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Condition Rating System for Thailand's Concrete Bridges

*Nukul Suksuwan and Bonaventure H.W. Hadikusumo

Abstract: The Bridge Management System (BMS) is designed to maximise use of available data and determine the optimal strategy to perform necessary improvements to bridges in the most cost-effective manner. This paper provides a condition rating system to meet the requirements of Thailand's Department of Highways (DOH). A rating system to assess the existing condition of bridges is proposed. Segmental inspection is developed to execute efficient element-level evaluations and collect data that demonstrate deterioration patterns in bridge elements. The paper also describes inspection procedures for field survey execution, which enables observed distresses at the level of sub-elements or members to be allocated. Recommendations from bridge experts reveal that the proposed rating system is robust, implementable in actual practice, and suitable for efficient application in evaluating the nation's concrete highway bridges. Although the bridge condition rating was developed in response to the specific characteristics of Thailand's bridges, the proposed methodology can easily be extended to other bridge agencies.

Keywords: Bridge condition rating, Visual inspection, Segmental evaluation, Bridge element distresses, Bridge data collection forms

INTRODUCTION

Infrastructure systems, such as bridges and other roadside structures, are key elements in a road network. The aging and extensive deterioration of these infrastructures present considerable challenges to designers, managers, and owners who must find an effective management system to preserve the safety and serviceability of the infrastructure with limited budgets (Stewart et al., 2004).

Bridge Management Systems (BMSs) are designed to help maximise the use of available information for the inspection, maintenance, rehabilitation, and replacement of bridges and to determine the optimal time to perform necessary improvements for any bridge (Minchin Jr. et al., 2006). The major features of a BMS include the data collection method, bridge condition rating, inspection and evaluation, models of bridge deterioration and the effect of maintenance activities, cost factors, bridge maintenance, repair and rehabilitation (MR&R) optimisation, and life-cycle economic analysis of project- and network-level tradeoffs.

Construction, Engineering and Infrastructure Management, School of Engineering and Technology (SET), Asian Institute of Technology, THAILAND *Corresponding author: snukul@wu.ac.th

In Thailand, the Bridge Management and Maintenance System (BMMS) was initially developed with cooperation from the Denmark Department of Highways in 1989 (TDOH, 1989). Lack of analytical resources and an insufficient number of specialised practical experts, however, are significant shortcomings in using such a BMMS program. Existing bridge maintenance programs are justified based on the rough data collected from field surveys by using visual observation to evaluate the physical conditions of bridge elements. Condition rating systems are not developed as systematic approaches in actual practice. In addition, data collected from visual inspections, condition ratings, and implemented improvements are not consecutively and systematically recorded in a BMS database. Lack of historical data of bridge conditions is a major problem in simulating bridge deterioration behaviours. As a result, the development of a bridge condition rating system to respond to the inspection of concrete highway bridges of Thailand's Department of Highways (DOH) is proposed.

This paper intends to develop a systematic approach for bridge condition ratings and inspection methods. It proposes a rating system to assess the physical condition of individual bridge elements. The method is suitable for use in practical operations for inspecting and rating the existing conditions of concrete highway bridges under the responsibility of Thailand's DOH. Comprehensive analysis with this method will reveal all element distresses with descriptions of damage types, severity and extent levels in any bridge component. The existing condition of inspected bridge elements integrated with descriptions of aggressive environments encountered and bridge inventory information in the database can be applied to generate deterioration models for bridges in the network. Strategic maintenance plans in timing and execution will be properly determined by considering the proposed deterioration prediction models.

BACKGROUND

Bridge Management System

A BMS is a decision support tool that supplies analyses and summary data, uses mathematical models to make predictions and recommendations, and provides the means by which alternative policies and programs may be efficiently considered (FHWA, 1996). It includes formal procedures for collecting, processing, and updating data; predicting deterioration; identifying alternative actions; predicting costs; determining optimal policies; performing short- and long-term budget forecasts; and recommending programs and schedules for implementation within policy and budget constraints (Thompson, 2004). BMSs were developed to help maximise the use of available information for the inspection, maintenance, rehabilitation, and replacement of bridges. They help determine the optimal time for bridge-managing agencies to perform necessary improvements to a bridge (Minchin Jr. et al., 2006).

Currently available BMSs, including the earliest Pontis (Thomson et al., 1998), BRIDGIT (Hawk and Small, 1998; Small, 2002), Finnish (Soderqvist and Veijola, 1998), Danish (Lauridsen et al., 1998), German (Haardt, 2002), and Japanese (Miyamoto et al., 2000) BMSs, were developed to manage a bridge network (Gattulli and Chiaramonte, 2005). Speiran et al., (2004) presented the implementation of a BMS in the province of Nova Scotia, Canada. The Nova Scotia BMS (NS BSM) is a customised version of the Ontario Bridge Management System (OBMS) that is specific to Nova Scotia. Most bridge agencies develop their own management systems to meet all their specific requirements. Although several countries have attempted to adopt BMSs that were developed by reliable agencies, various constraints and limitations in applying them to specific environments still exist.

Thailand Bridge Management and Maintenance System

The BMMS used in Thailand's DOH was developed primarily with the cooperation of the Danish Road Directorate in 1989. Due to several limitations in using the developed BMMS, it is not fully implemented in current practice.

There are about 12,814 concrete highway bridges throughout the road network in Thailand (TDOH, 2005). Four Bridge Construction and Rehabilitation Centers are the main agencies responsible for construction and maintenance, repair, rehabilitation, or replacement. Operational-level organisations inspect bridge conditions and report the results in different local areas known as sub-districts. Only serious cases of deteriorated bridges that require repair, rehabilitation, or replacement are reported in a database. For standard bridge inspections, manual and condition rating systems are not developed for implementation in actual national practice.

To recognise and improve the durability and safety of the nation's bridges, Thailand's DOH has attempted to perform inspection, data collection, and evaluation of the bridges' condition to monitor future deterioration trends. In 2008, Thailand's DOH, in cooperation with TESCO Ltd., took limited action on the inspection and evaluation of bridge conditions and load carrying capacity to assess slab bridges located in Southern Thailand (TDOH, 2008). In addition, many bridge agencies and researchers in Thailand, such as Namee (2002), TDOH (2005), Seachan (2005) and some agencies of Thailand's DOH, have also studied the development of bridge inspection methods and related approaches to evaluate bridge condition ratings.

Bridge Condition Rating and Inspection Method

In general, good bridge management starts with good information on bridge conditions. The bridge data, which is stored in a management system, allows engineers to prioritise maintenance and rehabilitation needs, and to make sound decisions as to how to best take care of the bridge (FHWA, 2002). Rating the condition of bridges as a whole and individual bridge elements is vital for performing the right treatment at the right time on the right bridge.

FHWA (1995) has published the *Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges* in Report No. FHWA-PD-96-001. This guide has been widely used by several Department of Transportation (DOTs) in the United States and other countries to record and code the nation's bridge data. The National Bridge Inspection Standards (NBIS) were developed for use as federal regulations for inspection procedures and reports and preparation and maintenance of a state bridge. To meet their specific BMS requirements, several United State DOTs have developed individual systematic approaches for managing a bridge network. The State of New York's DOT (NYDOT, 1997) published the *Bridge Inspection Manual* to explain the requirements for general bridge inspections as required by New York State's Uniform Code of Bridge Inspection, NYCRR PART 165. Ohio's DOT (ODOT, 2006) provided the Bridge Inspection Manual to compile the policies and procedures of the ODOT related to its Bridge Inspection Program. The manual describes the following: (1) the responsibilities of various parties for bridge safety inspections, (2) the technical standards and specifications for bridge inspection, and (3) the administrative requirements to meet state and federal regulations for recording and reporting inspection information. The Washington State Bridge Inspection Manual M36-64 (WSDOT, 2006) was released in December 2006. The manual is written to guide inspectors through the inspection and inventory coding of bridges. The bridge condition inspection techniques and reporting of the results are presented. The manual also assists planners in improving management of bridges by defining elements that require maintenance, repair, rehabilitation, or replacement.

