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BRIDGE EVALUATION THROUGH NONDESTRUCTIVE TESTING IN COMPARISON WITH VISUAL INSPECTION

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ABSTRACT: This paper presents a nondestructive testing method in evaluating bridge condition in comparison with visual inspection that has been used for ages. While condition ratings are all qualitative and defined primarily as sets of visual indicators in routine inspection, nondestructive testing are more quantitative and has large potential in determining damages inside the structure that are not visible. Hence, an attempt to integrate the nondestructive evaluation and bridge management system has been carried out by several researchers. This study is aimed to determine bridge strength through non-destructive testing and thus establish correlation between visual inspection rating and the nondestructive testing results. 75 concrete bridges under the supervision of Public Works Department (Malaysia) have been selected for the preliminary testing which includes the Rebound Hammer test, Ultrasonic Pulse Velocity, and electromagnetic cover meter. However, this paper will only discuss the methodology and results from Rebound hammer test. Generally, this study indicates good correlation between visual rating and strength from Rebound Hammer result. Ratings assigned to the bridge during visual inspection are within an acceptable range in reflecting the bridge strength. Rebound hammer has a potential to be a preliminary test in evaluating the bridge condition. However, since the nondestructive testing is not always readily available and there may be problems occurred with the lack of experienced inspectors to conduct the test, the implementation of this method in routine inspection may be limited. Therefore, an initial study to develop an intelligent rating system combining both nondestructive test data and visual inspection rating has been conducted in the later stage of this research as part of the solution to this problem.

Keywords: Non-destructive testing, Rebound Hammer Test, visual inspection, bridge defects

1. INTRODUCTION

Bridges and other structures deteriorate with time and use. The deterioration process is affected by several characteristics: traffic, rain, freeze, thaw cycles, climate, pollution, temperature, and moisture variations (Rens et al., 2005). This deterioration process can lead to eventual failure of the bridge. Periodic bridge inspections are therefore necessary to assess the extension, implications, and current state of the deterioration process. Inspections not only help to prevent failure but also deliver information necessary to effective administration of the bridge network. During inspections, the need for urgent repairs, maintenance action, and replacements of bridges can be detected and reported. Based on this report, the administrative bodies can further define priorities and establish programs to apply available resources to the most critical bridges.

Currently, bridges are evaluated through either a visual inspection or structural analysis. Visual inspections are commonly used nowadays. When bridge evaluation is conducted using this method, a subjective rating will be assigned to the bridge components by the responsible inspector. Condition ratings are all qualitative and defined primarily as sets of visual indicators use in routine inspection (Hearn and Shim, 1998). Visual inspection provides no useful information until visible defects starts to appear in the structural members (Estes, 2003). For instance, the presence of crack can offer valuable information, but they will not appear until late into the fatigue life of the structure.

Damages inside the structure that are not visible are difficult to identify (Chang and Liu, 2003). The application of the nondestructive testing method in bridge inspections has gained interests among researchers due to its effective ability in evaluating structural condition of the bridge (Nash't et al. 2005; Parhizkar 2003; Rens et al. 2005; Hearn and Shim 1998; Rens and Transue 1998). This study looks at the application of Rebound Hammer Test as nondestructive approach in evaluating bridge condition.

2. NONDESTRUCTIVE TESTING IN BRIDGE EVALUATION

The use of nondestructive techniques could provide invaluable information to the engineers in evaluating the structural integrity and serviceability of an existing structure. Nondestructive testing of concrete includes methods of test on concrete structure or structural members which do not reduce the functional capability of the structure. Nondestructive test may be used to locate areas of unsound concrete or concrete suspected of being significantly below the specified level of strength required by the design or the required level of durability. Nondestructive testing may also be used to indicate changes with time in characteristic of concrete. Rebound hammer together with other testing like the penetration resistance, cast-in-place pullout tests, maturity method, and pulse velocity method are among the available methods in nondestructive testing as been standardized in ASTM.

