

Performance Assessment of Concrete Structure Urea Fertilizer Dust Scrubber

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ABSTRACT

The concrete dust scrubber building is a critical unit in urea fertilizer plants, tasked with processing urea dust emissions to mitigate environmental pollution. Given its structural degradation over time and Indonesia's location in the seismically active Pacific Ring of Fire, ensuring its functional viability is paramount. This study aimed to evaluate the structural performance of the scrubber building through a combination of Non-Destructive Testing (NDT) methods, including Ultrasonic Pulse Velocity (UPV) and Hammer Tests, due to safety constraints preventing Destructive Testing (DT). The research also assessed reinforcement steel quality and environmental effects such as carbonation and chloride exposure. Using Robot Structural Analysis Professional (RSAP) software, the analysis adhered to ASCE 41-17 and SNI 1726:2019 standards, focusing on Tier 1 and Tier 2 quantitative evaluations. Findings revealed a concrete compressive strength of 24.4 MPa and a 24 MPa reduction in steel yield strength (from 420 MPa to 396 MPa), attributed to chemical exposure. The building's remaining service life was estimated at 28.17 years. Structural performance met seismic safety requirements, achieving the "Limited Safety" level for a 2500-year earthquake recurrence period. Retrofitting recommendations included epoxy-based coatings for wall defects to enhance longevity. This study underscores the importance of regular structural assessments and targeted retrofits to maintain operational safety in industrial environments.

KEYWORDS dust scrubber, assessment, DT, NDT, structural performance, Tier 1, Tier 2, Tier 3, SRPMK, RASP..



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INTRODUCTION

The concrete dust scrubber building plays a critical role in the waste treatment system of urea fertilizer plants, serving as the primary control unit for urea dust emissions. Urea dust scrubbers, as highlighted by Masjedi et al. (2024), Toyo Engineering Corporation (2024), and the U.S. Environmental Protection Agency (2020), are essential in ensuring that particulate emissions meet stringent environmental standards. Constructed in 2012, the building has been in continuous operation and, over time, has experienced leakage issues that compromise its ability

to contain urea dust effectively, a phenomenon also observed in studies on scrubber performance and aging infrastructure (Wang et al., 2019; Tomaszewski et al., 2024; Hoyos et al., 2024).

Urea dust emissions are recognized as a significant contributor to air pollution, with several investigations such as those by Adah et al. (2021), Costa et al. (2023), and Khadra et al. (2022) documenting the environmental hazards and the importance of optimizing dust capture efficiency. Beyond emission control, the structural integrity of the scrubber housing is also a concern. Research by Słomka-Słupik (2020), Su et al. (2022), and Millán Ramírez et al. (2023) demonstrates that prolonged exposure to urea can alter the properties of cement-based materials, leading to deterioration. Experimental approaches, including those described in *A novel approach for testing of concrete affected by urea* (2021) and *Influence of urea on concrete* (2020), provide further evidence that urea crystallization within microcracks can accelerate damage, underscoring the need to evaluate the building's condition in relation to its functional performance.

The structural evaluation aims to restore the structural performance and extend the service life of the building, which has undergone structural degradation due to damage that may cause urea dust emission leaks. Consequently, rehabilitation of the concrete dust scrubber structure is required. Before conducting rehabilitation, a structural performance assessment must be performed.

The initial assessment steps include Destructive Testing (DT) and Non-Destructive Testing (NDT) on the structural components such as columns, beams, and walls. However, DT and NDT for concrete slab structures were not conducted due to safety concerns, as the building contains high levels of ammonia (NH_3), posing risks to the testing team. The next step involves processing the field test data as input parameters for structural performance analysis through quantitative evaluation using Tier 1, Tier 2, and Tier 3 in accordance with ASCE 41-17 standards. The building performance parameters are assessed based on SNI 1726:2019 standards.

According to Santosa and Hartono (2004), achieving optimal concrete structural strengthening requires three key phases: Investigation, Evaluation, and Implementation. According to Imran, S. Darmawan, I. Sulaiman, C. Lie, and Aryantho (2009), the initial step in understanding the actual field conditions to determine causes of deterioration and residual stress requires an initial observation methodology through visual investigation, followed by detailed investigation using non-destructive and semi-destructive testing.