Various approaches have been proposed to satisfy the bridge condition rating system at the overall and component level. Gattulli and Chiaramonte (2005) described a bridge condition assessment procedure based on visual inspection developed during the planning and preliminary design of the BMS. The main modules in the procedure are the following: bridge inventory, computer-aided visual inspection, automated defect catalogue, and priority-ranking procedure. The results of a visual inspection campaign conducted for a set of bridges with different structural characteristics are reported and evaluated within the framework of the developed BMS. Larsen and Holst (2000) presented different ways of describing and administering rehabilitation strategies, including the technical and economic consequences for the bridge stock. They describe collecting data through inspections and surveys, and entering them into a BMS to rank bridges based on operation/maintenance and repair/rehabilitation. The different types of inspections are also highlighted along with the degree of precision and detailed inspection information. Hearn (2000) developed methods for segmental inspection of bridges to execute efficient element-level inspections and collect data on element deterioration patterns. Segmental inspection determines the element conditions and element quantities required by bridge management systems and also captures the locations of conditions within bridges. Relevant bridge condition inspections and rating approaches are reviewed to develop the proposed method.

METHODOLOGY

The main objective of this paper is to develop the bridge condition rating method. The Bridge Condition Score (BCS) derived from the proposed method reflects a bridge's levels of deterioration, performance, and serviceability. Most of the highway bridge structures under the responsibility of Thailand's DOH are reinforced concrete. Plank Girder (PG) and Slab Type (ST), which are about 95% of all bridges in the highway network, are selected for this study. General types of distresses that can occur on each element of concrete bridges are classified. Each distress will be divided into ranges of severity and extent. The weight, or importance measure, of severity and extent levels, as well as harmful levels for each type of distress, is determined. The lowest level of evaluation is the assessment of the member's condition. All member indexes are summed to calculate the element index. By integrating the condition index over all its elements, the deterioration score of the component is determined. All bridge components will be grouped separately into a superstructure and substructure. Finally, an overall BCS is computed. Furthermore, the bridge inventory data collection forms, inspection forms, and field surveying method for a bridge are presented.

Development of Bridge Condition Rating System

The element condition rating characterises the type, severity and extent of distresses, the element's ability to function, and the harmful effects on the other elements. The condition rating of each element can be used as the primary criteria to establish proper methods and timing of maintenance activities. Consecutive bridge element condition rating records indicate a tendency or pattern in the deterioration of the element. The deterioration pattern will be used to forecast the need for corrective maintenance work and reveal the effect of preventive maintenance over the bridge's service life. Types and elements of these bridges will be categorised. Identification of individual element distresses, distress severity, and extent of distress will then be used to define bridge element condition rating levels.

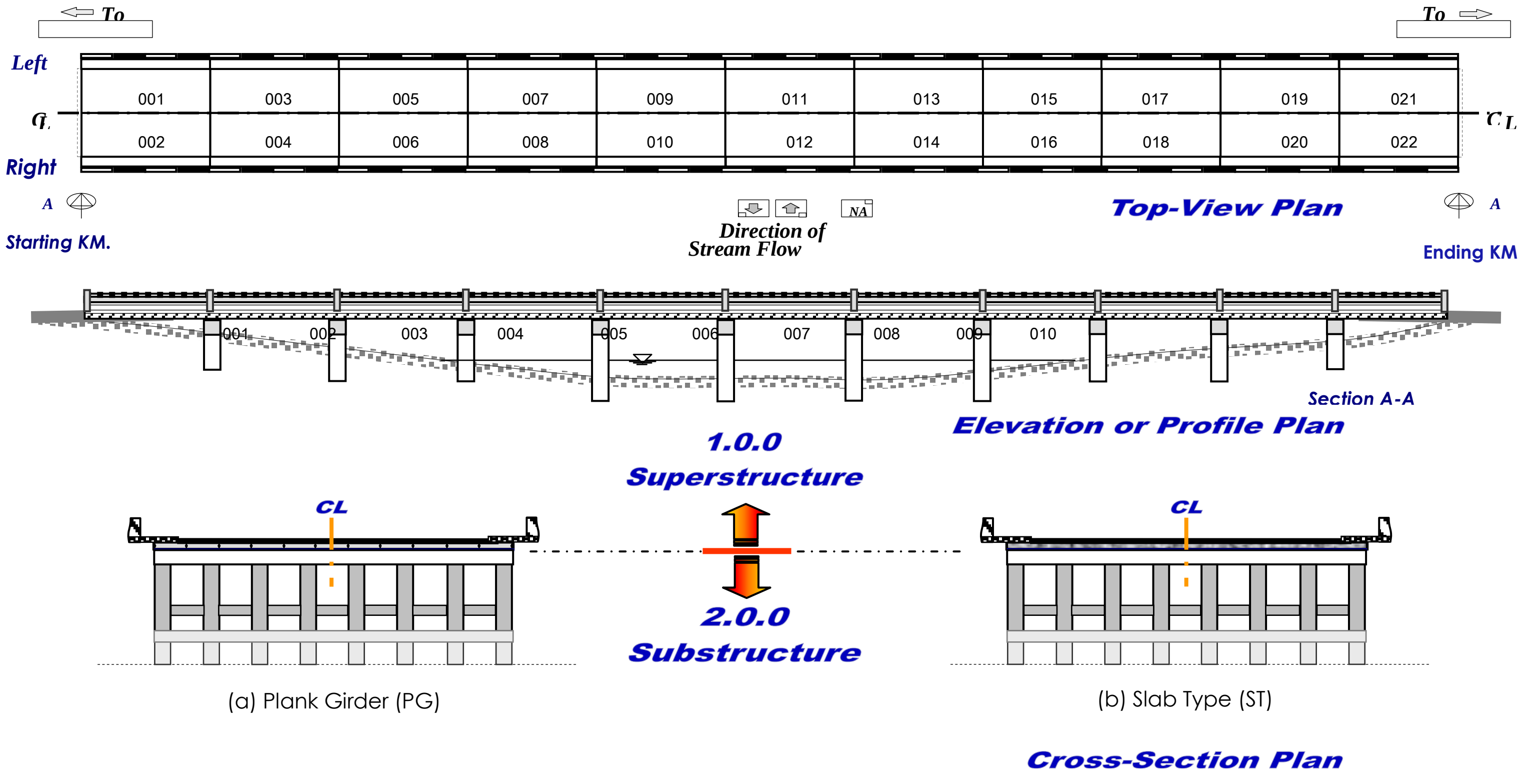
Thailand DOH Concrete Bridge Structures

There are 12,814 concrete highway bridges that are the responsibility of the Thailand's DOH over the road network (TDOH, 2005). Categorising by superstructure characteristics, the concrete bridges can be classified into five types: RC Slab Type (ST), PC Plank Girder (PG), PC Multi-Beam (MB), PC Box Girder (BG), and PC I-Girder (IG) bridges. The most common bridge in the network is the ST, which accounts for about 82% of the total. The second most common bridge is the PG Bridge, which makes up about 13% of all bridges across the country. The BG-, MB-, and IB-bridge types are 2%, 2%, and 1%, respectively (TDOH, 2005).

As mentioned previously, this paper presents the bridge condition rating system and inspection method to suit the evaluation of ST- and PG- bridge types, which are 95% of all bridges. Both bridge types span 5 to 10 meters in length, whereas the total bridge length will vary in the number of bridge spans. Figure 1 depicts the dimensions of a sample concrete highway bridge that is selected for this study. The structure of the bridge is considered as two portions, superstructure and substructure. The superstructure consists of two component groups: the bridge deck and accessories. The substructure is divided to three components: pier, abutment, and foundation. To determine the BCS, the elements are broken down into fifteen elements, as described in the following section.

