Research on the Improvement of Bridge Management System 1992

“Case of Bridge Condition Assessment in the Decentralized Indonesia”

March, 2016

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Graduate School of Social Systems and Management

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DEDICATION

I dedicate my dissertation work to my family and many friends. A special feel of gratitude to my loving wife, Nefi Andjarwati whose words of encouragement and push for tenacity ring in my ears. My daughter Nadia Najla and Ghisca Nabila, my mother Siti Chodijah have never left my side and are very special.

I also dedicate this dissertation to my many friends who have supported me throughout the process. I will always appreciate all they have done, especially Risma Putra, Rulli Ranastra, Gatot Sukmara, Septinurriandiani, Monang R. Pasaribu, Anton Surviyanto, N. Retno Setiati and Hanna Abdul Halim for helping me develop my technology skills, Adam Yazid for the many hours of proofreading, and Pantja Oetomo, Nazib Faizal, Setyo Hardono for helping me to master the important matters.

I dedicate this work and give special thanks to my colleague Waskito Pandu and Arie Setiadi Moerwanto for being there for me throughout the entire doctorate program.

ABSTRACT

This dissertation discuss bridge management system in regard bridge inspection and rating assessment as a tools for programming budget allocation for bridge infrastructure in Indonesia, and more concern in decentralized government era. The objective of this work is to show that such simplified bridge inspection will drive in increasing the accuracy of bridge maintenance strategies. The approach to achieve this goal is by improving existing system, and makes correlation with instrumented inspection result wherever possible.

Bridge management in various countries, related to inspection, including explanation on the performance of current Indonesian Bridge Management System in general is discussed. More detailed discussion emphasize to the inspection and rating system. To broaden views on inspection and rating system, knowledge about condition degradation based on instrumented assessment which has been widely used in the field of machinery and bridge inspection in recent years is also reviewed.

Critical review of existing inspection and rating system of Indonesian BMS'92 are explained. Secondary data collected by bridge authorities are reviewed, including feedback from bridge administrator through designed questionnaire. To narrow down scope of improvement, simulation of field inspection on selected bridges is carried out by ten (10) qualified inspectors.

Proposed improvement by considering several approaches is discussed. It is shown that when several factors affecting the condition rating were simplified, and guided, the result shows improvement and consistency among inspectors.

The correlation between visual ratings with the degradation of bridge natural frequencies is discussed. The correlation is made through the level of maintenance required, as the bridge condition rating had been dedicated to certain maintenance program. Since those bridges have their own natural frequency collected, therefore the range of natural frequencies related to similar required maintenance program can be defined. Accordingly, combined inspection rating between visual and instrumentation is introduced.

The dissertation concludes with some reflections on the existing systems, benefits of improvement, proposed solution and further research plans.

ACKNOWLEDGEMENT

I wish to thank my reviewers who were more than generous with their expertise and precious time. A special thanks to Professor Haruo ISHIDA my promoter for his countless hours of reflecting, reading, encouraging, and most of all patience throughout the entire process. Thanks you Professor Naohisa OKAMOTO, Professor Morito TSUTSUMI, Professor Mamoru TANIGUCHI, and Professor Ohsawa YOSHIAKI, for agreeing to attend on my seminar and delivering constructive advice. Thanks to DR. M. SHIRATO for developing my knowledge on bridge natural frequencies and DR. Shinri SONE who makes this arrangement in Tsukuba University become possible.

I would like to acknowledge and thank to Institute of Road Engineering (IRE), Ministry of Public Work and Housing for allowing me to conduct my research and providing any assistance requested. Special thanks go to the members of program and evaluation division and human resources division for their continued support.

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INTRODUCTION

1.1 General

Country's economic development and welfare of the people require adequate infrastructure, including road and bridge. The load as goods-per-km road transported in Indonesia is increasing and causing more bridges deteriorate earlier. To anticipate the trend, existing bridges should be managed in proper manner, and this requires systematic implementation, appropriate procedures and practices of asset management. Accordingly it is important to ensure that optimal intervention strategies determined and followed

To deal with the large number of bridges in Indonesia, a Bridge Management System is required. Even for moderate sized road networks, an increasing number of infrastructure make owners shall be supported with increasingly complex computerized management systems in their decision making process. Although ultimately, it is expected that management systems will include all infrastructure objects and their roles within their respective networks in an integrated manner, but the current state of the development and implementation of management systems 'best match' current practice and decision-making. Due to their individuality, complexity and significant impact on society, bridges have often been the starting point for the development of these systems, even if bridges do not function as intended.

In decentralization government era, several changes occur among others fund management for bridge development and maintenance is delegated to provincial as well district administration level. Available fund in each province or district depends on allocation of local budget from local revenue. Therefore, smaller the revenue is fewer funds for development and maintenance will deploy. In addition, limited resource in bridge management makes local government delegate some function on bridge management to consultants. This research on bridge inspection system believe rather than to improve quality of data collected and rating assessment of bridge condition at least to support the authority in managing bridges in decentralization era of government of Indonesia.

To operate the bridge management system comprehensively, beside data on bridges condition, road data information and traffic data are required. In addition, the updated database will also serves and maintenance accurate database that will use to improve quality and capacity of recommendation, as well as for early warning system and basis for bridges planning and programming. Accurate data on bridges will determine performance of existing management system.

Indonesian Bridge Management Systems (BMS '92) uses rating system which strongly depends on hierarchy of bridge elements in which the hierarchy of element system consists of irregularity pattern and does not fully follow real family tree concept. Moreover, the sequences of field investigation follows certain patterns or rule which is not reflected to bridge element defects which always happen in real cases of Indonesian situation. As consequence the assessment procedure becomes difficult and data collected become too many and the assessment results indicate bias and involved inspector judgments.

Furthermore, the existing hierarchy of bridge elements of Indonesian Bridge Management Systems (BMS '92) bias since they are not segregated between bridge structural risk and user risk. As this hierarchy of elements exists, therefore it shows the collected data condition more complicated and become inaccurate results.

For that reason, the main problem is how to collecting more accurate data on bridge condition in situation of lack human resources particularly bridge inspectors as well as budget availability in decentralized era of government Indonesia.

1.2 Objective and purposes

The objective of this research is to establish an updated Bridge Condition Inspection Manual of Indonesian Bridge Management System 1992 (BMS '92), that can be used as simple as possible within reasonable accurate result for

Indonesian bridges both for National and Provincial roads as well as for Local/City roads.

In addition to an updated Bridge Condition Inspection Manual, an instrumented bridge inspection techniques is also established, where bridge condition of this instrumented inspection will have correlations with the results from the visual inspection, hence those systems can be used for screening bridges which required visual inspection. Moreover, it is expected that the developed model can be used easily and the result shows an absolute-reference rating.

Furthermore, developed instrumentation inspection model and correlation technique can replace the visual inspection manual that have been used for more than two decades at least for bridges with minor to moderate defects. The achievement of this improvement will play important role for current Indonesian bridge asset management and in the future.

1.3 Scope of research

Scope of this research covers the implementation policy of bridge management on provincial and district level in the era of decentralized government of Indonesia. Furthermore, this research also observes the capacity of local inspectors on the implementation of bridge inspection from BMS '92 and verifies how the bridge inspection and assessment should be carried out properly.

