CORROSION OF REINFORCED CONCRETE BRIDGES

by

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ABSTRACT

Deterioration of steel reinforcement in bridges and marine structures subjected to aggressive environment pose major problem to the concrete construction industry in many countries. This paper presents two case studies with respect to corrosion conducted on reinforced concrete bridges in Malaysia. The results of NDT show that the steel reinforcement in bridges are experiencing corrosion whilst the chemical tests undertaken seems to confirm that chloride attack and carbonation are the major factors contributing to the corrosion process.

INTRODUCTION

Corrosion has for long been recognized as a serious problem in steel reinforced concrete structures. Structures such as bridges that are directly exposed to aggressive environments are very vulnerable to corrosion. Corrosion of steel in concrete can be initiated and maintained by two general mechanisms. The first mechanism is the reduction of alkalinity by leaching of alkaline substances with water or partial neutralization by reaction with carbon dioxide or other chemical agents. The second mechanism is the electrochemical action involving chloride ions in the presence of oxygen. Chemical agents can originate from the environment or within the concrete itself. This is caused by the reactions of the ions with each other which reduce the original characteristics of the reinforced concrete and hence induced corrosion to take place.

The electrochemical corrosion processes around a corrosion pit on steel in concrete are illustrated in Figure 1 and the electrochemical reactions can be summarized as the following:

$$Fe \iff 2e^- + Fe^{2+} \qquad \text{Eq.1}$$
$$1/2O_2 + H_2O + 2e^- \iff 2(OH)^- \qquad \text{Eq.2}$$
$$Fe^{2+} + 2(OH)^- \rightarrow Fe(OH)_2 \qquad \text{Eq.3}$$
$$4Fe(OH)_2 + 2H_2O + O_2 \rightarrow 4Fe(OH)_3 \quad \text{(Rust)}$$

In Malaysia, inadequate effort has been done to study corrosion. In order to get a general idea of the 'corrosive state' of some bridges in Malaysia, two bridges were selected for case studies which is the Peserai bridge in Batu Pahat and the Sarang Buaya bridge in Muar, Johor. The layout plan of the bridges are shown in Figure 2. Hence, the objective of the study is to detect the existence of corrosion on both bridges and to determine whether chloride, sulphate and carbonation were the major factors contributing to the corrosion.

EXAMINATION METHODS

The examination methods consist of visual inspections, non-destructive tests and chemical tests. An early investigation on the bridges was carried out to determine if chemical attack had occured. Visual inspections were made regarding the location of the bridges and the apparent damages such as crack patterns, seepages, staining, spalling, delamination, discoloration and honey-combing. These observations provide valuable clues regarding the possible cause of damage.

Non-destructive test methods have proved valuable in determining the condition of the steel reinforcement in concrete before there are visible signs of corrosion [1]. Sonic techniques are used to assess damage due to internal cracking and to determine the presence of subsurface delaminations while electrochemical methods are used to assess the state of corrosion. A combination of non-destructive tests was done on selective sections of the bridges to produce reliable results of detecting corrosion. Samples from the bridges were also taken to the laboratory to further test for the presence of chemical agents.

The samples were taken from the beams, columns and abutments and laboratory chemical tests were done in accordance with BS 1881:Part 124:1988 [2] in order to establish the extent of chemical action subjected on the concrete.

A brief explanation of the various tests and apparatus used during these case studies is described here.

Non-destructive Test:

1.Resistivity meter

A resistivity meter consists of a meter and a probe. The meter acts as a central processing unit which receives readings from the probe. The probe has four electrodes that are equally spaced from each other. One of the outer electrodes produces alternating current while the other outer electrode receives it. The two inner electrodes will then measure the voltage induced and therefore the resistance of the concrete can be determined.

The process of corroding involves the movement of electrons through concrete which act as its electrolyte. Therefore, when corrosion takes place, the number of electrons increases while the concrete resistance decreases. The possibility of finding corrosion can be related to the concrete resistance by using the criteria as the following:

CONCRETE RESISTANCE (K ohm cm)	POSSIBILITY OF CORROSION
< 5	Very High
5 - 10	High
10 - 20	Low
> 20	Not Significant
> 50	Negligible
> 60	Nil

This test was done on column C1/14, C2/14, C6/14; beams R1/7, R3/7 and abutments A3/14, A4/14 of Peserai Bridge; beams 1, 2 and abutments 1, 2 of Sarang Buaya Bridge.

2.Potential Wheel and Data Bucket [3]

This instrument has three main component which are the Data Bucket, the Pocket Terminal and the Potential Wheel. It works by using the half-cell concept. It can plot contours of the area of different potential as an indication of the probable corrosion area.

The Data Bucket is important in terms of receiving and processing data. It receives instructions from the Pocket Terminal and saves the data on a hard disk. It has a dot matrix printer to produce the output and it can be connected to a common personal computer.