A Bridge Hierarchy for Condition Assessment

To determine the condition rating index, the level of analysis, or the hierarchy of the bridge structure, will be classified into five levels, as shown in Figure 2. For the first step of a top-down procedure, a bridge level is the first state that is assessed to represent overall bridge performance. At the next level, the bridge is separated into two major portions, superstructure and substructure. The bridge deck and accessories are two groups of superstructure components in the third level, whereas the



(a) Plank Girder (PG)

(b) Slab Type (ST)

Figure 1. Sample Drawings of Concrete Highway Bridges' Structure

pier, abutment, and foundation are the three components of the substructure. The element level is the fourth level of the bridge hierarchical analysis. Each of the 5 bridge components will be divided into 3 elements at this level, thus generating the 15 elements for any bridge evaluation. All element sections or members of any bridge element will be specified by the field survey inspection process. For convenience and simple execution in inspection and analysis, numeric codes to represent the bridge components in each hierarchical level are identified in Figure 2.

Bridge Element Distress

To assess the physical condition of each bridge element, all feasible distresses that have the potential to cause these elements to deteriorate will be classified. Available data from historical condition inspections of bridges in Thailand will be used to generalise types of distresses. Suggestions and recommendations from interviewing experts will be used to support classifying element distress types. Furthermore, the results from field inspections of Thailand's DOH bridge conditions to investigate the distresses are also applied to generate the common types of bridge element distresses.

Distress types that reflect the deterioration of each bridge element are different and depend on various factors, such as the element's material type, usage behaviour, position on the bridge structure, environments encountered, or environmental threats. The effect or severity of the nature of each distress that affects the functions of bridge elements are studied and specified. Based on their harmful effects on the strength of bridge structures, the functionality of elements, and the public safety or comfort of road users, these levels of severity are divided into four levels: L, M, H, and VH. The L-level represents distresses with low severity or no effect on the strength of bridge structures or element functions, but lightly affects the comfort or ride quality of road users. On the other end of the spectrum, the VH-level reflects a very high distress type that seriously affects the strength or load capacity of bridge structures or element functions and the public safety or ride quality of road in users, along with the possibility of local failures. Examples of all possible distresses, classified for particular elements such as wearing surface, deck slab, and column, are presented Table 1.

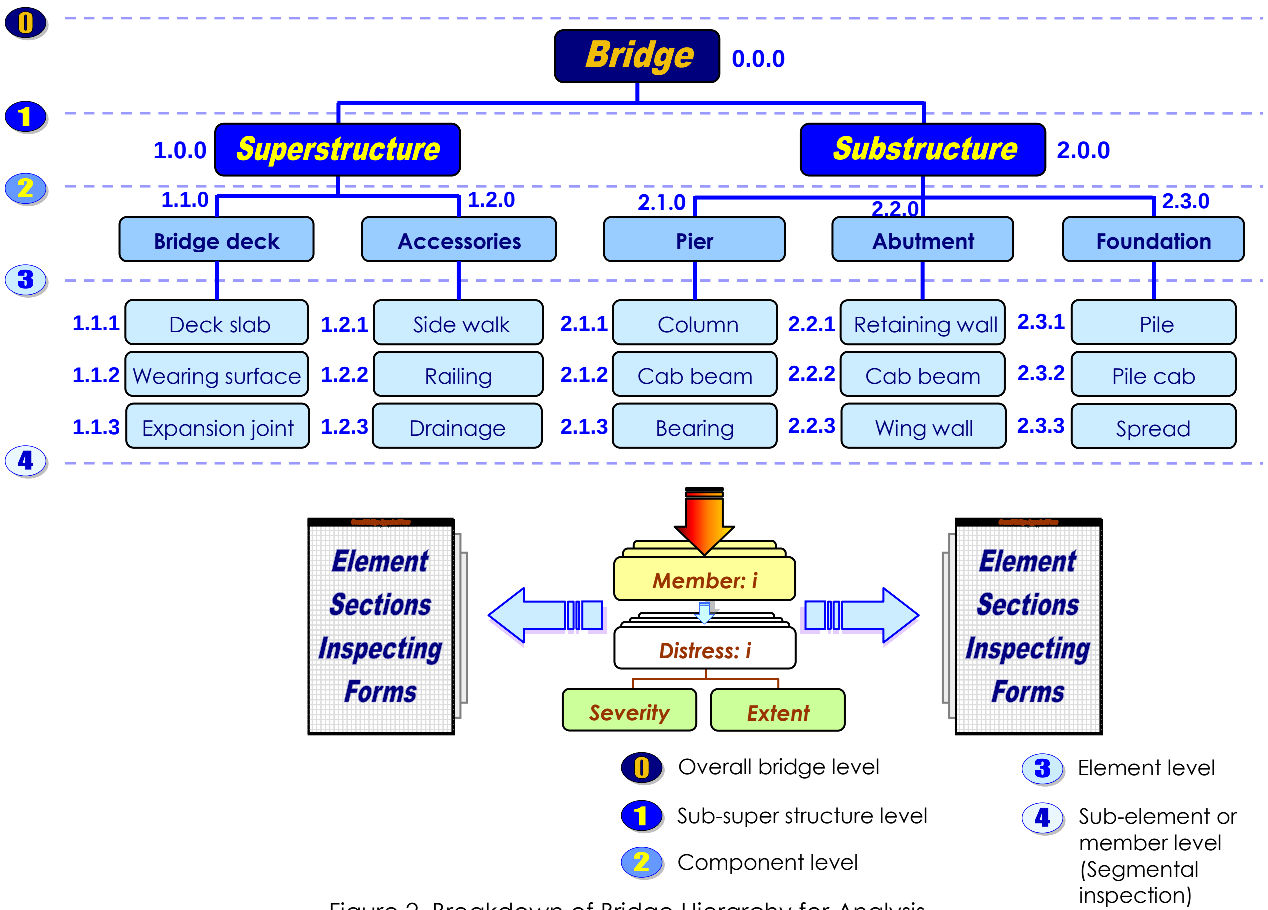


Figure 2. Breakdown of Bridge Hierarchy for Analysis

Table 1. Lists of Distress Types for Inspecting Wearing Surface, Deck Slab, and Column

Wearing surface	**Deck slab**	**Column**
1. Loss of friction due to polished aggregate	1. Cracks due to shrinkage and temperature of concrete cover	1. Cracking of concrete due to shrinkage and temperature variations
2. Raveling due to loss of adhesion	2. Scaling and wearing of concrete surface	2. Scaling and wearing of concrete cover
3. Corrugation of AC surface	3. Delaminations of concrete cover	3. Porous material due to deteriorated and aged concrete
4. Damaged patching of repaired area	4. Porous material due to deteriorated and aged concrete	4. Delamination of concrete cover
5. Transverse cracks at the end of span (edge cracks)	5. Spalling and popouts of concrete cover	5. Spalling and popouts of concrete cover
6. Rutting along wheel line due to repeated loading	6. Potholes of bridge deck	6. Fracture of concrete cover
7. Pothole and missing material of AC surface	7. Cracks and spalls around expansion joint of slabs	7. Honeycombing and cavities of pier
8. Alligator cracks along the wheel line due to overloading	8. Cracks and spalls at the end of deck over the cap beam	8. Structural cracks due to deficiency of load carrying capacity
	9. Corrosion and rusting of reinforcing steel	9. Deformation and movement of piers due to foundation scour
	10. Cracks and spalls due to rusting of reinforcing steel	10. Rusting of reinforcing steel due to corrosion (rebar exposure)
	11. Longitudinal cracks due to overloading or deformed girder	11. Cracks and spalls of concrete due to swelling of corroded reinforcing bars
	12. Shear /diagonal cracks at the end of deck span near column	
	13. Shear /diagonal cracks at the end of deck span near column	
	14. Alligator cracks due to deficiencies of load carrying capacity	

Weighting for the Severity and Extent Level

Distress types that strongly affect reduction of performance, service function, and service life of a bridge element are considered to have a high potential to influence the poor condition level. Therefore, to weight the index for several distress types, there are various levels of severity and extent and they must be determined properly in accordance with each bridge element. Through reviews of bridge distress identification manuals integrated with information from historical practice records, interviews of Thailand DOH experts' opinions, and direct field survey experiences on concrete bridge inspections, the appropriate weights and ranges of distress severity and extent level are established. Accurate, consistent, and repeatable distress evaluation surveys can be performed by using the severity and extent level identifications for each distress of each bridge element. Table 2 illustrates range scales for each level of severity and extent to evaluate various distress types that appear on the deck slab. The weightings or importance measures correspond with the distress types, the severity, and the extent levels, as shown in Table 3.

