DEVELOPMENT OF A RAPID CONDITION ASSESSMENT TOOL FOR REINFORCED CONCRETE MOMENT-RESISTING FRAME BUILDINGS IN THE PHILIPPINES: STRUCTURAL COMPONENT

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Abstract: This paper describes the development of a pre-earthquake assessment tool that is rapid, visual, and is based on the structural condition of reinforced concrete moment-resisting frame buildings in Metro Manila, Philippines. The Rapid Condition Assessment Tool (RCAsT) uses a basic structural score that is modified based on differences in attributes of the existing building and the base structure. These scores were derived using fragility curves for locally built structures. A near-source score modifier is also incorporated to account for the larger earthquake motion experienced when a building is near a fault line. Moreover, damage modification factors that quantify residual seismic capacity considering the damages observed in columns and beams were established. The tool was used to evaluate several buildings and the results were compared with assessments using the FEMA-154 tool.

Key words: Building assessment, Earthquake, Visual Screening, Fragility, Probability.

1 INTRODUCTION

The 7.2 magnitude earthquake that struck Central Visayas last October 15, 2013 caused extensive damage to existing infrastructures and loss of lives. The types of structures that were damaged and the severity of the damage inflicted make us pause and ask whether similar structures in Metro Manila can survive a similar large magnitude earthquake. PHIVOLCS has been warning Metro Manila of an imminent earthquake that will originate from the West Valley Fault, of equal magnitude with the earthquake in Bohol. An earthquake of the same magnitude caused by the West Valley fault will definitely damage building structures in Metro Manila. It is therefore necessary that existing buildings be assessed for structural integrity and if found lacking be recommended for repair, rehabilitation and/or retrofit in preparation for the large magnitude seismic forces that may be generated by the existing fault.

Past efforts in assessing the vulnerability of structures against earthquakes were conducted in the country. In 2004, a joint collaboration of Japanese researchers from JICA and scientists from PHIVOLCS conducted the Metro Manila Earthquake Impact Reduction Study (MMEIRS). Their work included risk assessment due to scenario earthquakes caused by movement from different active faults in the country. Their results indicate 40% of residential buildings will be damaged in the event of a magnitude 7.2 earthquake occurring in the West Valley Fault, resulting in 34,000 deaths and 110,000 injured (Solidum et al. 2004).

At present, continuous studies on disaster risk mitigation are conducted through programs and projects administered by local agencies. In particular, PHIVOLCS in collaboration with the University of the Philippines Diliman - Institute of Civil Engineering (UPD-ICE) and Geoscience Australia (GA), conducted a project that aims to develop vulnerability curves of key building types in the Greater Metro Manila Area considering earthquake hazard. These vulnerability curves are needed to enhance the risk assessment capability of the Rapid Earthquake Damage Assessment System (REDAS) software, allowing users to estimate the potential level of damage a building will incur for a given ground motion intensity.

The seismic performance of a building is described using fragility and vulnerability curves. Vulnerability curves are functions of the damage ratio and the ground motion intensity, whereas the fragility curves provide the probability of exceedance of a particular damage state (slight, moderate, extensive and complete damage states) due to ground motion intensity. The two curves are interrelated, with the vulnerability curve derived from the fragility curves. Currently, the UPD-ICE is continuously developing and improving these curves for key building types in Metro Manila.
There is a program that is geared towards response to reduce the damage caused by quick-onset events like earthquakes, known as the Earthquake Quick Response Program (EQRP formerly known as DQRP-Disaster Quick Response Program) that utilizes inspection surveys of structures before and after an earthquake. The pre-earthquake inspection survey tool uses the FEMA-154 Rapid Visual Screening of Structures for Potential Seismic Hazards while the post-earthquake inspection survey is based on ATC-20 Post Earthquake Safety Evaluation of Buildings. These instruments were developed in the United States and the conditions of structures considered were not locally based and hence exhibit different seismic capacity compared to the buildings in the Philippines. This was observed when a school building was judged safe using FEMA-154 but was judged otherwise by the local engineers after entering the building based on excessive deflection seen on the beams and large cracks on the interior walls due to settlement.

Therefore, a tool that can be used for rapid condition assessment, applicable to buildings locally constructed and capable of identifying which buildings should be prioritized for detailed investigation should be developed. The Rapid Condition Assessment Tool (RCAsT) Structural Component has two major parts that are used to assess the structural condition of the building. The first part uses basic structural hazard score and score modifiers that were derived using fragility curves for low- and mid-rise reinforced concrete frame buildings in the Philippines. Included in this part is a score modifier for near-source earthquakes which is not used in FEMA-154 but included in the provisions of the NSCP 2010. Thus, this part reflects the initial seismic capacity of the building in its undamaged state. The second part uses a damage modification factor that is based on the quantified residual seismic capacity of the building. The residual seismic capacity is quantified by considering the effect of existing damage observed in the columns and beams of the building. The product of these two parts gives the final structural hazard score. Therefore, the final score is indicative of the true condition of the building before an earthquake.

