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Disaster Preparedness Assessment Tools of Structural Performance for Indonesian School Buildings

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Abstract: It has been recorded so far that the earthquake in Indonesia has damaged many public facilities and claimed many victims. Most cases of casualties were not caused directly by the earthquake but as a result of falling debris from buildings that were unable to respond to the earthquake. To avoid similar incidents in the future, all buildings in Indonesia need to be inspected and ensured that they are safe from the threat of an earthquake, and school buildings are no exception. The absence of a specific assessment tool for earthquake-resistant school buildings underlies this research. The assessment tool was developed based on the results of a literature review of several building inspection standards in various countries. Several research variables that were previously identified were then validated and processed using the Analytical Hierarchy Process method. Some experts in related fields were involved in the process to formulate the significant variables, the respective weights as well as scoring systems. This research produced a preliminary assessment tool in two parts. The first one, which emphasizes examination by visual method, is translated into four new categories: Building Slope Inspection, Sub-structure Component Inspection, Upper Structure Component Inspection, and Document Inspection, with 12 sub-categories and 28 indicators. Meanwhile, the second part emphasizes on the non-destructive testing as additional scores. It includes three types of tests for concrete and two tests for steel materials. Finally, the level of preparedness for the structural components of a good school building needs to meet a minimum score of 70.

Keywords: Disaster preparedness, assessment tool, structural assessment

1. Introduction

The geological condition of Indonesia, which is flanked by four main plates, namely Eurasia, Indo-Australia, the Philippines, and the Pacific, makes it prone to earthquakes, tsunamis, and volcanic eruptions [1]. Indonesia's National Disaster Management Agency (Badan Nasional Penanggulangan Bencana in Indonesian) noted that in five years, between 2015 and 2019, 104 earthquakes occurred throughout Indonesia and caused at least 617,858 people to suffer and be displaced. In addition to claiming lives, the earthquake also damaged 1,472 educational facilities, which included school buildings. In detail, the Ministry of Education and Culture of the Republic of Indonesia recorded that 14,272 elementary schools were heavily damaged and 41 were totally damaged, 4,065 junior high schools were heavily damaged and 10 were completely damaged, 976 senior high schools and 628 vocational high schools were heavily damaged, and 6 were completely damaged. The large number of school buildings that were severely damaged, and the casualties caused by collapsing buildings, convey a message that the structure of most school buildings in Indonesia is still in poor condition. It is indicated by the inappropriate structural components of school buildings and the vulnerability of these structural components to the threat of earthquakes. Therefore, a school building is needed to guarantee the safety and security of school residents from the threat of natural disasters [1], which is a tangible manifestation of disaster mitigation and preparedness. Although the design code regarding the earthquake-resistance

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issue has already been established in Indonesian National Code, or Standar Nasional Indonesia in Indonesian, SNI 1726-2019 and SNI-2847-2013), the implementation has not been synchronized with the construction process. Besides, existing soft-story buildings were built before any seismic design was introduced, and thus, failures, such as "weak-column/strong-beam" mechanisms were often observed [2]. The Government of Indonesia, through the Ministry of National Education of the Republic of Indonesia, issued a Circular of the Minister of National Education Number: 70a/MPN/SE/2010 which is addressed to the Governor, Mayor or Regent to implement disaster risk reduction strategies in schools to embody disaster preparedness. Regarding disaster risk reduction, the Indonesian Institute of Sciences, or in the Indonesian called Lembaga Ilmu Pengetahuan Indonesia (LIPI) issued a Handbook for the Implementation of Disaster Preparedness Schools in 2013. The manual contains an assessment tool consisting of various aspects: School Facilities and Infrastructure, and School Environment. It includes an assessment of structural preparedness by evaluating both the structural and non-structural components of a school building.

The limitation of the existing assessment tools, especially in the structural components, is the scope of their implementation which only involves the role of school management. To obtain more valid and reliable results, the implementation needs to incorporate certified building inspectors who are competent in their fields. Therefore, this research aims to develop a more comprehensive and integrated preliminary assessment tool of earthquake-resistant school building structural components, whose use will be specifically targeted at building inspectors.

2. Disaster Management

To reduce the risks and impacts that can arise from disasters, the government of the Republic of Indonesia issued Law Number 24 of 2007 concerning Disaster Management which regulates the management of disaster prevention and management in Indonesia. According to [3], disaster management is defined as an applied science based on systematic observation and disaster analysis aimed at increasing preventive efforts, which consist of mitigation and preparedness efforts carried out before a disaster, the emergency response when a disaster occurs, and recovery acts immediately right after the disaster happened.

Disaster mitigation is a series of efforts to reduce disaster risk, either through physical development as well as awareness and enhancement of capacity to face disaster threats [4]. In general, mitigation can be classified into two types, namely structural and non-structural mitigation [5]. Structural mitigation is a form of risk reduction carried out by efforts to improve the physical condition of an environment or construction with the help of scientific solutions, such as by building threat-resistant construction, establishing building planning standards and applicable regulations, structural modification, and creating a detection system [5] On the other hand, non-structural mitigation focuses more on mitigation without the need for an engineered structure.

