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The Importance of Bridge Health Monitoring

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***Abstract*—**In the past, there were many bridge's collapses due to lack of bridge structural capacity information. Most of concrete bridge health was relied on information from visual inspection, which sometime was inadequate. This study was conducted in order to investigate relationship between bridge structural condition and bridge visual condition. This study was a part of a big project conducted at Department of Highways of Thailand. In this study, 31 bridges including slab-type bridges, plank-girder bridges, prestressed box-beam bridges, prestressed I-girder bridges and prestressed multi-beam bridges were selected for visual inspection and load test. It was found a positive correlation between bridge appearance and bridge's load carrying capacity. However, statistical characteristic revealed low correlation between them.

***Keywords*—**Bridge, Visual Inspection, Load Test, Condition Rating, Rating Factor

I. Introduction

DUE to many bridge collapses around the world in the past, it was expected that only visual inspection might not be adequate for bridge health assessment. Department of Highways (DOH) conducted a big project in order to determine safety of all bridges in Thailand.

The project also included a study to see if only visual inspection would ensure safety of bridges. Therefore, the study began with a process of selecting representative bridges. All bridges in Thailand were categorized into a certain groups according to bridge type, service period and traffic volume. Then 31 bridges were selected from those groups and those 31 bridges were used as representatives of all bridges in Thailand.

After that, the 31 bridges were carefully visual inspected, in which their visual service condition were rated using a parameter called OCR (Overall Condition Rating) by AASHTO. The 31 bridges were load tested by using Thai truck weighted 25 tons as shown in Fig. 1.

II. Bridge Grouping and Sampling

All bridges were categorized by using bridge type, which were slab-type bridge (ST), I-girder bridge (IG), prestressed box-beam bridge (BG), prestressed multi-beam bridge (MB) and prestressed plank-girder bridge (PG). Their cross sections are illustrated in Fig. 2a, 2b, 2c, 2d, and 2e accordingly.

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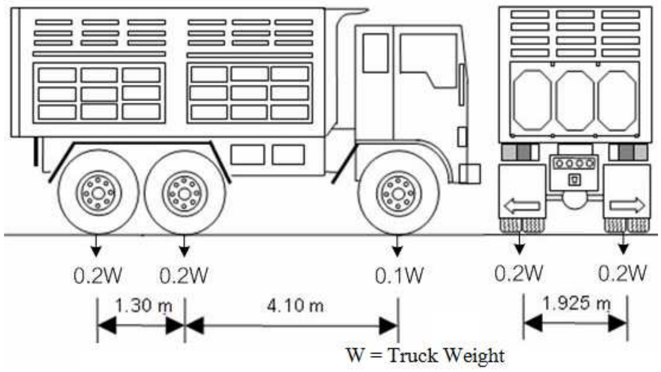

Fig. 1 Configuration of Thai truck weighted 25 tons

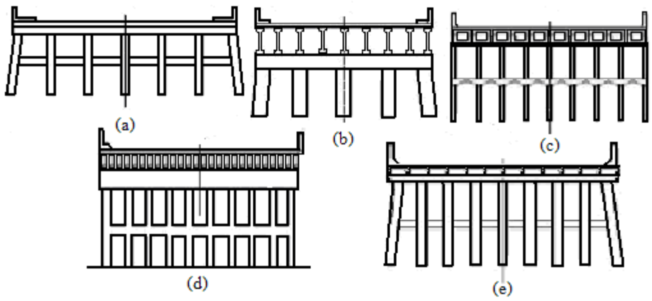

Fig. 2 (a) Cross section of slab-type bridge, (b) I-girder bridge, (c) Prestressed box-beam bridge, (d) Prestressed multi-beam bridge and (e) Prestressed plank-girder bridge

In addition, all bridges were categorized according to their service periods and their traffic volumes. Then 1 or 2 bridges were sampled for each group as shown in Table I.

TABLE I
NUMBER OF BRIDGE TESTED IN EACH GROUP.

AADT < 10,000 vehicles/day					
	ST	PG	MB	BG	IG
<10 yrs	1	1	-	2	2
10 – 20 yrs	1	2	1	1	1
> 20 yrs	1	1	-	1	2

AADT > 10,000 vehicles/day					
	ST	PG	MB	BG	IG
<10 yrs	1	1	-	1	1
10 – 20 yrs	1	1	2	1	1
> 20 yrs	1	1	-	1	1

Totally, the 31 bridges were selected for the next processes. The details of 31 bridges selected are described in Table II.

