A Study on the Feasibility of Merdeka Market Buildings in Terms of Earthquake Resistance and Structural Strength

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ABSTRACT

The structural integrity of the Merdeka Market building in Bogor City is a matter of particular concern for the Indonesian government, given its age of approximately 25 years and the resulting structural deterioration. The purpose of this study is to assess the overall reliability of the building, its seismic vulnerability, and structural safety, in order to provide effective recommendations for improving the building's performance, in terms of its architectural quality, stability, utility systems and accessibility. Data are collected through physical observations and non-destructive test, such as the Hammer test and Ultrasonic Pulse Velocity (UPV) test. The compressive strength of concrete is calculated and compared to the technical requirements. The seismic resistance is determined through simulation, using a 3D model of the building. The Rapid Visual Screening (RVS) test provides the vulnerability score of the structure. The results of the various tests determine the overall reliability of the Merdeka Market building.

Keywords-building reliability; building vulnerability; rapid visual inspection

I. INTRODUCTION

The Merdeka Market building in Bogor city does not meet the standards of safety, health, and comfort for its users. The lack of research on its structural integrity results in limited reference material for comparison, highlighting the insufficient government attention on the matter.

All buildings are required to meet technical standards, including both system and reliability requirements [1, 2]. To ensure reliability, the building must function based on the principles of safety, health, comfort, and convenience. The Merdeka Market building (Figure 1) entered its 25th year and is still operating as a place for the trade of vehicle spare parts, serving the needs of the surrounding community. However, it is considered suboptimal in terms of reliability. Its structural elements have deteriorated due to the exposure to humidity, a damaged drainage system and overgrown vegetation on the roof, all of which are results of inadequate maintenance. The reliability of the building will be assessed based on whether it meets the minimum requirements for structural concrete [3]. The seismic design and the applied loads will be taken into consideration, based on previous studies [4, 5].

(a) (b)

Fig. 1. External (a) and internal (b) view of the Merdeka Market building.

II. LITERATURE REVIEW

The assessment of the overall reliability of the building includes the evaluation of its structural adequacy, according to technical guidelines, as well as the evaluation of factors, such as comfort, health, safety, accessibility, and environmental harmony.

A. Building Reliability

Building reliability, based on function, refers to the ability of a building to perform its designed role or activity safely, comfortably, and sustainably throughout its service life. Buildings must meet the technical requirements according to their type of use, such as strong and earthquake-resistant structures for public buildings, good air circulation systems for residential buildings, and efficient spatial planning for commercial or industrial buildings. The aspects of the reliability evaluation are shown in Table I [6].

TABLE I. COMPONENT FUNCTIONING CONDITION

Component functioning condition	Reliable	Less reliable	Not reliable	Function weight (%)
Architecture	95 -100	75 - < 95	< 75	10.00
Structure	96 -100	85 - < 95	< 85	30.00
Utilities and fire protection	97 -100	95 - < 99	< 95	50.00
Accessibility	98 -100	75 - < 95	< 75	5.00
Building and environmental planning	99 -100	75 - < 95	< 75	5.00
Total building reliability score				100.00

The total reliability score will place the building in one of the following categories:

- Reliable, with an overall accumulated score for its reliability components ranging from 95% to 100%.
- Less Reliable, with a total score between 75% and 95%.
- Unreliable, with a total score below 75%.

To obtain reliability parameter values, the following equations are used [6]:

$$\text{NKA} = \text{Functional weight} - \frac{\text{Existing damage}}{\text{Existing condition}} \times \text{Functional weight} \quad (1)$$

$$\text{NK} = \frac{\text{Aspect weight}}{\text{Fuctional weight}} - \sum \text{NKA} \frac{\sum \text{NKA} \times \text{Aspect weight}}{\sum \text{Fuctional weight}} \quad (2)$$

where NKA is the Initial Reliability Value and NK is the Reliability Value.

B. Technical Aspects of the Building

The quality of the concrete is assessed by determining the compressive strength and the surface hardness, through non-destructive tests, namely the Hammer test, UPV test, and RVS.

The Hammer test or Rebound Hammer test is used to estimate the compressive strength of concrete. The UPV test measures the speed of the ultrasonic waves passing through concrete. This speed is related to the quality and density of the concrete; good concrete will allow the waves to travel faster. These three methods are often used together to obtain a comprehensive picture of the condition of the building structure.

The results are then compared to the required quality limits for concrete [7-9], as portrayed in Table II.