Disaster preparedness is one of the stages consisting of a series of activities to anticipate disasters through organizing and taking appropriate and efficient steps [1]. Mitigation and preparedness are step-in disaster management categorized as pre-disaster, which include disaster management plans, resource maintenance, and human resource training [3]. Like the mitigation approach, disaster preparedness schools must meet two criteria, namely structural and non-structural preparedness [6]. One of the indicators of structural preparedness is the physical condition of the school which must meet earthquake-resistant building standards and the availability of physical facilities for self-rescue and evacuation [7]. The results of the feasibility and vulnerability assessment of the structural components of the building can then become the basis for mapping the disaster risks in school buildings in Indonesia and thus, formulating coping strategies.

3. Building Inspection

If a building has the potential or is exposed to the risk of an earthquake, inspection, and evaluation of the building need to be carried out by experts or structural engineers [5]. It is intended to ensure the feasibility of a building structure based on predetermined structural parameters. Building inspections can be carried out non-destructively or destructively. A visually non-destructive examination is considered the easiest and most practical way since it does not require much equipment and testing, and therefore, this method is very commonly used so far. Rapid Visual Screening (RVS) is one of the methods commonly used, where the procedures and examination variables have been detailed in The Federal Emergency Management Agency (FEMA) P-154. The results of the RVS are in the form of an evaluation of the vulnerability of buildings that can be used as a basis for taking steps to reduce the risk of the threat of earthquakes [8]. Inspection of the building itself should be carried out periodically to maintain the feasibility of structural components from severe structural degradation. The higher the expected accuracy of inspections and assessments, the more detailed the human resource requirements, inspection methods, and budget will be. Inspection of school buildings should be included in the routine maintenance work plan, as stipulated in the Regulation of the Minister of National Education Number 24 of 2007.

4. Research Methodology

This research began by reviewing some literature related to building inspection standards, existing regulations on earthquake-resistant building design in Indonesia, as well as guidelines on disaster risk management and disaster preparedness for school environments. The standards being used were reviewed and cited predominantly from the United States of America (USA) and Japan due to their excellence in disaster management programs and regulations, while another standard from New Zealand was considered due to a similar high seismic risk zone to Indonesia. Those were Federal Emergency Management Agency (FEMA) P-154 from the United States, Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings (2001) from Japan, Assessment, and Improvement of the Structural Performance of Buildings in Earthquakes from New Zealand. Besides, several specific disaster risk management guidelines in schools included Disaster and Emergency Preparedness: Guidance for Schools from the International Finance Corporation and the School Disaster Risk Management Guidelines for Southeast Asia from Association of Southeast Asian Nations (ASEAN), and the Guide to Implementing Disaster Prepared Schools issued by LIPI were also used as references in this research. Both, technical standards, and disaster risk management guidelines were applied to ensure the developed assessment tool can be adapted exclusively to the school buildings. The results of the literature review produced several research variables that would be included in the assessment tool. Several factors, such as the condition of school buildings in Indonesia, both the type and shape of the building, environmental conditions, and the existing regulations/standards were taken into consideration in formulating these variables. Hierarchically, the research variables were further classified into categories, sub-categories, indicators, and sub-indicators.

Before further analysis, the research variables must be validated before the weight and the scoring system of each of these variables are carried out using the Analytical Hierarchy Process (AHP). Some of the experts involved in the validation process and determining the weight of the respondents in this research came from academics, building inspectors, designers, and engineers. A set of questionnaires that are formed by comparing the level of importance among research variables was distributed to respondents online. The tool development was continued by determining the minimum final value that must be met by earthquake-resistant school buildings based on the results of visual inspections. To complement the results, a non-destructive test can be performed and the results will only be treated as additional scores at this point.

5. Disaster Preparedness Assessment Tool

The tool for assessing the preparedness of the structural components of an earthquake-resistant school building that was developed in this research consists of two parts. The first part contains several variables related to visual inspection, while the other part discusses inspection variables related to non-destructive testing. This second part gives an additional (bonus) percentage in the result. This assessment tool will also be equipped with the assessor's data, as well as building technical data, such as building age, foundation types, building materials, layout, and building ground motion parameters that have been determined based on the Earthquake Resistance Planning Procedure for Building and Non-Building Structures maps contained in the Indonesian National Standard (SNI 1726-2019) [9]. Fig. 1 and Fig. 2 show the maps of the acceleration of the earthquake spectral response concerning the ground motion parameters of the building. Meanwhile, the building layout is referred to as the shape, either L, T, or U shape which potentially can cause horizontal irregularity and thus, increase the probability of structural degradation as stated in SNI 1726: 2019 [9].