2 DATA COLLECTION FORM

The data collection form for structural component has two major parts. The first being a quantification of the performance of a building based on the structural configuration, soil condition and other building attributes that might affect its structural integrity through computation of the structural rapid visual screening score. The procedure described in FEMA 155 was used to derive basic structural hazard scores and score modifiers using locally developed fragility curves for buildings found in the Philippines.

The second part, on the other hand, takes into account the damages incurred in the building components through damage modification factors. This portion was patterned after the quantification of post-earthquake damages in RC buildings in Japan using residual seismic capacity. In the paper of Maeda et al. (2004), the ratio of the residual seismic capacity to the initial seismic capacity can be estimated by visually classifying and accounting the damages in columns and walls. This ratio became the basis for the formulation of the procedure in quantifying the damage modification factor (DMF) in this tool. The DMF represents the percentage of the remaining seismic capacity of the building.

Additional information on the structural integrity of the building can be reflected through sketches, photos and commentary boxes that are also provided in the form.

In the succeeding sections, the derivation of the basic structural scores and score modifiers will be explained in detail. Moreover the process by which the quantification of the damage modification factor will also be explained.

2.1 Structural Score

In quantifying the structural score, one needs the basic score, which is generic for one building type, and the score modifiers.

Since in this project, the focus is on reinforced concrete moment frames (C1), only one basic score can be seen in the tool. The basic score corresponds to the structural hazard score computed for a base structure. In this study, the base structure used is a regular low-rise building on soil type D designed using post-1992 code and is situated far-field of a fault line. So if the structure is a base structure, the basic score becomes the structural score and no score modifiers are added. On the other hand, if the structure has different attributes or configuration from the base structure, score modifiers corresponding to the varying attributes are added algebraically to the basic score to account for the deviation.

There is a formula being followed in determining the structural hazard score for a given structure. The basic score is just the structural hazard score of a base structure, whereas the score modifier for each variation is the difference between the structural hazard score of a building with that variation and the basic structural hazard score.

In the following sub-sections, detailed discussion on the derivation of these scores will be presented.

2.1.1 Basic Structural Hazard Scores

In the second edition of the FEMA 154 Handbook, the Basic Structural Hazard Score is defined, for a particular type or class of building, as the negative of the logarithm (base 10) of the probability of collapse of the building, given the ground motion corresponding to the maximum considered earthquake (MCE). This can be written as follows,
The probability of collapse of a building is the product of the probability of being in the complete damage state (DS), multiplied by the fraction of buildings in the complete damage state that collapsed, written as follows, (FEMA 155)

\[ BSH \text{Score} = -\log_{10}[P(\text{Collapse|Complete DS given MCE}) \times P(\text{Complete DS})] \] (2)

Initial Basic Scores were derived using this definition together with the fragility curves developed by the UPD-ICE. However since the fragility curves used in the derivation were different from the ones used in HAZUS, the resulting scores were too small and the score modifiers were not meaningful. This observation caused the group to reexamine the equation.

From the equation, the probability of collapse is calculated by multiplying the probability of complete damage state exceedance and the probability of collapse given complete damage state. Since the product of two small numbers is an even smaller number, the additional step of getting the negative of the logarithm of base 10 of the product of probabilities, is seen as a way to make use of the probability as a convenient measure of the building performance. Hence the group decided to redefine the BSH Score.

The computation of the probability of collapse at the complete damage state was derived from the fragility curves by UPD-ICE. These fragility curves were defined by lognormal cumulative distribution curves. Hence the group decided to rescale the score using the same probability, by using the natural logarithm instead of the \( \log_{10} \). In equation form,

\[ BSH \text{Score} = -\ln[P(\text{Collapse|Complete DS given MCE}) \times P(\text{Complete DS})] \] (3)

2.1.1.1 Procedure for developing Basic Structural Hazard Scores
To compute for the basic structural hazard score for C1, fragility curve for C1L on soil type D is needed as shown in Figure 1. Before determining the probability of exceeding complete damage state at the given MCE, the peak ground acceleration of the maximum considered earthquake must be calculated first.

The maximum considered earthquake is the largest earthquake event applied in building code design. According to the collective opinion of the Seismic Design Procedure Group (SDPG), the minimum seismic margin contained in the 1997 NEHRP Provisions is about 1.5 times the design earthquake ground motions. (BSSC 1998, Appendix A, Commentary)

Since in the development of the fragility curves utilized in determining scores, the demand spectrum comes from the design response spectra, the maximum considered earthquake will be computed from the same, wherein the seismic coefficient \( Ca \) represents the peak ground acceleration in g. Hence to determine the MCE, the design earthquake in terms of the seismic coefficient will be multiplied by 1.5.