Based on ACI 224R-01: Control Cracking in Concrete Structures, the allowable crack width is provided in Table 1.

Table 1. Grid Concrete Izizn ACI 224R-01

Exposure condition	Crack width	
	in.	mm
Dry air or protective membrane	0.016	0.41
Humidity, moist air, soil	0.012	0.30
Deicing chemicals	0.007	0.18
Seawater and seawater spray, wetting and drying	0.006	0.15
Water-retaining structures†	0.004	0.10

*It should be expected that a portion of the cracks in the structure will exceed these values. With time, a significant portion can exceed these values. These are general guidelines for design to be used in conjunction with sound engineering judgement. Excluding nonpressure pipes.

The Tuutti Model (1982) [Tuutti, K., “Corrosion of Steel in Concrete”, Swed. Cem. Conc. Res. Ins., 17-21, 1982] is used to predict deterioration and divide the service life of reinforced concrete structures into two phases:

1. Initiation phase (t_{init})
2. Propagation phase (t_{prop})

According to Mitra et al. (2010) [Mitra, G., Jain, K.K., and Bhattacharjee, B., “Condition Assessment of Corrosion-Distressed Reinforced Concrete Buildings Using Fuzzy Logic”, J. Perf. Constr. Fac., 24(6), 562-570, 2010], the Condition Rating System and Prediction of Remaining Service Life can be calculated as follows:

$$Cd = K. t/2$$

$$t = \sqrt{(Cd/K)} \dots\dots\dots (1)$$

Where:

Cr = Condition rating of the structure (scale 0 to 9)

Cc = Concrete cover (mm)

Cd = Measured carbonation depth (mm)

Dccd = Difference between concrete cover and carbonation depth (mm) = Cc - Cd

Cl = Chloride concentration (% by weight of concrete).

Tcd = Time period for carbonation to reach reinforcement depth after construction, derived from Equation (2).

Tcl = Time required for chloride concentration to reach the threshold value (0.2%) at reinforcement elevation, calculated using the following equation:

$$t_{init} = \frac{c^2}{4D} \left[\operatorname{erf}^{-1} \left(1 - \frac{cth}{cs} \right) \right]^{-2} \dots\dots\dots (2)$$

Where:

- c = Selimut Beton
D = Difusi coeficient (10^{-8} cm²/s) –(Broompfield, 2011)
cth = Threshold chloride content (0.1%) – (ACI 201)
cs = Surface chloride content

Table 2: Threshold Chloride Levels Based on ACI and BS

Type	Maximum chloride content (% cem)			
	BS 8110	ACI 201	ACI 357	ACI 222
Presressed concrete	0.10		0.06	0.08
Reinforced concrete exposed to chloride in service	0.20	0.10	0.10	0.2
Reinforced concrete that will be dry or protected from moisture in service	0.4			
Other reinforced concrete		0.15		

Target Performance Level of Existing Building Based on ASCE 41-17.

Table 3: Target Performance Level of Existing Building

Risk Category	BSE-1E	BSE-2E
I and II	Life Safety Structural Performance	Collapse Prevention Structural Performance
	Life Safety Nonstructural Performance (3-C)	Hazards Reduced Nonstructural Performance ^a (5-D)
III	Damage Control Structural Performance	Limited Safety Structural Performance
	Position Retention Nonstructural Performance (2-B)	Hazards Reduced Nonstructural Performance ^a (4-D)
IV	Immediate Occupancy Structural Performance	Life Safety Structural Performance
	Position Retention Nonstructural Performance (1-B)	Hazards Reduced Nonstructural Performance ^a (3-D)

The structural performance levels and their corresponding ranges according to ASCE 41-17 are as follows:

Structural Performance Levels:

1. S-1 : Immediate Occupancy (IO)
2. S-2 : Damage Control
3. S-3 : Life Safety (LS)
4. S-4 : Limited Safety
5. S-5 : Collapse Prevention (CP)

6. S-6 : Not Considered

The performance range according to the level of structural performance level according to ASCE 41-17 is as follows:

1. Damage Control Range: Between Life Safety (S-3) and Immediate Occupancy (S-1)
2. Performance Range: Between Life Safety (S-3) and Collapse Prevention (S-4)

The Target Basic Performance Level of Existing Buildings based on ASCE 41-17 specifies seismic levels for evaluation. According to Wivia ON, Altho Sagara, and Iswandi Imran (2022), seismic rehabilitation strategies for existing concrete buildings in Indonesia must consider regional seismic characteristics, particularly for 225-year and 975-year return periods. However, since Indonesia lacks official seismic maps for these periods, an analysis is required to determine ratio values relative to MCER.