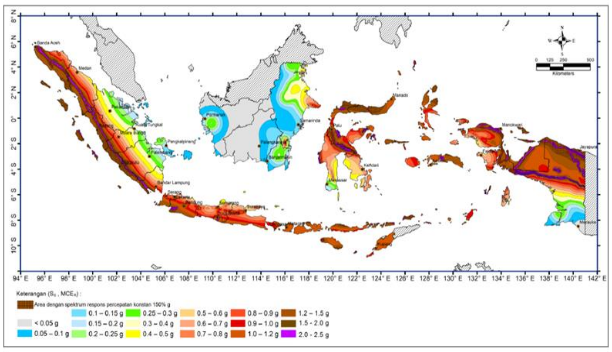


Fig. 1 - Risk-targeted MCER earthquake spectral response acceleration map in a short period, 5% damped, ss [9]

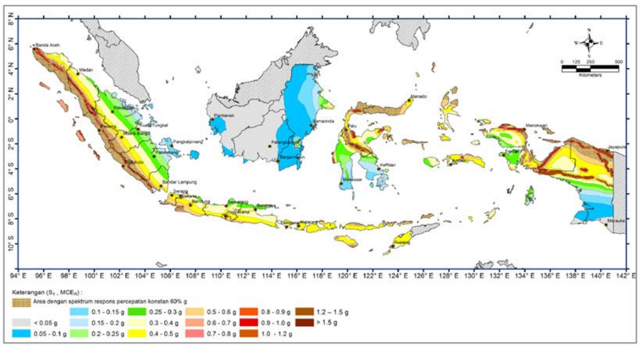


Fig. 2 - Risk-targeted MCER earthquake spectral response acceleration map in 1 second period, 5% damped, s1 [9]

5.1 Part One: Visual Inspection

This part consists of four categories, namely Building Slope Inspection, Sub-structure Components Inspection, Upper Structure Components Inspection, and Document Inspection. The Building Slope Inspection category is considered in the assessment tool because it has the potential to increase the quantity of structural degradation and intensify the risk of a building's vulnerability to earthquake threats. The inspection of the building slope must be carried out visually on-site. The elaboration of this category (see Table 1) is adjusted to the method of calculation and observation of the slope.

The second category, Sub-structure Components Inspection, consists of variables related to the foundation, pile cap, and tie-beam. Due to the limitations of visual inspections and associated budget in most school buildings in Indonesia, the inspection is focused only on the pile cap component for deep foundations without considering the pile group itself. In more detail, this category also considers the condition of the tie-beam, as a stiffener to the columns and load distributor in a building as can be seen from the derived indicators. Further inspections will only be carried out if there are indications of a soil settlement and subsidence in the building, bearing in mind that excavation requires considerable resources and has the potential to disrupt school building operations.

Meanwhile, the category of Upper Structure Components Inspection is divided into several sub-categories based on the type of structural components, i.e., beams, columns, brick walls, and slabs. Furthermore, each sub-category will be divided into several more detailed indicators regarding the degradation of the structure component (see Table 1). The variables in the sub-categories Beam Inspection, and Column Inspection (see Tables 1 to 2), were developed to consider the variations in building materials, namely concrete, steel, and composites. Degradation of concrete structural components can occur both due to weather and environmental influences, as well as inefficient maintenance. Cracking is one of the most common forms of degradation, which can cause damage to concrete elements over time. The sequence is characterized by the presence of spalling, chipping, and exposure of the reinforcement, and ultimately leading to failure of reinforced concrete in the tensile stress section. The first indicator of Crack in Concrete Beam and Column sub-category is divided into two sub-indicators: Crack Type, and Crack Width. The definition of the type of crack refers to the one described in the 1C module entitled Structural Engineering Systems (FEMA US&R Response System, 2020) [10] while the width of the crack is based on limits according to ACI 224R-01 [11]. The damage that is considered in steel elements includes buckling failure, and cracks or tears, while the joints consist of cracks, block shears, and incomplete steel connection configurations. The second indicator of Damage on Beam reflects actual conditions of the beam whether the beam happened to be damaged more than just cracks, or until it caused spalling and chipping. The third sub-category is Exposure of Reinforcement derived because it is the most dangerous condition that could occur on the beam as a structure. Exposure of reinforcement means the beam or column was highly damaged and the reinforcement could rust and can cause failure, and then collapse of the structure. The indicators of those sub-categories are assessed based on the severity of structural degradation that could occur on the beams and columns. On the other hand, structures that were made of steel can be assessed their condition by taking several variables at two important structural element locations, the member and joint. The conditions in both are considered in determining the existing sub-categories. Therefore, the first sub-category is Failure on Steel Beam/Column which focused on whether the beam or column happens to have a buckling failure. Sub-category Damaged on Steel Connection is derived to assess on the joint, assessing block shear damage on connection and damage on bolt or weld. The third and the last sub-category called Rust on Steel Beam/Column and Rust on Steel Connection focuses on the assessment of rust both on the member or the connection because rust could degrade the steel quality and sometimes minimize the steel profile's cross-section.