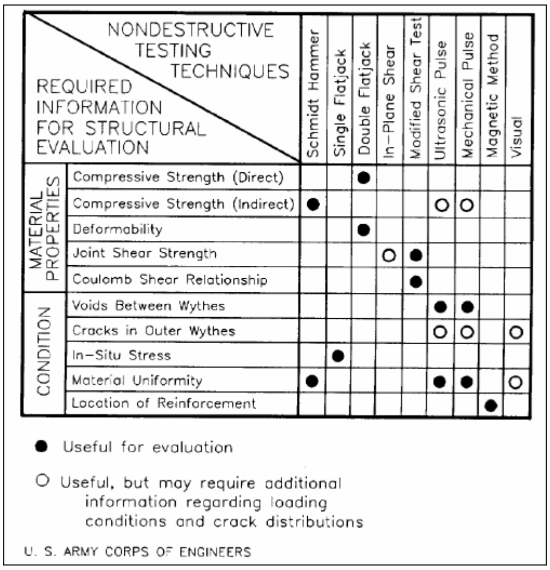
Survey conducted by Rens and Transue in 1993 and 1996 reveal that the use of nondestructive evaluation as a tool for maintenance decision is increasing. A case study has been conducted by Parhizkar et al. (2003) to revise the role of nondestructive test for evaluation of concrete structure in the Persian Gulf region. The tests that were carried out include concrete uniformity test, compressive test, concrete cover over reinforcement, potential corrosion, and chloride penetration depth determination. This study shows that nondestructive tests are effective methods of assessing deterioration in existing concrete structure.

Due to its large potential, an attempt to integrate the nondestructive evaluation and bridge management system has been carried out by several researchers. In 1998, Hearn and Shim have developed procedures to communicate data from quantitative nondestructive evaluation methods to bridge management system. Nondestructive evaluation method are used directly to assign condition ratings and it offer definite determinations of condition states, without the differences in condition reporting that occur among human inspector.

In 2005, Rens et al. have illustrated a methodology called Bridge Evaluation using Nondestructive Testing (BENT). The methodology used major bridge network under The City and Country of Denver Public Works Department supervision for the application of nondestructive evaluation methods in bridge inspection. The BENT method establishes criteria to determine the bridges to be inspected with nondestructive evaluation technique and also helps determine the nondestructive methods to be applied in the inspection.

2.1 Rebound Hammer Test

The Rebound Hammer test is the quickest, simplest, and least expensive method for nondestructive testing (BS 1881: Part 202). The Rebound hammer consists of a spring loaded steel hammer which, when releases, strikes a steel plunger in contact with the concrete surface, and rebounding indicates a rebound number on a calibrated scale (ASTM C 805 (CRD-C 22)). As shown in Figure 1, studies show a reasonably good correlation between rebound number and the compressive strength of a structure and most ideally suited to the measurement of material uniformity over large area of a structure. The main advantage of the Rebound hammer is its extreme portability so that many tests may be made easy in a short period of time. Due to this features and the limitation of other NDT tools, Rebound Hammer, Ultrasonic Pulse Velocity, and Electromagnetic Cover Meter are used in this initial research to gain as much information on the bridge condition. However it's only the Rebound hammer test will be discussed in this paper.



	REQUIRED INFORMATION FOR STRUCTURAL EVALUATION \ NONDESTRUCTIVE TESTING TECHNIQUES	Schmidt Hammer	Single Flatjack	Double Flatjack	In-Plane Shear	Modified Shear Test	Ultrasonic Pulse	Mechanical Pulse	Magnetic Method	Visual
MATERIAL PROPERTIES	Compressive Strength (Direct)			●						
	Compressive Strength (Indirect)	●					○	○		
	Deformability			●						
	Joint Shear Strength				○	●				
	Coulomb Shear Relationship					●				
CONDITION	Voids Between Wythes						●	●		
	Cracks in Outer Wythes						○	○		○
	In-Situ Stress		●							
	Material Uniformity	●					●	●		○
	Location of Reinforcement								●	

● Useful for evaluation

○ Useful, but may require additional information regarding loading conditions and crack distributions