The Pocket Terminal looks like a pocket calculator. It sends all the information to be programmed to the Data Bucket.

The Potential Wheel has a handle, a half-cell chamber, a sponge wheel, an internal encoder and AgCl solution. It collects data and sends them to the Data Bucket. The following criteria can be used to estimate the degree of corrosion.

VOLTAGE (mV)	POSSIBILITY OF CORROSION
< 200	5%
200 - 350	50%
> 350	95%

The tests were run on columns C2/14, C4/14, C6/14; beams R2/7, R4/7, R6/7 and abutments A2/14, A4/14 and A6/14 of the Peserai bridge.

3.Half-cell

Half-cell works on the same concept as the Potential Wheel and Data Bucket. It has a voltmeter and a half-cell. Either single or double electrodes can be used for the half-cell. It measures the difference in potential of two selected points on the concrete. Usually, it gives negative readings if corrosion exists because corrosive areas have higher electronegative potential. For this tests, column C6/14 and beam R2/7 have been chosen.

4.PUNDIT

In principle, this device measures the relative times for ultrasonic impulses to be reflected back from any defect in concrete and from the opposite face to the transducer. The speed of the impulse can be determined by dividing the distance travelled with time, where the higher the speed, the stronger the concrete. The test was done in accordance with BS 4408:Part 5:1985 [4] and was carried out on the Peserai Bridge only.

5.Rebound Hammer

A nondestructive impact test for determining the hardness and the probable compressive strength of the concrete is made using the Schmidt concrete rebound hammer. The tubular device is pressed against the surface of the concrete causing a spring-loaded hammer inside the tube to automatically strike the concrete. The rebound of the hammer is indicated on a scale. Once the rebound number is obtained, a calibration curve can be used to give the equivalent compressive strength of the concrete. This test is done in accordance with BS 4408:Part 4:1971 [5] on both bridges.

Chemical Test

Laboratory tests were conducted to test cement, chloride and sulphate content of the sample. The cement, chloride and sulphate content were determined in accordance with BS 1881:Part 6:1971 [6]. The existence of carbonation was tested using Phenolphthalein solution which is colorless in acid and pink in base.

RESULTS AND DISCUSSIONS

Visual Inspection

Visual inspection was only done on the Peserai bridge. Tables 1(a) to 1(c) shows the typical results obtained from this inspection. The type of damage that can be most clearly seen was severe cracking. This can be detected especially on the bridge columns and abutments but not on the beams.

The bridge columns are exposed to tidewater that caused the columns to experience wetting and drying regularly. This is known to accelerate corrosion. Besides cracks, there are also spallings and delaminations of the concrete indicating steel corrosion has taken place. Staining of concrete was evident on every column inspected. Staining has not been detected on the beam which means that the chances of having corrosion in the beam are small relative to the columns and abutments.

Non-Destructive Test

Resistivity Measurement

Tables 2(a) to 2(e) show the results of the test done on the Peserai Bridge. The results show that the lower parts of the bridge columns have high possibility of corrosion compared to the upper parts. The abutments have only low possibility of corrosion while the beams possibility is very low.

Tables 3(a) and 3(b) shows the results of the test done on the Sarang Buaya Bridge. There is low possibility of corrosion in the beams and abutments of this bridge.

Potential Wheel and Data Bucket

This test was only conducted on the Peserai Bridge because the Sarang Buaya Bridge is under reconstruction. The results of this test were printed graphically as shown in Figures 3(a) to 3(c).

From the graph, it was found that the bottom parts of the columns have readings of > 350 mV which means 95% possibility of having corrosion on the steel reinforcement. This has been expected to happen since the lower parts of the columns are in the splashed zone of the tidewater.

All abutments are also found to have voltages of > 350 mV at the bottom parts. This indicates that the abutments are deteriorating severely at their lower parts too.

This is not happening in the beams because they only give voltage readings of < 200 mV for 5% possibility of having corrosion.

Half-cell

This test was done only on the Peserai bridge. The results were also shown graphically in terms of voltage vs distance as displayed by Figures 4 and 5. From the graphs it can be seen that as the instrument moves from top to bottom of the column, the voltage increases to show that the bottom part have high degree of corrosion potential. This is supported by the criteria that the lower part of the column has voltage reading of > 350 mV which means 95% possibility of having corrosion. The graphs apparently have the same pattern as the graphs obtained from the Potential Wheel and Data Bucket test.

The results of beam R2/7 as shown in Figure 5 point out that the voltages along the beam are < 200 mV which convincingly means very low percentage of corrosion can be found in the beam.