TABLE II. LIMITATION OF CONCRETE QUALITY VALUES (FC')

Usage	Concrete Type	Minimum fc' value (MPa)	Maximum fc' value (MPa)
General usage	Normal and lightweight concrete	17	No Limitation
Special moment bearing frame systems and specialized structural walls	Normal concrete	21	No Limitation
	Lightweight concrete	21	35

RVS is a method of initial building assessment developed by the Federal Emergency Management Agency (FEMA) to identify, inventory, and observe buildings that are potentially hazardous to earthquakes [10]. RVS is based on field surveys and data collection forms, which are completed based on visual observations of the building's exterior and interior, recording its structural condition, geometric shapes, materials, and levels of visual damage [11, 12]. The results of this method determine the seismicity location, as depicted in Table III.

TABLE III. SEISMICITY LOCATION BASED ON SPECTRUM RESPONSE RESULTS

Seismicity location	Spectrum response acceleration, S_s (short period, or 0,2 s)	Spectrum response acceleration, S_1 (long period, or 0,1 s)
Low	$S_s \leq 0.250$ g	$S_1 \leq 0.100$ g
Moderate	$0.250 \text{ g} \leq S_s \leq 0.500$ g	$0.100 \text{ g} \leq S_1 \leq 0.200$ g
Moderate High	$0.500 \text{ g} \leq S_s \leq 1.000$ g	$0.200 \text{ g} \leq S_1 \leq 0.400$ g
High	$1.000 \text{ g} \leq S_s \leq 1.500$ g	$0.400 \text{ g} \leq S_1 \leq 0.600$ g
Very high	$S_s \geq 1.500$ g	$S_1 \geq 0.600$ g

Concrete is one of the main materials in building construction because it has high compressive strength and good resistance to the weather and structural loads [13]. However, over time, its strength and quality can decrease, especially if routine maintenance is not carried out. In buildings with high activity, such as markets, factors, like the dynamic loads from people and vehicles, and the exposure to humidity, water, organic waste, and cleaning chemicals, may accelerate the concrete degradation [14].

Even though concrete can undergo a hydration process to increase its strength in the long term, time significantly affects its durability. The cracks, carbonation, chloride penetration, and corrosion of steel reinforcement are some of the factors that lead to concrete degradation over time [15]. The carbonation process occurs when carbon dioxide from the air enters the pores of the concrete and reacts with calcium hydroxide, causing a decrease in the concrete's pH and potentially corroding the reinforcing steel. In addition, if the drainage system is poor, water can enter the structure and accelerate damage [16, 17].

Since the Merdeka Market building has been standing for almost three decades, a thorough evaluation of the structure's condition is needed, especially on the main elements, such as columns, beams, floors, and concrete roofs. Initial inspection can be done by visual observation to detect cracks, pores, peeling surfaces, or traces of moisture. Further inspection involves non-destructive testing and core drilling to determine the current concrete quality and potential internal damage [18].

The structural evaluation will indicate the elements that are in need of repair or reinforcement. Open cracks need to be patched with appropriate materials, such as grout or epoxy, depending on the depth and type of the crack. If there is corrosion on the reinforcement, it is necessary to strip the damaged area, clean the rust from the steel, and re-coat it with a protective layer before re-patching. The drainage system and waterproofing coating must also be repaired if there is seepage or waterlogging that can damage the structure in the long term. Market floors that are exposed to heavy loads and high humidity every day are likely to experience abrasion or wear, so re-coating with materials that are more resistant to heavy traffic and water can be considered [19, 20].

In addition to the physical improvements, adjustments to the building standards that may have developed over the past 30 years are also needed. These include adding a fire protection system, improving lighting and ventilation, and adjusting the structure to support the use of new technologies [21]. All of these actions are important not only to extend the life of the building, but also to ensure the safety of visitors and traders in the market. With proper maintenance a nearly 30-year-old market building can still function optimally for the decades to come [2, 22].

