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Henny Wiyanto, David Lie, James Kurniawan. "Critical Index Determination Method on Visual Assessment of Concrete Damage for Buildings", IOP Conference Series: Materials Science and Engineering, 2019

LOCAL AND GLOBAL CONDITION RATING DETERMINATION FOR CONCRETE DAMAGE BASED ON VISUAL ASSESSMENT Henny Wiyanto, Chaidir Anwar Makarim and Onnyxiforus Gondokusumo Civil Engineering Doctoral Program, Faculty of Engineering Universitas Tarumanagara, Jakarta, Indonesia E-Mail: hennyw@ft.untar.ac.id ABSTRACT This study is done to develop a concrete damage condition rating examination method for existing buildings based on visual assessment, changing it from a qualitative assessment to an assessment that can be measured quantitatively. Structural damage greatly affects building safety and will result in reduced building performance, or even building failure. Existing building structure damage is caused by many factors, one of which is poor construction implementation. To identify the extent of damage done, concrete structure condition rating assessment needs to be performed on the existing building. Assessment must be performed, either on functioning buildings or on post-disaster buildings, in order to provide an image of a building's condition and provide alternative steps that can be taken for a building in a bad condition. Right now, there is no clear reference that can be used to perform concrete damage condition rating assessment on existing building structure, so assessment results tend to be qualitative. This research suggests a concrete damage condition rating assessment method based on visual assessment. This assessment method has a scale and a condition rating reference, so that the resulted concrete damage condition rating assessment can be measured quantitatively. Aside from that, this assessment method also considers the critical weight and damage area of each concrete structure element on existing buildings. That way, the resulted assessment method can accommodate the need for visual-based concrete damage condition rating assessment for existing buildings. Keywords: condition rating; local and global concrete damage; existing building; visual assessment. 1. INTRODUCTION Concrete damage is a change to the concrete's condition and relates to the quality of the concrete. Concrete damage will cause a downgrade to the quality of concrete, which affects the reliability of the concrete structure. Concrete damage can occur on either new or existing buildings. On new buildings, concrete damage can be caused by natural factors and resource factors such as weather, poor construction implementation, material, or incompetent manpower. On existing buildings, damage can be caused by natural factors such as disaster or land condition, chemical factors, or human factors, such as overuse, function change, or poor maintenance [1, 2]. Poor construction implementation can result in damage to existing building. In order to fulfil building safety requirements, existing buildings need maintenance, reparation, or even demolition if it can't be maintained any further. Often a building's owner or manager ignores the condition of an operational building, and doesn't implement proper building examination because of the cost. In reality, building condition assessment can lower the risk of further building damage which can endanger building users. This can result in higher risk and higher costs compared to the cost of building maintenance through building structure condition assessment. One of the measures that have to be taken is building maintenance through building structure condition assessment. Regular building inspection is done to ensure building reliability. Building reliability requirements examination includes fulfilling a building's safety, health, comfort, and ease of use requirements [3]. One of the safety requirements includes building structure requirements [4]. Assessment isn't only performed on post-disaster or deteriorating buildings, but also on functioning buildings. Structural damage has a large effect on building safety and will result in a decrease in structure function, or even building failure. Building failure is a situation where a building is collapsed or non-functional after construction service final hand over. In every construction service execution, owner and contractor are required to fulfil safety, security, health, and longevity standards [5]. Visual assessment is the first assessment done in order to help detect early concrete damage on existing buildings before implementing reparation. Visual assessment is done by identifying and determining the concrete damage types seen on the building. Visual assessment is limited to building structure surface that can be accessed with the sense of sight (eyes). Concrete damage to a building structure is detected by assessing the concrete's physical condition, which can be seen from the concrete surface or the downgraded quality of concrete. To understand the condition ratings of concrete damage, it is necessary to perform an assessment to detect the damage, which is undertaken through a preliminary visual assessment [1]. These visual attributes are used for condition assessment in visual inspection. Condition assessed by means of visual inspection is primarily qualitative, i.e., condition is usually expressed in imprecise linguistic terms such as "poor," "good," and "excellent". Condition expressed in linguistic terms varies from person to person; for example, the distress state opined as poor by one person may not be poor for another person. Therefore, the qualitative information obtained from visual inspection, i.e., assessed condition, is subjective in nature and depends on the experience, knowledge, expertise, and judgment of the inspector carrying out the assessment [2]. Control inspection needs to be performed in order to identify the building structure condition. A building's functionality depends on the control inspection. A lack of control will accelerate building damage and have an impact on reparation costs. The first step in performing control inspection is visual assessment