The Tier 1 filtration process for existing buildings under ASCE 41-17 includes 14 key parameters, ranging from general building data to structural performance targets and defect evaluations. Tier 2 involves quantitative evaluation using linear static and dynamic analysis methods aligned with SNI 1726:2019, while Tier 3 focuses on post-failure retrofitting, such as epoxy injection, which can restore up to 62% of bending strength, as demonstrated by Lukman, HA. (2023). This method is supported by prior research showing even higher recovery rates. Additionally, Sulardi (2018) highlights the effectiveness of flowable microconcrete for repairing delamination and spalling in marine environments, further reinforcing the viability of these rehabilitation techniques.

RESEARCH METHOD

The structural performance assessment of the Urea Fertilizer Dust Scrubber Concrete Structure began with a visual inspection and the collection of secondary data, including soil surveys, structural calculations, and as-built drawings. Primary data was then gathered through destructive (DT) and non-destructive (NDT) testing of structural components, such as rebound hammer tests, ultrasonic pulse velocity (UPV), and rebar scans. The test results were analyzed for outliers in compliance with ASTM and SNI standards before the development of the research methodology. The evaluation progressed to Tier 1 screening per ASCE 41-17, including Remaining Useful Life (RUL) calculations, followed by Tier 2 quantitative analysis using structural modeling aligned with SNI 1726:2019.

The analysis employed Professional Robot Structural Analysis (RSAP) software to model the Special Moment Resisting Frame System (SRPMK), incorporating processed data on concrete quality (f_c' 24.4 MPa) and rebar strength (f_y 396 MPa). Key checks included mass participation, base shear control, interstory drift, and structural deflection per SNI 1726:2019. The reinforcement

area obtained from primary data was compared against the SRPMK model to assess structural adequacy. Finally, a retrofit method was selected based on damage assessment, ensuring the structure met performance standards for a 2500-year earthquake return period while maintaining functional integrity.

For the Tier 1-2-3 quantitative evaluation methodology flow based on ASCE 41-17 as shown in Figure 2, and for the Tier 2 quantitative evaluation flow according to the existing conditions of the dust scrubber concrete, there was a concrete wall that resisted chemical leakage resulting from the process of treating urea fertilizer waste dust emissions. This was conducted in accordance with the SNI 1726:2019 standard to obtain the structural performance of the dust scrubber concrete, as illustrated in Figure 1.