Composite concrete maintenance is essential to maintain the strength, durability, and service life of a building structure. Composite concrete, which is a combination of concrete and additives, such as steel fibers, polymers, or fly ash, has advantages in terms of the crack resistance and flexibility. However, without proper maintenance, the quality of this material can deteriorate due to environmental factors, like humidity, extreme temperatures, chemical exposure, and repeated loads. Maintenance includes regular cleaning, moisture control, and periodic visual and structural inspections to detect cracks, holes, or corrosion of reinforcement. If damage is found, repairs must be made using materials that are compatible with the composite concrete. In addition, the application of a protective coating or sealant can help prevent the water and hazardous substances from entering the pores of the concrete. With consistent maintenance, composite concrete can maintain its performance and provide long-term structural protection for buildings [23]. The connection between the columns and beams in composite concrete is an important part of the building's structural system, because it is the main support point in transferring the load from the beam to the column and then to the foundation. In composite concrete, this connection is designed to be able to withstand the shear forces, bending moments, and axial loads efficiently. The integration of composite materials at the beam-column connection strengthens the structural integrity and increases ductility, allowing the structure to absorb energy better, especially under earthquake conditions. The connection detailing must be designed precisely to ensure the continuity and strength of the structure [24].

III. RESEARCH METHODS

The Merdeka Market building is located on Jl. Perintis Kemerdekaan Kebon Kelapa, Central Bogor District (Figure 2). This research was conducted on the 9th April, 2024

Fig. 2. Research location map.

After the primary and secondary data are collected, they are analyzed through non-destructive tests, and simulations in order to determine the building vulnerability. The research procedure is described in Figure 3.

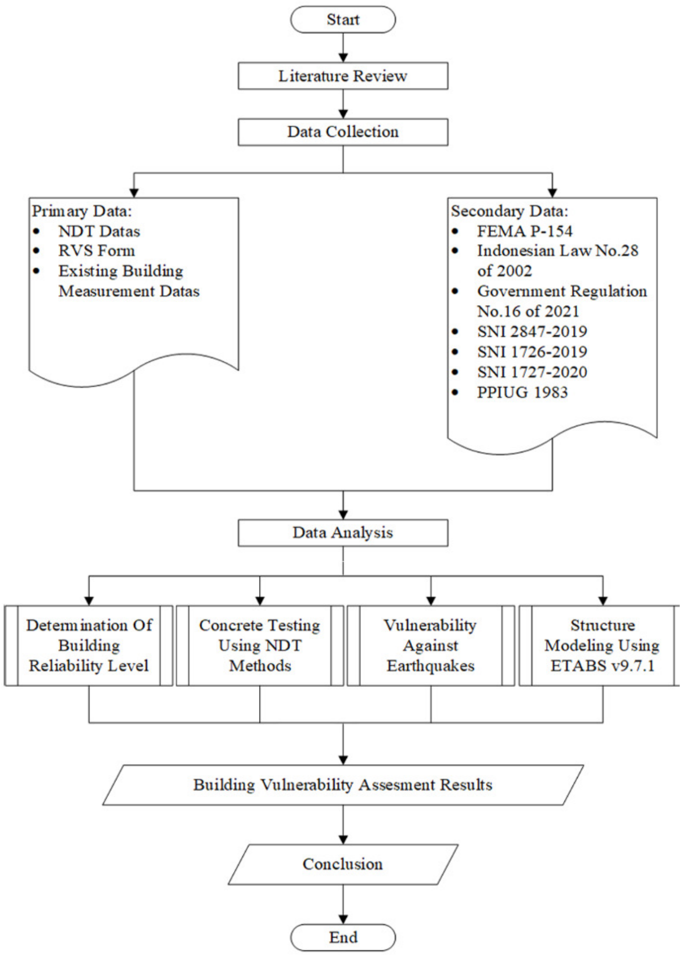

Fig. 3. Research flow chart.

SAP2000 and ETABS software are used as structural analysis tools to evaluate the reliability of buildings, especially those that are more than 25 years old. This software can perform load analysis and simulate the deformation and response to earthquakes or other dynamic loads, on a 3D model of the building. SAP2000 can be used for various types of structures, whereas ETABS is more specifically used for multi-storey buildings. Field data, such as the dimensions of structural elements, actual material quality (from Hammer or UPV tests), and damage conditions are collected and inserted in the model. Simulations are then run to determine whether the structure still meets applicable strength and stability standards. The software can indicate which elements are experiencing overstress or decreased performance and need reinforcement or renovation.

IV. RESULTS AND DISCUSSION

The building was constructed in 1998 by the Bogor City Government and consists of 4 floors with a total area of 6,290m^2, hosting shops and other related services, as illustrated in Table IV. The structural system is composed of concrete slabs, columns and beams, with a concrete slab roof.