The bridges to be assessed in more detail in this research are I-girder composite bridges, including RC-beams, PC-beams and voided slab system. This type of bridge is dominant type bridge in national highways with span of less than 20 meter. They are also represents dominant population of bridges in provinces and districts in Indonesia

1.4 Hypothesis

The critical issues as the objective of this research on bridge condition assessment of Indonesia Bridge Management System 1992 is described in the background. While, hypothesis to be resolved these critical issues are as follows:

a) Existing system was developed in 1990, very old and never updated to meet the dynamic advancement of information technology and current advance in bridge structural technology.
b) Reducing complexity level of field inspection procedure will guide to deliver more objective inspection data as well as updating logical system of inputting field data from the inspection in order to control consistency or to push the inspector to take certain predefined alternative inputs.
c) Hierarchy of bridge elements bias as the defect on non-structural elements led to bridge rating.
d) Due to decentralized governments since 2000 BMS '92 system needs to updated and adjusted with infrastructure condition such as local autonomy regulation including lack of human resources.
e) Some local inspectors require sufficient competency to deliver qualified bridge inspection.
f) Improvement in accuracy of bridge rating is introduced by mean of instrumented inspection. This hypothesis used to overcome inspectors subjectivity as well as competency, especially in era of decentralization government of Indonesia.
g) Hybrid bridge inspection model system as combination of visual and instrumented inspection lead to generate equal bridge condition rating. This will update manual of visual inspection of the BMS 92 for bridge rating which only need routine maintenance, where exact locations of defect on bridge superstructure are not required.

1.5 Research methodology

In this sub-chapter, research methodology is discussed. To have good results in research an activity, a systematic way is required (Kothari, 2004). Flow diagrams are required in order to directly describe all related field activities and analysis and evaluation to the objective of the research. In this flow diagram it is presented that the research consists of staging of field experiment both for visual inspection as well as instrumented inspection within available time frame. The objective of this research methodology is to show clearly, tasks to be carried out within available time frame as well as guidance to new original finding and recommendation. This will worthy to be used for developing country asset management, especially for maintenance and information management of bridge infrastructure.

Before embarking on the details of research methodology, it seems appropriate to present a brief overview of the research process. Research process consists of series of actions or steps necessary to effectively carry out research and the desired sequencing of these steps (Kothari, 2004). In this research the steps to be taken are as follows:

a) Review bridge condition rating according to Manual of BMS ’92 which was collected by Directorate General of Highway (DGH), Ministry of Public Works and Housing who responsible to collected bridge condition data for their asset management activity and for Information Management System as well, Early Warning System as well as for top manager Design Support System. The data selected from 3 region of north Java corridor (Pantura) highway as the main trunk road in Java Island. The highway is occupied with heavy traffic mainly big truck with carry overload. Those data condition of bridge along main trunk road are than compared to bridge data condition collected by Institute of Road Engineering (IRE).While in addition to that bridge accident data are also collected to inspiring the study areas as well as focus of improvement Indonesian Bridge Management System 1992 (BMS ’92). Justification on the results will also refer to the world Bridge Management System and to article and journal.

b) Field survey to local government and survey methodology. In this section, start from design questionnaire form and sampling technique to make result more accurate results. The questionnaire method are chosen due to the amount of stake holders related to bridge management in Indonesia are approximately 500 institutions samples were taken to represent the data statistically. The targets of respondents are engineer within bridge authorities or administration both in central government as well as provincial and district/city governments. Results from data analysis then used to control direction of improvement.

c) Simulation of field inspection on bridge condition assessment.

For this purpose of bridge inspection simulation, simple supported I-Girder composite is selected and 10 qualified engineers within Institute of Road Engineering (IRE) is deployed. These 10 engineers are known as the CMP (Candidate Master Engineer within IRE). The simulation was carryout by using visual bridge condition inspection manual of BMS ’92 and further simulation was carryout then re-inspection the same bridge by using an update bridge inspection than the results are analyzed in order to focusing direction of improvement.

d) Carry out instrumented field inspection to selected bridge than perform static load test and dynamic load test which is provided with displacement and accelerate transducer to monitor response of bridge structure undergo recognized loads apply. From static load test case, bridge deck displacements are measured than an equivalent deck stiffness can be defined, hence fundamental frequency can be identified either through elastic modal analysis of engineering package software or by using general dynamic formula such as written in “Structural Dynamics, Theory and Computation” by Mario Paz.

While from dynamic load test where bridge experiences normal traffic, fundamental frequency of concerned bridge can be measured by installing accelerometer transduced placing on bridge deck. Both fundamental frequencies measured from static and dynamic load test above represent current state of bridge condition. To determine bridge condition or deteriorated rate of bridge healthy, series of measurement are requires. In this research, unavailable information on bridge frequency before enter to operation, known as finger print of bridge, than full model elastic modal analysis is used, provided the properties of bridge structure as much as mentioned on the bridge specification and as stated in built drawing. Correlation to visual bridge condition inspection is made to instrumented inspection. One the instrumented inspection procedure is establish than hybrid model inspection can be used to inspect bridge to determine bridge condition as well as deteriorate rate.

To establish objective of this research as stated in background, the following approach applied as shown in flow diagram in **Figure 1-1**.