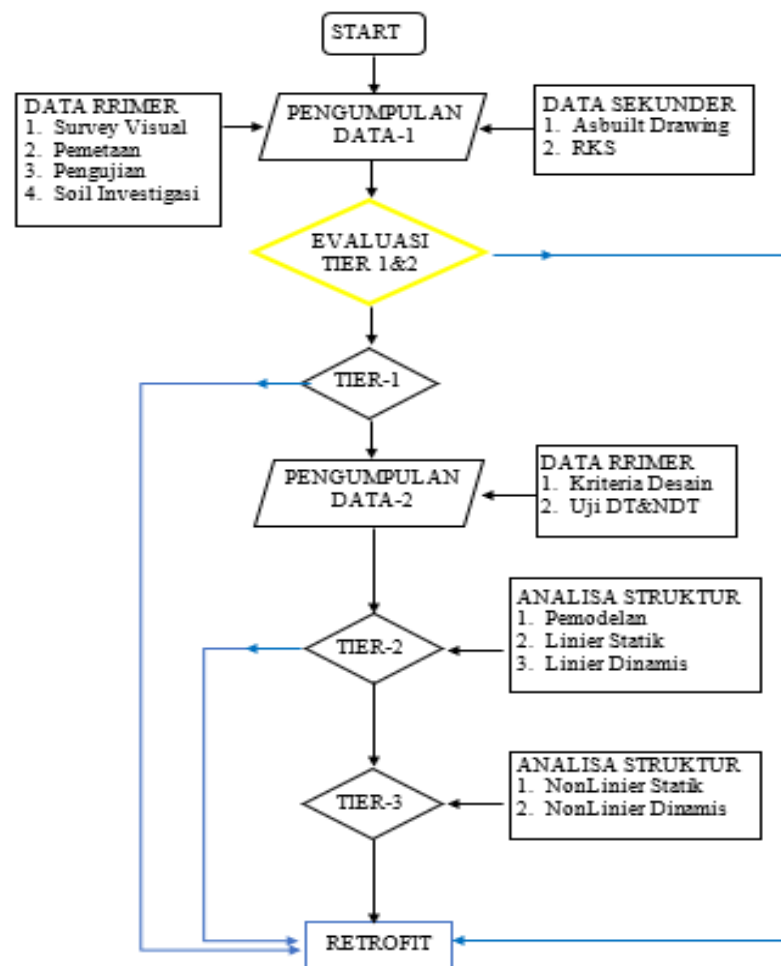


Figure 1. Tier 1-2-3 Evaluation Flowchart

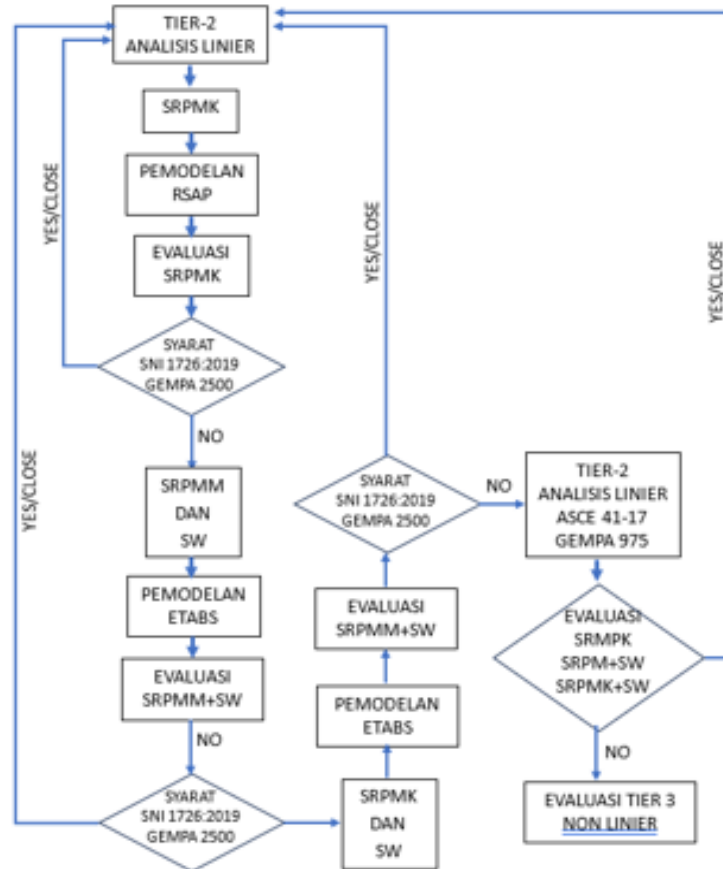


Figure 2. Tier 2 evaluation flowchart

RESULT AND DISCUSSION

Visual Investigation of Structures

The results of the visual investigation showed that structural damage occurred in the form of structural cracking, rebar corrosion, efflorescence and delamination

Secondary Data Collection

The data on the initial planning of the Urea Fertilizer Dust Scrubber building legality with the 2012 registration consists of:

- Asbuilt Drawing (exists)
- Structure Report (any)
- Investigation Soil Result Data (none)

Primary Data Collection

Data collection is as per Table 4.

Table 4. Testing of Tulanangan Concrete and Steel.