Although brick walls cannot be categorized directly as a structural component, their load, and function indirectly affect the distribution of loads on the associated structural components. This underlies the inclusion of the sub-category of Brick Wall in this assessment tool, as can be seen in Table 1. Cracks in brick walls can cause damage ranging from delamination, chipping, to holes so that they can interfere with the functional space and load distribution of the structure. Cracks in brick walls can be caused by various environmental factors such as rain leaks, technical conditions due to soil settlement and subsidence, and failure of load-bearing wall reinforcement. Rain leaks can increase moisture on the wall surface and further into the wall, potentially making the existing concrete mixture more porous and cracking. On the other hand, soil subsidence can cause the entire school building to no longer be on the vertical axis (disposition) and have the potential to cause the walls to lift and eventually break free from bonds between walls or to beams and slabs. Therefore, any possible structural degradation that can occur in brick walls will not only affect the preparedness of the structural components but the entire school building. These thoughts underlie the consideration to derive several sub-categories in this category. The indicators of the first sub-category, Rain Leak on Brick Walls focus on assessing rain leaks that occur in brick walls as the early stages of brick wall damage. The second sub-category, namely as Brick Wall Cracks sub-category are divided into several sub-indicators that can be identified from the location of the cracks, such as Cracks Due to Failure of Reinforcement, Cracks Due to Soil Settlement and Subsidence, Expansion Cracks, and Cracks Above the Opening as can be seen in Fig. 3 [12]. The last sub-category, Damage on Brick Walls sub-category is divided into several sub-indicators that can be identified from the severity of the damage besides cracking, such as Tilting, Delaminated, and Holed.

The roof serves as a building protector, as well as a distributor for external loads. The condition of the roof frame will affect the distribution of loads to the structural components underneath. A good condition can be interpreted if the roof structure has no damage such as weathered or bent. Lamination, welding, complete bolt configurations in wooden

Table 1 - Part I: visual inspection

Category [1]	Sub-Category [2]	Indicator [3]		Sub - Indicator [4]	
1. Slope deflection inspection (18%)	A. Visual screening (35%)	A.1	Building condition		
			(a) Tilted building (0)		
			(b) Straight building (100)		
	B. Field inspection with theodolite (65%)	B.1	Building condition		
			(a) Tilted building (0)		
			(b) Straight building (100)		
2. Sub-structure component inspection (33)	2.A. Foundation inspection (100%)	2.A.1	Soil movement against foundation damage		
			(a) Exist (further examination is needed)	2.A.1.1	Tie-beam condition (41% for shallow foundation, 52% for deep foundation)
					(a) Good condition, no damage founded (100)
					(b) Structural deterioration occurs on tie-beam (50)
					(c) Tie-beam does not exist (0)
				If shallow foundation is used,	
				2.A.1.2	Structural deterioration on foundation (59%)
					(a) Exist (0)
					(b) Does not exist (100)
				If deep foundation is used,	
				2.A.1.3	Structural deterioration on pile cap (48%)
					(a) Exist (0)
					(b) Does not exist (100)
			(b) Does not exist (100%)		
3. Upper structure component inspection (29%)	3.A. Beam inspection (22%)	3.A.1	Concrete structure		
		3.A.1.1	Cracking on beam (18%)		
			(a) Exist	3.A.1.1.1	Types of cracking (70%)
					(a) Cracking due to inner force failure (23)
					(b) Cracking due to moisture or environment factors (62)
					(c) Combinations of two types of cracking above (15)
				3.A.1.1.2	Crack width (30%)
					(a) Less than 0.3 mm (100)
					(b) Wider than 0.3 mm (0)
			(b) Does not exist (100)		
		3.A.1.2	Damage on beam (31%)		
			(a) Exist	3.A.1.2.1	Types of damage on beam
					(a) Delaminated (62)
					(b) Spalling (26)
					(c) Both of the selection above (12)
			(b) Does not exist (100)		

Table 1 - Part I: visual inspection

Category [1]	Sub-Category [2]	Indicator [3]		Sub - Indicator [4]	
		3.A.1.3	Exposed rebar on beam (51%)		
			(a) Exist	3.A.1.3.1	Exposure condition's detail
					(a) Damage rebar and rusted (12)
					(b) Rebar does not damage but rusted founded (25)
					(c) Rebar damage, no rust founded (21)
					(d) Rebar does not damage, and no rust founded (43)
			(b) Does not exist (100)		
		3.A.2	Steel structure		
		3.A.2.1	Buckling failure on beam (37%)		
			(a) Exist (0)		
			(b) Does not exist (100)		
		3.A.2.2	Damage on steel connection (*block shear, tearing, cracking*) (42%)		
			(a) Exist (0)		
			(b) Does not exist (100)		
		3.A.2.3	Rust on beam (9%)		
			(a) Exist (0)		
			(b) Does not exist (100)		
		3.A.2.4	Rust on steel connection (12%)		
			(a) Exist (0)		
			(b) Does not exist (100)		
	3.B. Column inspection (51%)	3.B.1	Concrete structure		
		3.B.1.1	Cracking on column [21%]		
			(a) Exist	3.B.1.1.1	Types of cracking (70%)
					(a) Cracking due to inner force failure (28)
					(b) Cracking due to moisture or environment factors (52)
					(c) Combinations of two or more types above (20%)
				3.B.1.1.2	Crack width (30%)
					(a) Less than 0.3 mm (100)
					(b) Wider than 0.3 mm (0)
			(b) Does not exist (100%)		
		3.B.1.2	Damage on column (30%)		
			(a) Exist	3.B.1.2.1	Types of damage on beam
					(a) Delaminated (55)
					(b) Spalling (27)
					(c) Both of the selection above (18)
			(b) Does not exist (100)		
		3.B.1.3	Exposed rebar on column (49%)		