Computation of BCS

To determine the bridge's condition rating, each bridge will be divided into 15 parts for assessment, as illustrated in Figure 2. When a bridge is inspected, the total quantity of the members of each element is allocated a condition state based on the visual observations of the inspector. A list of distresses number 1 – *i* are reserved on an inspection form to evaluate the condition of bridge element members. Each distress type is rated on a scale of four levels by the severity of deterioration and four levels of the extent of deterioration. Condition ratings are assessed separately for individual bridge elements; therefore appropriate addresses for distress types, severity and extent levels of different element types will vary. Distress information observed from field data collected separately for each bridge element member will be used to determine the member rating value by basic calculation through the developed condition rating method. The Distress Rating Value (DRV), which reflects the condition of individual distress types, can be computed from Equation (1).

$$\text{Distress Rating Value (DRV)} = (DW \times SW \times EW)\text{ , for distress } i \qquad \dots (1)$$

Table 2. Examples of Specific Scope of Severity and Extent Level for Evaluating a Column

Distress No.	**Severity Level**				**Extent Level**			
	LOW	**MEDIUM**	**HIGH**	**VERY HIGH**	**LOW**	**MEDIUM**	**HIGH**	**VERY HIGH**
01	< 1 mm	1–5 mm	5–10 mm	> 10 mm	< 5%	5%–10%	10%–20%	> 20%
02	< 5 mm	5–15 mm	15–30 mm	> 30 mm	< 10%	10%–20%	20%–40%	> 40%
03	Light	Moderate	Severe	Serious	< 10%	10%–20%	20%–40%	> 40%
04	< 5 mm	5–15 mm	15–30 mm	> 30 mm	< 5%	5%–10%	10%–40%	> 20%
05	< 5 mm	5–15 mm	15–30 mm	> 30 mm	< 2%	2%–5%	5%–10%	> 10%
06	< 5 mm	5–15 mm	15–30 mm	> 30 mm	< 5%	5%–10%	10%–20%	> 20%
07	Light	Moderate	Severe	Serious	< 2%	2%–5%	5%–10%	> 10%
08	Light	Moderate	Severe	Serious	< 2%	2%–5%	5%–10%	> 10%
09	< 2.5 mm	2.5–5 mm	5–10 mm	> 10 mm	< 5%	5%–10%	10%–10%	> 20%
10	Light	Moderate	Severe	Serious	< 5%	5%–10%	10%–20%	> 20%
11	< 2.5 mm	2.5–5 mm	5–10 mm	> 10 mm	< 5%	5%–10%	10%–20%	> 20%
12	Light	Moderate	Severe	Serious	Light	Medium	High	Very High

Table 3. Weighting of Distress Types, Severity, and Extent Levels for Evaluating a Column

Distress Types	DWi	Severity Level				Extent Level			
		LOW	MED.	HIGH	VERY HIGH	LOW	MED.	HIGH	VERY HIGH
01 Cracking of concrete due to shrinkage and temperature variations	**2.29**	0.25	0.50	0.75	1.00	0.25	0.50	0.75	1.00
02 Scaling and wearing of concrete cover	**2.36**	0.25	0.50	0.75	1.00	0.25	0.50	0.75	1.00
03 Porous material due to deteriorated and aged concrete	**2.43**	0.25	0.50	0.75	1.00	0.25	0.50	0.75	1.00
04 Delamination of concrete cover	**2.75**	0.25	0.50	0.75	1.00	0.25	0.50	0.75	1.00
05 Spalling and popouts of concrete cover	**2.86**	0.25	0.50	0.75	1.00	0.25	0.50	0.75	1.00
06 Corrosion of concrete cover	**2.92**	0.25	0.50	0.75	1.00	0.25	0.50	0.75	1.00
07 Fracture of concrete cover	**3.07**	0.25	0.50	0.75	1.00	0.25	0.50	0.75	1.00
08 Honeycombing and cavities of pier	**3.17**	0.25	0.50	0.75	1.00	0.25	0.50	0.75	1.00
09 Structural cracks due to deficiency of load carrying capacity	**3.24**	0.25	0.50	0.75	1.00	0.25	0.50	0.75	1.00
10 Rusting of reinforcing steel due to corrosion (rebar exposure)	**3.31**	0.25	0.50	0.75	1.00	0.25	0.50	0.75	1.00
11 Cracks and spalls of concrete due to swelling of corroded reinforcing bars (rusting)	**3.43**	0.25	0.50	0.75	1.00	0.25	0.50	0.75	1.00
12 Deformation and movement of piers due to foundation scour	**3.75**	0.25	0.50	0.75	1.00	0.25	0.50	0.75	1.00

Where,

DW = the important weight of distress type i

SW = the important weight of distress severity level

EW = the important weight of distress extent level

A simple summation of the evaluated distresses over all the element members will produce a deficiency indicator value for an assessed member in terms of the Member Condition Rating (MCR) according to Equation (2). The Element Condition Rating (ECR), therefore, can be determined directly by assembling the condition rating of all j members, as illustrated in Equation (3).

$$\text{MCR} = \sum_{i=1}^{n} (DWi \times SWi \times EWi) \text{ , for member } j \quad \text{… (2)}$$

$$\text{ECR} = \sum_{i=1}^{j} (MCRi) \text{, for element } k \quad \text{… (3)}$$

Equation (3) yields the ECR that reflects the element deterioration indicator. This indicator depends directly on the quantity (number j) of element members (or segments) of the observed bridges, which makes it impossible to directly compare bridges with similar characteristics (belonging to the same bridge group), but with a different number of element members in the same system (e.g., a different number of deck slab members for two bridges with different spans or traffic lanes). To eliminate these problems, the Effective Element Condition Rating (EECR) is proposed to represent the overall deterioration of the bridge element. The EECR is determined from the sum of the average value of all member conditions (Avg. of MCRi) and the maximum condition value of the highest deteriorated member (Max. of MCRi). The EECR, therefore, can be calculated from Equation (4) as follows.

$$\text{EECR} = \text{Sum of} (\text{Max. of } MCRi + \text{Avg. of } MCRi) \text{ , for element } k \quad \text{… (4)}$$

To aggregate the element level results to the component level, weights are assigned for each element by considering related factors, such as element functions and element locations on a bridge. Similarly, the component level results are applied to determine the indicator that reflects the overall deterioration as the Super- and Sub-structure Condition Rating (SCR). The weights for component types and super/sub structure are also established to calculate the overall BCS. Reviews of literature and interviews with DOH bridge experts were modified with the studies of Thailand concrete bridge characteristics and behaviours to generate the appropriate weights. The proposed weights for this study are specified in Table 4. Equations (5), (6), and (7) are used to determine the condition rating that reflects the overall deterioration state of the component, sub-super structure, and whole bridge, respectively.

