ANALYSIS OF CORROSION POTENTIAL OF 1st FLOOR COLUMN REINFORCEMENT IN RECTORATE BUILDING OF MUHAMMADIYAH UNIVERSITY OF WEST SUMATERA

*[1]**Indah Dwi Putri**,[2]**Deddy Kurniawan**,[3]**Asiya Nurhasanah Habirun**

[1, 2, 3]Department of Civil Engineering, Faculty of Engineering,
Muhammadiyah University of Sumatera Barat, Bukittinggi, Indonesia

Author's email:
[1]indahdwiputri62@gmail.com;[2]deddydk22@gmail.com;[3]asiya2021ce@gmail.com

**Corresponding author:indahdwiputri62@gmail.com*

Abstract. *One of the structural elements of the column of the rectorate building of campus I of UM West Sumatra has experienced cracks in the pedestal area so that the concrete covers are peeled off and the reinforcements are exposed to corrosion. The spread of corrosion is suspected to occur due to exposure to seaside air for a long time. The purpose of this research is to determine the value of the difference in corrosion potential in the column reinforcement of the building structure and the strength of the reinforcement bond against the concrete that has undergone corrosion. The non-destructive test method was carried out on the corrosion potential test in the area around the exposed column reinforcement using the Half Cell Potential method with Ag/AgCl as the reference electrode. The K250 concrete sample was printed in the form of a cube measuring 150mm x 150mm x 15 cm with Ø19 plain reinforcing steel to simulate the condition of the rebar installed in the field, then tested for binding strength against rebar corrosion that occurred at the age of 28 days in the laboratory. The corrosion potential shows that the reinforcement in the concrete has significant corrosion activity. The strength of the corroded plain rebar bond has a low value of 0.446 and the strength value of the non-corrosive plain rebar bond has a value of 2.421.*

Keywords: *Bond Test; Corrosion Potential; NDT*

1. INTRODUCTION

Reinforced concrete can experience a decrease in structural strength when corrosion occurs. Corrosion occurs due to the high moisture content in the air and is also caused by high air temperature (Elma et al., 2020). Corrosion on concrete reinforcement steel is the most detrimental type of damage to infrastructure which is characterized by a decrease in material quality and structural capacity (Astuti & Wingky Sandi Pratama, 2023). Corrosion damage will cause the performance of concrete buildings to decrease, and if the damage continues, the concrete structure is no longer suitable for use (Astuti, 2022).

Research in 2023 on the Rectorate Building of Muhammadiyah University of Sumatera Barat found damage to the 1st-floor column. The structural elements of the column have been cracked until the reinforcement is exposed. Due to exposure to air on the coast of Padang City, the rebar has been corroded for a long time. This will affect the durability of the column structure (Habirun et al., 2024).

Based on previous research that has been carried out, this study was carried out to determine the impact of corroded reinforcement with strong concrete and steel reinforcement ties. The probability of corrosion of reinforcing steel will be tested. The results will be simulated as a strong test piece of concrete fish with corroded reinforcing steel. The percentage of corrosion, steel quality, steel diameter, and concrete quality are adjusted to what happens in the field.

2. LITERATURE REVIEW

2.1 History of the Structure

The Rectorate Building of the University of Muhammadiyah West Sumatra has been operating since 1990 and has never been checked for its structural condition. Buildings can experience a decrease in capacity during decades of service due to loads inside the structure, additional floors, and loads outside the building such as earthquakes (Kurniawan et al., 2024) (Habirun, 2021)(Habirun, 2023). Several columns in the pedestal area have many cracks, so the concrete covers peel off. Exposed reinforcement is corroded due to exposure to seaside air at a distance of ± 1 km from the building (Habirun et al., 2024).

Fig. 1 Condition of the 1st-floor column of the Rectorate Building
Muhammadiyah University of Sumatera Barat (Private documentation, 2024).

2.2 Structure Details

The column structure to be simulated in this study was printed in 1990. It has a length of 4000mm with a cross-sectional area of 500mm x 500mm with 40mm concrete covers using plain reinforcement steel with a diameter of 19 mm and a compressive strength fc' 20.75 Mpa.