In determining the seismic source type it is necessary to determine the maximum moment magnitude for a given site which can be estimated from the nearest fault or seismic source. There are two active valley fault systems dividing Metro Manila namely, the West Valley Fault System and the East Valley Fault System shown in Figure 2. The West Valley Fault is the nearest seismic source capable of producing a maximum credible earthquake of 7 (Nelson et.al. 2000), wherein the seismic source type can be classified as A. Assuming a far-field seismic source type, the near source factor \( Na \), is determined to be equal to 1.0 from Table 208-4 of the NSCP 2010 and consecutively the seismic coefficient \( Ca \) for soil type D under seismic zone 4 is computed as 0.44Na as provided in Table 208-7 of the NSCP 2010. MCE of 0.66 g is computed.

![Figure 1](image1.png)  
**Figure 1** Fragility curves for reinforced concrete moment frame low-rise on soil type D. (SOURCE: UPD-ICE, Development of Vulnerability Curves of Key Building Types in Greater Metro Manila Area, [October, 2013]).

![Figure 2](image2.png)  
**Figure 2** Topographic and Political Boundary Map of Metro Manila showing the existing active fault systems (Bautista, 2001).
The probability of collapse or collapse rates for different structure types may be found in HAZUS-MR4 Table 13.8. The collapse rate for C1-L is equal to 13%.

2.1.1.2 Sample Calculation of a Basic Structural Hazard Score
To determine the probability of exceeding the complete damage state, the MCE is projected to the fragility curve for complete damage state and the corresponding probability is determined. From Figure 1, the corresponding probability, P[Complete DS given MCE] is equal to 71% for an MCE of 0.66 g. The collapse rate is determined to be equal to 13%. Therefore, using equation (3), BSH for C1-L is computed as follows,

\[
BSH = -\ln [(0.71 \times 0.130)] = 2.40
\]

2.1.2 Basic Structural Hazard Score Modifiers
The base structure used is a regular low-rise building on soil type D designed using post-1992 code and is situated far-field from existing faults. If the building differs from the base structure, score modifiers are used to take these variations into account. The parameters that can vary include the following: elevation of the structure that can either be low-rise (1-2 stories) or mid-rise (3-7 stories); the irregularities present in the structural configuration (plan and vertical irregularities); the code used in the design of the structure which can be identified with the vintage of the structure namely pre-code (buildings designed before 1972) , low-code (buildings designed between 1972-1992) or high-code(post-1992 buildings); the soil profile type where the structure is constructed (in Metro Manila only three soil types exist: soil type C, soil type D, and soil type F); and the nearness to a fault line. The score modifiers for each variation are quantified by taking the difference between the structural score for each variation with the basic structural score of the base structure. Summarized in Table 1 are the structural scores computed for each structure with varying attributes.

2.1.2.1 Score Modifier for Mid-rise Buildings
The score modifier for mid-rise buildings was calculated using two sets of structural scores. One for low-rise reinforced concrete buildings and the other is for mid-rise reinforced concrete buildings, both having the same soil type. From Table 1, the basic structural hazard score is 2.4 which was based from low-rise and designed under high code, and the structural score for C1M designed under high code for the same soil type is 3.00. Hence the score modifier is +0.60.

2.1.2.2 Score Modifier for Plan Irregularity
According to FEMA-155, there was no Score Modifier for plan irregularity that is straightforward to calculate, principally because eccentricity is specific to each building. Hence, to approximate the effect of plan irregularity the spectral response values were increased by 50% where the fragility curve will be based and correspondingly the structural score. Employing such increase will yield a structural score of 2.22. Hence the Score Modifier for Plan Irregularities is -0.18. A value of -0.20 was used in the tool as the final score modifier.

<table>
<thead>
<tr>
<th>Table 1 Summary of Structural Scores.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEDIAN</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>C1-L (D)</td>
</tr>
<tr>
<td>C1-L (C)</td>
</tr>
<tr>
<td>C1-L (E)</td>
</tr>
<tr>
<td>C1-M(PRE)</td>
</tr>
<tr>
<td>C1-M(LOW)</td>
</tr>
<tr>
<td>C1-M(HI)</td>
</tr>
<tr>
<td>Near Source (C)</td>
</tr>
<tr>
<td>Near Source (D)</td>
</tr>
<tr>
<td>Near Source (E)</td>
</tr>
<tr>
<td>Plan</td>
</tr>
</tbody>
</table>