$$\text{Component Condition Rating (CCR)} = \sum_{i=1}^{k} (El.Wi \times EECRi) \quad \text{, for component } m \qquad \ldots (5)$$

$$SCR = \sum_{i=1}^{m} (Cp.Wi \times CCRi) \quad \text{, for super- or sub-structure} \qquad \ldots (6)$$

$$BCS = \sum_{i=1}^{2} (St.Wi \times SCRi) \quad \text{, for a bridge} \qquad \ldots (7)$$

Where,

EECR*i* = The effective element condition rating of element *i*

El.Wi = The importance weight of component *i*

St.W*i* = The importance weight of structure *I* (*i* = 1 for superstructure and *i* = 2 for substructure)

n = The number of distress types for element member *j*

j = The number of element members comprised of an element *k*

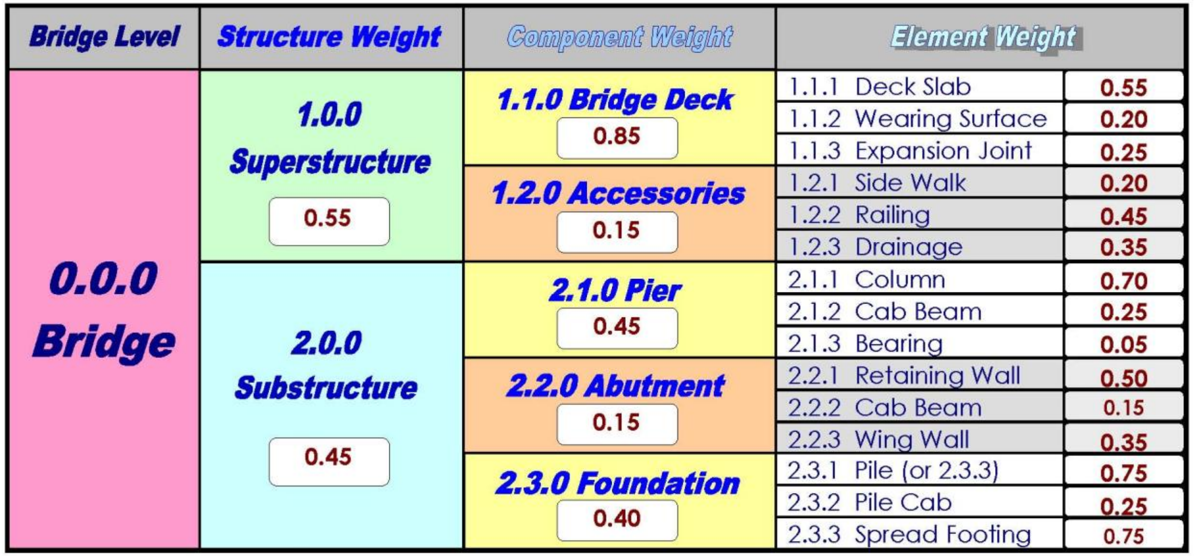
k = The number of elements consisting of a component *m*

m = The number of components comprised of a sub- or super-structure

Bridge Inspection Module

Among various BMS tasks, field inspection is an essential procedure in evaluating the existing condition of a bridge structure. Bridge inspection provides the basis for monitoring, evaluating, and prioritising the work to be carried out for any individual bridge. This section presents the bridge inspection method and describes how to conduct the distress survey in field practice. The new procedure to assess bridge condition for the DOH bridge network is developed. Visual inspection is especially important to obtain critical information about the deterioration of the bridge elements. Although visual inspection requires the subjective interpretations of inspectors, a clear understanding of distress severity and extent definitions and identifications can alleviate these problems.

Table 4. The Importance Weight of Bridge Element (El.W*i*), Component (Cp.W*i*) and Structure (St.W*i*).



Bridge Level	Structure Weight	Component Weight	Element Weight	
0.0.0 Bridge	1.0.0 Superstructure 0.55	1.1.0 Bridge Deck 0.85	1.1.1 Deck Slab	0.55
			1.1.2 Wearing Surface	0.20
			1.1.3 Expansion Joint	0.25
		1.2.0 Accessories 0.15	1.2.1 Side Walk	0.20
			1.2.2 Railing	0.45
			1.2.3 Drainage	0.35
	2.0.0 Substructure 0.45	2.1.0 Pier 0.45	2.1.1 Column	0.70
			2.1.2 Cab Beam	0.25
			2.1.3 Bearing	0.05
		2.2.0 Abutment 0.15	2.2.1 Retaining Wall	0.50
			2.2.2 Cab Beam	0.15
			2.2.3 Wing Wall	0.35
		2.3.0 Foundation 0.40	2.3.1 Pile (or 2.3.3)	0.75
			2.3.2 Pile Cab	0.25
			2.3.3 Spread Footing	0.75

Bridge Field Inspection Procedures

In the inspection process, the bridge information to be collected and recorded in the database is divided into two main parts: inventory data and distress condition data.

Bridge Inventory Data Collections

Inventory data are crucial in presenting all characteristics and descriptions of any bridge. These data will cover all general information, traffic volume information, structural characteristics, and bridge sketches. The location and reference of a bridge, agency responsible, year built, and inspection date are gathered as general information. Necessary traffic volume information will show the Average Daily Traffic (ADT), percentage of heavy trucks, and traffic growth rate, which directly affect a bridge's deterioration. In the bridge characteristics section, details for each component of the bridge are recorded. Structural dimensions, types, materials, and sizes of all components will be inspected and tracked on data collection forms. It is important to sketch the bridge structure drawings, which consist of a top view plan, elevation plan, and cross-section plan, to illustrate the overall characteristics of the assessed bridge and clearly refer to a location of inspected bridge element.

Element Distress Data Collections

Because the bridge structure is composed of complex and exhaustive elements with various specific distresses appearing on different element sections, efficient execution of the segment or member-level inspections and data collection are needed. Segments or members are specific portions of bridge elements. Each member has a fixed location and quantity. During field inspection, distress condition ratings are assigned separately to all segments. Element level condition reports are formed as sums of individual member condition ratings. Examples of specific members are illustrated in Figure 1. Deck slab members are bounded by lane stripes, deck expansion joints, and sidewalks or railings. Pier members are defined by each row of columns. Member identifications of a bridge are permanent. The segmental model of an individual bridge changes only if the bridge structure is modified. The total number of element members is determined by the characteristics and dimensions or size of the bridge. It is of the greatest importance to identify numerical member codes systematically for convenient analysis and referral to specific members of the presented bridge, as well as re-inspection for future assessment.

