DEVELOPMENT OF A RAPID CONDITION ASSESSMENT TOOL FOR REINFORCEDCONCRETE MOMENT-RESISTING FRAME BUILDINGS IN THE PHILIPPINES: MATERIAL COMPONENT

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Abstract: Many buildings in the Philippines use reinforced concrete, in whole or in part, as the structural system. Proper inspection procedures, based on a visual investigation, can help identify deficiencies in concrete before they become critical to the overall stability of the structure. This paper describes the development of a rapid visual assessment tool for rating the condition of a reinforced concrete moment-resisting frame buildings. The developed tool considers both the structural and nonstructural deficiencies in concrete. It focuses on specific building elements for condition evaluation such as beams, columns, slabs and walls. This Tool provides engineers with background information and a systematic methodology for inspecting reinforced concrete buildings, focusing on deterioration conditions that can be seen and, more importantly, those conditions that can lead to a structural failure. The adopted scoring system is based on the proposed methodology by Coronelli which is a modification of the evaluation procedure by the CEB (1998): Condition Rating. This methodology was proposed for wide variety of structures to identify the most deteriorated cases by a damage index and plan more detailed analyse and repair interventions. Because the procedure of Coronelli considers several factors that are non-existent in the Philippine condition such as freeze thaw, etc it is further modified taking into account local conditions.

Key words: *Building assessment, Condition evaluation, Deterioration, Rapid visual assessment*

1 INTRODUCTION

Various factors adversely affect structural condition and hence the performance of RC structures. These factors may include inadequate material selection, poor workmanship, severe environments, exposure to harmful chemicals, unexpected loadings, fatigue, and catastrophic events (Jain *et al* 2012). Safety management of structures for public and property security must be performed regularly throughout the structure's life cycle. Visual inspection provides important information on performance and durability of structures (ACI 201 2008). In deteriorating structures, several visible distresses may develop with time, of which the commonly detected ones are cracks, leaching/staining, spalling, delamination, and efflorescence. In line with this, inspection activities and condition evaluations are done to assess the current serviceability and structural function of existing structures. Condition assessment and visual inspection are concerned with estimating the likely future safety and performance of an existing structural system. Many buildings in the Philippines use reinforced concrete, in whole or in part, as the structural system. Proper inspection procedures, based on a visual investigation, can help identify deficiencies in concrete before they become critical to the overall stability of the structure. This Tool provides engineers with background information and a systematic methodology for inspecting reinforced concrete buildings, focusing on deterioration conditions that can be seen and, more importantly, those conditions that can lead to a structural failure.

There exist different levels of investigation when it comes to condition survey of reinforced concrete structures. In seismic evaluation of structures, for example, FEMA 310 which is one of the "most advanced seismic evaluation procedure" for buildings categorizes the levels of inspection to a three-tiered process as enumerated by Rai (1998). Tier 1 is the screening phase in which the inspection is mainly visual. In this phase, the engineer looks on potential deficiencies and expected behavior of the structure. This screening helps provide evaluation statements for structural, nonstructural and foundation aspects in the form of checklist. Tier 2 is the evaluation phase where complete analysis of the building is made while Tier 3 is the more detailed evaluation phase.

Building performance can be measured in many ways, the most common being condition. Condition survey is defined as the “examination of concrete for the purpose of identifying and defining areas of distress”. (ACI 201) The building‘s condition gives a measure of the effectiveness of current maintenance programs because it determines the remaining useful life of components or systems and compares it with the full economic life expected, given good maintenance (Abbott, et al, 2007). In terms of condition survey of in-service concrete for the purpose of rehabilitation, the American Concrete Institute (364) classifies condition assessment of concrete structures under two categories: preliminary investigation and detailed investigation.