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Figure 1: Use of NDT method

2.2 Method of Inspection

In this research, concrete bridges on the federal highway in Johor state (Malaysia) are chosen as research samples. 75 concrete bridges from various samples are chosen for the testing. Full tests are carried out on the bridge deck, pier, and abutment. Findings from this testing will be correlated indirectly with the overall strength of the bridges. Figure 2 shows the distribution of bridge samples used in this research. Based on interspan relationship, bridge sample are divided in two main types; simply supported and continuous bridge. Number of samples for each type is almost equal with 47% and 53% respectively. Deck type for the selected bridge sample are categorized in two groups; precast (I-beam and inverted T-beam) and cast-in-situ (RC beam and RC slab). Most of the bridge deck samples are from precast type; 37% inverted T-beam and 35% I-beam. There's only 5% deck from RC slab type and 23% from RC beam.

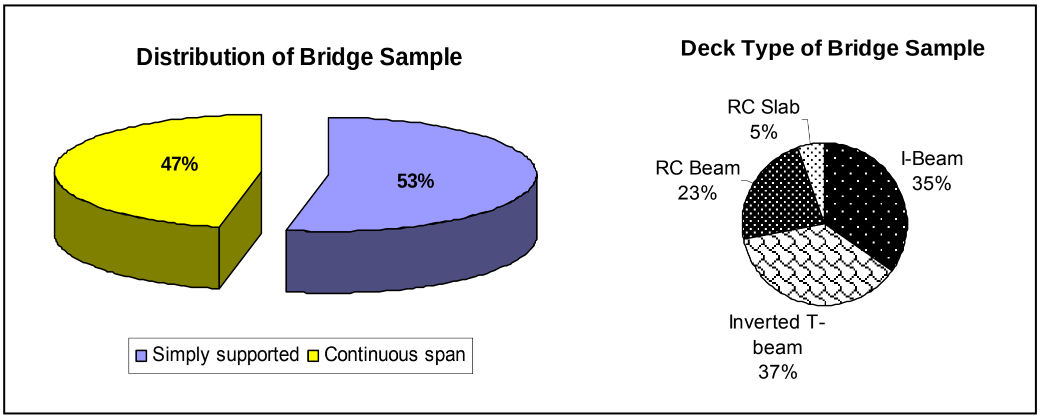


Figure 2: Distribution of bridge samples

Method used in the application of Rebound hammer test in this research is based on the standard specification outlined in British Standard BS 1881: Part 202. Rebound Hammer Type N with impact energy = 0.225 mkg is used in this research. Smooth and clean surface are selected prior to the testing since rough surface will not give reliable results. 12 readings are taken to estimate surface hardness at each location. Readings are confined to an area not exceeding 300mm x 300mm. A regular grid of lines approximately 50mm apart are drawn on the sample and readings are taken on the intersection of the lines as shown in Figure 3. The mean rebound number obtained in this research is likely to be accurate within ± 4.3% with 95% confidence. To take readings, the plunger of the Rebound hammer is pressed strongly against the concrete surface under test. An impact will cause, and while the hammer is still in position, the index is taken to the nearest whole number. The mean of each set of readings are calculated using all the readings (including abnormally high and abnormally low results).

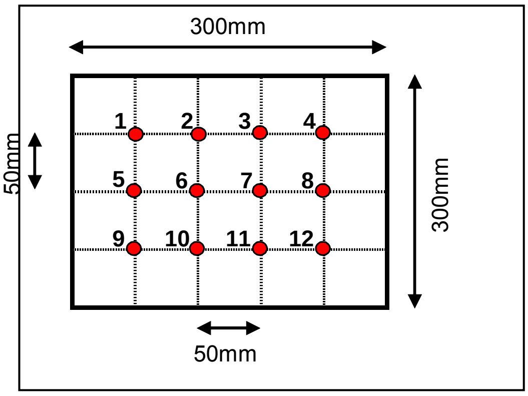


Figure 3: Readings on each location sample

Before Rebound hammer test are conducted on the bridge structure, sketches are drawn to identify the most suitable area to conduct the testing in order to develop a contour of concrete quality on the structure. Reference numbers are assigned to each location so it'll be easy to manage the readings data during analysis. Number of location sample for each element is depends on the size of the bridge structure and visible concrete defects. Larger bridge will require more reading sample compare to the smaller bridges. Figure 4 shows a standard form that has been developed to record Rebound readings during site inspection. Element type and test location are recorded based on the sketches made earlier. Each Rebound number is recorded.