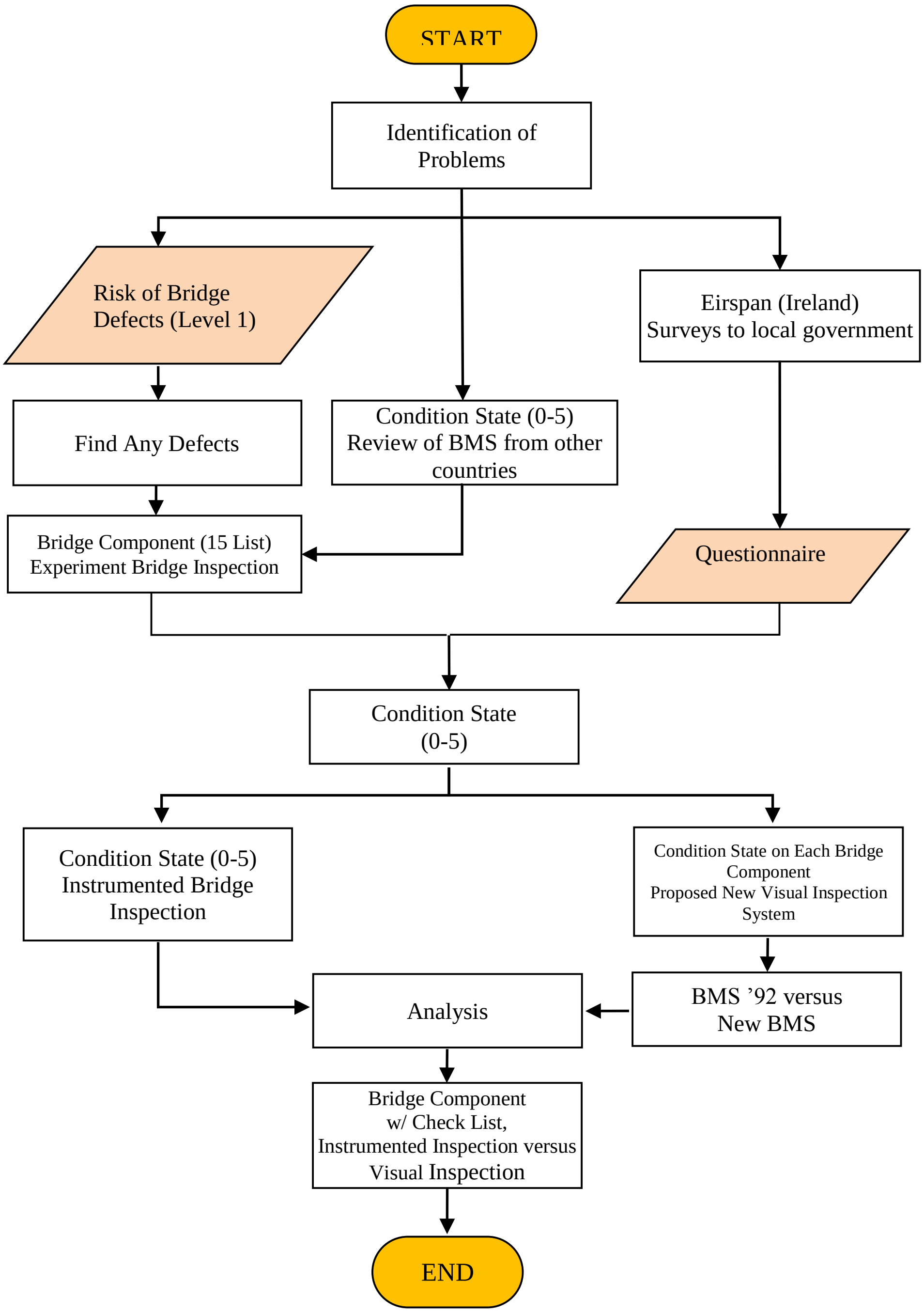


Figure 1-1 Flow diagram of research methodology

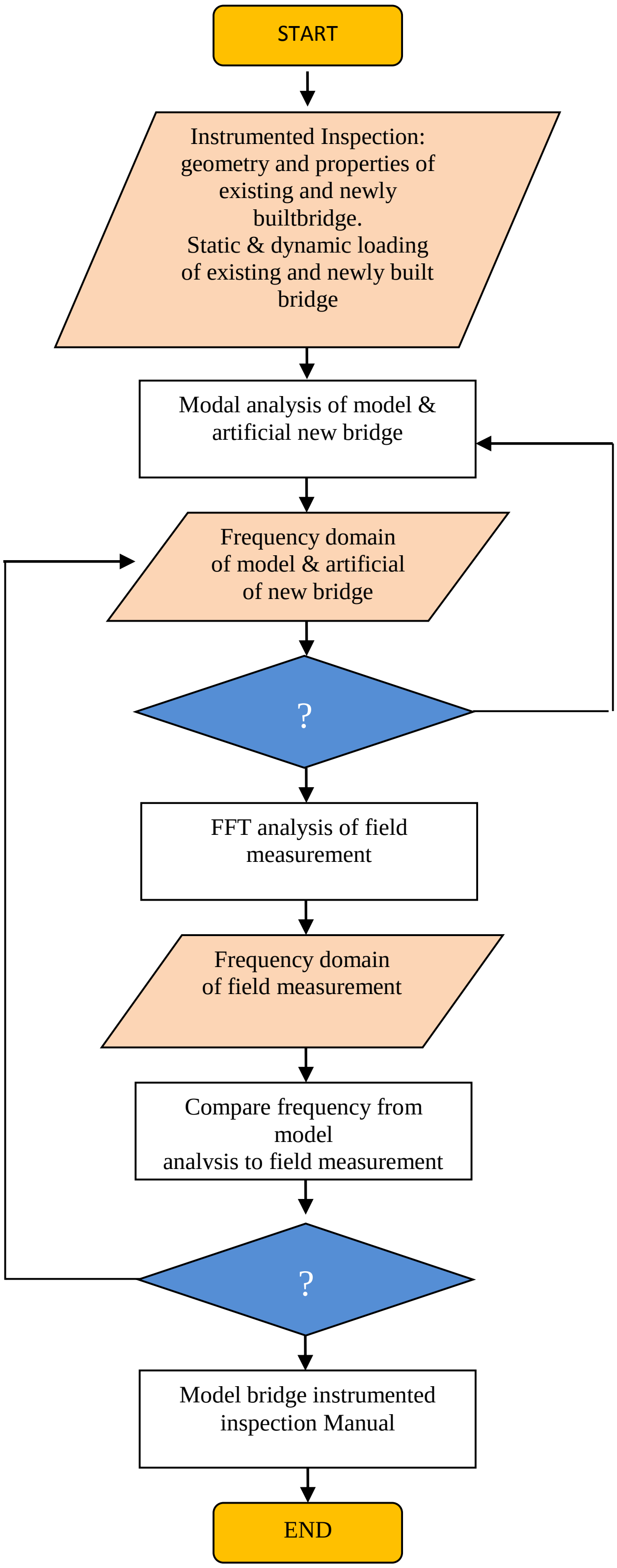


Figure 1-2 Flow diagram of research methodology for instrumented inspection

1.6 Dissertation outline

This dissertation is divided into six chapters:

a) Chapter 1 Introduction. This chapter consists of general information, objective of dissertation, scope of research, hypothesis, research methodology and dissertation outline.

b) Chapter 2 Bridge Management and Inspection System. This chapter explains on general description of Bridge Management System in Indonesia and other countries, especially related to data on bridge condition as main component of bridge management system. Comparison with system of other countries and trend, including journal, which used as basis for Bridge Management System ’92 development.

c) Chapter 3 Review of bridge inspection and rating assessment of BMS’92. This chapter contains research results on use of BMS’92 as guidance for bridge examination in Indonesia which has been operated, both ease factor and constraints, including its performance.

d) Chapter 4 Propose improvement of bridge condition rating. This chapter looking for improvement of the bridge inspection and rating assessment which is based on the issues finding in previous chapter. There are several approaches of improvement of current inspection system are discussed. The main approaches to solve these issues are used expert experiences consensus in conjunction with focused group discussions with relevant parties. In addition, to compare to similar international bridge inspection system and rating assessment as well as technical references.

   It is shown that when several factors affecting the condition rating were guided and make it simplified, the result shows an improvement and consistency in assessing bridge rating amongst 10 inspectors. There are some improvements amongst others are as follows:

e) Chapter 5 Further improvement on bridge condition inspection. This chapter contains degradation natural frequency of single span of I-

Girder bridges including voided slab systems. In this chapter, the correlation between visual inspection ratings to degradation of bridge natural frequencies is discussed. This correlation is made as the development of instrumentation for non-destructive test nowadays is more advance, especially in field of bridge inspection. Some methods to evaluate the bridge structure can be used to determining the condition and damage rate in more accurate way. Selection of methods depends on complexity level of parameters will be evaluated. Therefore, one of the strategic solutions to overcome this condition is by introducing non-destructive testing which is already bonded in updated bridge inspection manuals. Based on this procedure, the results are more objective and the influence from inspector opinion will be reduced significantly.

f) Chapter 6 Conclusion and Recommendation. The dissertation concludes with some reflections on the existing systems, benefits of improvement, proposed solution and further research plans.

CHAPTER 2
BRIDGE MANAGEMENT AND INSPECTION SYSTEM

2.1 General

Owner and developer of bridge management systems in Indonesia may take benefit from an up-to-dated capability of the most advanced system. Under this research, Indonesian Bridge Management System 1992 (BMS'92) are compared to similar system in other countries. Such knowledge and best practices could be used to help in directing future development of BMS'92 as well as allow identification of who to contact to investigate in detail, how others have done, or are doing, what they are planning to do.

Bridge inspection is primarily conducted to assess the structural safety and related maintenance urgency for individual bridges. Accordingly, bridge inspection demands are a comprehensive engineering (or subjective) judgment for structural safety and maintenance urgency at the structural member level or component level or bridge level. (Shirato, M., Tamakoshi, T., 2013).

To perform effectively any Bridge Management System should have relevant input of information about the bridge as much as possible, Ryall (2010). Documents related to inspection system in Indonesian Bridge Management System 1992 have been identified and grouped. Special grouping on part of bridge management system related to inspection of bridge condition and its rating has been determined.

The development of a comprehensive bridge management system (BMS) for existing bridges is essential. Such a system should enable not only the evaluation of bridge performance, but also the suggestion of rehabilitation strategy which takes into account the limited funds that are available for bridge construction/maintenance. (Miyamoto, A. et.al, 2001).