No	Primary Data Collection	Number Of Test Sample Points		
		Structural Component Test Data		
		Column	Beam	Wall
1	Vertical Test (Drift Story)	Not Executed		
2	Rebound Hammer Test	11	9	22
3	Ultrasonic Pulse Velocity (UPV) Test	8	4	16
4	Concrete Crack Test	-	-	20
5	Carbonation Test	14	2	7
6	Chloride Test	-	-	8
7	Potential of Hydrogen Test	-	-	8
8	Half Cell Potential (CANIN) Test	-	-	15
9	Rebar Scan Test	17	3	8
10	Steel Hardness Test	-	-	8
11	Soil Investigation Test	NOT EXECUTED		

Source: Analysis Results

Primary Data Processing

Evaluation of outlier data according to ASTM E 178-02 against primary data according to Table 5.

Table 5. Results of outlier data evaluation

No	Primary Data Processing	Number of Test Sample Points		
		Structure Component Testing Outlier Data		
		Column	Beam	Wall
1	Reborn Hammer Test	2	2	11
2	Ultrasonic Pulse Velocity (UPV) Test	NO	NO	NO
3	Concrete Crack Test	NO	NO	NO
4	Carbonation Test	NO	NO	NO
5	Chloride Test	NO	NO	NO
6	Potential of Hydrogen Test	NO	NO	NO
7	Half Cell Potential (CANIN) Test	NO	NO	NO
8	Rebar Scan Test	NO	NO	NO
9	Steel Hardness Test	NO	NO	NO

Source: Analysis Results

The results of primary data verification for the evaluation of outlier data were only carried out on the hammer test and Ultrasonic Pulse Velocity (UPV) tests according to the Table

Property Design Criteria for Existing Buildings

The results of primary data processing on concrete are equivalent according to Table 6.

Table 6. Results of Primary Data Processing of Concrete Compressive Strength

Primary Data Processing Results	Concrete Quality f_c' (Mpa)		
	Average	Minimum	Maximum
A. Concrete Quality			
1 Secondary Data	20.59		
2 Reborn Hammer Test	32	30	35
3 Ultrasonic Pulse Velocity (UPV) Test	28	24,4	29,9

Source: Analysis Results

The existing building design criteria for Tier 2 evaluation are as follows:

1. The equivalent concrete quality was taken at least to the UPV (Ultrasonic Pulse Velocity) test of 24.4 MPa
2. The quality of rebar steel is taken from the results of the steel hardness test of 396 MPa
3. The dimensions of the structural components are taken from the processing of secondary and primary data with the results as assessment data as follows:
 - a. Column Assessment Data according to Table 7.
 - b. Block Assessment Data according to Table 8.
 - c. Plate Assessment Data according to Table 9.

Table 7. Column Assessment Data

Column Component Assessment Data Results					
Column Type	Longitudinal Reinforcement			Transversal Reinforcement	
	Column Dimension	Reinforcement Area	Reinforcement Diameter	Sengkang	Cross Tie
	Mm	Mm ²	Pieces	D – Mm	D – Mm
As-Built Drawing Data					
C1	400 X 400	2267.08	8 – D19	D13 - 200	2d – 10 @450
C2	400 X 500	5100.93	18 – D19	D13 - 150	2d – 10 @450
C3	500 X 400	5100.93	18 – D19	D13 - 150	2d – 10 @450

Source: Analysis Results

Table 8. Beam Assessment Data

Beam Component Assessment Data Results							
Beam Type	Column Dimension	Longitudinal Reinforcement				Transversal Reinforcement	
		Total Reinf. Area	Top Reinforcement Diameter	Bottom Reinforcement Diameter	Web Reinforcement Diameter	Sengkang	Cross Tie
		Mm²	Bh - D	Bh - D	Bh - D	D – Mm	D – Mm
Design Data (Ded)							
B1	500x1400	13167.6	7 - D29	7 - D29	8 - D25	D16 - 150	4d10-450
B2	400x800	5887.5	4 - D25	4 - D25	4 - D25	D16 - 200	2d10-450
B3	300x700	3474.4	3 - D25	3 - D25	4 – D13	D13 - 150	2d10-450
B4	250x600	1664.2	2 - D19	2 - D19	4 – D13	D13 - 150	2d10-450
B5	400x400	1061.3	3 - D13	3 - D13	2 – D13	D13 - 150	2d10-450
B6	200x600	1061.3	2 - D13	2 - D13	4 – D13	D10 - 200	2d10-450