Table 1 - Part I: visual inspection

Category [1]	Sub-Category [2]	Indicator [3]		Sub - Indicator [4]	
			(a) Exist	3.B.1.3.1	Exposure condition's detail
					(a) Damage rebar and rusted (8)
					(b) Rebar does not damage but rusted founded (15)
					(c) Rebar damage, no rust founded (20)
					(d) Rebar does not damage, and no rust founded (57)
			(b) Does not exist (100)		
		3.B.2	Steel concrete		
		3.B.2.1	Buckling failure on beam (29%)		
			(a) Exist (0)		
			(b) Does not exist (100)		
		3.B.2.2	Damage on steel connection (*block shear, tearing, cracking*) (44%)		
			(a) Exist (0)		
			(b) Does not exist (100)		
		3.B.2.3	Rust on beam (13%)		
			(a) Exist (0)		
			(b) Does not exist (100)		
		3.B.2.4	Rust on steel connection (14%)		
			(a) Exist (0)		
			(b) Does not exist (100)		
	3.C. Brick wall inspection (5%)	3.C.1	Damage on the brick wall (48%)		
			(a) Exist	3.C.1.1	Types of damages:
					(1) Tilted (19)
					(2) Delaminated (45)
					(3) Holed (25)
					(4) Two or more types of damages (11)
			(b) Does not exist (100)		
		3.C.2	Cracking on the brick wall (36%)	3.C.2.1	Cracking type (see Figure 3)
			(a) Exist		(1) Number 1, *expansion cracks* (38)
					(2) Number 2, crack above the opening (21)
					(3) Number 3, crack due to failure on rebar (20)
					(4) Number 4, crack due to soil settlement (13)
					(5) Number 5, crack due to soil subsidence (11)
					(6) More than one type of cracking occurs (7)
			(b) Does not exist (100)		
		3.C.3	Rain leak on the brick wall (16%)		

Table 1 - Part I: visual inspection

Category [1]	Sub-Category [2]	Indicator [3]	Sub - Indicator [4]
			(a) Exist (0)
			(b) Does not exist (100)
	3.D. Roof structure inspection (10%)	3.D.1	Wooden roof structure
		3.D.1.1	Structural deterioration on roof structure (32%)
			(a) Exist (0)
			(b) Does not exist (100)
		3.D.1.2	Structural deterioration on roof connection (68%)
			(a) Exist (0)
			(b) Does not exist (100)
		3.D.2	Light-weighted steel roof structure
		3.D.2.1	Structural deterioration on roof structure (32%)
			(a) Exist (0)
			(b) Does not exist (100)
		3.D.2.2	Structural deterioration on roof connection (68%)
			(a) Exist (0)
			(b) Does not exist (100)
	3.E. Floor slab inspection (11%)	3.E.1	Ground floor
		3.E.1.1	Indications of soil movement that damages the floor slab/slab do not on the same elevation (48%)
			(a) Exist (0)
			(b) Does not exist (100)
		3.E.2	Above the ground floor
		3.E.2.1	Indications of structural deterioration that damage floor slab (crack on the floor, slab does not on the same elevation) (52%)
			(a) Exist (0)
			(b) Does not exist (100)
4. Document Inspection (19%)	4.A. Dimensional examination in as-built drawings (18%)	4.A.1	Concrete structure
		4.A.1.1	The dimensions of the beams and columns designed (33%)
			(a) Comply with the minimum requirements according to SNI 2847: 2013 (100)
			(b) Does not comply (0)
		4.A.1.2	The column has a bigger section area than beam to comply strong-column-weak-beam aspect (SCWB) (41%)
			(a) Yes (100)