PUNDIT

Table 4 shows the results of this test. These values should be used correlatively to compare the uniformity of the strength of the concrete on different part of the bridges. It can be seen that the strength of the upper parts of the columns are greater than the lower parts which is the results of damage done by corrosion. The strength of the beams and abutments are quite uniform.

Rebound Hammer

This test was done on both bridges. Table 5(a) shows the results obvtained from the Peserai bridge. It is found that the average strength of the concrete varies from 43 N/sq.mm to 55 N/sq.mm except for the lower parts of the columns which varies from 36 N/sq.mm to 39 N/sq.mm. This big difference in strength indicates the possibility of corrosion in the lower parts of the columns. Table 5(b) shows the results of the Sarang Buaya bridge where the results are only available from the beams. The results pointed out that the possibility of corrosion is low since the strength is high and does not vary that much.

Chemical Tests

Carbonation

The results shown in Table 6(a) are taken from the Peserai bridge. There are changes of colour at the upper parts of the columns and along the beams but not at the bottom parts of the column. These show that carbonation have taken place at the upper columns and beams so that the concrete has lost its alkalinity. This can also be recognized as an early warning of the initiation of corrosion in the reinforcement.

Ironically, the results of the other tests point out that the bottom parts of the columns are experiencing severe deterioration caused by corrosion and the beams are less likely affected by corrosion. Therefore, it can be concluded that carbonation is not the major cause of corrosion on the Peserai bridge.

The abutments also display positive results but that only happened where cracks have existed. Carbonation is expected to happen only after the reinforcement has been exposed by the cracks.

Table 6(b) contains the results taken from the Sarang Buaya bridge. It can be seen that the beam have been tested positive to carbonation but not in the abutments. The carbonate in the abutment probably could not be detected because of the action of wetting and drying of the tidewater. We can therefore include carbonation as one of the major factors of corrosion on the Sarang Buaya bridge.

Cement Content

The cement content needs to be calculated to get the chloride content of the concrete. The results are shown in Table 7 The cement content of the Sarang Buaya bridge is found to be higher than the Peserai bridge.

Chloride Test

All of the results tabulated in Table 8 indicate chloride contents higher than the maximum amount allowed. The maximum limit is 0.5% of the cement content in order to avoid the chloride attack.

The most severe part of the Peserai bridge is the column with a chloride content of 2.2%. The chloride ion is most probably supplied by the tidewater.

Sulphate Test

As shown in Table 9(a) and 9(b), there are significant differences in the sulphate contents of the two bridges. The high content of sulphate in the abutments of the Sarang Buaya bridge is the result of being partially submerged in the tidewater during high tide.

Sulphate attack can therefore be considered as a factor that contributes to the deterioration of the concrete surface.

SUMMARY OF RESULTS

A summary of NDT results from Peserai bridge is shown in Table 10. The PUNDIT and Rebound Hammer tests display good strength of concrete in the beams, upper columns and abutments. There is a significant difference in strength between the upper and lower columns.

The potential wheel and half-cell tests on the beams and columns demonstrate similar patterns. The voltage is quite uniform as the instrument moves from the left to the right of the beams but it greatly increases as it moves from the top to the bottom of the columns and abutments. This indicates corrosion at the lower parts. High voltage readings were accompanied by low resistivity meter readings; hence the possibility of corrosion at the location is high. Tables 11(a) and 11(b) show that the chloride and sulphate contents are exceeding the limit to initiate corrosion. The negative reading for carbonation at the lower columns could be the result of the carbonate being washed away by the tidewater.

Table 12 shows that the cement content of the Sarang Buaya bridge is greater than the Peserai bridge. Both bridges have been attacked by chloride which most probably comes from the tidewater. Sulphate contents are also high in both bridges and this further contributes to the deterioration of concrete.

CONCLUSION

Based on the results obtained, it can be concluded that both bridges have been experiencing severe state of corrosion on the lower parts of the columns and abutments. The presence of chloride and carbonation seems to be the major factors that accelerate the process. Sulphate was also considered as a factor of corrrosion as it aggravates the situation by causing the concrete surface to deterioriate.

ACKNOWLEDGEMENT

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REFERENCES

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[2] British Standard BS 1881: Part 124: 1988

[3] Potential Wheel and Data Bucket Manual, London C.N.S. Electronics Ltd.

[4] British Standard BS 4408: Part 5: 1985, "Non-Destructive Methods of Test for Concrete, Measurement of the Velocity of Ultrasonic Pulses in Concrete".

[5] British Standard BS 4408: Part 4: 1971, "Non-Destructive Methods of Test for Concrete."