2.1.2.3 Score Modifier for Vertical Irregularity
The score modifier for vertical irregularity cannot be quantified due to large variation in the configurations and conditions. Hence the value is approximated using engineering judgment. But since this study derived scores applicable to existing moment-frame buildings in Metro Manila, score modifier for vertical irregularity presented in FEMA-154 cannot be utilized directly. To be consistent with that of FEMA 154, an initial value of -1.00 was selected.
2.1.2.4 Score Modifier for Pre-code and Low-code Construction

Design codes are frequently updated and improved over time. Three important vintages were identified based on how drastic a change was made in terms of seismic design philosophy. The years 1972 and 1992 are based on the year of publications of the different editions of the National Structural Code of the Philippines where a paradigm shift in design philosophy occurred. Buildings that were built before 1972 were designated to be under Pre Code, whereas those that were built between 1972 and 1992 were designated to be under Low Code and Post 1992 were designated under High Code.

The same procedure on how the score modifier for mid-rise was calculated is employed here. However since there is only one vintage used in the development of the fragility curve for C1L, score modifiers for vintages will be based on C1M. Hence three sets of structural scores will be determined with the one in high code as the default score. Again as summarized in Table 1, structural scores for pre and low code is 2.80 while for high code is 3.00. Hence the score modifier for both pre and low code is -0.20.

2.1.2.5 Score Modifier for Soil Type C, D, and F.

Employing the same procedure, structural scores for C1L on soil types, D, C, and E were computed as 2.40, 2.46, and 2.36 respectively. Hence the score modifiers for soil type C and E are +0.06 and -0.04 respectively. Values of +0.10 and -0.10 were adopted in the tool, respectively.

In NSCP 2010, no seismic coefficients were provided for buildings built on soil type F, because a site-specific geotechnical investigation and dynamic site response analysis is suggested to be performed to determine seismic coefficients that are necessary for modeling and developing the fragility curve. Hence buildings built on soil type F would automatically warrant a detailed evaluation.

2.1.2.6 Score Modifier for Nearness to Fault

UPD-ICE is currently improving the fragility curves being developed by incorporating the nearness to fault effect. These are taken into account in the seismic coefficients used as an input in the design of the model structures. The seismic coefficients for the soil types present in Metro Manila are provided in Table 208-7 and 208-8 of the NSCP 2010.

Na and Nv are the near source factors that account for the proximity to the nearest active fault. The values of Na and Nv ranges from 1.6 to 1 and are linearly interpolated depending on the location of the structure under consideration. For simplicity, the location of the structures were lumped as to whether it is located in a near field or far field. Instead of interpolating for every value of the near source factor the group decided to use the upper and the lower limit to represent the two fields. Hence for seismic source type A, the Na and Nv used for structures located less than or equal to 5 km to the nearest fault line are 1.2 and 1.6 respectively, and 1.0 for both Na and Nv for structures located more than 5 km to the nearest fault line. For seismic source type C on the other hand, according to the NSCP the near source factors Na and Nv are both equivalent to 1.0 regardless of the location of the structure relative to an active fault.

The same building databases were used for the model structures in the far field and near-source. Both sets of models were analyzed and its members were designed by software capable of performing a pushover analysis such as ETABS. From the pushover analysis, the capacity curves for both sets of models can be obtained. It was observed that the same capacity curves are obtained for structures in far field and near-source. Figure 3 shows a selection of corresponding models in far field and near-source exhibiting similar capacity curves.

![Figure 3 Capacity Curves for (a) Near-Source Structures and (b) Far-Field Structures.](image-url)
This suggests that based on the building configurations used there is no significant change in the design of structures in far field and near-source for a low-rise reinforced concrete building. However, the earthquake shaking is considerably higher near a fault than far field. Hence it follows, that the fragility curve developed for near-field structures would appear more vulnerable than far-field structures as illustrated in Figure 4, due to the increase in demand without increase in the capacity of the structure.

![Figure 4 Fragility Curves at the Complete Damage State for Soil Types C, D and E in Far Field and Near-Source.](image)

Since in this study, only the probability of being in or exceeding the complete damage state is used in computing the structural hazard score, comparison is shown in Figure 4 for far-field and near-source structures in soil types C, D and E.

As summarized in Table 1, the Basic Hazard Scores (BHS) for structures built on near fault regions of soil types C, D and E are 2.25, 2.22 and 2.22 respectively. It also follows that the score modifiers taken as the difference from the BHS of a regular structure are -0.15, -0.17 and -0.18 respectively. It has been decided to report only one score modifier to represent the nearness to source effect by adopting the value of -0.2.

The score modifiers derived above are summarized in Table 2.