to the building structure [6]. Visual assessment is often used as the first step to evaluate structure, analyze strength or deformity, or determine maintenance and rehabilitation needs [7]. Building material condition assessment on existing buildings is done with visual assessment, non-destructive testing, and destructive testing methods, including field and laboratory procedures [1]. The problem is how to identify an acceptable existing building structure condition rating. Existing buildings are buildings that have been used, or buildings that have been given the final hand over in terms of building construction implementation with a contractor, or a building that has been built for at least 1 (one) year in case the building's construction implementation isn't using a contractor [4]. Currently, the visual assessment is the descriptive assessment, because there is no standard reference for measurement yet. In order to establish a reference for visual assessment, the concrete damage rating needs to be determined. The concrete damage can be differentiated based on the damage condition rating. The concrete damage is determined based on the condition rating value and concrete damage type. In order to assess reliability, a reference value is needed as condition ratio scale. Because of this, the building structure reliability acceptable value [8] first needs to be determined. This acceptable value can be determined from the planned target reliability level [9]. Field assessments usually come as general recommendations from field examination results which explain the existing building structure condition. These results in the form of recommendations are delivered descriptively without any condition rating measurement. This is because there is not yet a reference and code for measuring existing building condition rating assessment, so assessment results are qualitative. Qualitative assessment will result in opinion differences, since they are made based on the perception of each appraiser. To reduce these differences, an assessment method that can be measured quantitatively is needed. Therefore, concrete structure condition rating assessment method that can be measured quantitatively for existing buildings needs to be developed. 2. MATERIALS AND METHODS This concrete condition assessment method for buildings is set as an assessment method based on visual assessment. 2.1 Concrete Damage Condition Rating Condition rating scale and reference for visual assessment is determined based on the scale and reference used in concrete testing. In order to apply this assessment method in Indonesia, the scale and reference set here refers to codes that apply in Indonesia. Several older researches perform assessment using concrete condition rating comparison scale for each condition rating. But, that scale and reference hasn't been able to accommodate all possible building conditions that can happen in field work, because the scale with the lowest criteria reference is unable to describe the worst building condition where the building can't be used anymore. The condition rating assessment scale and reference used in assessment based on visual assessment can be seen in [2, 6], [10-20]. Based on the research review about concrete damage condition rating determination on a visual assessment, stating a concrete's damage rating is determined with six condition ratings, ranging from a condition that does not require repair to a condition requiring immediate action. The condition rating is determined based on concrete repair priority that is processed with the fuzzy logic approach [2], [10-12]. 2.2 Local and Global Condition Rating Determination This concrete condition assessment method for buildings is set as an assessment method based on visual assessment. A visual assessment of concrete damage is the first step taken before testing the concrete quality [1]. Visual assessment is conducted by identifying the concrete damage that is visible on the surface of the concrete to the naked eye. This assessment is limited to the condition of the concrete that can be seen visually. Identification of concrete damage that can be assessed visually refers to [1, 7]. Local and global condition rating values for each damage type is determined by processing questionnaire data using the fuzzy logic approach which refers to [2], [10-12], [20], [23-24]. Data in the form of condition rating for each concrete damage type from appraisal consultants is processed using data validation. Data validation is done by removing invalid data and removing responses that are less than 10% of the total amount of respondents. The condition rating assessment is completed by determining the condition rating value of each type of concrete damage. The condition rating value of each type of concrete damage is determined based on expert analysis using the fuzzy logic approach. The condition rating value is determined using the following formula. CRse = i=n1 and ?i = ? ?ii n Ri ? ?i R i,max i=1 where CRse is structure element condition rating, μ is membership function based on questionnaire results, i is condition rating, and R is number of respondents. Concrete damage condition rating is determined based on the amount of damage done on the building. Therefore, local and global concrete damage condition rating for each damage type needs to be analyzed. Local damage is damage on a smaller surface area, while global damage happens on a wider scale. 25% of the reviewed element surface is taken. Local and global condition rating assessment is done by determining condition rating with membership function on each point that exists between each condition rating using linguistic hedges known as Vertex Method using the following formula. ix = ilw + ??txp −− ??llww (itp − ilw) where ix is condition rating on the reviewed point, μx is membership function on the reviewed condition rating, lw is the value on the lower condition rating, and tp is the value on the higher condition rating. Membership function for local damage and global damage on each reviewed location is determined by using the following formula. If xi< x?i,max then ?xlc = ?i0.5 and ?xgl = ?i2 If xi> x?