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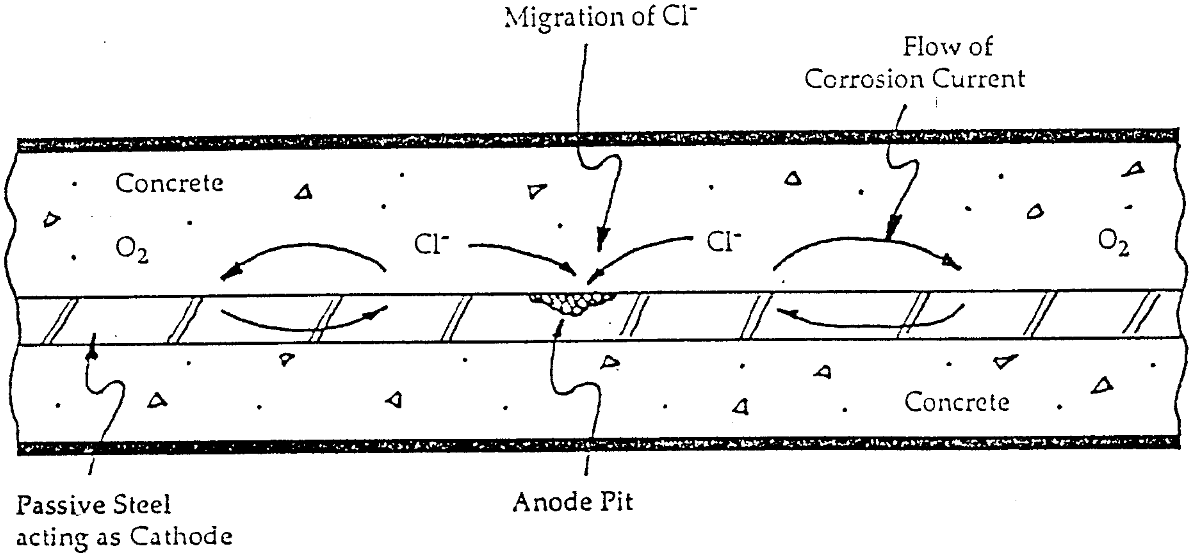

Figure 1: Electrochemical Corrosion Processes around a Corrosion Pit on Steel in Concrete