Table 1 - Part I: visual inspection

Category [1]	Sub-Category [2]	Indicator [3]	Sub - Indicator [4]
			(b) No (0)
		4.A.1.3	Floor slab thickness designed with minimum thickness according to SNI 2847: 2013 (26%)
			(a) Comply minimum thickness according to SNI 2847: 2013 (100)
			(b) Less than minimum thickness according to SNI 2847:2013 (0)
		4.A.2	Steel structure
		4.A.2.1	Steel profile dimensions designed
			(a) Comply standard requirements (slenderness and compactness) (100)
			(b) Does not comply (0)
	4.B. Configuration of structural elements in as-built drawings (27%)	4.B.1	Concrete structure
		4.B.1.1	Spacing and cover to rebar in beams and columns (28%)
			(a) Followed the minimum and maximum spacing as in SNI 2847: 2013 (100)
			(b) No (0)
		4.B.1.2	Configuration installed on beams and columns (37%)
			(a) meets the minimum reinforcement area requirements according to SNI 1726: 2019 and SNI 2847: 2013 (100)
			(b) less than minimum area requirements according to SNI 1726: 2019 and SNI 2847: 2013 (0)
		4.B.1.3	The existing reinforcement configuration rebar ratio: (35%)
			(a) under the terms of the ratio of reinforcement according to SNI 2847: 2013 (100)
			(b) more than the terms stated in SNI 2847:2013 (0)
		4.B.2	Steel Structure
		4.B.2.1	Bolt distance and/or length of the weld designed
			(a) Comply with the requirements in SNI 1729: 2015 (100)
			(b) Does not comply (0)

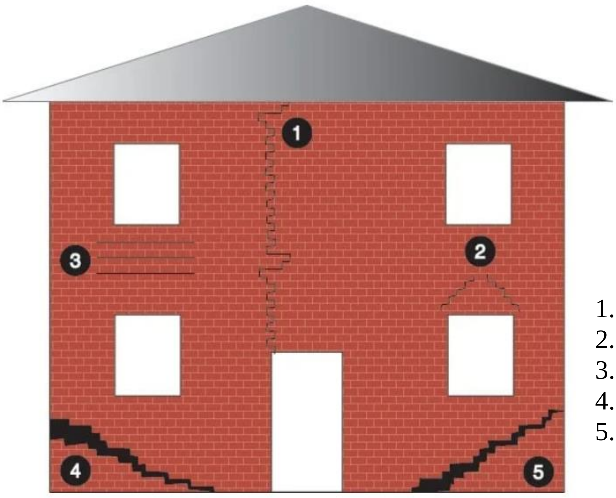
Table 1 - Part I: visual inspection

Category [1]	Sub-Category [2]	Indicator [3]		Sub - Indicator [4]
	4.C. Accuracy of built construction towards as-built drawing (30%)	4.C.1	Concrete structure	
		4.C.1.1	The dimensions of the structural components are matched with those in the as-built drawings (58%)	
			(a) Match (100)	
			(b) Does not match (0)	
		4.C.1.2	The location of placement and the length of the structural components are matches (42%)	
			(a)Match (100)	
			(b)Does not match (0)	
		4.C.2	Steel Structure	
		4.C.2.1	The beams and columns profile dimensions are matches (42%)	
			(a) Match (100)	
			(b) Does not match (0)	
		4.C.2.2	Connection details match (33%)	
			(a) Match (100)	
			(b) Does not match (0)	
		4.C.2.3	The location of placement and the length of the structural components are matches (25%)	
			(a) Match (100)	
			(b) Does not match (0)	
	4.D. Compatibility between as-built drawing and geotechnical report (25%)	4.D.1	By matching with the as-built drawing, is the foundation built-in hard soil? (33%)	
			(a) Yes (100)	
			(b) No (0)	
		4.D.2	By matching the As-built drawings, is the foundation built at the proper depth as recommended in the geotechnical report (67%)	
			(a) Yes (100)	
			(b) No (0)	
Score - Part I = ∑ ([4] x [3] x [2] x [1])				

Table 2 - Part II: non-destructive testing

Category [1]	**Sub-Category [2]**		**Indicator [3]**	
1. Non-destructive test for beams and columns	1.A.	Non-destructive test for concrete structure		
	1.A.1	Concrete uniformity test (Schmidt hammer test) (24%)	1.A.1.1	Average rebound number of Schmidt hammer test
				(a) > 40 (100)
				(b) 30 until < 40 (75)
				(c) 20 until < 30 (50)
				(d) < 20 (25)
				(e) 0 (0)
	1.A.2	Concrete cracking test (ultrasonic pulse velocity) (33%)	1.A.2.1	Average pulse velocity speed of ultrasonic pulse velocity test
				(a) > 4.0 km/sec (100)
				(b) 3.5 to 4.0 km/sec (75)
				(c) 3.0 to 3.5 km/sec (50)
				(d) < 3.0 km/sec (25)
	1.A.3	Concrete cover and rebar configuration test (*rebar scan)* (42%)	1.A.3.1	Average concrete cover measurement of rebar scan (40%)
				(a) < 40 mm (not following the minimum thickness of SNI 2847: 2013) (100)
				(b) ≥ 40 mm (following the minimum thickness of SNI 2847: 2013) (0)
			1.A.3.2	Are the configurations of beams and columns are matched with as-built drawings? (60%)
				(a) Matched (100)
				(b) Does not match (0)
	1.B	Non-destructive test for steel structure		
	1.B.1	Steel hardness test (*hardness brinell test*) (80%)	1.B.1.1	Tensile strength of the steel
				(a) Comply with the minimum tensile strength requirements under SNI 1729: 2015 (100)
				(b) Does not comply (0)
	1.B.2	Steel coating thickness test (coating thickness gauge test) (20%)	1.B.2.1	The thickness of the coating on the steel still meets the minimum standards according to ASTM 123 / 123M or EN ISO 1461?
				(a) Comply the minimum standards according to ASTM 123 / 123M or EN ISO 1461 (100)
				(b) Does not comply (0)
Score - Part II= ∑ ([4] x [3] x [2] x [1])				