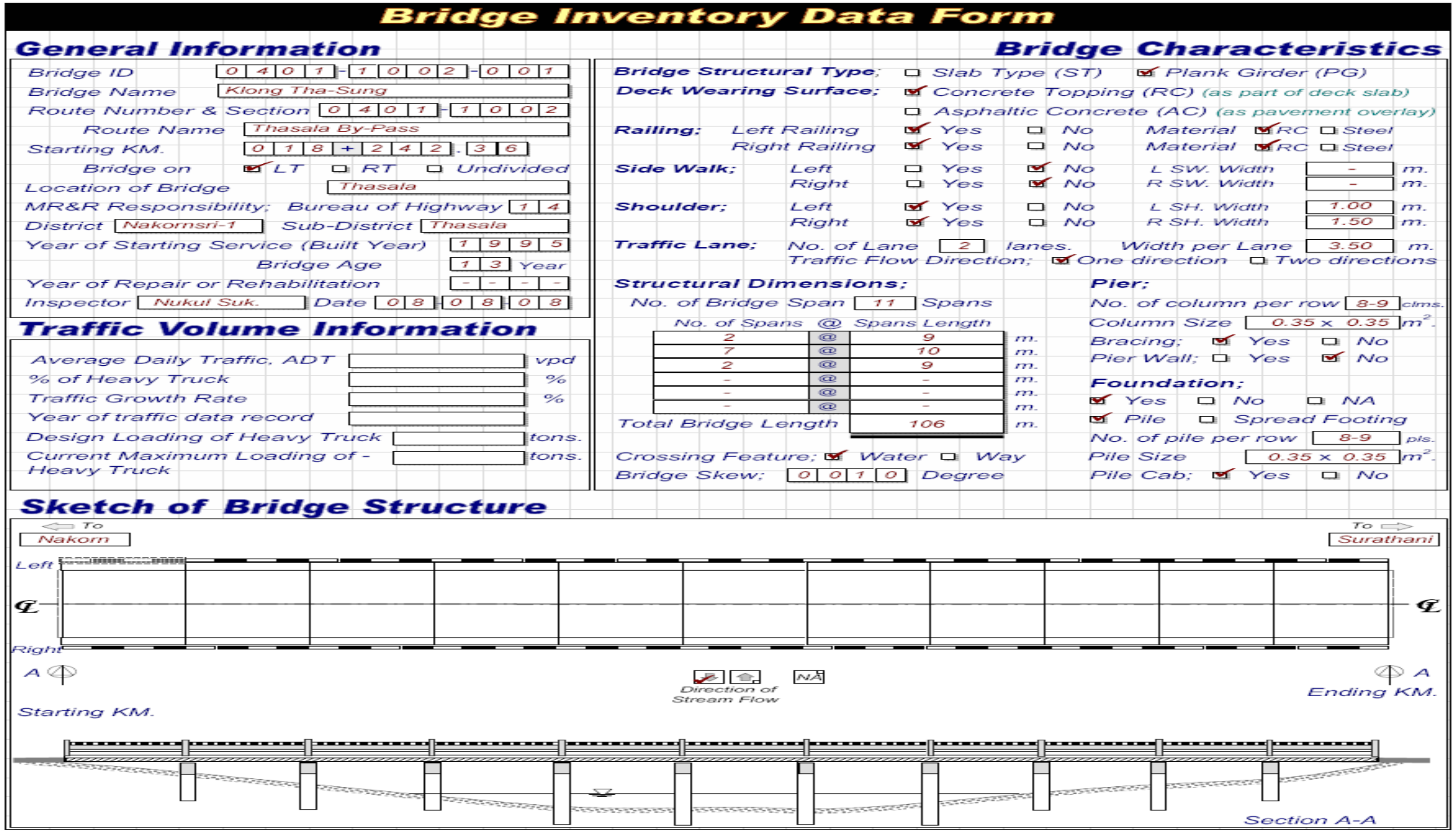
Element distress condition ratings are vulnerable to subjective interpretation of the inspection team because the rating includes multiple distress symptoms, and several distress severity and extent levels. A catalogue of the most common distresses occurring on concrete highway bridges in Thailand, especially for any single element type, is provided to inspectors to complete a comprehensive study before implementing a field survey. The description, location, and evaluation of any single distress is also completely defined and managed within the proposed condition rating methodology. Inspectors on the same team, however, can directly compare the member distress condition ratings accumulated from field assessments.

Bridge Data Collection Forms

This section presents examples of field inspection forms for assessing and gathering bridge distress condition information during surveys. These forms are specially designed and intended for use in conjunction with the developed bridge condition rating system. The following figures describe and illustrate the sample inspection forms designed in the proposed rating method for concrete highway bridges.

Figure 3 demonstrates a form to accumulate all inventory data for an individual bridge. The form consists of a complex and exhaustive database, including sufficient data to accurately describe any bridge inventory. As described in Figure 3, the bridge inventory is organised into four blocks of information: (1) general information, (2) traffic characteristics, (3) bridge structural characteristics and (4) sketches of the bridge showing standard views of specific individual structures (deck top plan and elevation plan). Figure 4 depicts a sample form for evaluating a member condition of deck slab. This member inspection form is divided into two main blocks of information: member description and tabular distress rating data. All bridge inspection forms are permanent. Once created as electronic files, the forms can be printed out for each new inspection.

For ease and convenience in field inspections, however, brief data collection forms are generated like the sample shown in Figure 5. All members' evaluations of any bridge element are shortened so that all information can be recorded on a single data sheet. The member descriptions, observed distresses ratings, and relevant environmental factors are presented alphabetically and numbered for inspectors' handwritten checking. This form will be used in conjunction with a standard on-site inspection procedure and also applied as the data entry form for collecting all information necessary to evaluate the condition of a bridge element.



Bridge Inventory Data Form

General Information

Bridge ID: 0401-1002-001
Bridge Name: Klong Tha-Sung
Route Number & Section: 0401-1002
Route Name: Thasala By-Pass
Starting KM.: 018+242.36
Bridge on: ☑ LT ☐ RT ☐ Undivided
Location of Bridge: Thasala
MR&R Responsibility; Bureau of Highway: 14
District: Nakornsri-1 Sub-District: Thasala
Year of Starting Service (Built Year): 1995
Bridge Age: 13 Year
Year of Repair or Rehabilitation: - - - -
Inspector: Nukul Suk. Date: 08-08-08

Traffic Volume Information

Average Daily Traffic, ADT: ____ vpd
% of Heavy Truck: ____ %
Traffic Growth Rate: ____ %
Year of traffic data record: ____
Design Loading of Heavy Truck: ____ tons.
Current Maximum Loading of - Heavy Truck: ____ tons.

Bridge Characteristics

Bridge Structural Type; ☐ Slab Type (ST) ☑ Plank Girder (PG)
Deck Wearing Surface; ☑ Concrete Topping (RC) (as part of deck slab)
☐ Asphaltic Concrete (AC) (as pavement overlay)
Railing; Left Railing ☑ Yes ☐ No Material ☑ RC ☐ Steel
Right Railing ☑ Yes ☐ No Material ☑ RC ☐ Steel
Side Walk; Left ☐ Yes ☑ No L SW. Width: - m.
Right ☐ Yes ☑ No R SW. Width: - m.
Shoulder; Left ☑ Yes ☐ No L SH. Width: 1.00 m.
Right ☑ Yes ☐ No R SH. Width: 1.50 m.
Traffic Lane; No. of Lane: 2 lanes. Width per Lane: 3.50 m.
Traffic Flow Direction; ☑ One direction ☐ Two directions

Structural Dimensions;

No. of Bridge Span: 11 Spans

No. of Spans	@	Spans Length	
2	@	9	m.
7	@	10	m.
2	@	9	m.
-	@	-	m.
-	@	-	m.
-	@	-	m.
Total Bridge Length		106	m.