The preliminary investigation develops an initial assessment of the concrete structure’s behavior, condition and existing performance. A preliminary investigation is not intended to be a comprehensive study and is visual in nature. The tasks involved in preliminary survey are:

a. Documents review
b. Site Inspection
c. Preliminary Analysis

A detailed investigation is performed when the initial site visit or preliminary investigation has identified a need for more indepth assessment of concrete structure’s behavior. A detailed investigation includes additional filed observation, measurements and field and laboratory testing.

2 DEVELOPMENT OF THE TOOL

The tool was developed from a review of documentation on deterioration conditions in concrete and of accepted industry recommendations and practices. For the development of this tool, review and full consideration of the following were given to:

- American Concrete Institute 201.1: Guide for Making a Condition Survey of Concrete in Service
- American Concrete Institute 364: Guide for Evaluation of Concrete Structures before Rehabilitation
- ASCE 11 Guidelines for Structural Condition Assessment of Existing Buildings
- US Army Corps of Engineers: Guide for Visual Inspection of Structural Concrete Building Components

2.1 Components of the Tool

The tool considers both the structural and nonstructural deficiencies in concrete. It focuses on specific building elements for condition evaluation. These elements primarily include columns, slabs and beams. Walls are also considered but because it is non-load bearing in nature, it is not included in the overall rating of the building. Also, because there are a number of defects in concrete, only the major defects and visible deteriorations are considered. The tool can be divided into six parts: plan frame, critical areas, visible deterioration, building component, condition rating and the recommendations part.

2.1.1 Nonstructural deficiencies

Nonstructural deficiencies in general are surface deficiency resulting from the conditions of the design, construction or service life of the building. These deficiencies are not immediately critical to the structure but they can cause further deterioration, which can eventually lead to structural deficiencies. Examples of nonstructural deficiencies are: abrasion, blistering, chemical reaction cracking, cracking due to construction practice, crazing, discoloration, efflorescence, flaking, honeycombing, pop-out, etc.

2.1.2 Structural deficiencies

Structural deficiencies on the other hand indicate a breakdown of the material to a point that threatens the structural capacity of the members. Common structural deficiencies are chemical deterioration, corrosion cracking, distortion, reinforcement corrosion, scaling, spalling, shear cracking, moment cracking, etc. For a detailed explanation and corresponding photographs for the abovementioned deterioration, please refer to Appendix A

3 SCORING SYSTEM

The adopted scoring system is based on the proposed methodology by Coronelli (2007). This rating system is a modification of the evaluation procedure by the CEB (1998): Condition Rating. This methodology was proposed for wide variety of structures to identify the most deteriorated cases by a damage index and plan more detailed analysis and repair interventions. Because the procedure of Coronelli considers several factors that are non-existent in the Philippine condition such as freeze thaw, *etc* it is further modified taking into account local conditions

The scoring system begins by first examining the structural configuration and its division or components and subsequently judging the relative importance of these components. In general, more importance is given to columns since its failure is brittle and could trigger incremental collapse of more parts of the structure. The failure of the floor however has limited effects with a beam failure. The structural factor, as adopted from the study of Coronelli, which gives the relative importance of each structural element, is shown in Table 1. After examining the structural component, damage of each individual element will be rated.

Table 1 Structural element factor values for framed buildings (adopted from Coronelli, 2007)

Structural Element	**Factor**
Columns	1.2
Beams	1.1
Slabs	0.3
Walls	0.0

3.1 Condition Rating

The condition rating is a numerical score given to the structure relative to its most deteriorated case. The score can range from 0 to 100 % with 100% representing the worst case scenario or the case in which all members are deteriorated. A brief description of each of the deterioration case is sown in Table 2.