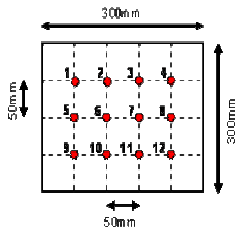
Element Type	Test Location	Readings Location	Location Point	Rebound Number	Strength (N/mm^2)	Concrete Quality
■ Deck	■ B1		1	30		
☐ I-Beam	☐ B2		2	36		
☐ Inverted T-Beam	☐ B3		3	30		
■ RC Beam	☐ B4		4	28		
☐ RC Slab	☐ A1		5	30		
☐ Abutment	☐ A2		6	28		
☐ Piers	☐ A3		7	29		
☐ Others:	☐ A4		8	29		
	☐ P1		9	28		
	☐ P2		10	28		
	☐ P3		11	29		
	☐ Others:		12	30		
			Mean	**30**		

Figure 4: Form used to record Rebound reading

Many trials were carried out to predict the correlation between rebound number and strength. Study has been conducted by Giovanni Pascale et al. (2003) in order to obtain relationship between nondestructive test parameters and strength. The following power function was obtained:

$$\mathbf{R_{c,s} = \alpha x^{\beta}} \tag{1}$$

Where $R_{c,s}$ = estimated cube strength and x = nondestructive parameter typical of the method used.

While in 2005, a study conducted by Dr. Isam H. Nash't et al. (2005) has obtained the following equation for rebound number and strength relationship:

$$\mathbf{Sc = 0.788R^{1.03}} \tag{2}$$

Where, Sc = Crushing strength (N/mm2) and R = Rebound number
Even though this value are subjected to other factors and core sample has to be taken to evaluate specific concrete strength for each sample, for comparison purposes, this value will be used in this preliminary study.

Figure 5 shows Rebound hammer test conducted on selected abutment location.

Figure 5: Rebound hammer test conducted on selected abutment

2.3 Discussion of Results

Table 1 shows the distribution of Rebound hammer reading in different type of bridge decks. For cast-in-situ deck type; RC beam, the Rebound numbers are 15 to 50 on the hammer scale, with an average of about 36 and a deviation of ± 6.4, while for RC slab; it ranges from 26 to 60, with average of 42 and a deviation of ± 5.92. It shows the concrete quality is very non-uniform. As for precast deck type, Rebound numbers are 41 to 55 for I-beam and 31 to 55 for inverted T-beam with average of 49 and 46 respectively. Deviation is equal to ± 3.16 for I-beam and ± 4.83 for inverted T-beam, which also indicates non-uniformity in the concrete quality. Precast deck shows higher Rebound numbers and lower deviation compare to cast-in-situ deck type. Figure 6 illustrate the differences.

Table 1: Distribution of Rebound Hammer readings

Rebound No.	No. of Readings			
Range	RC Beam	RC Slab	I-Beam	Inv. I-beam
15≤R≤20	2	0	0	0
21≤R≤25	0	0	0	0
26≤R≤30	11	1	0	0
31≤R≤35	11	5	0	1
36≤R≤40	17	18	0	11
41≤R≤45	13	21	8	12
46≤R≤50	4	9	30	31
51≤R≤55	0	5	22	5
56≤R≤60	0	1	0	0
61≤R≤65				
66≤R≤70				
Avg. Strength	**36**	**42**	**49**	**46**
Std. Dev.	**6.38**	**5.92**	**3.16**	**4.83**