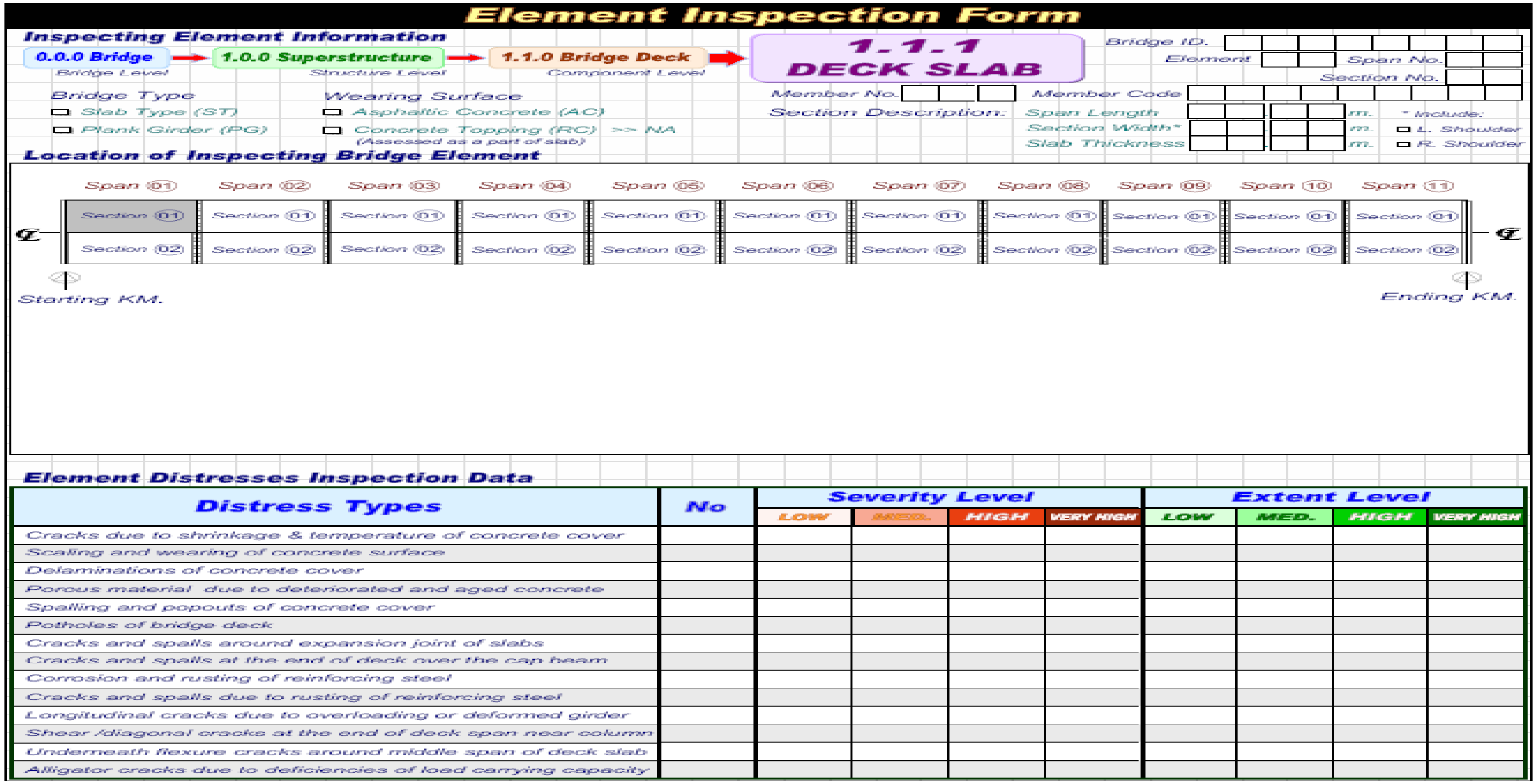
Crossing Feature; ☑ Water ☐ Way
Bridge Skew; 0010 Degree

Pier;
No. of column per row: 8-9 clms.
Column Size: 0.35 x 0.35 m^2.
Bracing; ☑ Yes ☐ No
Pier Wall; ☐ Yes ☑ No

Foundation;
☑ Yes ☐ No ☐ NA
☑ Pile ☐ Spread Footing
No. of pile per row: 8-9 pls.
Pile Size: 0.35 x 0.35 m^2.
Pile Cab; ☑ Yes ☐ No

Sketch of Bridge Structure

Figure 3. Bridge Inventory Data Collection Form



Element Inspection Form

Inspecting Element Information

0.0.0 Bridge → **1.0.0 Superstructure** → **1.1.0 Bridge Deck** → **1.1.1 DECK SLAB**

Bridge Level | Structure Level | Component Level

Bridge ID. ☐☐☐☐☐☐☐☐

Element ☐☐ Span No. ☐☐

Section No. ☐☐

Bridge Type
☐ Slab Type (ST)
☐ Plank Girder (PG)

Wearing Surface
☐ Asphaltic Concrete (AC)
☐ Concrete Topping (RC) >> NA
(Assessed as a part of slab)

Member No. ☐☐☐ Member Code ☐☐☐☐☐☐☐☐☐

Section Description:
Span Length ☐☐.☐☐ m.
Section Width* ☐☐.☐☐ m.
Slab Thickness ☐☐.☐☐ m.

* Include:
☐ L. Shoulder
☐ R. Shoulder

Location of Inspecting Bridge Element

Span (01)	Span (02)	Span (03)	Span (04)	Span (05)	Span (06)	Span (07)	Span (08)	Span (09)	Span (10)	Span (11)
Section (01)	Section (01)	Section (01)	Section (01)	Section (01)	Section (01)	Section (01)	Section (01)	Section (01)	Section (01)	Section (01)
Section (02)	Section (02)	Section (02)	Section (02)	Section (02)	Section (02)	Section (02)	Section (02)	Section (02)	Section (02)	Section (02)

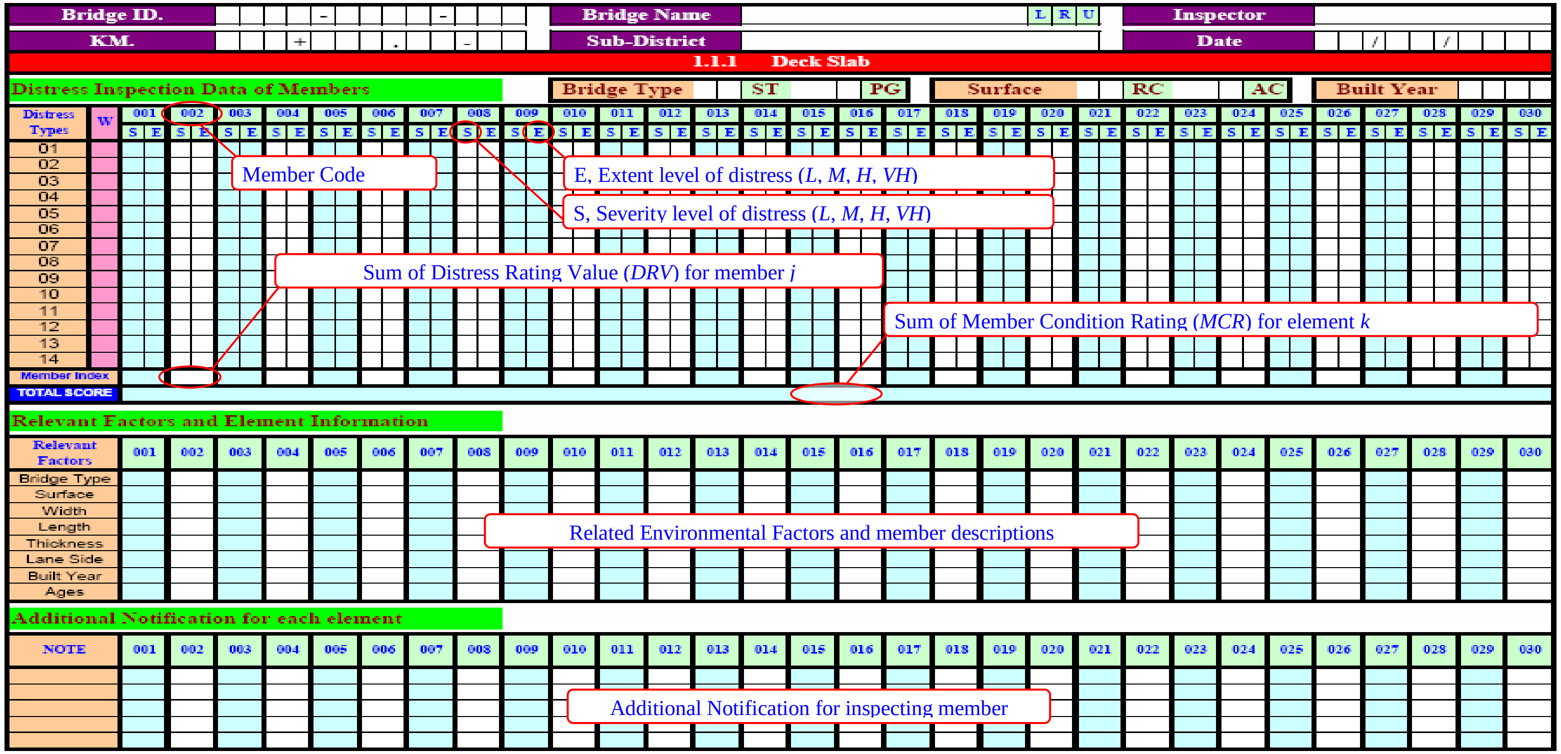
Starting KM.