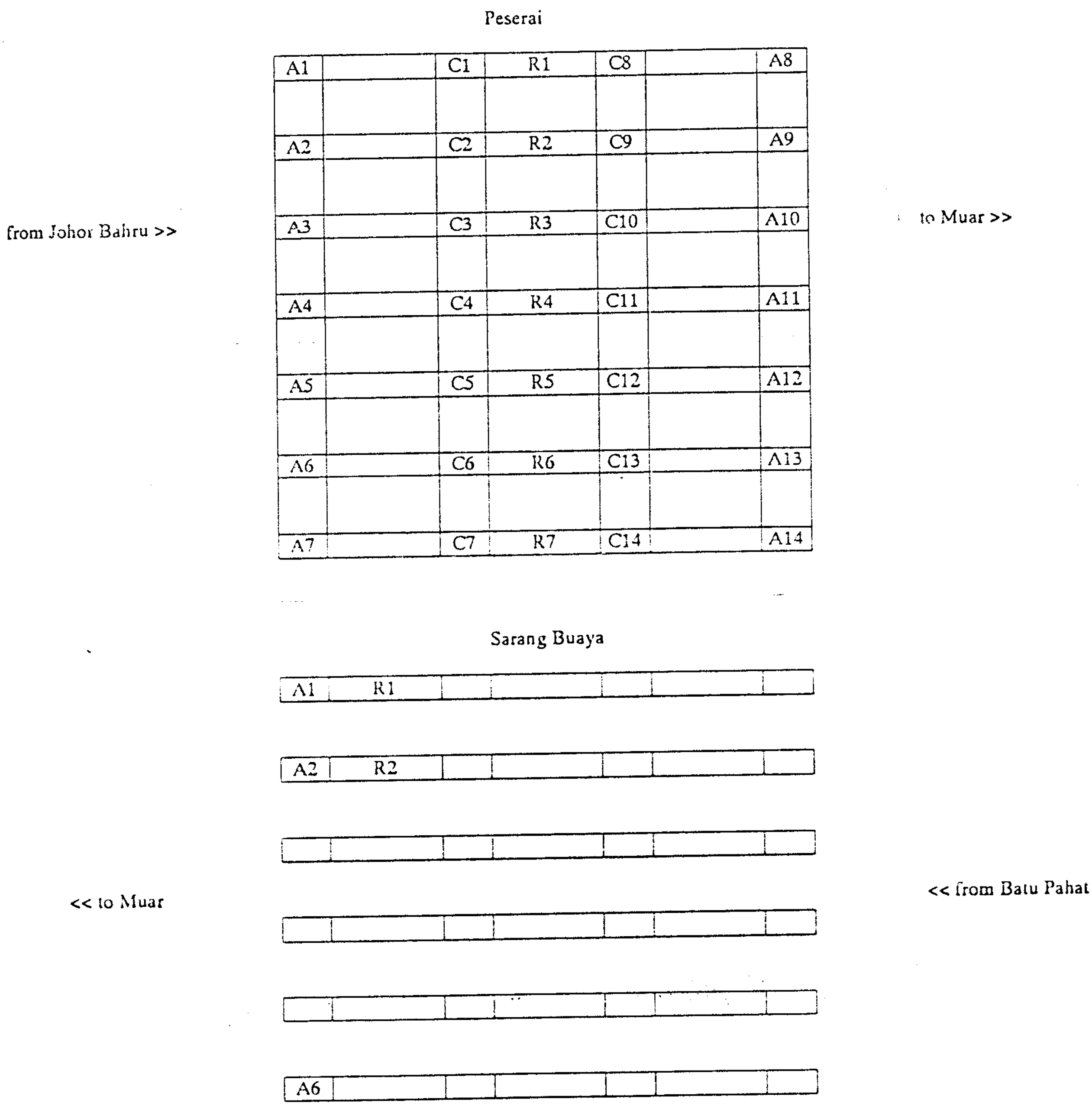

Figure 2: Plan view of the Peserai and Sarang Buaya bridge

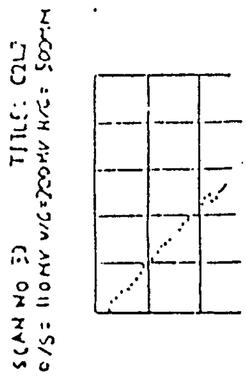

Figure 3(a): Potential Wheel Test on Column C2/14 of Peserai bridge

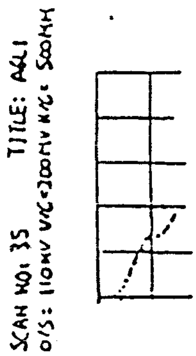

Figure 3(b): Potential Wheel Test on Abutment A6/14 of Peserai bridge

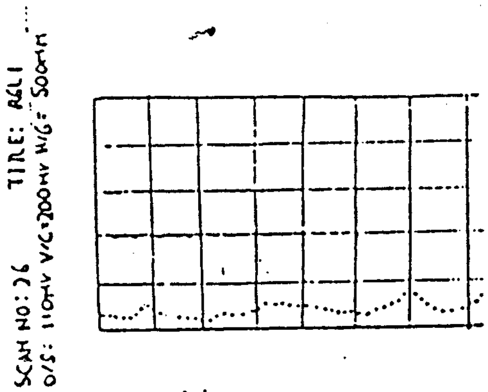

Figure 3(c): Potential Wheel Test on Beam R6/7 of Peserai bridge

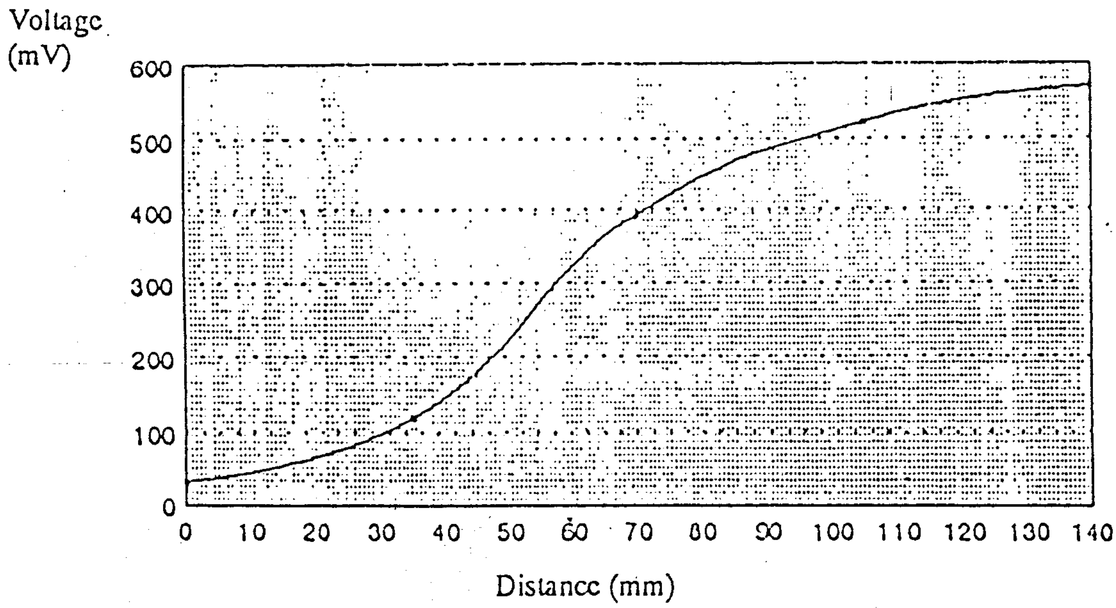

Figure 4: Half-cell Results on Column C6/14

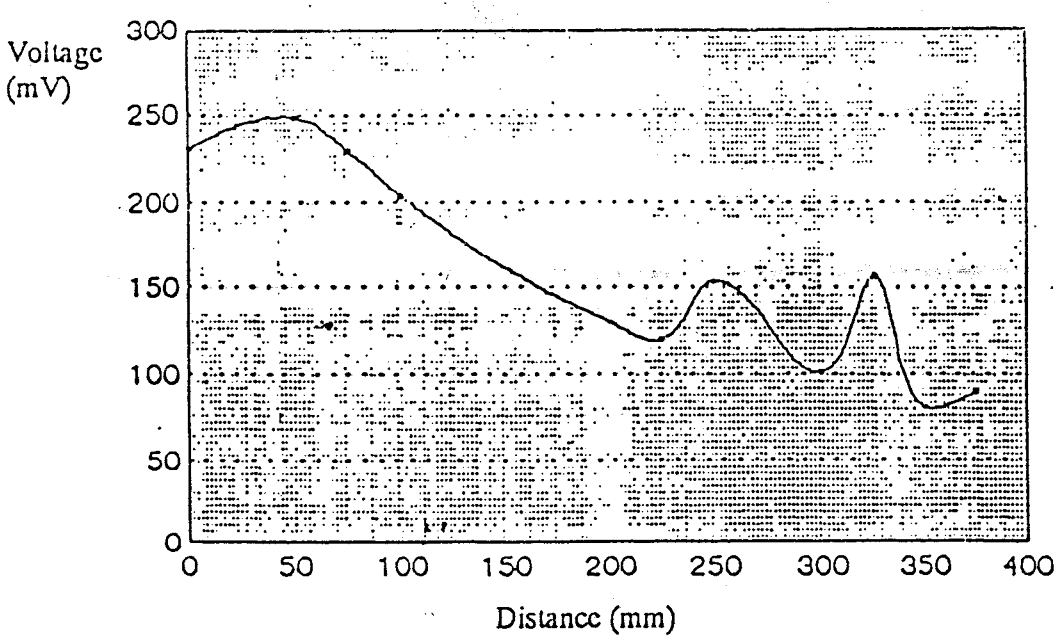

Figure 5: Half-cell Results on Beam R2/7

Table 1(a): Visual Inspection on Beams of Peserai bridge

Visual Damage	Location						
	R1/7	R2/7	R3/7	R4/7	R5/7	R6/7	R7/7
CRACKS							
PATTERNED CRACKS							
SEEPAGES							
INCRUSTATIONS						X	
STAIN							
DAMPNESS							
PUNCHED HOLES							
SPALLINGS							
DELAMINATIONS							
WEATHERING			X				
TEARING							
HONEY COMB				X		X	
CONSTRUCT. JOINTS							
PANEL JOINTS							

Table 1(b): Visual Inspection on abutments of Peserai bridge

Visual Damage	Location						
	A1/14	A2/14	A3/14	A4/14	A5/14	A6/14	A7/14