TABLE II
RESULTS FROM BRIDGE VISUAL INSPECTION AND LOAD TESTING

No.	Span	Age	AADT	OCR	M-RF	V-RF	Bridge-RF
ST-1	9	10	1962	7	0.91	1.04	0.91
ST-2	10	8	15143	7	1.04	1.06	1.04
ST-3	10	15	7038	6	1.00	1.01	1.00
ST-4	10	16	30435	7	1.01	1.02	1.01
ST-5	10	34	7833	6	0.99	1.00	0.99
ST-6	10	35	46412	5	0.97	0.98	0.97
PG-1	10	4	9116	8	1.48	2.11	1.48
PG-2	10	11	14544	8	1.60	2.28	1.60
PG-3	10	13	2158	8	1.42	2.03	1.42
PG-4	10	16	2185	7	1.30	1.86	1.30
PG-5	10	14	29260	7	1.36	1.95	1.36
PG-6	10	27	3882	7	1.46	2.08	1.46
PG-7	10	24	19134	6	1.44	2.08	1.44
MB-	12	14	2990	8	1.60	2.19	1.60
MB-	12	14	81550	7	0.99	2.74	0.99
MB-	12	14	-	7	1.68	2.18	1.68
BG-1	20	8	6057	8	1.09	1.66	1.09
BG-2	20	7	7892	7	1.00	1.53	1.00
BG-3	20	8	13915	7	0.93	1.43	0.93
BG-4	20	15	3239	6	0.71	0.88	0.71
BG-5	20	-	18966	7	0.90	1.40	0.90
BG-6	20	34	5687	7	0.90	1.39	0.90
BG-7	20	55	10117	6	0.95	1.47	0.95
IG-1	30	10	9587	7	1.07	1.10	1.07
IG-2	30	7	9053	7	1.05	1.08	1.05
IG-3	30	11	23805	8	1.04	1.06	1.04
IG-4	30	-	-	7	1.04	1.07	1.04
IG-5	25	20	14544	7	1.20	1.24	1.20
IG-6	21	39	8413	7	1.03	1.05	1.03
IG-7	30	40	6153	5	1.03	1.06	1.03
IG-8	30	39	15720	7	1.05	1.09	1.05

III. BRIDGE VISUAL INSPECTION

The 31 bridges were visually inspected by bridge experts. For each bridge, all bridge components were inspected and were rated by criteria as shown in Table III. It should be acknowledged here that it was quite difficult to give actual condition rating to a bridge. However, the overall condition rates (OCR) of 31 bridges are shown in Table II.

TABLE III
BRIDGE RATING CONDITION CRITERIA [1]

OCR	Condition	Description
9	Excellent	
8	Very Good	No problem noted.
7	Good	Less minor problems. Hairline crack or no spalling is noted.
6	Satisfactory	Some minor problems without effect on overall strength. Crack with width less than 0.5mm or spalling less than 2% is noted.
5	Fair	All primary structural elements are sound with minor section loss. Crack with width 0.5-1.0mm or spalling 2-5% is noted
4	Poor	Advanced section loss or spalling. Crack with width 1.0-2.5mm or spalling greater than 5% is noted. Bridge needs local repair and additional supporting.
3	Serious	Loss of section or spalling have seriously affected on structural component. Crack with width 2.5-5.0mm is noted. Bridge needs temporary support and repair.
2	Critical	Advanced damages present in structural component. Fatigue crack or shear crack is noted. Crack width is greater than 5mm. Bridge needs some repair.
1	Imminent Failure	Major damages present in critical structural component, or obvious movement affecting structural stability is noted. Ex. crack with width greater than 5mm. Bridge needs major rehabilitation and strengthening.
0	Failed	Out of service and have to be reconstruction.

IV. Material Testing

In order to determine material properties of the 31 bridges, three types of testing were conducted, which were compressive strength test, carbonation test, and chloride test. The results from compressive strength test showed that the compressive strength of the 31 bridges were greater than the value specified in the standard drawing (fc'=320 kg/cm^2). For the carbonation test, the result showed the depth of carbonation reaction at 0.5cm, while reinforcing steel was at the depth of 3.5cm from the surface. The result from chloride test showed that no chloride content was found from the powder collected from concrete material.

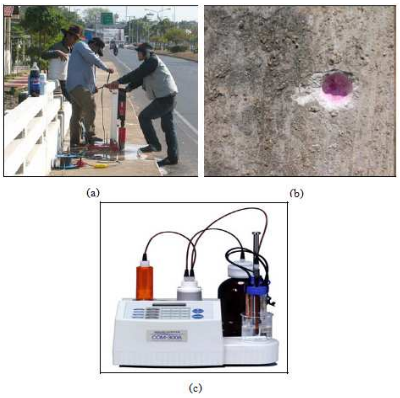

Fig. 3 (a) Compressive strength test, (b) Carbonation test and (c) Chloride test

V. Bridge Load Testing

In addition to visual inspection, the 31 bridges were load-tested. Three types of electronic instruments, strain gauge, displacement transducer and accelerometer were installed on each bridge. Two 25-ton Thai trucks were used to load the bridge during bridge load test as shown in Fig. 4. After bridge load test, all data collected were used in bridge strength evaluation.