<table>
<thead>
<tr>
<th>MID RISE</th>
<th>VERT. IRREG.</th>
<th>PLAN IRREG.</th>
<th>PRE CODE</th>
<th>LOW CODE</th>
<th>SOIL TYPE C</th>
<th>SOIL TYPE E</th>
<th>SOIL TYPE F</th>
<th>NEAR SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>-1.0</td>
<td>-0.2</td>
<td>-0.2</td>
<td>-0.2</td>
<td>0.1</td>
<td>-0.1</td>
<td>**</td>
<td>-0.2</td>
</tr>
</tbody>
</table>

2.1.3 Damage Modification Factor

Part of the limitations observed in using FEMA-154 as an assessment tool is it evaluates buildings based on exterior observations only. The final score acquired by the building after being assessed using this tool represents the initial seismic capacity of the buildings before earthquake. However it lacks interior damage ratings should they exist.

In the paper entitled, Guideline for Post-Earthquake Damage Evaluation and Rehabilitation of RC Buildings in Japan, the damage rating procedure was based on the residual seismic capacity ratio index $R$. Utilizing a similar concept, by quantifying the residual seismic capacity and determining its ratio from the initial seismic capacity, the factor can be used to represent a modification factor for the structural scores to account for the damage incurred by the building approximated from visual assessment of interior components such as columns and beams.

With the use of a normalized strength index for each typical member section which often appears in existing RC buildings in Japan considering ultimate shear stress and effective sectional area of each section type, an alternative simplified procedure of calculating the R-index is proposed in the same paper. By classifying and accounting the type of columns and walls with its corresponding damage classification, the R-index can be approximated. (Maeda et al., 2004)

Since this study is focused on low-rise reinforced concrete moment resisting frames, the procedure presented in the paper can be further simplified by considering both columns and beams – since these comprise the major structural components for a moment-resisting frame system – in the evaluation. As an approximation, ductile columns are associated with long columns defined as columns with clear span to smallest depth ratio greater than or equal to 6 and short columns otherwise. Moreover, the beams are classified as long, intermediate and short depending on the length of the clear span (L) as having greater than or equal to 6 m, between 2 m and 6 m, and less than or equal to 2 m, respectively.

Once every structural element is categorized, the state of damage of each structural member is then classified. In the paper by Maeda et al. (2004), where the quantification of the damage modification factor was based, there were originally five (5) damage classes – no damage, slight damage, light damage, heavy damage and collapse. For ease in classifying damages in a rapid visual inspection, this research employs three damage classifications – “no-slight damage”, “light-moderate damage”,

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Figure 4 Fragility Curves at the Complete Damage State for Soil Types C, D and E in Far Field and Near-Source.
and “heavy damage - collapse”. The same reduction factors for Damage Class 0, Damage Class III, and Damage Class V respectively will be adopted from Maeda’s paper.

To aid in accounting the structural element types and their corresponding damages, a table shown in Figure 5 was formulated. Damages in columns have greater influence in the structural integrity compared to damages in beams. For this reason, damage modification factors for columns \(DMF_{col}\) and beams \(DMF_{beam}\) are computed separately. The equations below show how to compute the damage modification factor for each structural element.

\[
DMF_{col} = \frac{\text{\# of columns with reduced seismic capacity}}{\text{\# of columns}}
\]

\[
DMF_{beam} = \frac{\text{\# of beams with reduced seismic capacity}}{\text{\# of beams}}
\]

The numerator represents the reduced strength and the denominator represents the original strength of the structural elements. To quantify the reduced strength, the number of a certain type of structural element having a certain state of damage is tallied correspondingly in the space provided in the form. The tallied numbers per element type and damage class are multiplied by the corresponding reduction factors before taking their weighted sum horizontally. The weighted sums are combined for all types of columns to obtain the reduced number of columns which corresponds to the numerator of \(DMF_{col}\). Similarly, for all types of beams, the numerator of \(DMF_{beam}\) is obtained using the same procedure.

The denominator is calculated by counting all the columns and beams inspected regardless of the type and damage class.

![Figure 5 Portion in the data collection form calculating the damage modification factor.](image)

The damage modification factors for each structural type are further weighted by the contribution factors 1.2 and 1.1 for columns and beams respectively (Coronelli 2007). In this way, a damage modification factor for the entire structure can be computed given in the equation below:

\[
DMF = \frac{1.2 \times DMF_{col} + 1.1 \times DMF_{beam}}{2.3}
\]

2.1.4 Cut-off Score

According to the second edition of FEMA-155 which provides the technical manual for the FEMA-154, the selection of the cut-off score is a prerogative of the community utilizing the inspection tool. The cut-off score of about 2.0 was recommended after fifteen years of experience in the use of FEMA-154 that validated this decision. There are cases wherein users opted to use higher cut-off scores which imply a safer environment, at a correspondingly higher cost. (FEMA-155, 2nd edition).
In order to come up with a rational choice of the cut-off score in this case, DQRP case studies and reports were reviewed. One of the major observations from DQRP case studies and reports is that concrete hollow block (CHB) and wood low-rise structures that were inspected received only either a yellow or a red tag. This implies that these structures may pose a greater threat to the safety of its occupants during and after an earthquake. Thus, it may be rational to say that these existing structures must be evaluated in detail for seismic considerations.