Ending KM.

Element Distresses Inspection Data

Distress Types	No	Severity Level				Extent Level			
		LOW	MED.	HIGH	VERY HIGH	LOW	MED.	HIGH	VERY HIGH
Cracks due to shrinkage & temperature of concrete cover									
Scaling and wearing of concrete surface									
Delaminations of concrete cover									
Porous material due to deteriorated and aged concrete									
Spalling and popouts of concrete cover									
Potholes of bridge deck									
Cracks and spalls around expansion joint of slabs									
Cracks and spalls at the end of deck over the cap beam									
Corrosion and rusting of reinforcing steel									
Cracks and spalls due to rusting of reinforcing steel									
Longitudinal cracks due to overloading or deformed girder									
Shear /diagonal cracks at the end of deck span near column									
Underneath flexure cracks around middle span of deck slab									
Alligator cracks due to deficiencies of load carrying capacity									

Figure 4. A Sample of Member Distress Field Inspection Form



Bridge ID. - -

KM. + . -

Bridge Name L R U

Sub-District

Inspector

Date / /

1.1.1 Deck Slab

Distress Inspection Data of Members

Bridge Type ST PG

Surface RC AC

Built Year

Distress Types	W	001		002		003		004		005		006		007		008		009		010		011		012		013		014		015		016		017		018		019		020		021		022		023		024		025		026		027		028		029		030	
		S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E	S	E
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Member Index																																																													
TOTAL SCORE																																																													

Member Code

E, Extent level of distress (*L*, *M*, *H*, *VH*)

S, Severity level of distress (*L*, *M*, *H*, *VH*)

Sum of Distress Rating Value (*DRV*) for member *j*

Sum of Member Condition Rating (*MCR*) for element *k*

Relevant Factors and Element Information

Relevant Factors	001	002	003	004	005	006	007	008	009	010	011	012	013	014	015	016	017	018	019	020	021	022	023	024	025	026	027	028	029	030
Bridge Type																														
Surface																														
Width																														
Length																														
Thickness																														
Lane Side																														
Built Year																														
Ages																														

Related Environmental Factors and member descriptions

Additional Notification for each element

NOTE	001	002	003	004	005	006	007	008	009	010	011	012	013	014	015	016	017	018	019	020	021	022	023	024	025	026	027	028	029	030

Additional Notification for inspecting member

Figure 5. A Sample of a Brief Distress Data Collection Form for Deck Slab

VALIDATIONS

Applications of a BMMS in Thailand are not fully executed in practice due to a lack of analytical resources and expertise. In addition, a standardised bridge condition rating system has not been developed. As a result, both the inventory information and the distress condition rating data are not recorded consecutively and systematically. When validating the proposed condition rating, therefore, it is impossible to directly compare the results of condition ratings derived from the developed methodology with available historical ratings data of the nation's bridges from DOH practice results.

The Likert Scale method is applied to validate and strengthen the developed rating method. Questionnaire surveys for recommendations and opinions of bridge experts are requested. Interviews of 15 respondents from the experienced experts of the bridge agencies of Thailand's DOH, including the Bureau of DOH Bridges, the 3rd and 4th Bridge Construction and Rehabilitation Center, the Bureau of 14th Highway (Nakhon Si Thammarat), the Nakhon Si Thammarat Highway District, and the 6 local highway sub-districts were performed. The questionnaire results demonstrate that the proposed condition rating system is robust, implementable in actual practice, and suitable for efficient evaluation of the nation's concrete highway bridge network.

The respondent's opinions also revealed that inspection procedures on field surveys for a bridge are simple, requiring only a short time with a few instruments and resources. Assessment of the details of individual bridge element members or segmental inspections completely presents the locations and conditions of observed distresses on each bridge structure. Computation of the BCS is not complicated, and the results can be efficiently applied in reflecting, comparing and prioritising the deterioration state of a bridge network. In addition, the systematic and consecutive data gathering and tracking in the BMS database allow the respondents to check and monitor all bridge performance at any time as needed. The results of expert interviews applying a Likert Scale are summarised in Table 5.

CONCLUSIONS

This paper presents the developed bridge condition rating system to support the requirements of Thailand's DOH. The BCS derived from the proposed method reflects a bridge's levels of deterioration, performance,

Table 5. The Results from Expert Interviews to Validate the Proposed Condition Rating System and Inspection Method

Attributes		Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)	Average score
1.	Can be implemented in actual practice to evaluate concrete highway bridges of Thailand DOH.	33%	60%	7%	0%	0%	4.27
2.	Assessment through the proposed rating method covers all elements of a bridge structure.	67%	33%	0%	0%	0%	4.67
3.	Ratings Index derived from the proposed method is reliable, directly reflects bridge performance, and efficiently ranks the priorities for bridge MR&R actions.	13%	80%	7%	0%	0%	4.07
4.	Provides complete breakdown structure for assessing a bridge's hierarchy and classification of its elements at each level.	87%	13%	0%	0%	0%	4.87
5.	Complete element distress identifications and specific scales for different severities and extent levels.	20%	67%	13%	0%	0%	4.07
6.	Weightings reflect importance measures for bridge structures, components, and elements.	27%	60%	13%	0%	0%	4.13
7.	Weightings reflect importance measures for bridge element distress types.	13%	73%	13%	0%	0%	4.00
8.	Weightings reflect importance measures for different levels of distress severity and extent.	20%	73%	7%	0%	0%	4.13

(continued on next page)

Table 5. *(continued)*

Attributes		Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)	Average score
9.	Equations for calculating bridge condition score BCS, structure, component, element, and member condition ratings.	67%	33%	0%	0%	0%	4.67
10.	Ease in applying field inspection methods and procedures in practice, including recommended inspection teams and times required for field surveys.	87%	13%	0%	0%	0%	4.87
11.	Clear, easy-to-use designed data collection forms for survey practices and data entry.	80%	20%	0%	0%	0%	4.80
12.	Collected data completely and efficiently supports further analysis, such as developing bridge deterioration prediction models and MR&R priority plans.	40%	60%	0%	0%	0%	4.40
13.	In summary, the proposed condition rating system as developed is recommended for use in actual practice for concrete highway bridges for Thailand DOH.	60%	40%	0%	0%	0%	4.60

and serviceability. To determine the BCS, the assessment hierarchy was divided into four levels: member, element, component, and structure. General types of distresses that can occur in each element of concrete bridges are classified. Each distress will be divided into ranges of different levels for severity and extent. The weights or importance measures of severity and extent levels, as well as harmful levels for each type of distress, are determined. The formulae for calculating condition ratings of member (MCR), element (ECR), component (CCR), structure portion (SCR), and an overall bridge condition index (BCS) are established.

The paper also describes field inspection procedures, which enables the allocation of observed distresses at the level of sub-elements or members. Inspection forms are designed to collect and store assessment information. The field practice by visual inspection is simple and requires only the inspectors' observation and assessments.

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