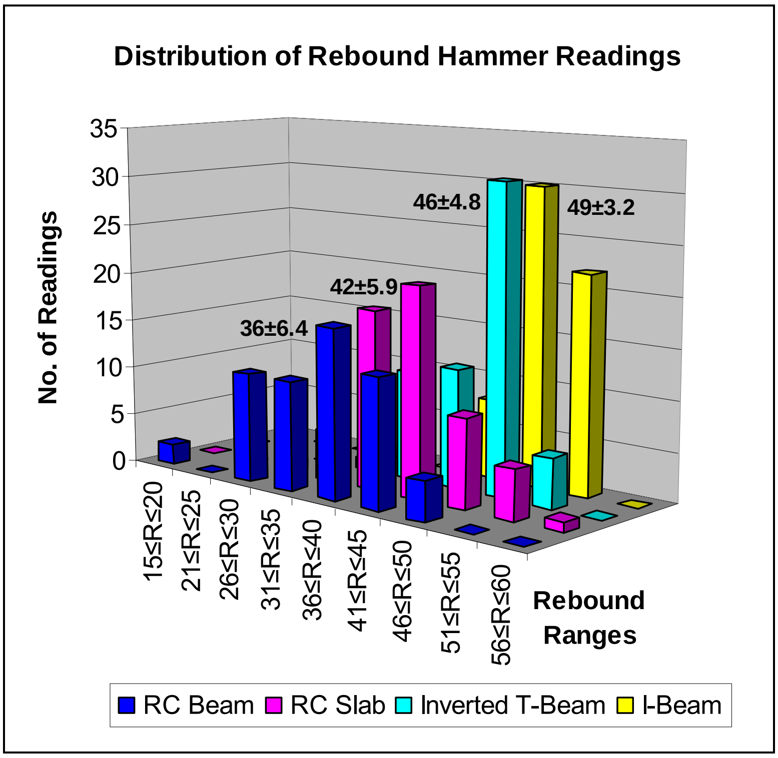


Figure 6: Distribution of Rebound numbers in bridge deck

Figure 7 shows the concrete strength for simply supported bridge sample plotted against age for deck and abutment. Concrete strength is higher in bridge deck then in the abutment. From the age of 7 years old, the concrete strength starts to decrease with time but it is still within the allowable range. The same behavior occurs to continuous bridge sample. At the age of 39 years old, the concrete strength has dropped below the 'sound' level. Concrete strength in bridge deck is also higher compared to the pier as shown in Figure 8.