CRACKS	X		X	X	X	X	X
PATTERNED CRACKS	X	X	X	X	X	X	X
SEEPAGES							
INCRUSTATIONS							
STAIN	X	X	X	X	X	X	X
DAMPNESS							
PUNCHED HOLES							
SPALLINGS				X		X	
DELAMINATIONS				X		X	
WEATHERING							
TEARING							
HONEY COMB							
CONSTRUCT. JOINTS							
PANEL JOINTS							

Table 1(c): Visual Inspection on columns of Peserai bridge

Visual Damage	Location						
	C1/14	C2/14	C3/14	C4/14	C5/14	C6/14	C7/14
CRACKS		X					
PATTERNED CRACKS		X	X	X	X	X	X
SEEPAGES							
INCRUSTATIONS							
STAIN							
DAMPNESS							
PUNCHED HOLES							
SPALLINGS		X	X		X		X
DELAMINATIONS			X		X		
WEATHERING	X		X	X			
TEARING							
HONEY COMB							
CONSTRUCT. JOINTS							
PANEL JOINTS					X	X	

Table 2(a): Resistivity Measurements on beams of Peserai bridge

LOCATION	RESISTANCE (K ohm cm)				MEAN	POSSIBILITY OF CORROSION
R 1/7	32.4	28.6	27.7	26.5	28.8	Very Low
R 3/7	20.3	24.5	25.4	26.3	24.1	Very Low

Table 2(b): Resistivity Measurements on abutments of Peserai bridge

LOCATION	RESISTANCE (K ohm cm)				MEAN	POSSIBILITY OF CORROSION
A 3/14	16.4	17.0	15.3	18.4	16.8	Low
A 4/14	17.4	19.5	21.2	17.5	18.9	Low