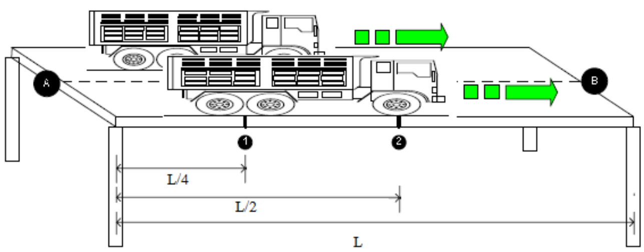

Fig. 4 Loading configuration on tested bridge

VI. Bridge Strength Evaluation

The procedure to estimate load carrying capacity of a bridge (or bridge strength) was followed a report from *National Cooperative Highway Research Program* [1]. The load carrying capacity of a bridge was represented by a parameter called "Rating Factor" (RF).

RF = (Bridge Strength – Factored Dead Load) / (Factored Live Load Plus Impact)

If $RF \geq 1.0$, a bridge could carry the rating vehicle safely. In this study, the rating vehicles were two 25-ton Thai trucks. The rating factors of the 31 bridges are shown in Table III. It could be seen that some bridges had rating factors less than 1.0 as shown in Fig. 5. This means they would need special care. It is noted from this study that moment rating factors (M-RF) were less than shear rating factors for all tested bridges.

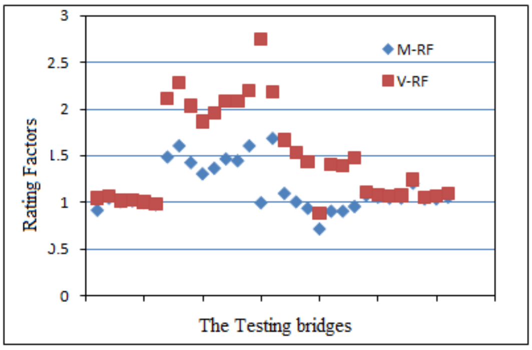

Fig. 5 Rating factors of the 31 bridges

In addition, it is interesting to examine a relationship between bridge visual inspection conditions and bridge strength conditions. The data from visual inspection was plotted with the data from bridge load test as shown in Fig. 6. The Fig. 6 reveals the positive relationship between bridge visual inspection and bridge strength, in which higher OCR value comes up with higher RF. However, the regression analysis provides low R-square value. This could imply that the positive correlation between both factors is not certain. In other word, structural condition of a bridge should not be relied on its appearance. Visual inspection condition could sometime mislead bridge strength. If possible, a bridge should be load tested in order to determine its actual response and its load carrying capacity.

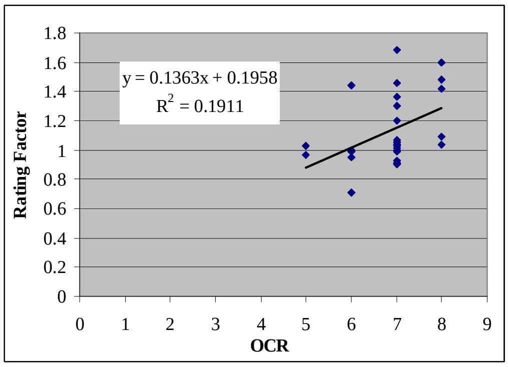

Fig. 6 Relationship between overall condition rating (OCR) and rating factor

VII. Conclusions

Thailand Department of Highways conducted a project to investigate the safety of all bridges in Thailand. A part of this project was to confirm that bridge visual inspection was inadequate to describe safety of a bridge. In this study, all bridges were grouped by bridge type, service period and traffic volume (AADT). One or two bridges were sampled from each group, in which total 31 bridges were selected. Those 31 bridges were then visually inspected and the overall condition rating (OCR) were given. Then, those 31 bridges were load tested and their load carrying capacities were evaluated in term of load rating factor (RF). This study reveals that safety due to bending moment was less than safety due to shear force. In addition, the positive relationship between bridge visual condition and bridge structural condition was found. However, result from statistic analysis confirmed that the data from the visual inspection was not enough to indicate the bridge structural condition.

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