i,max then ?xlc = ?i2 and ?xgl = ?i 0.5 If xi = x?i,max then ?xlc = ?i,max and ?xgl = ?i,max where xi is the reviewed condition rating point, x?i,max is the condition rating point with the highest membership function, xlc is the membership function for local ? damage, ?x gl is the membership function for global damage, μi is the membership function with interval 0.1, and μi,max is the membership function with the highest condition rating (value 1). The condition rating value for each local and global damage type is determined using the Centroid Method. Structure element critical weight values are used to determine the building concrete condition rating value. Concrete damage condition rating for building structure condition as a whole is determined with the weighted average method formula as follows: BCR = ?nse=1 wse.CRse ?nse=1 se w where BCR is building condition rating, w is critical weight, CR is condition rating, and se is structure elements. Concrete damage condition rating characteristics for the building is determined based on building condition rating (BCR) values. The type of concrete damage on structure element will result in different effects on building structure. Therefore, concrete condition rating on a building will be affected by the critical weight of each structure element against the building structure. Structure element critical weight against building structure is determined on Table-1 [20, 25]. Table-1. Structure element critical weight. Structural Elements Critical Weight Shearwall 1 Column 1 Beam 0,7 Slab 0,5 Rating method has been validated on existing buildings and the results are in agreement with the appraisal consultants, which makes it a method that is quantitatively measured. 3. RESULTS AND DISCUSSIONS The building structure could be on the lowest rating, meaning demolition is required. So, a worst-case scenario approach should be used for the condition rating. The condition rating of concrete must refer to the relevant codes. There is a code already available for concrete damage testing, which can be used for reference, but such a code is not yet available for visual assessment. To determine the condition rating of concrete damage when conducting a visual assessment, the code used for testing will be applied, so that the same condition rating is used for both examination results. To accommodate that problem, damage rating characteristics such as those shown in Table-2 [19-22] are used. Table-2. Concrete damage condition rating characteristics. Condition Rating Description Criteria and Measure 1 Very Good No damage. No repairs needed, but routine maintenance needed. 2 Good Light damage. Repair is needed in routine maintenance. 3 Medium Medium damage. Further testing is needed as soon as possible. 4 Bad Heavy damage. Structure needs to be strengthened, or weight needs to be reduced. 5 Very Bad Very heavy damage or critical damage. Cannot be maintained or demolished. These concrete damage condition rating characteristics are used as a reference in determining the condition rating of each concrete damage type and building condition rating. This condition rating scale and reference can describe all kinds of building conditions, from buildings with very good conditions where the building is perfectly undamaged, to buildings with very bad conditions where the building can't be maintained anymore, and has to be demolished. In order to determine concrete damage condition rating, concrete damage type is identified, which can be assessed visually such as in Table-3. No 1 2 3 4 5 6 7 Table-3. Concrete damage type. Damage Type Craze Crack Crazing D-Cracks Hairline Crack Maping Crack Random Cracks Transverse Crack 8 Delamination 9 Honeycomb 10 Pop-outs (small) 11 Pop-outs (medium) 12 Pop-outs (large) 13 Scaling (light) 14 Scaling (medium) 15 Scaling (severe) 16 Scaling (very severe) 17 Spall (small) 18 Spall (large) 19 Distortion 20 Stratification Responses on each damage type and validation results can be seen on Figure-1. Figure-1. Response on each damage type and validation result. Based on validation results from Figure-1, a membership function is determined on each concrete damage type which can be seen in Table-4. This membership function will be used to determine the local and global concrete damage membership function.

