.0 corresponds to a very vulnerable classroom building. The grading system was developed in this way to be consistent with an assessor's intuition wherein a higher grade would correspond to a more resilient structure and vice versa. A similar concept of relative grades was used in the WIND-RITE program developed by Sandri, P. [7] were the grades were based on the material composition of structures.

Figure 2. Scenario for Major Repairs (10-79%) of Roof Structure (Bote Integrated School, Catanduanes)

The grades are computed according to equation (1) for all of the wind zone classifications in the National Structural Code of the Philippines [3]. Following section 207.4.4 of the NSCP, these zone classifications serve as the minimum design wind speeds on building and other structures. The design wind speeds are 250, 200 & 125 kph for zone I, II, & III respectively. Since the section indicates that there are wind speeds not considered in the development of the wind zones, grades will also be developed for wind speeds of 360 kph. This is to account for extreme wind speeds of super typhoons such as Typhoon Haiyan.

Grade:	Description
10	Safe, Resilient in corresponding Wind Speed
9	No Damage on RCC. May have Minor Damage on Roof Coverings and Exterior Windows
8	Minor to Major Damage on Windows, RCCs & Roof Coverings
7	Moderate Damage on Roof Coverings.
6	Minor Damage on Roof Structure
5	Moderate to Major Damage
4	Major Damage on Roof Coverings, Windows, RCC
3	Possible Uplift of Roof Structure, Major Damage to Windows
2	Major to Total Destruction of Building Envelopes
1	

Table 1. Grading system with the qualitative description for each corresponding grade

A cut-off grade was then set as a criterion to check if a level 2 assessment is required. The minimum grade was based on how DepEd engineers categorize damage. The repair definitions were taken from the DepEd Division office of Albay, Region V wherein minor repairs are components with a damage ratio of less than 10%. For this category, the repairs will be facilitated by the local school while for the major damages to total replacement categories (damage ratio greater than 10%), a request for funding is submitted to the central office of the Department of Education.

The minimum grade is then set at a grade corresponding to a damage ratio of 10% which is classified as the limit for minor repairs. A grade below this would result to a recommendation of a detailed investigation (level 2 assessment) to mitigate the predicted major damages.

A qualitative description for each grade is then defined using the possible individual damage of each building component for a certain damage ratio (*DR*).

RVAT Program Logic

The android application provides two kinds of assessments for typhoon hazards. A pre and post disaster assessment module. The pre-disaster assessment module facilitates the level 1 assessment of the resilience of the classroom building while the post-disaster assessment module is an added function wherein the tool assists local engineers in the quantification of damages of classroom buildings due to a typhoon.

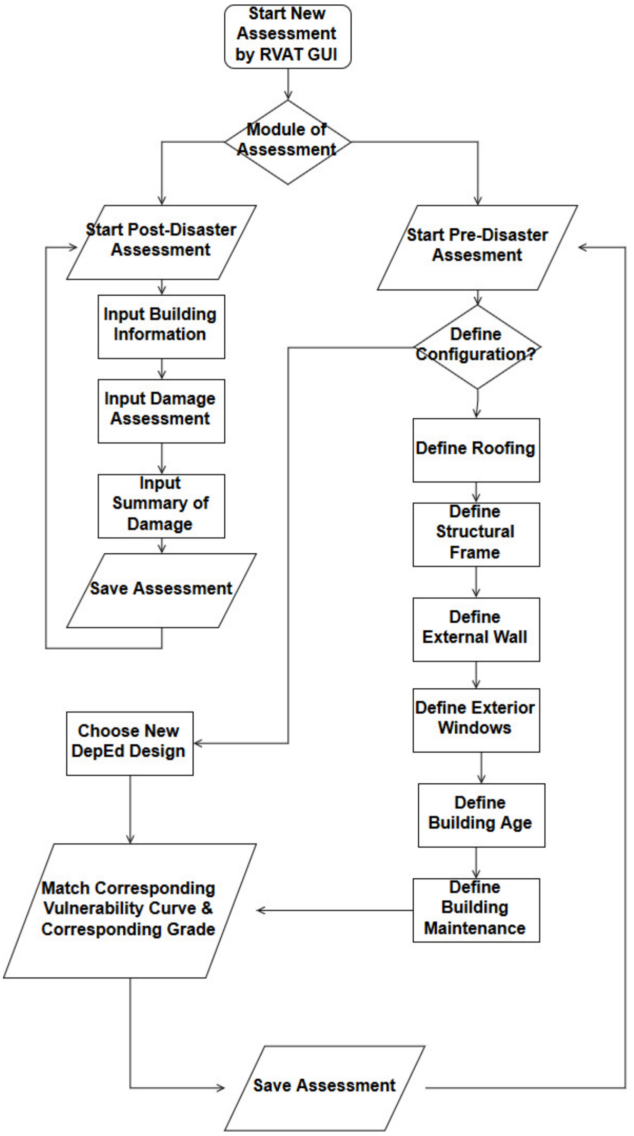

Figure 3. Post & Pre-disaster assessment program logic for RVAT

For the pre-disaster module, the mobile application provides two ways on computing the grade for a classroom building. The first method is giving the assessor the option to compute the grade based on the standard design provided by the Department of Education. This assumes that the classroom building is new and strictly follows the component specifications per design type. The second method allows the assessor to specify the actual on-site components/characteristics (roof fastener, roof-to-column connection, roof geometry, roof span exterior window material, roof frame material, percent of walls occupied by windows, wall structure material, building age and building envelope maintenance) of the classroom building being assessed.