Table 2(c): Resistivity Measurements on Column C 1/14 of Peserai bridge

LOCATION	SURFACE	RESISTANCE (K ohm cm)		MEAN (K ohm cm)	POSSIBILITY OF CORROSION
C 1/14 (Upper)	A	56.7	59.8	58.3	Negligible
	B	50.4	56.4	53.4	Negligible
	C	40.7	38.9	39.8	Very Low
(Middle)	A	20.9	15.4	18.2	Low
	B	18.5	16.7	17.6	Low
	C	17.5	22.46	20.0	Low
(Lower)	A	8.2	7.1	7.6	High
	B	10.8	11.8	11.3	High
	C	6.5	6.8	6.7	High

Table 2(d): Resistivity Measurements on Column C 2/14 of Peserai bridge

LOCATION	SURFACE	RESISTANCE (K ohm cm)		MEAN (K ohm cm)	POSSIBILITY OF CORROSION
C 2/14 (Upper)	A	75.3	86.8	81.1	Nil
	B	87.9	58.4	73.2	Nil
	C	58.5	44.3	51.4	Negligible
(Middle)	A	30.8	31.5	31.2	Very Low
	B	32.8	28.1	30.5	Very Low
	C	23.3	19.7	21.5	Very Low
(Lower)	A	14	10.8	12.4	Low
	B	6.2	13	9.6	High
	C	6.4	5.3	5.9	High

Table 2(e): Resistivity Measurements on Column C 6/14 of Peserai bridge

LOCATION	SURFACE	RESISTANCE (K ohm cm)		MEAN (K ohm cm)	POSSIBILITY OF CORROSION
C 6/14 (Upper)	A	43.3	54.6	49.0	Very Low
	B	67.3	66.5	66.9	Nil
	C	45.5	50.1	47.8	Very Low
(Middle)	A	13.2	15.8	14.5	Low
	B	30.3	21.7	26.0	Very Low
	C	12.4	18.6	15.5	Low
(Lower)	A	11.9	10	11.0	Low
	B	13.5	15.3	14.4	Low
	C	5.2	4.7	5.0	Very High

Table 3(a): Resistivity Measurements on beams of Sarang Buaya bridge

LOCATION	RESISTANCE (K ohm cm)				MEAN (K ohm cm)	POSSIBILITY OF CORROSION
R 1	26.2	22.5	13.6	16.8	19.8	Low
R 2	26.1	14.6	20.6	12.2	18.4	Low

Table 3(b): Resistivity Measurements on abutments of Sarang Buaya bridge

LOCATION	RESISTANCE (K ohm cm)				MEAN (K ohm cm)	POSSIBILITY OF CORROSION
A 1	15.0	19.4	17.7	19.0	17.8	Low
A 2	9.5	13.5	16.5	12.3	13.0	Low

Table 4: Pundit Tests on Peserai bridge

LOCATION	TIME (microsec.)	DISTANCE (mm)	VELOCITY (km/sec.)	STRENGTH (N/sq.mm)
R2/7	94.70	390	4.12	21.04
R4/7	91.70	390	4.25	24.45
R6/7	92.00	390	4.24	24.19
A2/14	101.90	430	4.22	23.66
A6/14	102.60	430	4.19	22.88
C6/14 (Upper)	95.40	430	4.51	31.26
C6/14 (Lower)	98.40	430	4.37	27.59
C2/14 (Upper)	101.70	430	4.23	23.93
C2/14 (Lower)	107.60	430	4.00	17.90

Table 5(a): Rebound Hammer tests on Peserai bridge

LOCATION	REBOUND NUMBER						MEAN	STRENGTH (N/sqmm)
R 2/7	51	45	47	49	51	47	48.3	49
	51	45	50	50	44	50		
R 4/7	56	50	57	40	53	55	52.7	53
	60	52	46	54	54	55		
R 6/7	55	49	45	50	51	53	52.3	52
	56	54	51	53	52	58		
A 2/14	30	38	49	46	40	48	41.6	43
	38	47	40	37	34	52		
A 6/14	43	45	50	54	40	42	42.5	43
	36	46	40	36	44	34		
C 6/14(Upper)	40	37	54	42	53	40	42.9	44
	36	47	54	40	36	36		
C 6/14(Lower)	36	37	35	40	32	38	37.0	39
	40	30	38	39	37	42		
C 2/14(Upper)	53	55	50	54	53	52	55.1	55
	56	54	60	54	60	60		
C 2/14(Lower)	32	32	40	35	32	34	34.7	36
	30	40	34	38	34	35		