Table-4. Membership function. No Damage Type 1 Membership Function (μi) 2 3 4 5 1 Craze Crack 0 0,86 1 0 0 2 Crazing 0 0,63 1 0,38 0 3 D-Cracks 0 0 1 0,25 0 4 Hairline Crack 0 1 0,5 0 0 5 Maping Crack 0 0,18 1 0,18 0 6 Random Cracks 0 0 1 0,56 0 7 Transverse Crack 0 0 1 0,4 0 8 Delamination 0 0 1 0,33 0 9 Honeycomb 0 0 1 0,75 0 10 Popouts (small) 0 1 0,86 0,43 0 11 Popouts (medium) 0 0,3 1 0,2 0 12 Popouts (large) 0 0 1 0,56 0 13 Scaling (light) 0 0,88 1 0 0 14 Scaling (medium) 0 0,14 1 0 0 15 Scaling (severe) 0 0,2 1 0,4 0 16 Scaling (very severe) 0 0 1 0,88 0 17 Spall (small) 0 0,17 1 0 0 18 Spall (large) 0 0 1 0,67 0 19 Distortion 0 0 0,27 1 0,18 20 Stratification 0 0 0,2 1 0,4 Condition rating with membership function (u) is determined on each point that exists between each condition rating using linguistic hedges known as the Vertex Method. Membership function for local and global condition rating is determined based on condition rating data validation results for each concrete damage type, and is processed with formulas 2 and 3. Local and global membership functions are used to determine the local and global condition rating of each concrete damage type. Membership function total value on each local and global condition can be seen in Table-5. Table-5. Membership function total value on each local and global condition. No. Concrete Damage Type ? n ?ii Local i =1 n ? ?ii Global i =1 1 Craze Crack 22.81 29.32 2 Crazing 25.12 32.17 3 D-Cracks 28.38 32.68 4 Hairline Crack 18.97 24.27 5 Maping Crack 27.60 32.13 6 Random Cracks 29.09 34.61 7 Transverse Crack 28.66 33.56 8 Delamination 28.53 33.16 9 Honeycomb 29.86 36.07 10 Popouts (small) 20.98 29.02 11 Popouts (medium) 26.99 32.04 12 Popouts (large) 29.09 34.61 13 Scaling (light) 22.66 29.21 14 Scaling (medium) 27.59 31.49 15 Scaling (severe) 27.90 33.35 16 Scaling (very severe) 30.52 37.07 17 Spall (small) 27.48 31.47 18 Spall (large) 29.50 35.43 19 Distortion 37.06 41.81 20 Stratification 37.80 42.71 The condition rating of each local and global which means this damage type has a high risk and affects damage type is determined using the Centroid Method the existing building negatively. On the contrary, there is (formula 1), with a total μi value of 9.96. Based on the no damage type with value nearing one, which means that membership function for each damage type, the local and the small damage done on the existing building cannot be global condition rating for each damage type has been ignored. Because no matter how small the damage is, it obtained, which can be seen in Figure-2. still poses a risk that can cause further building damage if proper building maintenance isn't practiced. To explain this resulted method, concrete condition rating assessment is performed on a 8-floor building with 13 years of operation which functions as a mall. Visual assessment results show the structural concrete damage condition on a number of building structure elements, and concrete damage condition rating assessment based on local and global damage area. There are several concrete damage types on the building structure elements in each floor. The concrete damage types identified in this building are Craze crack, Random cracks, Scaling, Spalling, and Popouts. The description for building visual assessment in the form of concrete damage type and area on each Figure-2. The local and global condition rating for each structure element, concrete damage type condition rating damage type. value, and building concrete damage condition rating value determination can be seen in Table-6. In Figure-2, the concrete damage type which is the damage type with bad condition rating can be seen, Table-6. Concrete damage condition rating assessment. No Concrete Damage Type Area CRse wse wseCRse 1 Craze Crack L 2.29 1 2.29 2 Random Cracks L 2.92 0.5 1.46 3 Scaling (severe) L 2.80 0.7 1.96 4 Spall (small) L 2.76 0.7 1.93 5 Spall (small) L 2.76 1 2.76 6 Random Cracks G 3.48 0.5 1.74 7 Scaling (light) L 2.28 0.5 1.14 8 Scaling (severe) L 2.80 0.5 1.40 9 Scaling (light) G 2.93 0.5 1.47 10 Random Cracks L 2.92 1 2.92 11 Spall (large) L 2.96 1 2.96 12 Popouts (medium) L 2.71 0.7 1.90 13 Scaling (medium) L 2.77 0.7 1.94 14 Spall (small) L 3.44 1 3.44 15 Spall (small) L 2.76 0.5 1.38 16 Scaling (severe) L 2.80 0.7 1.96 17 Spall (small) L 2.76 0.7 1.93 18 Spall (small) L 2.76 0.7 1.93 19 Scaling (light) L 2.28 1 2.28 20 Spall (small) L 2.76 1 2.76 21 Spall (small) L 2.76 0.7 1.93 22 Scaling (severe) L 2.80 0.7 1.96 23 Random Cracks G 3.48 0.5 1.74 24 Spall (small) L 2.76 0.7 1.93 25 Spall (small) L 2.76 0.7 1.93 26 Scaling (severe) L 2.80 1 2.80 27 Scaling (severe) L 2.80 1 2.80 28 Random Cracks L 2.92 0.7 2.04 ∑ 20.9 58.68 BCR 2.81 The building condition rating (BCR) value, presented in Table-6 is the building condition rating with concrete damage characteristics that refer to Table-2. The building condition rating (BCR) value of this building shows a medium concrete damage condition rating, or more specifically, a good condition rating which is nearing medium. This means that concrete testing needs to be implemented as soon as possible, especially on the structure elements that are nearing medium condition rating. Aside from that, reparation also needs to be implemented on structure elements that are damaged, so the damage won't spread and worsen. This reparation is part of a building's routine maintenance. Based on this explanation, it can be seen that building condition rating assessment results are a number that describes concrete damage condition rating with concrete damage criteria as well as the follow-up action that needs to be taken on each condition rating. Therefore, this visual assessment based concrete damage condition rating assessment method is a method that is quantitative for existing buildings. 4. CONCLUSIONS This resulted condition rating assessment method is a concrete damage condition rating assessment method that is measured quantitatively, by taking into account the structure element critical weight and the damage area for existing buildings. This method is presented to accommodate the need for concrete damage condition rating assessment. The critical rating of each structure element is surely different based on the function of each structure element on the building. The same concrete damage type can result in different effects on building structure if it happens on different structure elements, so the critical rating of structure elements against building structure can't be considered the same. Therefore, structure element critical weight against building structure needs to be considered in concrete damage condition rating assessment. Concrete damage surface on structure element also affects the concrete damage condition rating, therefore local and global damage area on a given structure element must be taken into account in concrete damage condition rating assessment. ACKNOWLEDGEMENT This acknowledgment is dedicated towards article reviewers who have studied and reviewed this article, editors, as well as all that are involved in this paper's publication on ARPN Journal of Engineering and Applied Sciences (JEAS). REFERENCES [1] 2000. Structural Engineering Institute American Society of Civil Engineers (SEI/ASCE), SEI/ASCE 11-99. [2] K. K. Jain and B. Bhattacharjee. 2012. Application of Fuzzy Concepts to The Visual Assessment of Deterioration Reinforced Concrete Structure. Journal of Construction Engineering and Management ASCE. 138(3): 399-408. [3] 2018. Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat Republik Indonesia, Permen PUPR Nomor 11/PRT/M/2018. [4] 2018. 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