Table 2 Condition rating and corresponding deterioration class with description

Deterioration Class	Description of the condition	Rating
I	*No defect*, Only construction deficiencies.	**0-5**
II	*Low degree deterioration,* which only after a long period of time might be the cause for reduced serviceability or durability of the affected structural component, if not repaired in proper time	**3-10**
III	*Medium degree deterioration*, which can be the cause for reduced serviceability and durability of the affected structural component, but still not requiring any limitation of use of the structure	**7-15**
IV	*High degree deterioration*, reducing the serviceability and durability of the structure, but still not requiring serious limitation of use	**15-25**
V	*Very heavy deterioration*, requiring limitation of use, propping of most critical components, or other protective measures	**22-35**
VI	*Critical deterioration*, requiring immediate propping of the structure and strong limitation of use, for example, closing	**>30**

The form includes two condition ratings as follows:

3.1.1 LOCAL Condition Rating (LCR)

The local condition rating or LCR is the rating for each of the building component. This includes individual ratings for beams, columns, floor slabs and walls. The LCR is computed as:

$$LCR = \frac{\Sigma B_1 K_2 K_3 K_4}{72} x\ 100\% \qquad \text{Equation (1)}$$

where:

B_1 is the basic value of i^{th} damage type, expressing its potential effect on the safety and durability of the structural component under observation; values range 1–4;

K_1 is the structural element factor characterizing its importance for the safety of the whole structure or one of its parts;

K_2 is the intensity factor for the i^{th} damage, determined by qualitative visual criteria and experimental measurements in a scale of four degrees, with the corresponding numerical values $K_2 = 0.5, 1, 1.5, 2$

K_3 is the extension factor for the i^{th} damage within the elements under consideration, defined uniquely by descriptive criteria and applied in a scale of $K_3 = 0.5–1.0–1.5–2$

K_4 is the urgency of intervention factor for the i^{th} damage, with values varying from 1 to 5, grouped into four classes on the basis of direct consequences of the deterioration type on the safety of the structure and the users, and related to an indication of time for intervention

3.1.2 GLOBAL Condition Rating (GCR)

The global condition rating gives the condition index of the structure as a whole considering all the structural components. It is the condition rating for the whole building. It is computed as:

$$GCR = \frac{1.2 * LCR\ Column + 1.1\ LCR\ Beams + 0.3\ LCR\ Slabs}{2.6} \qquad \text{Equation (2)}$$

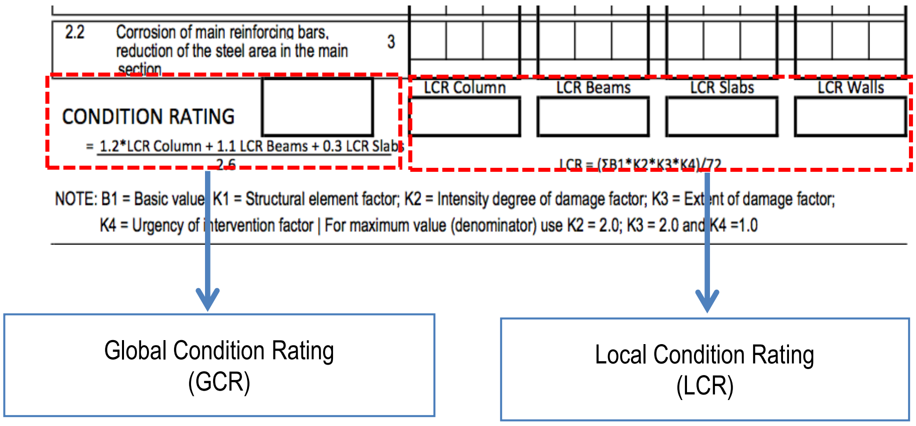

Figure 1 Global and local condition ratings

3.2 Cut-off Score and Making Recommendations

Three recommendations can be made upon computation of the condition rating of the building such as:

a. No further investigation required
b. Detailed local investigation
c. Overall detailed investigation or Level 2 assessment

This recommendation is based on the computed local and global condition rating. If the condition rating is greater than 15% a detailed investigation is recommended. This value is based on the fact that at 15% deterioration condition, a building is already considered medium to high degree deteriorated (Coronelli, 2007).