Collecting and identifying of similar Bridge Management Systems (BMS's) around the world is equally important. This process represents initial activities started with collecting of bridge management system in Indonesia and similar system from other countries, especially those related to inspection system and rating assessment. Subsequently, it is followed by identification of its relevance to this research.

For benchmarking purpose, Indonesian BMS'92 will be compared with similar BMS applies in other countries, such as Denmark, Thailand, Vietnam, Australia, New Zealand, Japan, and United States. Those BMS are also collected and grouped. Subsequently, substance of each country inspection system is reviewed and identified its significant difference with Indonesia's BMS and then challenged to improvement of current system.

From the "Bridge Maintenance and Management: A Look to the Future", bridge owners today must make decisions pertaining to maintenance and improvements by taking into account both funding constraints and overall needs of the highway system. The States, the Federal Highway Administration, and the American Association of State Highway and Transportation Officials have been working to develop and implement automated decision-support models to assist bridge managers (Hearn, G., et al, 2000).

There are many countries use bridge management system as a current practice to support in decision-making. **Table 2-1** shows twenty-one (21) Bridge Management Systems around the world being reviewed to see the state-of-the-art of bridge management systems. The BMS '92 is compared to the BMS of those countries, which is compiled from the report of the IABMAS Bridge Management Committee Overview of Existing Bridge Management Systems, (2012).

Table 2-1 State-of the-art of international bridge management system

No.	Country	Name of System	Current Version
1	Canada (Ontario)	OBMS	2011
2	Canada (Quebec)	QBMS	2009
3	Canada (Edmonton)	EBMS	2011
4	Canada (Prince Edward Island)	PEI BMS	2011
5	Denmark	DANBRO	2010
6	Finland	FBMS	2010
7	Germany	GBMS	N/A
8	Ireland	Eirspan	2008

No.	Country	Name of System	Current Version
9	Italy	APTBMS	2011
10	Japan	RPIBMS	2009
11	Korea	KRMBS	2010
12	Latvia	Lat Brutus	2004
13	Netherlands	DISK	2006
14	Poland (Railway Lines)	SMOK	2007
15	Poland (Local Road)	SZOK	2010
16	Spain	SGP	2011
17	Sweden	BaTMan	2011
18	Switzerland	CUBA	2011
19	US (Alabama)	ABMS	1994
20	US	Pontis	2011
21	Vietnam	Bridgeman	2010

Source: The IABMAS Bridge Management Committee Overview of Existing Bridge Management Systems, 2012

2.2 Bridge Management System and Comparison

The bridge management system means sort of an administrative decision making model (Response Note, 2015) which in general contains: (1) Development of Rehabilitation and maintenance strategy; (2) Bridge maintenance prioritizing; (3) Economic evaluation ; and (4) Bridge asset valuation (ARRB, 2010).

The bridge data of BMS from the perspective of its function and role in decision making model (Response Note, 2015) can be in the form of:

a) The only parameter for decision making and expressing the needs to repair and requires a high accountability of bridge load-carrying capacities that are affected by all types, degrees, locations, causes of damage in different structural elements.
b) The only parameter for expressing the seriousness of damage condition, but decision is made in consideration of other factors considered in the bridge management software.
c) Not the only parameter for expressing the needs to repair.
d) The bridge management system has a function to predict the transition of bridge condition states and future expenditure for replacement,

rehabilitation, repair, maintenance, and preventive maintenance for individual bridges.

Bridge inspection (data collection) is the basis of Bridge Management System, where the level of accuracy for prioritizing instead of visual inspection, can be also by structural investigation such as structural measurement and testing, analytical structural assessment and fatique study (ARRB, 2010).

Furthermore, those structural investigation can be classified into 5 categories namely: (1) Bridge inspection; (2) Bridge condition rating for prioritizing; (3) Maintenance strategy for general planning; (4) Maintenance program for budgeting; and (5) Contract document for maintenance procurement. **Figure 2-1** shows state of practice of BMS in recent years.

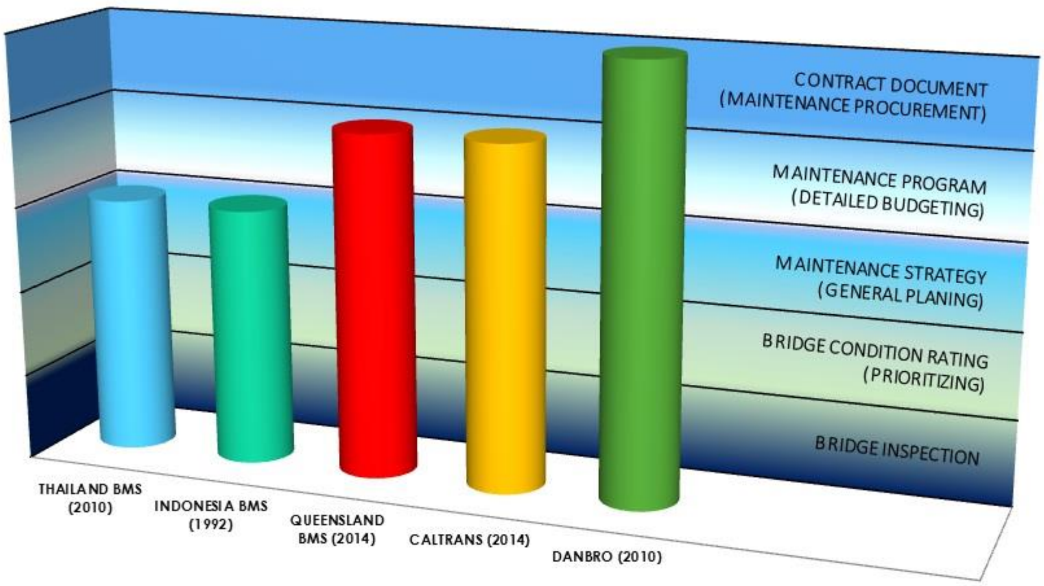


Figure 2-1 State of practice of BMS

Bridge Management System 1992 (BMS ’92) have not been revised, so there has been no further development from the existing system since 1992. As advancement in the field of information technology, data management systems and data sharing, BMS'92 need to be developed to address these challenges. It is expected that the use of BMS'92 is not limited to hardcopy format but also in softcopy, so will be useful for other purposes. Some tools already included in the existing system, such as mobile computers in examination at field inspection. Therefore, it is very easy for the field inspectors to prepare bridge inspection reports.

Hierarchy of BMS'92 bridge element is divided into certain types of bridges and its constituent materials (concrete, steel, timber, etc.). Thus, the use of Bridge Inspection Manuals in examining the conditions refers to type of bridge's material. Unlike with the BMS '92, in several other countries single BMS applies for all types regardless of its constituent materials.

Safety and risk is the most recent issue in assessment of the bridge element, so some existing BMS in other countries only assess the condition of the structural elements such as girders, decks, column, bearings, etc. In BMS '92 the non-structural elements such as barriers, railings, asphalt deck, etc., has been part of the assessment of the bridge condition. However, this does not lead to the bridge rating, as the elements do not contribute to catastrophic failure.

Bridge assessment in several countries has adopted a weighting system, where each element of the bridge and the type of defect has different weight rating depends on the level of defect occurs. Thus, final assessment of the bridge condition represented in the form of total score of defect to the bridge elements has a correlation to the existing condition state. Elements assessed contribute directly to the bridge structural conditions. BMS'92 only uses Condition State to assess the bridge elements. A structural or non-structural element is crucial to the final rating of bridge condition in BMS'92.