or light steel roofs need to be considered to ensure the strength of the roof frame joints. Therefore, Roof Structure is stipulated in the tool for assessing the preparedness of earthquake-resistant school buildings as a sub-category with two indicators, namely the Frame Structure, and Joints, for both types of materials. The development of roof structure inspection sub-categories can be seen in detail in Table 1.



1. Expansion cracks
2. Crack above opening
3. Crack due to failure of reinforcement
4. Crack due to settlement.
5. Crack due to subsidence

Fig. 3 - Types of cracking in brick wall [12]

Floor slabs are horizontal structural components that function as distributors of live and dead loads to beams and columns. Generally, soil settlement and subsidence will cause unevenness of slab elevation. The Floor Slab inspection sub-category has two indicators that are distinguished based on the location of the floor slabs, i.e., On the Ground Floor, and Above the Ground Floor where the loads are designed differently for each slab. Besides, the distribution of slab loads other than on the ground floor is not directly accepted by the soil, but by other structural components which can cause differences in structural degradation. The description of the sub-categories can be seen in Table 1.

The last category is Document Inspection. The document consists of as-built drawings and soil testing documents. It is carried out to clarify the design against the standards, as well as their suitability with the built construction. This category has four sub-categories which can be described in Table 1. The first sub-category of Dimensional Examination in As-built Drawings emphasizes the structural component designed and built according to SNI 2847: 2013 (for concrete) [13] and SNI 1729: 2015 (for steel) [14]. Inside, the minimum dimensions, as well as the requirement that the column section must be greater than the beam section are elaborated. The second sub-category of Configuration of Structural Elements in As-built Drawings focuses on examining the details in structural components such as the Thickness of The Concrete Cover, Minimum Reinforcement Area, and Rebar Reinforcement Ratio. The minimum thickness of the concrete cover is required to protect the steel reinforcement at an effective distance considering possible deflections in the concrete, as regulated in SNI 2847: 2013. The minimum reinforcing area in concrete indicates the minimum capacity that a concrete structural component must have, which is influenced by the cross-sectional area. The area of reinforcement itself is an element that functions to withstand the forces on reinforced concrete structures. On the other hand, the installed reinforcement must not exceed the maximum reinforcement ratio set out in SNI 1726: 2019. If the ratio is too large, it can cause the concrete mixture in it to become less dense and not sufficiently monolithic. The same applies to the bolt spacing and the weld length on steel elements, as stated in SNI 1729: 2015. The third sub-category Accuracy of Built Construction towards As-built Drawing is developed based on the consideration that the construction implementation process must be following the design. The last category, Compatibility between As-built Drawing and Geotechnical Report is developed to consider that the foundation is designed at the compatible depth based on Geotechnical report and recommendation.

5.2 Part Two: Non-Destructive Test

This part consists of two categories to produce supporting data from the results of the visual examination. In the meantime, the second part of the structural component preparedness assessment tool will certainly not be mandatory due to the considerable costs involved in testing. Non-destructive testing of preliminary assessment to the school buildings is distinguished based on the materials, namely concrete, steel, and composite (see Table 2). The Uniformity of Concrete Testing sub-category is implemented as supporting data on the results of visual inspection of cracks and damage to concrete structural components. In this case, the Schmidt Hammer test is carried out to determine the number of rebounds that represent the concrete uniformity. Furthermore, the result will show the feasibility of the material and structural degradation. The indicator in this sub-category refers to the Number of Hammer Rebound as determined by Gopal Mishra [15]. The second sub-category of Crack Testing in Concrete Beams is also considered to support the results of examining cracks and structural component damage using the Ultrasonic-Pulse Velocity test. This test uses the principle of fast-wave propagation as a response to the depth of cracks and damage to a concrete structural element. The indicators in this sub-category apply the British Standards [16]. The third sub-category of Concrete Cover Thickness and Reinforcement Configuration was developed as supporting data for the Document Inspection category in the first part. In this case, the rebar scan test is used to produce outputs, i.e., number and dimensions of reinforcement, as well as the thickness of the concrete cover.