1. Material

Based on SNI 2847 the definition of concrete is a mixture of Portland cement or other hydraulic cement, fine aggregate, coarse aggregate, and water, with or without additives that form a solid mass (SNI, 2013).

a. Cement: Based on SNI 15-2049, Portland cement is a hydraulic cement produced by grinding cement slag, especially consisting of calcium silicate which is hydrolyzed and ground together with additives in the form of one or more crystalline forms of calcium sulfate compounds and may be added with other additives (SNI, 2004).

b. Aggregate: Granular materials, such as sand, gravel, crushed stone, and incandescent furnace crust, are used together with a binding medium to form a concrete or hydraulic cement mix (SNI, 2002). Aggregates are divided into 2 types, namely:

1. Fine Aggregate: Natural sand results from the 'natural' disintegration of rocks or sand produced by the rock-breaking industry and has the largest grain size of 5.0 mm (SNI, 2002). According to the SNI S-04-1989-F, fine aggregate is sand that functions as a filler for concrete cavities with the following conditions: Consists of sharp and hard grains; Fine aggregate grains must be permanent which means they are not broken or destroyed by weather influences; Fine aggregates do not contain more than 5% sludge, if it exceeds the fine aggregate must be washed; Fine aggregates do not contain much organic matter; The fineness modulus of the grain is between 1.5 – 3.8 with grain variation according to the grading standard (Daniel Limantara et al., 2020).
2. Coarse Aggregate: According to the Decree of SNI S-04-1989-F, coarse aggregate has conditions that must be met, namely: Coarse aggregate must consist of hard and non-porous grains; it is eternal, meaning it does not break or be destroyed by weather influences; The coarse aggregate should not contain more than 1% sludge, if the sludge content exceeds 1% then the coarse aggregate should be washed; Coarse aggregates should not contain substances that are reactive to alkalis; The fineness modulus of the grain is between 6 – 7.1 with grain variation according to the gradation(Daniel Limantara et al., 2020).

c. Water: Water used for concrete mixtures, must be clean, and free of harmful substances such as oils, salts, acids, bases, sugars, or organics (Spesifikasi Umum Bina, 2018). Water must be tested and meet the provisions in SK SNI S-04-1989-F, namely: Water must be clean; Does not contain mud, oil and visually visible floating objects; Does not contain more than 2 grams per liter of suspension; It must not contain salts, acids, dissolved organic substances that can damage concrete more than 15 grams per liter, chloride (Cl) not more than 500 ppm and sulfate compounds not more than 1000 ppm as SO3; When compared to the compressive strength of the mixture and concrete using distilled water, the decrease in strength is not more than 10%; Dubious water must be chemically analyzed.

2.3 Corrosion on Reinforced Concrete

The reinforcing steel in concrete is in a strongly alkaline environment with a pH value of ± 12.5. This is because concrete contains 20-30 percent Calcium Dihydroxide ($Ca(OH)_2$), some in the form of a saturated solution of $Ca(OH)_2$ in the concrete, some of which precipitate in the form of Ca(OH)2 crystals in the concrete (Fahirah, 2007). Corrosion of reinforcing steel is a chemical or electrochemical reaction between reinforcing steel and its environment. Corroded rebar steel has a rust volume greater ± 3 times the volume of the original material, resulting in cracks in the concrete. The reinforcing steel in the concrete is corroded if the passive state is lost, i.e. the environmental pH in the contact area of the concrete steel drops to < 9,5 (Fahirah, 2007).

2.4 Consequences of Corrosion on Concrete Reinforcement

According to Fahirah, the consequences caused by corrosion circles on concrete reinforcement are: (1) Washing of the hardened cement paste; (2) The dissolution and washing of new compounds, the result of chemical reactions that have very expanded properties until the concrete cracks and breaks; (3) Stress loss of cracking between concrete and reinforcement due to slip (Fahirah, 2007).

3. RESEARCH METHODS

3.1 Structural Observation

Visual observation of the structure is carried out by checking the parts that are in cracked condition, the concrete covers are peeled off, and corrosion on the reinforcing steel.