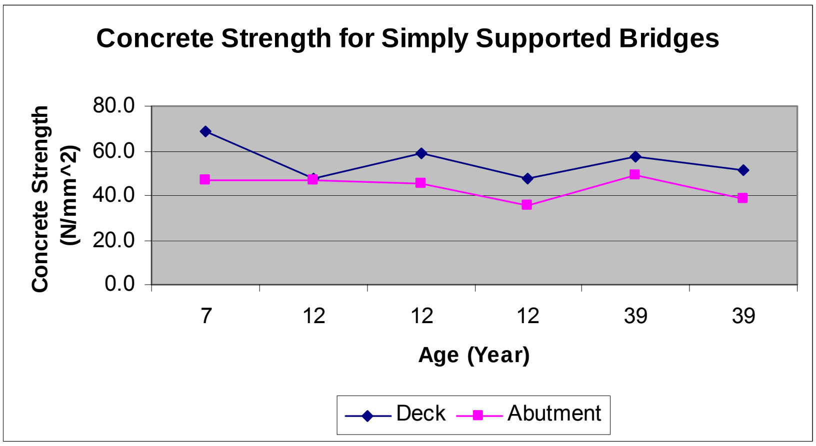


Figure 7: Concrete strength in simply supported bridge sample

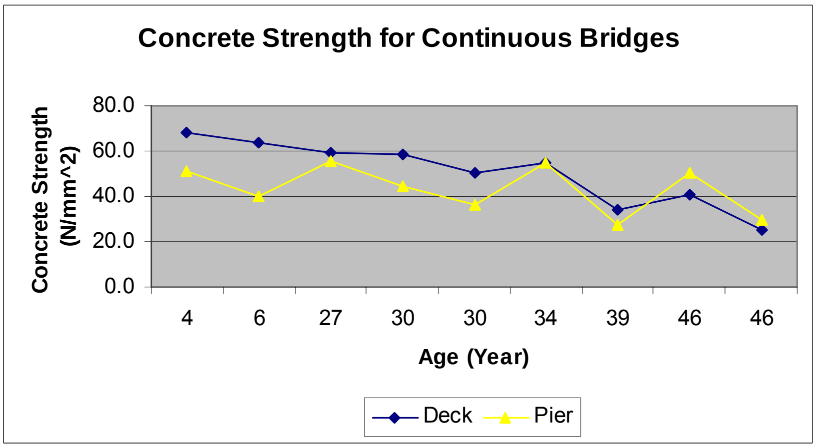


Figure 8: Concrete strength in continuous bridge sample

Concrete strength obtained from Rebound hammer test is also compared with visual rating assigned to bridge members during inspection to evaluate the correlation between these two parameters. Visual ratings used in this research are based on rating assigned by the inspector for the year 2005. The inspection processes are based on the Public Works Department (Malaysia) specifications and format. Ratings are ordinal and range from 0 to 5; '1' indicates no visible defects while '5' designate critical defects. '0' rating will be assigned if the members can't be accessed.

Figure 9 shows the correlation between concrete strength and visual rating for simply supported bridge sample. It can be seen that visual rating does not really tend to change with time in a specific trend while concrete strength tend to decrease with time. For continuous bridge sample, the correlation between visual rating and concrete strength are more comparable (Figure 10). Concrete strength decreases with time while visual rating increases, which indicates the presence of visible sign of defects in structure. Higher visual rating represents bad condition.

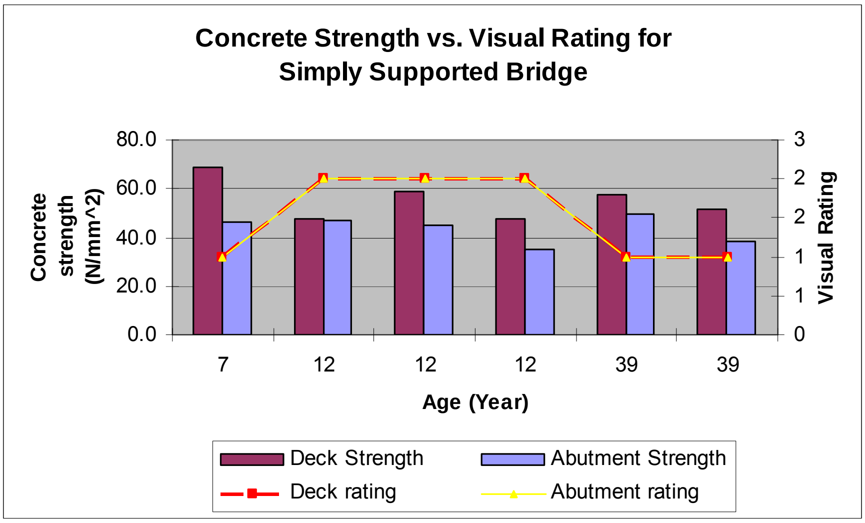


Figure 9: Concrete strength in comparison with visual rating (Simply supported bridge sample)