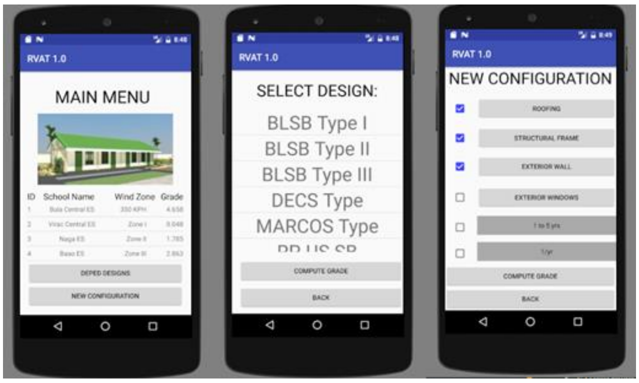

Figure 4. Graphic User Interface for the Pre-Disaster Module of the RVAT

Once all the building components have been specified, it then processes the data to retrieve the corresponding vulnerability curve from a SQLite database. The user is then able to compute the relative grade for the desired wind speed/zone. The corresponding grade is then checked with the cut-off grade to determine if a detailed investigation is recommended. A short description of the damage to the assessed building is also attached to the recommendation.

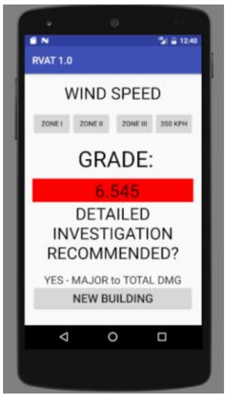

Figure 5. Graphical User Interface for the computation of grades depending on the wind zone.

The post disaster assessment module was based on the “Damage Assessment Per Bldg.” form used by the Department of Education – Albay Division when assessing typhoon damage to classroom buildings.

This module was added so that the engineers can rapidly document the damage to classroom buildings after a typhoon. This also allows the assessor to do away from the paper form to save time in the encoding process. Databases can automatically be exported as text files/csv files to be processed easier. The objective of this modules is to help in the development of program of works of repairs after a typhoon occurs. The objective is met by allowing the assessor to record the damage ratio for the roofing sheets, ridge roll, flashing, gutter, fascia boards, purlins, trusses, ceiling boards (exterior & interior), ceiling frame (exterior & interior), concrete hollow blocks walls (exterior & interior), partition walls (boards & frame), doors, windows, electrical fixtures, electrical wires, electrical rough-ins, flooring, beams and columns.

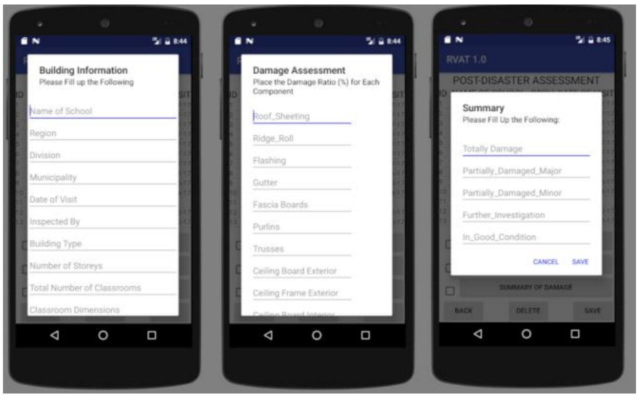

Figure 6. Graphic User Interface for the Pre-Disaster Module of the RVAT

Discussion

The pre-disaster module was then used to assess 7 types of standard DepEd designs for classroom buildings. The grades were computed for all wind speed options. Each classroom type is then ranked according to their respective grades with the rank of 1 being the most vulnerable configuration as shown in "Table 2". The BLSB Type II classroom would be the top priority for retrofits while the least prioritized would be the DepEd Standard. According to Altman's Benchmark, a good level of agreement between the RVAT and DepEd local engineers in recommending retrofits was computed with an average Gwet's AC1 value of 0.6327. An average Kendall's coefficient of concordance of 0.6804 was computed to show a good level of agreement between the DepEd engineers and RVAT in ranking the classroom designs for urgency in retrofits. The RVAT allows the complex task of vulnerability assessment to be simplified and it is able present the results in a simplified and understandable manner for non-technical personnel outside the profession of engineering.

Building	125 kph	200 kph	250 kph	360 kph	RANK
DepEd STD	9.9	9.2	8.8	5.5	6
Marcos Type	9.9	8.2	6.7	2.8	3
BLSB Type 1	9.9	9.2	5.8	3.8	5
BLSB Type 2	9.9	8.0	3.9	0.5	1
BLSB Type 3	9.9	8.0	3.9	0.6	2
DECS	9.9	8.5	5.7	3.8	4
RP-US SB	9.9	9.2	5.8	3.8	5

Table 2. Tabulated RVAT Grades and Rank for 7 types of Classroom Designs which are of 30 years of age

One suggested form of implementation is for the Department of Education to require each school principal to use the RVAT in assessing the classroom buildings under their jurisdiction. The results will then be collected to form a database of the predicted performance of each schools in different regions. The information will help respective authorities and local governing units in the implementation and prioritization of repairs, maintenance, retrofits and demolition.

Conclusion

A rapid visual assessment tool was developed, in the form of a user-friendly android application, to assist in typhoon related assessments. The developed pre-disaster module is able to quantify the resilience of classroom buildings to different wind speeds. The vulnerability is based on 11 parameters that constitute the envelope component, material specification and building characteristics. Resilience is then expressed as grades so that personnel outside the field of engineering have an easier and better understanding of the performance of existing classrooms. A post-disaster module was also developed to assist local engineers in the quantification of damage due to Typhoons. The RVAT will be helpful for local authorities in disaster risk reduction mitigation strategies.

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