3.2 Half Cell Potential (HCP)

The corrosion potential of the attached reinforcement can be measured by the Non-Destructive test method with the Half Cell Potential (HCP) method. Several researchers have carried out this method in analyzing the potential for corrosion in building structures exposed to extreme conditions (Fonna et al., 2017). According to ASTM C876-15, the half-cell potential research method examines the possibility of corrosion without damaging the concrete surface using a digital multimeter and SCE (silver-silver chloride electrode). It must be converted to CSE (copper-copper sulfate electrode) using equation 3.1. A sketch of the HCP test can be seen in Figure 2 (ASTM, 2017).

$$\text{Potential CSE} = \text{Potential SCE} -74.5 - 1.66\ (T-25℃) \tag{3.1}$$

Description:
Potential CSE = Potential value CSE (mV)
Potential SCE = Potential value SCE (mV)
T = Air temperature when HCP is performed

Based on ASTM C876-91 (ASTM, 2017), the classification of corrosion potential values is shown in Fig. 2.

Table 1. The ASTM C876 criteria for corrosion risk of reinforced concrete [2].

Reference electrode $Cu/CuSO_4$	Reference electrode Ag/AgCl	Corrosion risk
≥ -200 mV	≥ -106 mV	Low (10% risk of Corrosion)
-200 to -350 mV	-106 to -256 mV	Intermediate corrosion risk
≤ -350 mV	≤ -256 mV	High (<90% risk of corrosion)
≤ -500 mV	≤ -406 mV	Severe corrosion

Fig. 2. Corrosion Classification

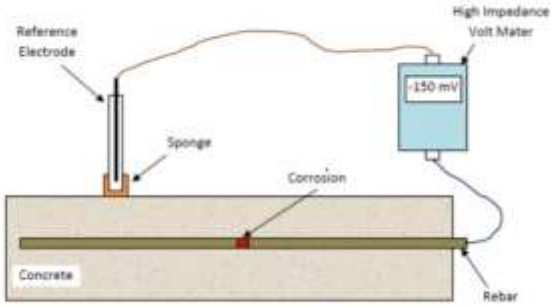

Fig.3 Half cell potential testing sketch (Fonna et al., 2017)

3.3 Mix-design

Mix design is a way to determine how much cement, coarse aggregate, fine aggregate, and water are used to obtain the planned compressive strength value. The calculation method used in this study is the SNI method 03-2834-2000.

3.4 Fresh concrete test

The fresh concrete test carried out in this study is a slump test, slump is one of the measures of the viscosity of concrete mixture expressed in mm with an Abrams cone tool (SNI, 1990)

3.5 Concrete Compressive Strength Testing

According to SNI 03-1974-1990, Compressive strength is the amount of load per unit area, that causes the concrete test piece to collapse when loaded with a certain compressive force produced by the press machine (SNI, 1990). To find the compressive strength value use equation 3.2.

$$\text{Compressive strength of concrete} = \frac{P}{A} \qquad (3.2)$$

Description:
P = Maximum load (kg)
A = Cross-sectional area of the test piece (cm^2)

3.4 Bond test

According to ASTM C.234-1980 a bond test is performed to calculate the shear force of rebar with concrete (ASTM, 1980). The formula for calculating the adhesion between concrete and reinforcing steel can be seen in equation 3.3.

$$\tau = \frac{Pmax}{\pi\, D\, t} \qquad (3.3)$$

Description:
Pmax = Maximum press load (kn)
D = Diameter of reinforcing steel (mm)

t = Height of reinforced steel covered in concrete (mm)
π = 22/7

4. RESULTS AND DISCUSSION

4.1 Half Cell Potential

Observations were made on the column support area that suffered severe damage such as cracks, peeled concrete, and corrosion of reinforcing steel. The corrosion potential of reinforcing steel is tabulated in Table 1. The corrosion potential value in pic 2 shows that the intermediate corrosion risk occurs at the bottom of the column from the point of exposure to reinforcement due to peeling off the concrete covers. Meanwhile, the risk of corrosion is low at the top of the column.

Table 1. The value of the HCP test results is in the 1st-floor column of the Rectorate Building, Muhammadiyah University of Sumatera Barat.