Fragility curves developed by UPD-ICE for CHB is based on a compilation of empirical observations of damage for corresponding ground motion intensities in terms of Modified Mercalli Intensity (MMI) from past earthquakes in the Philippines. Hence this data will be used in calculating the cut-off score. However, the resulting fragility curve is in terms of MMI and needs to be converted to PGA before utilizing it to compute for the probability of being in or exceeding the complete damage state given the MCE.

Using the mean and standard deviation of 7.4 and 0.14 respectively of the fragility curve under complete damage state for CHB as reported in the UPD-ICE report, the probability of exceedance is computed for an arbitrary set of ground motion intensities in MMI. The ground motion intensity in MMI is then converted to Peak Ground Acceleration in (g) using the Gutenberg-Richter MMI to PGA relationship defined in the following equation.

\[
\log(a) = \frac{I}{3} - 0.5
\]

where \(a\) is acceleration in terms of gals (cm/s\(^2\)) and \(I\) is the ground motion intensity in terms of MMI.

The probability of exceeding complete damage state is plotted against the peak ground acceleration. These points will be regarded as the data points where a lognormal cumulative distribution curve will be fitted and the corresponding mean and standard deviation will then be used to compute for the probability of being in or exceeding the complete damage state at the given maximum considered earthquake. This is illustrated in Figure 6 wherein the corresponding mean and standard deviation is also presented.

![Figure 6. Fragility Curve at Complete Damage State for CHB.](image)

Illustrated below is the computation of basic structural hazard score for CHB.

\[
BSH = -\ln(0.99 \times 0.15) = 1.90
\]

The probability of being in or exceeding complete damage state with the mean and standard deviation of 0.097 and 0.8, respectively, is 0.99. Since there are no CHB building type in HAZUS the collapse rate used was for Unreinforced Masonry equivalent to 15%. Hence the basic structural hazard score for CHB which will also be used as the cut-off score is 1.90.

These are low-rise structures with walls made of concrete hollow blocks interlocked at the corners, and have no reinforced concrete frame. The floors consist of either plywood or board sheathing, supported by wood subframing. The roofs are corrugated galvanized iron sheets attached to wooden or light metal roof trusses.
3 SAMPLE APPLICATION
The proposed rapid condition assessment tool was applied to several buildings. Two of which were selected to be presented in this paper. These buildings were labeled as Building A and Building B.

3.1 BUILDING A
The structure is made of reinforced concrete and stands 4 storeys high; hence it is categorized as a mid-rise reinforced concrete building or C1-M. The structure has vertical irregularity, because of the presence of a basement at the South-West corner of the building. Building A was built in 1970, hence it was assumed that the design code used is pre code. The structure has an opening at the center, therefore there is plan irregularity. The soil was assumed to be Soil Type D which is stiff soil. The structural score evaluated by the team is 1.40. The damage modification factor (DMF) is equal to 1.0 because no damages were observed in the beams and columns of the building.

Since 1.40 is less than 1.90, a more detailed seismic evaluation is required. Error! Reference source not found. shows a filled out RCAsT Structural Form for Building A.

A comparison with FEMA 154 was performed. Error! Reference source not found. summarizes the score evaluation of the two rating systems.

The results show that FEMA 154 also suggests that a detailed seismic evaluation is recommended for Building A. The RCAsT Structural Score further reduces the building score due to the nearness to fault effect which is not considered in FEMA 154. Furthermore, the RCAsT structural score will always yield a positive value, whereas FEMA 154 scoring can result to a negative score. Though the score only indicates which building needs to be evaluated in detail, a negative structural score for a building may be understood as a very poor seismic performance in the event of an earthquake.