In the examination of the bridge elements, some existing BMS use a priority system by using a checklist system to ensure that each element has been examined properly. Each element is guided with a few checklists of common types of defect. Unlike BMS'92, some systems use inspection in sequence as in **Figure 2-2,** so some elements and types of defect possibly unchecked. **Figure 2-3** shows summary of the condition inspection manual of BMS'92 compares to similar system from other countries.

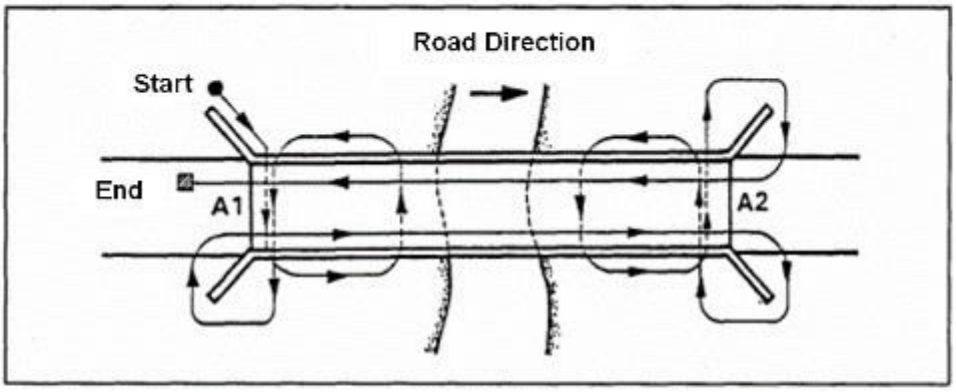


Figure 2-2 Inspection in sequences BMS '92

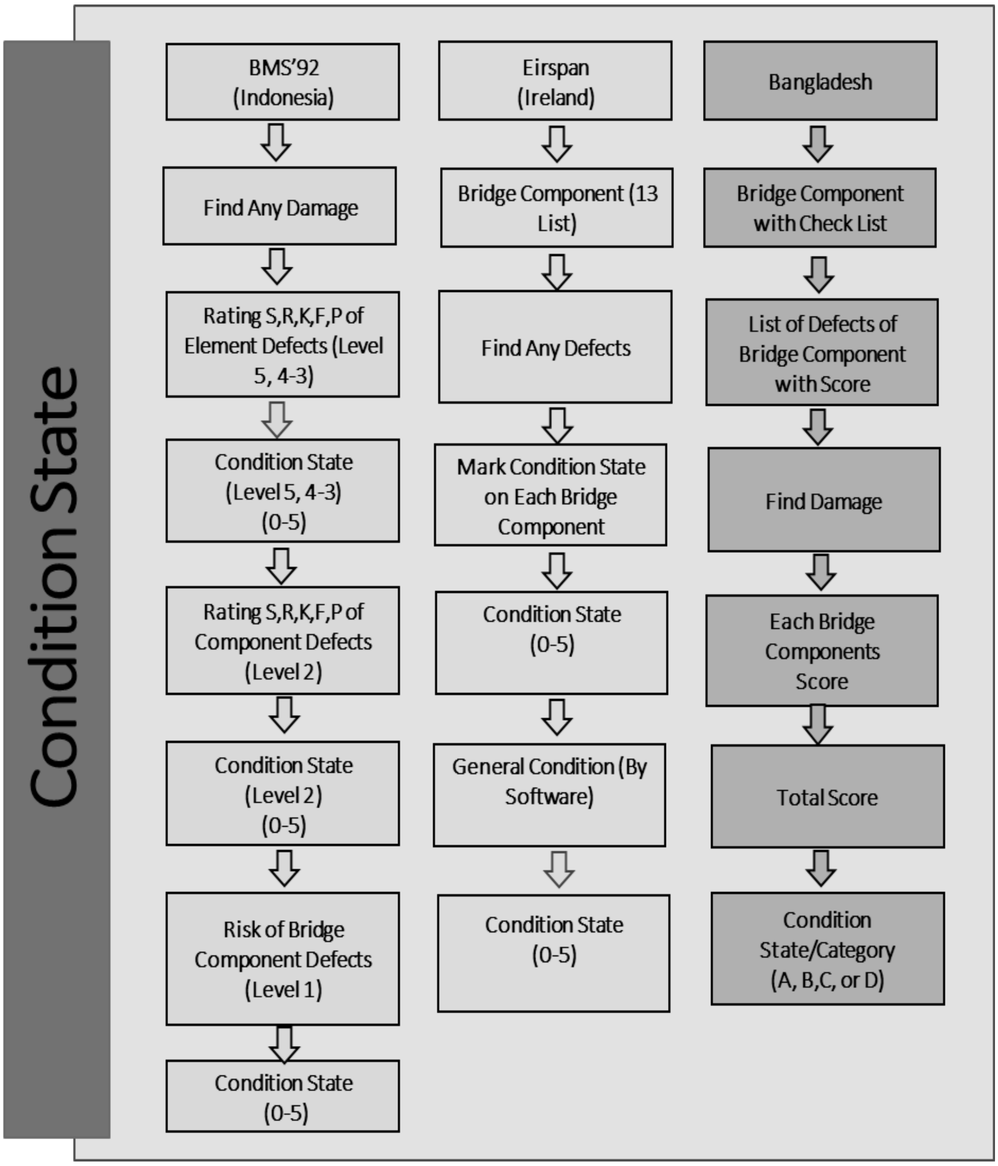


Figure 2-3 Bridge condition assessment system

Learning from other countries assessment system, most of them use the bridge component/element checklist. Such checklist is useful to guide the inspector to fill the inspection form and make finding the damage or defect easier. While in BMS'92 Bridge Inspection Manual, the bridge element is not directly written on the form, so possibility of error may occur during the bridge inspection.

Quoting from the "Development of Bridge Management System for Expressway in Japan", (Yokoyama,K., et.al, 2006) the variations of BMS applied in other countries have the following characteristics:

(1) The system is in place for qualifying inspection engineers.
(2) The soundness of bridge elements is evaluated using deterioration models focusing on transitional probability.
(3) State governments use BMS as a tool to obtain funds from Federal Government.
(4) The main goal of BMS is to maintain groups of bridges rather than to evaluate the soundness or predict the deterioration of individual bridges.

The Japan Highway Bridge Management System (JH-BMS), use the typical characteristics of BMS in other country to develop the JH-BMS deterioration prediction formulas. JH-BMS evaluates bridges with respect to individual elements/components. The soundness of individual bridge elements is evaluated and their deterioration is predicted at the time of inspection based on the inspection data, the environmental condition and traffic prediction corresponding to the deterioration mechanism. JH-BMS is aimed to repair or strengthen bridge planning support system that uses a bridge maintenance database integrating bridge specifications and inspection data. Specifically JH-BMS is aimed to evaluate soundness of bridge elements, predict deterioration, select optimal timing and method of repair or reinforcement and calculate repair or reinforcement cost (**Figure 2-4**). Briefly JH-BMS offers the following features:

a) Soundness evaluation

The reliability of elements is determined at the time of inspection based on inspection data, element specifications and environmental data.

b) Deterioration prediction

The deterioration of elements is predicted at a given point at future based on their soundness, conceivable/ possible deterioration mechanism, and environmental and element data at the time of inspection.

c) Selection of repair or reinforcement method

The effect and unit cost of repair or reinforcement method are determined for each deterioration mechanism. The timing and method of repair or reinforcement are selected to optimize the maintenance costs.

d) Calculation of repair or strengthen cost

The maintenance cost required for the throughout design service life is calculated for each bridge. Calculating sub-total costs for respective routes, jurisdiction areas or other classification made possible. Thus, future maintenance costs can be estimated.