4 CONCLUSION

A rapid visual condition rating tool that can be used to evaluate the deterioration condition of a moment-resisting reinforced concrete frame building was developed. This tool was developed from review of documentation of deterioration from different standards. A quantitative scoring system from the study of Coronelli (2007) was adopted and localized to be useful in the Philippine setting. This Rapid Condition Assessment Tool (RCAsT): Materials Component can be used as a preliminary tool that will help decision makers if it is necessary to proceed with detailed investigation of the building.

RAPID'CONDITION'ASSESSMENT'TOOL

MATERIAL Component

SKETCH'PLAN'FRAME'OF'THE'BUILDING

CRITICAL MEMBERS*

COLUMNS (% with defect: ____)

BEAMS (% with defect: ____)

FLOORS (% with defect: ____)

WALLS (% with defect: ____)

				COLUMNS			BEAMS			FLR SLABS			WALLS		
1.0 CONCRETE		B1	K2	K3	K4	K2	K3	K4	K2	K3	K4	K2	K3	K4
1.1	Poor workmanship: peeling, stratification, honeycomb, voids	1												
1.2	Cracking cause by direct loading, imposed deformation and restraint	3												
1.3	Efflorescence, exudation and popout	1												
1.4	Mechanical damage: erosion, collision	1												
1.5	Wet surfaces	1												
1.6	Cover defects caused by reinforcement corrosion	2												
1.7	Spalling caused by corrosion of reinforcement	3												
1.8	Open joints between segments	2												
2.0 REINFORCEMENTS														
2.1	Corrosion of stirups	1												
2.2	Corrosion of main reinforcing bars, reduction of the steel area in the main section	3												

CONDITION'RATING	LCR'Column	LCR'Beams	LCR'Slabs	LCR'Walls
0	0.00	0.00	0.00	0.00

= (1.2*LCR'Column'+'1.1'LCR'Beams'+'0.3'LCR'Slabs) / 2.6

LCR'='(ΣB1*K2*K3*K4)/72

NOTE: B1 = Basic value; K1 = Structural element factor; K2 = Intensity degree of damage factor; K3 = Extent of damage factor; K4 = Urgency of intervention factor | For maximum value (denominator) use K2 = 2.0; K3 = 2.0 and K4 =1.0

RECOMMENDATION

- ☐ No further actions required
- ☐ Detailed local investigation required for the following areas
- ☐ Overall further investigation needed (Level 2 inspection - Condition Rating > 15%)

*Consider the component critical in the presence of the following cracks: (a) Columns - Longitudinal (b) Beams - Transverse at midspan (c) Walls - Diagonal

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Table of factors as adopted from Coronelli (2007)

APPENDIX A

Table A1. List of factors for computation of condition rating and corresponding descriptions`

Factor		Description	Reference Table
B1	Basic value	Expresses its potential effect on the safety and durability of the structural component under observation;	
K1	Structural Element Factor	Characterizes its importance for the safety of the whole structure or one of its parts;	Table A2
K2	Intensity Factor	Intensity factor for the ith damage, determined by qualitative visual criteria and experimental measurements in a scale of four degrees, with the corresponding numerical values K_2 = 0.5, 1, 1.5, 2	Table A3 and Table A4
K3	Extension Factor	Extension factor for the ith damage within the elements under consideration, defined uniquely by descriptive criteria and applied in a scale of K_3 = 0.5–1.0–1.5–2 (Table 3);	Table A5
K4	Urgency of Intervention Factor	Extension factor for the ith damage within the elements under consideration, defined uniquely by descriptive criteria and applied in a scale of K_3 = 0.5–1.0–1.5–2 (Table 3);	Table A6

Table A2. K1 values for framed buildings

Structural Element	K1
Columns	1.2
Beams	1.1
Slabs	0.3
Walls	0.0

Table A3. General criteria for the intensity degree of a damage type

Degree	Criterion	K2
Low - initial	Damage of small size, generally appearing on single localities 0.5 of a member	0.5
Medium–propagating	Damage is of medium size, confined to single localities, 1.0 or damage is of small size appearing on few localities or on a small area of a member (eg< 25%)	1.0
High – active	Damage is of large size, appearing on many localities or 1.5 on a greater area of a member (25 and 75%)	1.5
Very high – critical	Damage is of a very large size, appearing on a major part 2.0 of a member (>50%)	2.0