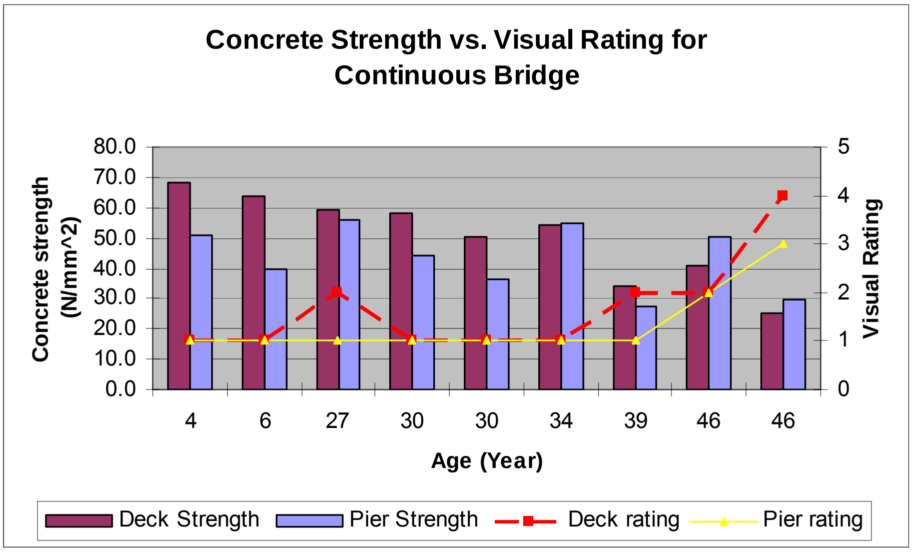


Figure 10: Concrete strength in comparison with visual rating (Continuous bridge sample)

During the inspection process, some visible defects are observed in few samples of the selected bridges which some of them had been repaired. Figures 11 to 13 show some pictures of bridge defects captured during the inspection process. For bridge sample 1, cracks had developed on piers and abutments. The abutments are from skeleton type while the piers are of multi column type. Hair line cracks can be observed on the column support (Figure 11 (a)) while severe cracks are developed on the lower part of the abutment as shown in Figure 11 (b). From the Rebound hammer test, the overall concrete strength on abutment is 19 N/mm^2 which indicated very poor concrete strength. Readings on deck is 55 N/mm^2 while on pier is about 35 N/mm^2 which indicates sound and moderate condition respectively. According to visual inspection, condition rating for abutment is 5, pier is 3, and deck is 3. This can definitely be evaluated since the visible defects are really obvious.

Bridge sample 1	
	
Figure 11 (a) *Cracks on pier*	*Figure 11 (b)* *Cracks on abutment*

Figure 12 shows another example in concrete deterioration and corrosion in reinforcement. Rating 4 are assigned to the bridge deck through visual inspection, while pier and abutment were both rated 3. Through Rebound hammer test, the overall concrete strength on bridge deck is 25 N/mm^2, while both pier and abutment has the overall strength of 30 N/mm^2. The visual inspection value is comparable with that of visual inspection.

Bridge sample 2	
	
Figure 12 (a) *Corrosion of reinforcement and concrete crack on beam (near abutment)*	*Figure 12 (b)* *Corrosion of reinforcement and concrete crack at middle span of beam*

Figure 13 show some other example in bridge defects. Hairline cracks are developed on the bridge deck and spalling occurs on the wing wall abutment. Both abutments and decks are rated 1 during the visual inspection process which indicate no defects detected. Through Rebound hammer test, the overall concrete strength on bridge deck is equal to 40 N/mm^2 while abutment is 35 N/mm^2 respectively. This indicates the concrete strength is relatively moderate.

Bridge sample 3	

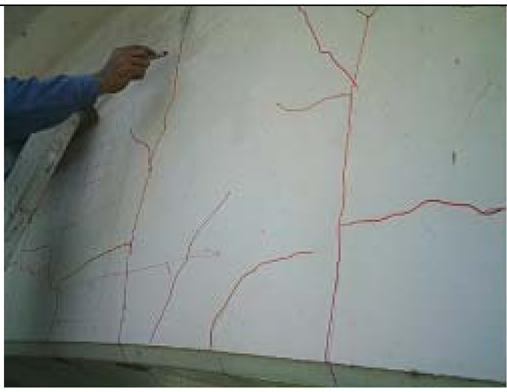



Figure 13 (a) *Crack patterns on beam*	*Figure 13 (b)* *Spallings on abutment*

3. CONCLUSIONS

In general, this study indicates good correlation between visual rating and strength from Rebound Hammer results. Ratings assigned to the bridge during visual inspection are within an acceptable range in reflecting the bridge strength. Rebound hammer has a potential to be a preliminary test in evaluating the bridge condition. The Rebound hammer test method described in this study can be used as future guideline in conducting this test on site. However, since the nondestructive testing is not always readily available and there may be problems occur with the lack of experienced inspectors to conduct the test, the implementation of this method in routine inspection may be limited. Therefore, an initial study to develop an intelligent rating system combining both nondestructive test data and visual inspection rating has been conducted in the later stage of this research as part of the solution to this problem.

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