TABLE IV. ROOM FUNCTION OF MERDEKA MARKET BUILDING

No.	Function	Amount	Area (m^2)
1	Management office	1	95
2	Shop	467	1,868
3	Parking area	1	671
4	Hallway	1	3,422
5	Stairway	15	188.1
6	Toilet	2	10
7	Praying room	3	36
Total building area			6,290

A. *Building Reliability Assessment*

The reliability assessment result for the building marked it as "Unreliable," with a percentage of 33.37%, as displayed in Table V.

TABLE V. TOTAL RELIABILITY VALUE OF THE BUILDING

No.	Component functioning condition	Function weight (%)	Results (%)
1	Architecture	10.00	4.80
2	Structure	30.00	11.25
3	Utilities and fire protection	50.00	11.52
4	Accessibility	5.00	1.65
5	Building and environmental planning	5.00	4.15
Total building reliability score		100.00	33.37

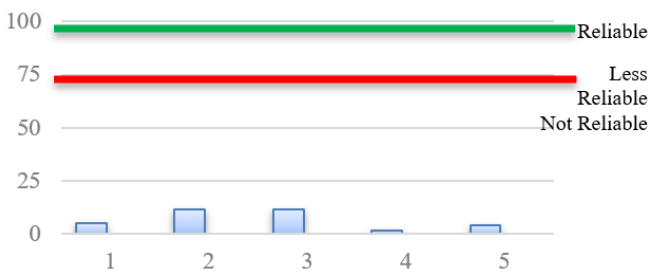

Fig. 4. Reliability graph of Merdeka Market building.

B. *Concrete Strength Testing*

The Hammer test was conducted on concrete elements suspected of experiencing weathering. Samples were taken from 96 columns, 9 plates, and 21 beams that were selected visually, due to damage and their compressive strength was determined (Table VI). The UPV test took 120 concrete sample points from columns, beams, and concrete slabs providing the results shown in Table VII.

TABLE VI. SUMMARY OF CONCRETE COMPRESSIVE STRENGTH VALUES WITH THE HAMMER TEST METHOD

Structural elements	Estimated value of concrete compressive strength		
	Description	Kg/cm^2	MPa
Basement floor column	Maximum	532.55	52.23
	Minimum	223.11	18.52
1st floor column	Maximum	542.00	53.15
	Minimum	279.11	27.37
2nd floor column	Maximum	558.66	54.79
	Minimum	118.55	11.63
1st floor beam	Maximum	400.56	38.28
	Minimum	267.67	27.13
2nd floor beam	Maximum	359.11	32.21
	Minimum	155.11	15.21
Rooftop beam	Maximum	393.00	38.54
	Minimum	216.44	21.22
1st floor slab	Maximum	337.12	33.06
	Minimum	250.89	24.61
2nd floor slab	Maximum	454.89	44.61
	Minimum	317.56	31.14
Rooftop slab	Maximum	337.12	33.06
	Minimum	263.33	25.82

TABLE VII. SUMMARY OF CONCRETE COMPRESSIVE STRENGTH VALUES WITH THE UPV TEST METHOD

Structural elements	Estimated value of concrete compressive strength		
	Description	Kg/cm^2	MPa
Column	Maximum	553.53	45.94
	Minimum	264.91	21.99
Beam	Maximum	377.61	31.34
	Minimum	203.63	16.90
Slab	Maximum	481.98	40.00
	Minimum	194.44	16.14

The average value of compressive strength is above the minimum required limit of the fc' value, which is 21 MPa.

C. *Calculation of Vulnerability to Earthquakes*

The building consists of 4 floors, including a concrete slab roof. The structural material used is reinforced concrete, forming slabs, columns, and beams. The columns are fully fixed at their base, due to a deep foundation system. Gravity loads, including dead loads, live loads, wind loads, and earthquake loads, are transferred from the slabs to the beam and then distributed to the columns. The structure and its components are designed to ensure that all cross-sections meet the required strength standards, as determined by the applicable load combinations and factored forces.

The D/C ratio is a measure of the demand on a member against its capacity, where D stands for "demand" and C stands for "capacity." In order to ensure that the member is not subjected to loads beyond its carrying capacity, D/C should be less than 1. However, ratios below 0.1 would suggest that the section of the member might be too big. Table X shows the security level, depending on the D/C ratio [25].

TABLE VIII. DEMAND/CAPACITY RATIO (D/C)

No	Color	D/C ratio	Security level
1	Blue	0,00 s/d 0,50	Very safe
2	Green	0,50 s/d 0,70	Safe
3	Yellow	0,70 s/d 0,90	Safe
4	Purple	0,90 s/d 0,95	Quite safe
5	Red	≥0,95	Overstrength

The results of the modeling analysis (Figure 5) determined that the building is unsafe against the external forces, with the structural elements experiencing overstrength.