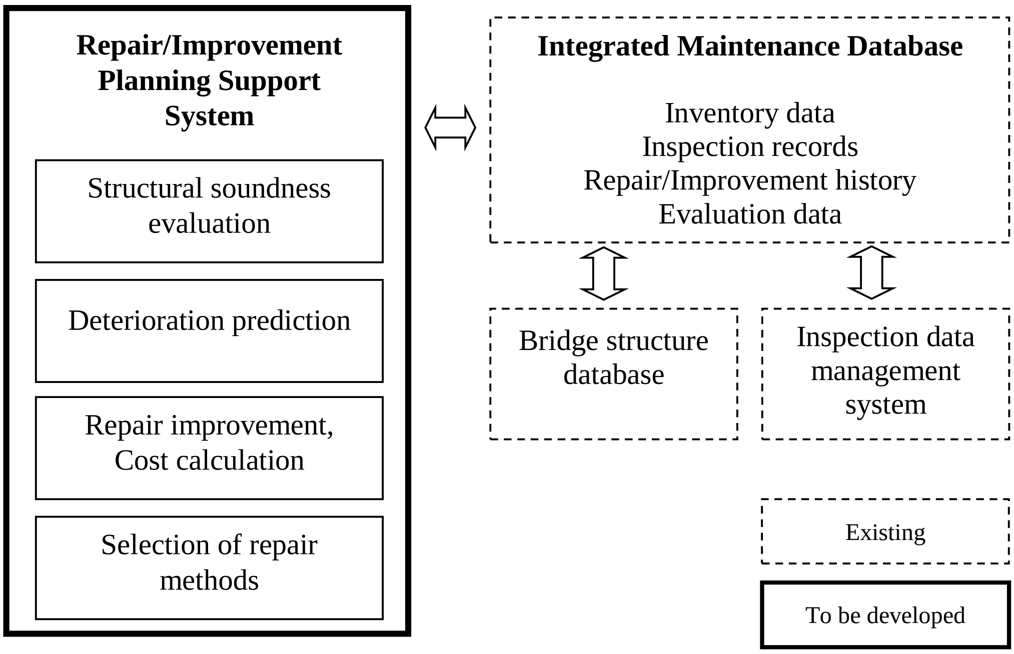


Figure 2-4 Components of JH-BMS

2.3 Inspection system

Inspection is "the keystone of BMS knowledge" to establish accurate database, improve quality decision, establish early warning system, and make accurate planning and budgeting of bridge assets. Regular inspection produces resulted regular reports on bridge's condition that provides a way of alerting bridge engineers to deterioration of the bridge from whatever causes and enable bridge engineer to assess maintenance requirements (Emoto,H.,et al, 2014).

The results of an inspection must be accurately and fully recorded including nil returns, so a complete history of the structure is available at any time. The primary aim of the inspection is to determine whether any degradation occurred, and if so identify the cause and extent of the damage. Every defect caused by certain condition that should be identified and rectified to prevent further deterioration. Besides, the defect may also triggered by physical causes due to (over) loading, environment, accidental impact, and any defects resulting from faults in design (poor detailing, inadequate cover, errors in calculation, etc.), materials (poor quality, use of inappropriate admixtures or contaminated water), or workmanship (poor mixing of concrete, compaction, curing, placement of reinforcement, placing of false work, etc.). This inspection involves both visual examination and recording (graphic and photographic), and in some cases testing as well.

Regular inspection, carried to provide:

a) A consistent record of state of the structure, which allow analyzing and taking action upon significant changes (accidents, overloading, or environmental deterioration).
b) Data which can be used for safety and serviceability assessment.
c) Information on any spot of potential trouble.
d) Information which can be basis for establishing a consistent maintenance strategy.
e) Data for monitoring effect of any changes in traffic loads and the use of new structural forms and materials.
f) Data for monitoring behavior of new strengthening techniques.

g) Data for research purposes.

Due to limited resources fully comprehensive inspections of every bridge under an agency's responsibility are not possible. Most authorities, therefore, have a hierarchical system of visual inspection routines with limited tests varying from superficial to the most detailed. The lower-order inspections are scheduled more frequent than the higher-order ones. The standard inspections carried out on similar structures by different people must be consistent, and the results should be useful in assessing the bridge's load-carrying capacity and monitoring of its condition. If available, all design information such as drawings, design calculations, and soil investigation reports should be used to facilitate the inspection.

2.4 Inspector qualification

A great deal of experience and technical understanding is required to expedite a comprehensive and systematic inspection. Inspection, therefore, has to be carried out by professional engineers (Emoto,H.,et al, 2014) or at least supervised by a professional engineer. Each bridge is unique, and its form and layout will dictate the focus of the inspection. For example, inspection of arch bridges requires totally different ways from pre-stressed concrete box girder bridges. Similarly steel bridge is different from timber bridges.

Suitably qualified personnel to carry out the bridge inspection should be selected carefully to ensure efficient use of human resources. Generally, it is the responsibilities of senior engineers who responsible for management and programming such as maintenance management and undertake principal and special inspections. Junior engineers and technicians are usually responsible for assisting senior engineer in collecting data/information, carrying out general inspections, assessments, and site supervision of remedial and/or strengthening works.

The education and qualification required for inspectors who enter data into the systems for all BMS system specifically specified. A number of BMS systems prerequisite certification for the inspectors who enter data into the systems, education requirements for users, and certification requirements for the users. In addition, the BMS also set forth for data checking requirements, data verification as well as prediction verification.

2.5 Bridge managed by the system

Bridge managed by the system as well as countries which developed the system is discussed in this section. Number of bridges managed by Indonesia Bridge Management System recorded about 35,000 bridges consisting of those on national and provincial roads. These data had been collected and stored in bridge database since early of system development (1992). The comparison of bridges quantity in world is presented in **Table 2-2**.

Table 2-2 Number of Bridges in the World

No.	Country	Number of Bridge
1	Canada (Ontario)	5,400
2	Canada (Quebec)	9,200
3	Canada (Edmonton)	352
4	Canada (Prince Edward Island)	1,200
5	Denmark	2,250
6	Finland	17,065
7	Germany	46,500
8	Ireland	2,900
9	Italy	1,024
10	Japan	750
11	Korea	5,481
12	Latvia	1,779
13	Netherlands	5,018
14	Poland (Railway Lines)	33,276
15	Spain	35,719
16	Sweden	35,370
17	Switzerland	9,372
18	US (Alabama)	15,842
19	US	750,000
20	Vietnam	4,239

Source: The IABMAS Bridge Management Committee Overview of Existing Bridge Management Systems, 2012

2.6 Bridge program and budgeting

Majority of the systems handle intervention costs. Some systems handle costs of traffic delay impact, either by calculating or entering the cost in program. Few systems which handle on inspection cost, accident impact costs, and environmental impact costs. Majority systems have prognostic capabilities on:

a) Deterioration: physical condition and performance indicators.
b) Effects of intervention or improvement, i.e.: changes that follow an intervention in physical condition and performance indicators.
c) Optimal intervention strategies: period of analysis time, cost types.
d) Work program: period of analysis time, cost types, budget items.
e) Some systems use prediction information such as preparing budgets, setting performance standards, matching funding resources, and managing special transportation such as heavy duty trailer, etc.
f) Data collection of majority systems applies:
   - Inventory information is normally collected and entered by both infrastructure owner and private companies;
   - Inspection and assessment information is normally collected and entered by the infrastructure owner and private companies;
g) The infrastructure owner normally enters intervention information. The planning of intervention using the systems is normally only carried out by the owner.

2.7 Bridge development in Indonesia

Bridge development requires data for basis of evaluation in determining the maintenance program in line with asset management system. In order to ensure the system should have input data in regular base. Bridge data collected in accordance with Bridge Management System - Bridge Inspection Manual (BMS'92) intended to establish Management Information Systems (MIS), as well as basis for Planning and Programming (P/P) of bridge maintenance under Bridge Asset Management. The aim is to keep the bridges in good condition to ensure safety road network system.