Table 5(b): Rebound Hammer tests on Sarang Buaya bridge

LOCATION	REBOUND NUMBER						MEAN	STRENGTH (N/sqmm)
R 1/1(Upper)	44	44	52	40	48	49	47.3	48
	46	48	52	52	44	48		
R 1/1(Lower)	50	54	52	50	50	50	51.0	51
	50	52	51	51	51	51		

Table 6(a): Carbonation Test on Peserai bridge

LOCATION	CHANGE OF COLOUR
Beam	Positive
Column (Upper)	Positive
(Lower)	Negative
Abutment	Positive

Table 6(b): Carbonation Test on Sungai Buaya bridge

LOCATION	CHANGE OF COLOUR
Beam	Positive
Column (Upper)	NA
(Lower)	NA
Abutment	Negative

Table 7: Cement Contents of Peserai and Sarang Buaya bridge

LOCATION	WEIGHT OF SAMPEL (g)	E (mg CaO/mL)	EDTA (mL)	(mL)	(mL)	MEAN (mL)	CaO %	CEMENT %
PESERAI								
Column	5	1.193	22.2	21.2	21.8	21.7	10.4	16.1
Beam	5	1.193	19.6	19.7	20.0	19.8	9.4	14.6
S.BUAYA								
Column	5	1.193	23.4	22.8	23.6	23.3	11.1	17.2
Beam	5	1.193	25.6	25.0	24.5	25.0	11.9	18.5

Table 8: Chloride Contents of Peserai and Sarang Buaya bridge

LOCATION	WEIGHT OF SAMPEL (g)	AgNO (mL)	THIOCYANATE (mL)	THIOCYANATE (MOL)	CEMENT %	CHLORIDE %
PESERAI						
Column	5	12	7.0	0.1	16.1	2.2
Beam	5	12.5	10.0	0.1	14.8	1.2
S.BUAYA						
Column	5	10	7.2	0.1	17.2	1.2
Beam	5	12	10.0	0.1	18.5	0.8

Table 9(a): Sulphate Contents on Pesrai bridge

ITEMS	BEAM R2/7	COLUMN C6/14	ABUTMENT A3/14
Sample Weight (g)	5.0000	5.0000	5.0000
Burning Weight (g)	11.906	12.0413	11.8066
Crucible Weight (g)	11.8331	11.8317	11.6953
Cement Content (%)	14.63	16.08	14.63
BaSO Weight (g)	0.0729	0.2096	0.1113
Sulphate Content (%)	3.42	8.56	5.22

Table 9(b): Sulphate Contents on Sarang Buaya bridge

ITEMS	BEAM R1 (Upper)	BEAM R1 (Lower)	ABUTMENT A1
Sample Weight (g)	5.0000	5.0000	5.0000
Burning Weight (g)	11.8255	12.0405	12.1206
Crucible Weight (g)	11.6956	11.8325	11.8326
Cement Content (%)	18.52	18.52	17.22
BaSO Weight (g)	0.1299	0.2079	0.2078
Sulphate Content (%)	4.81	7.70	11.47

Table 10: Summary of Non-Destructive Test Results on Peserai Bridge

Type of Test / Items	PUNDIT N/sq.mm	Rebound Hammer N/sq.mm	Potential Wheel	Half-cell	Resistivity K ohm cm
Beams	24.45	53.18	< 200 mV	< 200 mV	24.12
Columns(Upper)	23.93	54.89	< 300 mV	< 300 mV	48.95
Columns(Lower)	17.90	36.44	> 300 mV	> 300 mV	4.95
Abutments	23.66	43.28	> 300 mV	> 300 mV	16.78

Table 11(a): Summary of Chemical Tests & Cement Content on Peserai Bridge

Type of Test / Items	Cement Content %	Carbonation	Chloride Content %	Sulphate %
Beams	14.63	Positive	1.21	3.42
Columns	16.08	Negative	2.20	8.56
Abutments	NA	Negative	NA	5.22

Table 11(b): Summary of Chemical Test and Cement Content on Sarang Buaya Bridge

Type of Test / Items	Cement Content %	Carbonation	Chloride Content %	Sulphate %
Beams	18.52	Positive	0.77	7.70
Columns	17.22	NA	1.15	NA
Abutments	NA	Negative	NA	11.47

Table 12: Comparison between Peserai and Sarang Buaya Bridge in terms of Chemical and Cement Content

Items	Tests	Cement Content %	Carbonation	Chloride Content %	Sulphate %
Beams	Sarang Buaya	18.52	Positive	0.77	7.70
	Peserai	14.63	Positive	1.21	3.42
Columns	Sarang Buaya	17.22	NA	1.15	NA
	Peserai	16.08	Negative	2.20	8.56
Abutments	Sarang Buaya	NA	Negative	NA	11.47
	Peserai	NA	Negative	NA	5.22