Distance	**Loc.**	**mV, SSE**			**Temperature**	**mV, CSE**		
		1st	**2nd**	**3rd**	**C**	**1st**	**2nd**	**3rd**
-0,65	1	-307	-282	-240	29	-388,14	-363,14	-321,14
-0,6	2	-280	-255	-226	29	-361,14	-336,14	-307,14
-0,55	3	-260	-227	-208	29	-341,14	-308,14	-289,14
-0,5	4	-286	-234	-206	29	-367,14	-315,14	-287,14
-0,45	5	-261	-226	-206	29	-342,14	-307,14	-287,14
-0,4	6	-264	-225	-202	29	-345,14	-306,14	-283,14
-0,35	7	-268	-254	-289	29	-349,14	-335,14	-370,14
-0,3	8	-245	-223	-204	29	-326,14	-304,14	-285,14
-0,25	9	-267	-247	-226	29	-348,14	-328,14	-307,14
-0,2	10	-271	-242	-225	29	-352,14	-323,14	-306,14
-0,15	11	-244	-216	-210	29	-325,14	-297,14	-291,14
-0,1	12	-239	-211	-200	29	-320,14	-292,14	-281,14
-0,05	13	-220	-199	-190	29	-301,14	-280,14	-271,14
0	14	-209	-177	-178	29	-290,14	-258,14	-259,14
0,05	15	-192	-168	-169	29	-273,14	-249,14	-250,14
0,1	16	-180	-156	-161	29	-261,14	-237,14	-242,14
0,15	17	-174	-147	-158	29	-255,14	-228,14	-239,14
0,2	18	-100	-145	-156	29	-181,14	-226,14	-237,14
0,25	19	-170	-147	-157	29	-251,14	-228,14	-238,14
0,3	20	-160	-139	-157	29	-241,14	-220,14	-238,14
0,35	21	-157	-133	-156	29	-238,14	-214,14	-237,14
0,4	22	-150	-134	-165	29	-231,14	-215,14	-246,14
0,45	23	-96	-78	-129	29	-177,14	-159,14	-210,14
0,5	24	-76	-54	-77	29	-157,14	-135,14	-158,14
0,55	25	-46	-20	-39	29	-127,14	-101,14	-120,14
0,6	26	-20	-10	-33	29	-101,14	-91,14	-114,14
0,65	27	-19	-1	-30	29	-100,14	-82,14	-111,14
0,7	28	-11	-5	-24	29	-92,14	-86,14	-105,14
0,75	29	-18	-1	-24	29	-99,14	-82,14	-105,14

0,8	30	-11	-15	-18	29	-92,14	-96,14	-99,14
0,85	31	-18	-22	-18	29	-99,14	-103,14	-99,14
0,9	32	-51	-43	-20	29	-132,14	-124,14	-101,14
0,95	33	-55	-42	-11	29	-136,14	-123,14	-92,14
1	34	-63	-42	-10	29	-144,14	-123,14	-91,14
1,05	35	-61	-37	-19	29	-142,14	-118,14	-100,14
1,1	36	-64	-32	-10	29	-145,14	-113,14	-91,14
1,15	37	-61	-45	-14	29	-142,14	-126,14	-95,14
1,2	38	-60	-34	-21	29	-141,14	-115,14	-102,14
1,25	39	-51	-31	-24	29	-132,14	-112,14	-105,14
1,3	40	-56	-7	-11	29	-137,14	-88,14	-92,14

Source: Personal data, 2024.

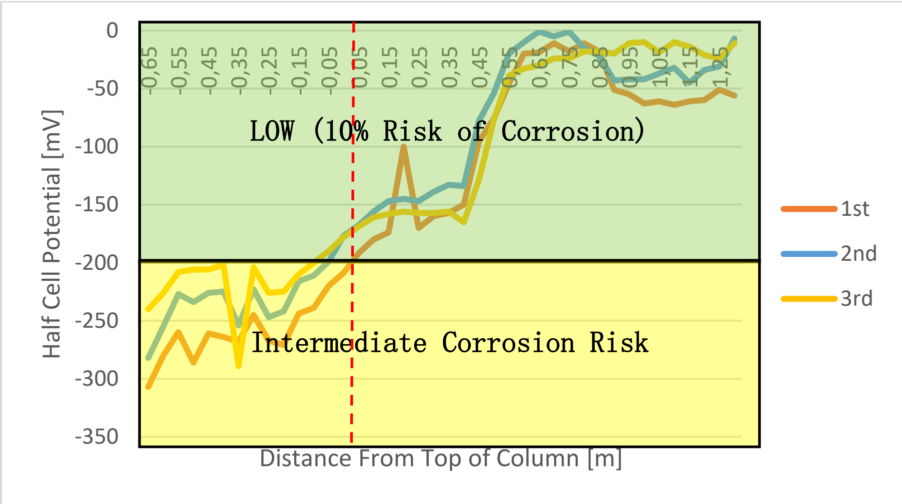

Fig.2. Half cell potential value of column reinforcement (2024)

4.2 Mechanical Constituent Concrete

The testing of the mechanical properties of concrete can be seen in Table 2.