The data collection for MIS and asset management for bridges under authority of central government was developed, i.e., for bridge at national road. At the beginning, data collection for provincial road was considered in the system but under decentralization, the budget system was separated. Under this circumstance no updating was carried out by provincial road authority.

When BMS'92 system completely developed, a similar system for bridges on district roads was also initiated (District Road Management System). Data collection system for district roads is simpler since it represents part of the Road Management System as well as bridges at district roads with relatively short span bridges of an average length of 7.40 meter per-bridge and relatively simple structure and foundation. No information and data record was found of this system. While the bridges on national and provincial are on average span of 18.85 meter per-bridge (Vaza, 2014).

2.7.1 Bridge population

Population of Warren-Truss Steel Bridges is dominant in Indonesia as past government's policy in accelerating the construction of bridges in early 1970s. Since that era, procurement program of steel truss bridge until 2010 by total length recorded more less 280 km (Vaza, 2014) or 40% of total length of existing bridges on National and Provincial road, i.e.: 660 km/35,000 bridges (National road: 325 km/16,962 bridges; and Provincial road: 335 km/18,038 bridges). While total length of bridges on district and urban road recorded 400 km/54,000 bridges (Vaza, 2014). The statistic of bridge rating condition is shown on **Table 2-3**.

Table 2-3 A Bridge statistic in Indonesia – condition rating

No.	Condition rating	Population (%)
1	0 - good condition	46
2	1 - minor damage	22
3	2 - moderate damage	15
4	3 - heavily damage	8
5	4 - critical	6
6	5 - failed	3

Due to large number of the bridges, therefore continuous bridge data collection strategy is required. The data on bridge condition then evaluated in the context of MIS requirements and assets management system so the bridge can function as planned, as well as to ensure road network system in good condition. The population of bridge spans length in Indonesia as seen on **Table 2-4**.

Table 2-4 A Bridge statistic in Indonesia – span length

No.	Bridge Span (m)	Population (%)
1	0 - 20	78
2	20 - 30	9
3	30 - 60	9
4	60 - 100	2
5	> 100	2

2.7.2 Bridge inspection Manual of BMS‘92

Bridge Inspection is "the keystone of BMS knowledge" for updating database. It used to improve quality decision, as early warning system, as well as for bridge asset planning and budgeting system.

Bridge data collection system in accordance with BMS '92 consists of several stages and represents an optimum strategy to produce the best maintenance program in the limited funding available. The data collection carried out through several stages of inspection as shown in **Figure 2-5**, with the following explanation.

a) Inventory: performed once in bridges service life, unless there is change in information of bridges properties. Data collected covers administrative data, bridges geometry, and bridge general condition (at level-2 of bridge element hierarchy system). The data on bridge condition is filled with general information and did not use procedure as described in detail in Bridges Inspection Manual of BMS'92, which dedicated to determine bridge condition.

b) Detailed Inspection: Performed once in 5 years or can be performed earlier (in 3 years) if it is urgently required. Wooden bridges usually deteriorate faster than steel or concrete bridges, so they require earlier Detail Inspection. Data collected covers structural condition of bridge elements.

c) Routine Inspection: Performed every year. This inspection carried out by Routine Maintenance Team. The inspector records all defects that require Major Routine Maintenance at future. Routine inspection covers the bridges not scheduled for Detail Inspection in 5 years period, to ensure that they are in good condition. Inspector who performs routine maintenance at field might report to office in case of finding the bridges more severely defected, then information in bridge database and ask for Detailed Inspection carried earlier.

d) Special Inspection: this inspection is required in case of detail inspection requires testing equipment or instrumented measurements.

As data collection strategy in BMS'92, bridge inspection and maintenance works are carried out in contract or force account basis. To inspect bridges conditions, it is usually performed by different team or crew. The inspector only collects data on bridges and reports them to headquarter as well as prescribed in maintenance plan.

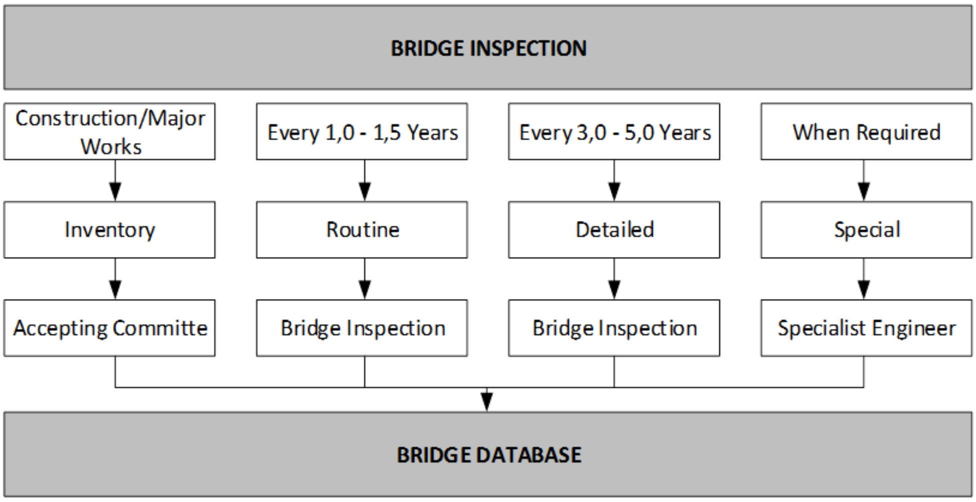


Figure 2-5 Bridge Condition Inspection Procedure

The U.S. Department of Transportation in regard to the National Bridge Inventory says that, most bridges in the NBI are inspected once every 24 months. Structures with advanced deterioration or other conditions warranting close monitoring may be inspected more frequently. Certain types of structures in satisfactory or better condition as well as other factors, including but not limited to structure type and description, structure age, and structure load rating, may receive an exemption from the 24-month inspection cycle. With FHWA approval, these structures may be inspected at intervals that do not exceed 48 months.

The New York State Department of Transportation (NYSDOT) inspects all publicly owned highway bridges for a general inspection at least once every two years. Bridges are inspected annually if they meet certain condition deficiency criteria or are posted for limited load weights. In a typical calendar year, NYSDOT fields about 65 teams of state employees and consultants to conduct biennial and interim inspections on approximately 9,500 NYSDOT and municipal bridges. Tolling authorities and commissions conduct inspections on their bridges, in accordance with the State Uniform Code, and submit their findings to NYSDOT.

Based on discussion above, there are several items need to be improved to existing system in Indonesia in order to achieve sustainable updated bridge database, namely number of inspectors who assigned to inspect bridges periodically or routinely.

2.7.3 Bridge condition assessment

Bridge play important role on supporting the welfare development in every region. Law No. 38 Year 2004 on Road states that “roads (including bridges) as part of national transportation network play important role especially for supporting economics, social and culture and environment which developed through regional development approach in order to achieve balance and equitable development among regions”. In order to support the approach, existing bridges shall be always in good condition, therefore periodical bridges inspection and maintenance shall be carried out (Shirato, M., Tamakoshi, T., 2013).

As the flowchart of BMS ’92 as presented in **Figure 2-6**, implementation of bridges maintenance carried out after completing bridge inspection.