For school buildings that use steel as the material, this assessment tool also accommodates two sub-categories. The first sub-category, Steel Hardness Testing emphasizes the output of the Brinell Hardness test results which represent the tensile strength of a steel profile. The minimum value must follow the requirements as determined on SNI 1729: 2015. Another sub-category, namely Coating Thickness Testing, emphasizes the output of the coating thickness gauge test results as the remaining thickness of the coating paint on a steel profile which is regulated by the minimum value in ASTM 123/123M [17]. Coating paint protects steel against rust, which is a form of structural degradation that can reduce the cross-sectional area and tensile strength of a profile. The detailed development of this part can be seen in Table 2.

5.3 Assessment Tool: How to Use?

At this stage, the newly developed assessment tool will be provided with weights and a scoring system to produce a percentage indicating the level of preparedness of the school building being reviewed. Based on the results of the AHP, the weight of each variable is obtained as in Tables 1 and 2 (column 1 to 4). In Part I: Visual Inspection (Tabel 1), the Sub-structure Components Inspection category has the greatest weight compared to other categories because the foundation is a structural component that has an important role in maintaining stability, slope, and load distribution from the upper structure. If there is an indication of soil movement that can cause damage or destruction to the foundation, the effect will be very dangerous for the whole building. The category with the second greatest weight is the Upper Structure Components Inspection because it is directly related to the preparedness of the structure of a school building. In the next hierarchy, the sub-category in the Upper Structure Components Inspection category that has the biggest weight is the Column Inspection. The function of the column as the recipient of the lateral force from the earthquake, and at the same time as the support of the beam, makes it a structural component that receives the greatest distribution of forces, both axial and moment forces. Also, the column functions to receive and transmit forces from the floor above to the floor below, and therefore, the column must be in good condition. The next biggest weights belong to the sub-categories of Beam Inspection, Floor Slab Inspection, and Roof Structure Inspection, and Brick Wall Inspection, respectively.

In Part II: Non-Destructive Testing (Table 2), the weights are the result of validation from several experts with the consideration that greater weight is given to the tests that are more efficient to carry out, especially in school buildings in Indonesia. The test has not been made mandatory due to the large costs involved, and the limited budget that most schools in Indonesia have in common. Therefore, the scores obtained from this part will be treated as additional scores to the previous part scores. Possible combinations of materials (composite structure) are included in this tool and weighed separately. The results of the weighting of the composite structure can be seen in Table 3. For composite structures, schools with the number of floors more than one, and types of possible combinations the total percentage of the sub-category will be multiplied by the weight of each variable that would be the factor of the combination.

Table 3 - Combination of variables

Combination of Variables	Weight	
Structure material	Concrete 41 (%)	Steel 59 (%)
Roof structure material	Wooden 76 (%)	Light-weighted steel 24 (%)
Number of Floors	Ground floor 48 (%)	Above the ground floor 52 (%)
Types of foundation	Shallow foundation 59 (%)	Deep foundation 48 (%)

The assessment tool that was successfully developed as shown in Tables 1 to 2 are used by filling the columns from the far left to the right. However, the final percentage is obtained by multiplying the score and the weights of the variables from right to left, namely starting from the Sub-Indicator's Weight in columns (4) to Category's weight in column (1). This rule applies in both parts of the assessment tool. To achieve the minimum preparedness for the structural components of an earthquake-resistant school building, the minimum score for Part I: Visual Inspection was set at 70 (out of 100) due to several considerations as follows:

- The building is not tilted,

- No indication of subsidence indicating damage to the foundation structure,
- There is no indication of any exposed reinforcement to chipping on concrete beams and columns, and/or there is no damage and rust on the joints of steel beams and columns,
- Only experience delamination on the wall and only expansion cracks occur in the wall (if there is a crack),
- Slab, frame, and roof joints are in good condition without damage, or
- Meet the requirements of strong-column-weak-beam dimensions, minimum reinforcement area, and maximum reinforcement ratio, as well as as-built drawing checked by built construction and geotechnical report.

6. Conclusions

This research produces a preliminary assessment tool to measure the level of preparedness of the structural components of an earthquake-resistant school building by considering two main parts. The parts include Visual Inspection, with 4 categories, 12 sub-categories and 28 indicators, and Non-Destructive Testing which contains 5 sub-categories. Three types of non-destructive tests for concrete structural components and 2 types for steel components are proposed in this tool. The assessment tool also produces variables that consider the composite structure materials used in school buildings in Indonesia with their respective weight proportions, including roof structure material, structural components material, number of slabs, and type of foundation.

A minimum score of 70 has been determined for Part I: Visual Inspection to indicate the level of preparedness of the structural components of the earthquake-resistant school building, with an additional score that can only be obtained if the school building has been tested using the Non-Destructive method. This assessment tool that has been validated and verified by the experts involved in this area is expected to provide input for related parties, such as the National Disaster Management Agency, the Regional Disaster Management Agency West Java Province, the Ministry of Education and Culture of the Republic of Indonesia, and building inspectors in supporting the preparedness of the structural components of school buildings as an effort to reduce the risks of earthquake disasters on educational facilities.

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