Source: Analysis Results

Table 9. Plate Assessment Data

Slab Component Assessment Data Results			
Slab Type S1	Slab Thickness	Reinforcement Area	Reinforcement Diameter & Spacing
	Mm	Mm ² / M'	Mm
Top Reinforcement			
X - Direction	200	1.6	D16 - 125
Y - Direction	200	1.6	D16 - 125
Bottom Reinforcement			
X - Direction	200	1.6	D16 - 125

Y - Direction	200	1.6	D16 - 125
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Source: Analysis Results

Tier 1 Screening

The Tier screening in this study does not fully refer to the standard checklist in ASCE 41-17 but for the Tier 1 screening checklist data, it is carried out according to the existing conditions of the dust scrubber concrete building.

Tier 1 Filtration Results for existing concrete dust scrubber buildings according to Table 10.

Table 10. Tier 1 Screening Evaluation Results

No.	Tier - 1 Screening	Tier - 1 Evaluation Result
1.	General Parameters Of Existing Building	
A.	Function	Waste Handling Facility
B.	Seismic Risk Category	Iii
C.	Structural Design	Reinforced Concrete
D.	Initial Design Technical Standard	Sni-03-1726-2002
E.	Maintenance Quality	Good
F.	Change In Building Function	No Change
G.	Building Height	14 M
H.	Roof Structure	Conventional Steel Frame
I.	Structural System	Frame And Reinforced Concrete Wall
J.	Soil Type	Se (Soft Soil) - Secondary Data
2.	Existing Building Seismic Data	
C.	Sds	0.339 G
D.	Sd1	0.347 G

Source: Analysis Results

Results of Evaluation of the Remaining Service Life of the Building

a. Corrosion initial time analysis based on carbonation data (tcd) according to Table 11.

Table 11 Initial Results of Corrosion to Carbonation

Structural Component	Year Of Construction	Building Age (T Existing)	Maximum Carbonation Depth (Cd)	Carbon Diffusion Constant (K)	Tcd
		Years	Mm	Mm/Year	Year
Column	2012	12	2.00	0.25	2.83
Wall	2012	12	2.00	0.25	2.83
Beam	2012	12	2.00	0.25	2.83

Source: Analysis Results

b. Corrosion initial time analysis based on chloride data (tcl) according to Table 12.

Table 12. Initial Results of Corrosion to Chloride

Structural Component	Building Age (T Existing) Years	Maximum Chloride Content (Cs) (% of concrete weight)	Cth (Aci 201) (%)	Concrete Cover (C) cm	Diffusion Coefficient (D) cm ² /s	tcl Years
COLUMN	12	0.027	0.10	4.00	0.0000001	65.84
WALL	12	0.027	0.10	4.00	0.0000001	65.84
BEAM	12	0.027	0.10	4.00	0.0000001	65.84

Source: Analysis Results

- c. Analysis of Carbonation and Chloride Rating Conditions based on Verma, et al (2013) according to Table 13.

Table 13. Analysis of Carbonation and Chloride Rating Conditions

Structural Component	Maximum Chloride Content (Cs) % concrete weight	Maximum Carbonation Depth (Cd) mm	Concrete Cover (C) mm	Difference Between Concrete Cover and Carbonation mm	Rating Condition Description CR	Rating Condition Description
COLUMN	0.027	2.00	40.00	38.00	3	Required frequent inspection
WALL	0.027	2.00	40.00	38.00	3	Required frequent inspection
BEAM	0.027	2.00	40.00	38.00	3	Required frequent inspection

Source: Analysis Results

- d. Determination of residual life based on carbonation testing and chloride as per Table 14.