<p>| Table 3. Rating Systems between RCAsT and FEMA 154 for Buildings A and B. |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Criteria</th>
<th>RCAsT</th>
<th>FEMA 154</th>
<th>RCAsT</th>
<th>FEMA 154</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Score</td>
<td>2.4</td>
<td>2.5</td>
<td>2.4</td>
<td>2.5</td>
</tr>
<tr>
<td>Mid rise</td>
<td>0.6</td>
<td>0.4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Vertical Irregularity</td>
<td>-1</td>
<td>-1.5</td>
<td>0</td>
<td>0</td>
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<td>Plan Irregularity</td>
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<td>-0.5</td>
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<td>Pre Code</td>
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<td>Low Code</td>
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<td>High Code</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Soil Type C</td>
<td>0</td>
<td>0.07</td>
<td>0</td>
<td>-0.4</td>
</tr>
<tr>
<td>Soil Type D</td>
<td>0</td>
<td>-0.6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Soil Type E</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Soil Type F</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Near Source</td>
<td>-0.2</td>
<td>N.A.</td>
<td>-0.2</td>
<td>N.A.</td>
</tr>
<tr>
<td>Structural Score</td>
<td>1.40</td>
<td>0.30</td>
<td>1.90</td>
<td>0.4</td>
</tr>
<tr>
<td>DMF</td>
<td>1.0</td>
<td>N.A.</td>
<td>0.98</td>
<td>N.A.</td>
</tr>
<tr>
<td>Final Score</td>
<td>1.40</td>
<td>0.30</td>
<td>1.87</td>
<td>0.4</td>
</tr>
<tr>
<td>Cut off Score</td>
<td>1.90</td>
<td>2.00</td>
<td>1.90</td>
<td>2.00</td>
</tr>
<tr>
<td>Detailed Evaluation</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
</tbody>
</table>

3.2 BUILDING B
Building B is a low-rise (2 stories) reinforced concrete moment-resisting-type structure. The plan configuration of the building shows that it has a plan irregularity. It was built on a Type C soil before the 1972 Building Code was enacted. The Structural Score of the building is 1.90.

The total number of columns inspected is 141. Three of these columns have moderate damage – two of which are long columns. Six intermediately long beams of the 141 inspected beams were found to have moderate damage. The total Damage Modification Factor for the Structural Score is 0.98.

The Final Score for the building with DMF considered is 1.87 which is below the cutoff score of 1.9. Therefore Building B is recommended for detailed evaluation. Error! Reference source not found. shows a filled out RCAsT Structural Form for Building B.
A comparison with FEMA 154 was performed. Table 3 summarizes the score evaluation of the two rating systems. Similar to Building A, both tools recommend detailed evaluation for Building B. Note further that aside from the inclusion of the nearness to fault effect, the damage modification factor (DMF) for Building B farther reduces its score from 1.90 to 1.87. This particular building demonstrates how the current damages seen on the building is taken into account through the DMF, which is another factor not considered in FEMA 154.
Rapid Condition Assessment Tool

**RCAsT Structural Score for Low- (1-2 stories) and Mid- (3-7 stories) Rise Reinforced Concrete Frame**

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Basic Score</th>
<th>Mid-Rise</th>
<th>Vertical Irregulari</th>
<th>Plan Irregulari</th>
<th>Pre Code</th>
<th>Low Code</th>
<th>Soil Type C</th>
<th>Soil Type E</th>
<th>Soil Type F</th>
<th>Near Source</th>
<th>Structural Score, S</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1,C1M*</td>
<td>2.40</td>
<td>0.60</td>
<td>-1.00</td>
<td>-0.20</td>
<td>-0.20</td>
<td>-0.20</td>
<td>-0.10</td>
<td>-0.10</td>
<td>**</td>
<td>-0.20</td>
<td>1.60</td>
</tr>
</tbody>
</table>

**NOTE:** *C1 is a reinforced concrete moment resisting frame building type.
** If selected, automatically proceed to detailed analysis.

**Damage Modification Factor (DMF)**

<table>
<thead>
<tr>
<th>Type</th>
<th>No-Slight Damage</th>
<th>Light-Moderate Damage</th>
<th>Heavy Damage - Collapse</th>
<th>Total*** Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Columns</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long: h/d&gt;6</td>
<td>All x1</td>
<td></td>
<td>x0.5</td>
<td></td>
</tr>
<tr>
<td>Short: h/d≤6</td>
<td>All x1</td>
<td></td>
<td>x0.3</td>
<td></td>
</tr>
<tr>
<td>Total # of Columns****</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

| Beams           |                   |                       |                         |                 |
| Long: L > 6m    | All x1            |                       | x0.7                    |                 |
| Intermediate:   |                   |                       |                         |                 |
| 2m<L<6m         | All x1            |                       | x0.5                    |                 |
| Short: L≤2m     | All x1            |                       | x0.3                    |                 |
| Total # of Beams**** |              |                       |                         | 1               |

---

**Notes:**

- The **Total Factor** is equal to the sum of the products of the number of columns/beams and the corresponding reduction factor per damage state.
- **Total # of Columns/Beams** is the sum of the number of columns/beams counted on site regardless of damage observed (i.e. no factors incorporated).