Table A4. Damage types to be evaluated, associated basic values B_1 and special criteria for the evaluation of the class of types (see Table for corresponding values of K_2)

Item	Damage type	B1	Degree of Damage			
			I (K2=0.5)	II (K2=1.0)	III (K2=1.5)	IV (K2=2.0)
1.0 CONCRETE						
1.1	Poor workmanship: peeling, stratification, honeycomb, voids	1	Single small defect	Several different small defects	Few stronger defects	Several different stronger defects
1.2	Cracking caused by direct loading, imposed deformations and restraint	3	Single < 0.5 mm	Several <0.5mm	Single >0.5mm	Several >0.5mm
1.3	Efflorescence, exudation, popout	1	General criteria (Table 2)			
1.4	Mechanical damage: erosion, collision	1	General criteria (Table 2)			
1.5	Wet surfaces	1	Light	Medium	Heavy	Severe
1.6	Cover defects caused by reinforcement corrosion	2	Rust stains, light	Rust stains, heavy	Cracks over stirrups	Delamination over stirrups
1.7	Spalling caused by corrosion of reinforcement	3	Finer cracks along reinforcing barsin corners	Finer cracks along other reinforcing bars and/or wider longitudinal cracks or exposed reinforcement along corners	Wider cracks along other bars, or exposed reinforcement	Hollow areas and surface spalling
1.8	Open joints between segments	2	1mm	1–3 mm	3-5 mm	>5mm
2.0 REINFORCEMENT						
2.1	Corrosion of stirrups	1	General criteria (Table 2)			
2.2	Corrosion of main reinforcing bars, reduction of steel area in the section (if in critical section, K_4=2)	3	Uniform < 10%	Pitting <10%	Uniform >10%	Pitting >10%

Table A5. General criteria for the extent of a damage type

Criterion	**K3**
Damage is confined to a single unit of the same type of member	0.5
Damage is appearing on several units (eg less than 1/4) of the same type of member	1.0
Damage is appearing on the major part of units (eg 1/4 to 3/4) of the same type of member	1.5
Damage is appearing on the great majority of units (more than 3/4) of the same type of member	2.0

Table A6. Factor to stress the urgency of intervention

Criterion	**K4**
Intervention is not urgent because the damage does not impair either the overall safety and/or durability 1 (service life) of the structure or the durability of the affected member	1
Damage must be repaired within a period not longer than five years, to prevent further impairment of the 2–3 overall safety and/or durability of the structure, or, solely, the durability of the affected member exposed to the aggressive attack	2-3
Immediate repair is required, as the damage is already jeopardizing the overall safety and/or durability of the 3–5 structure (especially in aggressive environment), or, if there is direct danger to people from falling pieces of disintegrated concrete	3-5
Temporary propping or limitation of traffic loads is require	5

Table A7. Deterioration classes

Deterioration Class	Description of the condition	Rating
I	*No defect*, Only construction deficiencies.	**0-5**
II	*Low degree deterioration,* which only after a long period of time might be the cause for reduced serviceability or durability of the affected structural component, if not repaired in proper time	**3-10**
III	*Medium degree deterioration,* which can be the cause for reduced serviceability and durability of the affected structural component, but still not requiring any limitation of use of the structure	**7-15**
IV	*High degree deterioration*, reducing the serviceability and durability of the structure, but still not requiring serious limitation of use	**15-25**
V	*Very heavy deterioration*, requiring limitation of use, propping of most critical components, or other protective measures	**22-35**
VI	*Critical deterioration*, requiring immediate propping of the structure and strong limitation of use, for example, closing	**>30**

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