Table 14. Residual Life Due to Carbonation-Chloride

Structural Component	Building Age (T Existing) Years	tcd Years	tcl Years	Check tcd < tcl
COLUMN	12	2.83	65.84	tcd determines
WALL	12	2.83	65.84	tcd determines
BEAM	12	2.83	65.84	tcd determines

Source: Analysis Results

- e. Determination of Rating Condition and Building Age Graph

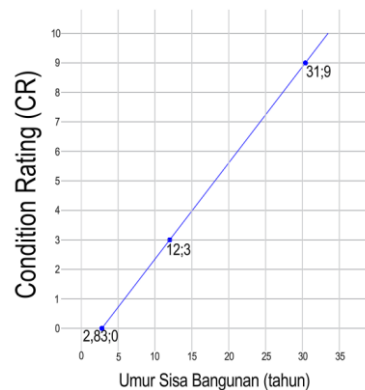


Figure 3. Graph of Rating Conditio

f. Estimated Age of Remaining Concrete Dust Scrubber Buildings.

The results of the estimated life of the remaining life of the dust scrubber concrete building are according to Table 15.

Table 15. Results of the life of the rest of the concrete building dust scrubber

Structural Component	Estimated Remaining Building Life	Condition Rating
	Years	(Cr)
Column	28.17	Replacement Of Structure
Wall	28.17	Replacement Of Structure
Beam	28.17	Replacement Of Structure

Source: Analysis Results

Tier 2 Quantitative Evaluation

The Tier 2 quantitative evaluation was conducted using structural analysis software (Robot Structural Analysis Professional) to assess the performance of a concrete dust scrubber structure in compliance with SNI 1726:2019 and ASCE 41-17 standards. The process began with verifying input data, load combinations (ULS and SLS), and structural analysis to ensure compliance with seismic requirements. Key evaluations included mass participation (achieving 98.47% in Mode 10), effective seismic weight, inter-story drift (within permissible limits), and P-Delta effects, all of which met the specified criteria. Additionally, unexpected torque magnification and vertical deflection assessments confirmed structural stability, while beam, column, and plate strength evaluations demonstrated safe conditions, except for minor concerns in B6 beams due to concentrated loads.

The analysis further examined component-specific performance, with longitudinal and transverse reinforcement comparisons confirming structural safety. Plate reinforcement assessments also indicated compliance, as RSAP software results showed smaller reinforcement requirements than manual calculations. The Tier 2 evaluation concluded that the special moment-resisting frame system performed safely, with all critical checks—including mode shapes, base shear, drift, and component strength—meeting SNI 1726:2019 standards.

However, wall deficiencies were identified as non-structural issues, requiring targeted repairs without compromising overall building integrity.

For retrofitting, epoxy-based materials—such as injection resins, castable mortar, and fiber-reinforced microconcrete—were recommended for wall repairs, based on prior research by Lukman (2023) and Sulardi (2018). These materials are suitable for addressing spalling and delamination, particularly in harsh environments. The retrofit strategy focuses on non-structural wall components, ensuring durability while maintaining compliance with seismic performance standards.

The final evaluation confirmed that the urea fertilizer dust scrubber building remains structurally sound, with retrofit measures limited to non-load-bearing elements. The use of advanced repair materials ensures long-term performance, aligning with environmental and structural requirements. This comprehensive assessment provides a reliable basis for maintenance and reinforcement, ensuring continued operational safety and compliance with national and international standards.

CONCLUSION

The correlation testing using hammer and Ultrasonic Pulse Velocity (UPV) tests confirmed a minimum concrete strength of 24.4 MPa, while non-destructive testing of reinforcing steel indicated a 24 MPa reduction in yield strength due to chemical exposure from urea fertilizer. Carbonation and chloride tests estimated the building's remaining service life at 28.17 years. Structural assessments following ASCE 41-17 and SNI 1726:2019 standards demonstrated that the dust scrubber building meets Tier 1 and Tier 2 seismic performance criteria, achieving the Limited Safety level for a 2500-year earthquake return period within the Level III risk category. The structure's stiffness, strength, and deformability were adequate, supported by a Special Moment Bearing Frame System, ensuring safety and functionality under current standards. Retrofitting via epoxy-based coatings on concrete wall defects effectively mitigated corrosion, enhancing durability. Future research could focus on long-term monitoring of corrosion progression and performance validation of different retrofitting materials to optimize maintenance strategies and extend the structure's service life further.

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