**DMF Calculation:**

\[
DMF = \frac{1.2 \times DMF_{col} + 1.1 \times DMF_{beams}}{2.3}
\]

**Final Score:**

\[
\text{Final Score} = (\text{Structural Score}) \times (\text{Damage Modification Factor})
\]

**Final Score:**

1.60

---

**Sketches:**

[Sketch of reinforced concrete structure]

**Scale:**

[Scale diagram]

**Comments:**

---

***** If Final Score $S \leq 1.9$, then the structure will be recommended for Detailed Seismic Evaluation.

**Detailed Evaluation Recommended?**

- YES
- NO

---

**Figure 7** RCAsT Structural Component Filled out form for Buildings A.
### RAPID CONDITION ASSESSMENT TOOL

**RCAsT STRUCTURAL SCORE for Low- (1-2 stories) and Mid- (3-7 stories) Rise Reinforced Concrete Frame**

<table>
<thead>
<tr>
<th>TYPE</th>
<th>BASIC SCORE</th>
<th>MID-RISE</th>
<th>VERTICAL IRREGULARITY</th>
<th>PLAN IRREGULARITY</th>
<th>PRE CODE</th>
<th>LOW CODE</th>
<th>SOIL TYPE C</th>
<th>SOIL TYPE E</th>
<th>SOIL TYPE F</th>
<th>NEAR SOURCE</th>
<th>STRUCTURAL SCORE, S</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1L,C1M*</td>
<td>2.40</td>
<td>0.60</td>
<td>-1.00</td>
<td>-0.20</td>
<td>-0.20</td>
<td>0.10</td>
<td>-0.10</td>
<td>-0.20</td>
<td>**</td>
<td>1.90</td>
<td></td>
</tr>
</tbody>
</table>

**NOTE:** *C1 is a reinforced concrete moment resisting frame building type.

**If selected, automatically proceed to detailed analysis.**

### DAMAGE MODIFICATION FACTOR (DMF)

#### COLUMNS

<table>
<thead>
<tr>
<th>TYPE</th>
<th>NO-SLIGHT DAMAGE</th>
<th>LIGHT- MODERATE DAMAGE</th>
<th>HEAVY DAMAGE - COLLAPSE</th>
<th>TOTAL*** FACTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>LONG: h/d&gt;6</td>
<td>4 x 1</td>
<td>2 x 0.5</td>
<td>0 x 0</td>
<td>5</td>
</tr>
<tr>
<td>SHORT: h/d≤6</td>
<td>134 x 1</td>
<td>1 x 0.3</td>
<td>0 x 0</td>
<td>134.3</td>
</tr>
<tr>
<td>TOTAL # OF COLUMNS****</td>
<td>138</td>
<td>3</td>
<td>0</td>
<td>0.99</td>
</tr>
</tbody>
</table>

#### BEAMS

<table>
<thead>
<tr>
<th>TYPE</th>
<th>NO-SLIGHT DAMAGE</th>
<th>LIGHT- MODERATE DAMAGE</th>
<th>HEAVY DAMAGE - COLLAPSE</th>
<th>TOTAL*** FACTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>LONG: L&gt;6m</td>
<td>0 x 1</td>
<td>0 x 0.7</td>
<td>0 x 0</td>
<td>0</td>
</tr>
<tr>
<td>INTERMEDIATE: 2m&lt;L≤6m</td>
<td>135 x 1</td>
<td>6 x 0.5</td>
<td>0 x 0</td>
<td>138</td>
</tr>
<tr>
<td>SHORT: L≤2m</td>
<td>0 x 1</td>
<td>0 x 0.3</td>
<td>0 x 0</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL # OF BEAMS****</td>
<td>135</td>
<td>6</td>
<td>0</td>
<td>0.98</td>
</tr>
</tbody>
</table>

**DMF**

DMF<sub>col</sub> = 1.2 \( \text{DMF}_{\text{col}} \) + 1.1 \( \text{DMF}_{\text{beams}} \)

\[
\text{DMF}_{\text{beams}} = \frac{0.98}{2.3}
\]

**FINAL SCORE** = \( \text{STRUCTURAL SCORE} \) * (DAMAGE MODIFICATION FACTOR)

**FINAL SCORE** = 1.87

### Comments:

***** If Final Score S < 1.9, then the structure will be recommended for Detailed Seismic Evaluation

Figure 8 RCAsT Structural Form Filled out for Building B.
4 CONCLUSION
A rapid visual assessment tool was formulated that quantifies the building performance based on the exterior attributes of the building and the interior state of building components. The tool uses structural scores derived from the locally developed fragility curves of moment resisting frame buildings in Metro Manila. Moreover, a score modifier was added, not found in FEMA 154 that takes into account the nearness to fault of a structure. In addition, quantification of the damage modification factor (DMF) was formulated using similar concepts employed in quantifying post-earthquake damage of RC buildings in Japan. The Rapid Condition Assessment Tool (RCaST) for the Structural Component and FEMA 154 were both applied to two Buildings for comparison. Though both tools have the same recommendation for the two buildings, the Final Score resulting from RCaST is more indicative of the true condition of the building before an earthquake with consideration to nearness to fault and damages observed in the building.

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