Table 2. Concrete Constituent Mechanism

Cement	1. Specific Gravity	2.830
Coarse Aggregate	1. Specific Gravity 2. Aggregate Volume Weight 3. Modulus of Fineness 4. Moisture Content	2.594 1.609 4.548 1.237
Fine Aggregate	1. Specific Gravity 2. Aggregate Volume Weight 3. Modulus of Fineness 4. Filter Passing Material No.200 5. Sludge Content	2.798 1.371 3.261 3.080 4.950

Source: Personal Data, 2024.

4.3 Mix-design

After testing the mechanical properties of concrete, the mix-design results of this study are shown in Table 3.

Table 3. Mix-design / m3 Concrete Fc'20.75

1	Cement	1.265	Kg
2	Water	0.680	Kg
3	Fine aggregate	1.855	Kg
4	Coarse aggregate	3.149	Kg

Source: Personal Data, 2024.

4.4 Compressive Strength Testing of Concrete

After the curing process is carried out, followed by a compressive strength test, the concrete compressive strength test result can be seen in Table 4. The average compressive strength value of concrete is 20.86 MPa.

Table 4. The compressive strength value of normal concrete is 28 days old.

No	**Heavy (kg)**	**Broad (mm2)**	**Load (KN)**	**Load (N)**	**Compressive Strength (MPa)**	**Kg/cm2**	**SD**	**∑**	**fc' (Mpa)**
a	b	c	d	e = (d) x 1000	f = (d) / (c) x 10	g = (g) x 0.83 x 10	h	i = (g) + (h)	j = (i) x 0.083
1	7,009	225000	470	470000	20,89	251,67	3,354	255,03	21,167
2	7,232	225000	455	455000	20,22	243,64	3,354	247,00	20,500
3	7,117	225000	460	460000	20,44	246,32	3,354	249,67	20,722
4	7,237	225000	470	470000	20,89	251,67	3,354	255,03	21,167
5	7,126	225000	460	460000	20,44	246,32	3,354	249,67	20,722

Average compressive strength = 20,86 MPa

Source: Personal data, 2024.

4.5 Bond Test

The bond test results can be seen in Table 5 and Table 6. The bond strength value of non-corrosive reinforcing steel is higher than that of corrosive reinforcing steel, the result of the binding strength value of non-corrosive reinforcing steel = 2.421 N/mm2 and the binding strength value of corrosive reinforcing steel = 0.446 N/mm2. This shows that corrosion on the rebar surface can aggravate the strength of the rebar bond on concrete. This result will have an impact on the cross-sectional durability of structural elements in bearing the load (Rasyid et al., 2021)(Prihantono & Saefudin, 2006).

Table 5. Bond test values on non-corrosive reinforcing steel.

Concrete age (days)		**28**		
Sample		**I**	**II**	**III**
Maximum Compressive Strength	Kn	30	15	20
Reinforcement Diameter	mm	19		
Length of Reinforcement Covered in Concrete	mm	150		
Strong Adhesion	N/mm^2	3,352	1,676	2,234
Average adhesion strength score	N/mm^2	2,421		

Source: Personal data, 2024.

Table 6. Bond test value on corroded reinforcing steel

Concrete age (days)		**28**		
Sample		**I**	**II**	**III**
Maximum Compressive Strength	Kn	4	5	3
Reinforcement Diameter	mm	19		
Length of Reinforcement Covered in Concrete	mm	150		
Strong Adhesion	N/mm^2	0,446	0,558	0,335
Average adhesion strength score	N/mm^2	0,446		

Source: Personal data, 2024.

CONCLUSION

1. Intermediate corrosion occurs on the columns due to exposure to coastal air because the concrete covers peel off towards the bottom of the concrete.
2. Low corrosion occurs because the reinforcement is still well covered.
3. Corrosion on the rebar surface can reduce the cross-sectional capacity of structural elements in bearing loads.
4. The low strength value of concrete bonds with corroded reinforcing steel is caused by concrete reacting with rust.
5. Rust/corrosion products are brittle and easily separate from the main steel layer so that when tensile force occurs, the reinforcement is easily detached from the concrete bond.

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