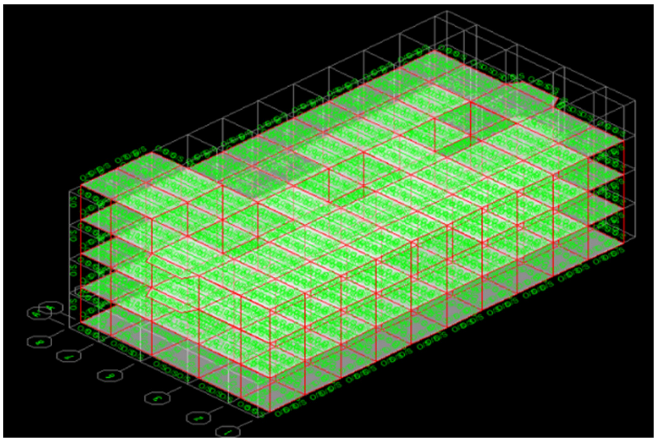

Fig. 5. Building structure model

D. *Rapid Visual Screening Test*

The score of the building in the RVS test carried out, according to FEMA P-154, was 2.9, as presented in Figure 6. The vulnerability index (S) of the building was then calculated as:

$$S = \frac{1}{10^{SL_1}} = \frac{1}{10^{2.9}} = 0.00126 \qquad (3)$$

A vulnerability value of 0.126% is very low; therefore, the building is safe.

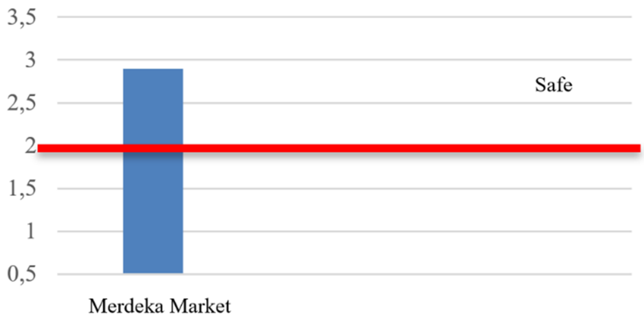

Fig. 6. Vulnerability final score graph of Merdeka Market building.

Structural analysis is the process of calculating the internal forces that act on the building structures and determine the structural behavior and safety under expected conditions. The data used as parameters for analyzing the existing structures are primary data, including the dimensions and elevations of the building (Table IX), as well as secondary data, such as the quality of the concrete obtained from the Hammer test (Table X).

TABLE IX. BUILDING PROPERTIES

No	Type of data	Description
1	Building function	Market
2	Building width	15.5 m
3	Building length	33 m
4	Number of stories	3 stories and 1 basement
5	Building height	12 m
6	Column dimensions	40x40 cm column (continuous column structures)
7	Beam dimensions	60x30 main beam and 30x15 cm secondary beam
8	Slab thickness	12 cm

TABLE X. MATERIAL PROPERTIES

No	Type	Description
1	Concrete quality	Column, Ec = 4,700 x √(fc') = 4,700 x √53 = 34,216.52 MPa.
		Beam, Ec = 4,700 x √(fc') = 4,700 x √35 = 27,805.57 MPa
		Slab, Ec = 4,700 x √(fc') = 4,700 x √35 = 27,805.57 MPa
2	Rebar steel quality	Threaded rebar D-19 with fy = 400 MPa (BJTP 35)
		Reinforcing bars Ø 12 with fy = 400 MPa (BJTS 40).

V. CONCLUSION

Based on the results of the vulnerability assessment, it can be concluded that the Merdeka Market building is not safe, for the following reasons:

1. The overall reliability score is 33.37%, categorizing it as "unreliable."
2. The Hammer test and the Ultrasonic Pulse Velocity (UPV) test revealed signs of concrete degradation. Although the average compressive strength was higher than the required value, some measurements were below this limit.
3. The results of the modeling analysis on the existing structure of the building indicated overstrength of the structural elements, marking it unsafe against the external forces.
4. Rapid Visual Screening (RVS) test was conducted through site survey and the RVS form was completed, including building identification, soil data, and geolocation. The results showed a low vulnerability value.

Therefore, the building should be demolished and rebuilt.

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