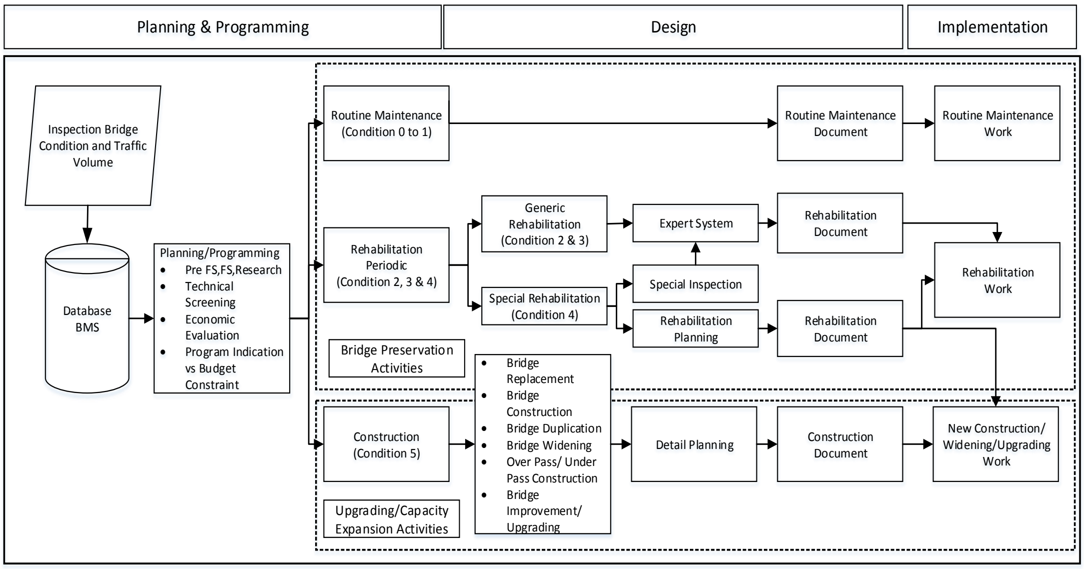


Figure 2-6 Flow bridge asset management of BMS’92

In accordance with BMS’92 bridge inspection system, the procedure to evaluate condition of individual elements of bridge defined by answering the questions of rating parameter S, R, K, F, and P.

Table 2-5 of bridge condition rating with parameters: S, R, K, F, and P show relatively objective evaluation on bridge elements. Assessment on rating parameters made by answering the questions with Yes (1) or No (Null) in which for parameter S and R are provided with manual for classification according defect appearance and causes. The results are relatively accurate for rating parameter S and R. Table 2-5 provides brief manual of defect classification and evaluation criteria for rating parameter S and R for any defects on the bridge elements. The detail manual can be found in attachment-A.

The parameter K is given based on technical capability of inspector in predicting the defect rate or volume or fraction of defect on the object evaluated. The parameter F represents FUNCTION of the elements, while parameter P represents INFLUENCE of the elements defects to other elements at nearby in structural system.

Table 2-5 Rating system of BMS'92

Parameter Evaluation	Criteria	Rating	
		No	**Yes**
S (Structure)	Are the defects harmful or otherwise?	0	1
R (Rating)	What is the level of defects, severe or mild?	0	1
K (Quantity)	Is the defect extensive (widespread) or localized? For example, the defect only affects to more less 50% of the length, width or volume of the element	0	1
F (Function)	Do these elements still function?	0	1
P (Effect)	Whether the elements defects seriously affect other elements or traffic flow?	0	1
Bridge Rating = S + R + K + F + P		0	5

Based on these rating assessment procedure, type of bridge elements and its defects is presented in the following **Table 2-6**, then bridge condition rating can be implemented properly if the types of defects at bridge elements are identified.

Table 2-6 Defects on Element and Material

Code	Defects
	WATERWAY
501	Siltation
502	Debris accumulation and obstruction of the waterway
503	Scour
504	Excess afflux
	SCOUR PROTECTION
511	Missing material
	EMBANKMENTS
521	Scour
522	Cracking/settlement/bulging of fill
	REINFORCED EARTH
531	Bulging of facing panels
532	Cracking/spalling/breaking of panels
	ANCHORS
541	Instability
	ABUTMENTS/PIERS
551	Movement
	EARTHQUAKE RESTRAINT BLOCK
561	Loose or missing element
	BEARING
601	Loss of movement ability

Code	Defects
602	Improper seating
603	Cracked or spalled mortar pad
604	Excessive movement or deformation
605	Defective material including aged, split torn, cracked or broken bearings
606	Loose parts
607	Dry metal bearing
	SLAB AND DECKING
701	Excess movement in longitudinal deck joint
702	Excessive deflection
	WEEP HOLES/SCUPPERS/DECK DRAINAGE
711	Blocked scuppers and weep holes
712	Missing Material
	RUNNING SURFACE
721	Slippery surface
722	Potholed/rough/cracked surface
723	Heaving/rutting of pavement
724	Excessive overlay
	FOOTWAY AND KERBS
731	Slippery footway
732	Potholed/rough/cracked footway
733	Missing Material
	DECK JOINTS
801	Rough/uneven joints
802	Loss of movement ability
803	Loose parts/loss of adhesion
	Broken/Missing Parts
	Cracked asphalt due to joint movement
	GAUGES
901	Damaged/Missing gauges
	ROAD SIGN AND MARKING
911	Aged or worn material
912	Missing Element
	LIGHTING, POLES AND CONDUITS
921	Aged or deteriorated materials
922	Missing materials
	UTILITIES
931	Malfunction
	MASONRY
101	Deterioration and cracking
102	Bulging or change of shape
103	Broken or missing material
	CONCRETE
201	Defective concrete including spalling, honeycombing,
	drumminess, porous and poor quality concrete

Code	Defects
202	Cracking
203	Corrosion of steel reinforcement
204	Worn, weathered, aged or deteriorated concrete
205	Broken or missing material
206	Deflection
	STEEL
301	Deterioration of corrosion protection
302	Corrosion
303	Deformation
304	Cracking
305	Broken or missing element
306	Incorrect element
307	Frayed cables
308	Loose connection
	TIMBER
401	Defective timber due to rot, insect attack, splitting,
	crookedness, knots or sloping grain
402	Broken or missing element
403	Shrinkage
404	Deterioration of surface protection
405	Loose element

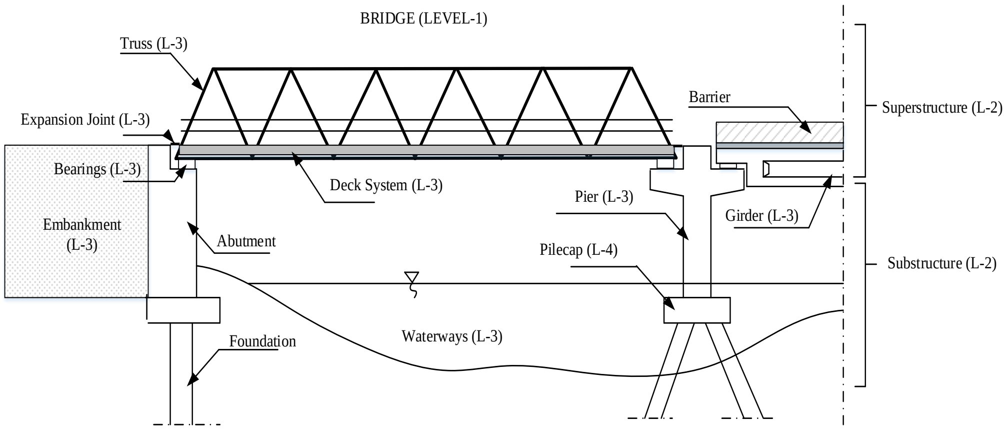
Brief manual for defect rating assessment of bridge elements based on its causes, nature, and severity level of damage refer to BMS'92, is presented in the following **Table 2-7**.

Table 2-7 Manual for assessment of rating parameter of defects in material

Code	Appearance	Cause	Nature Marks (S)	Criteria for Assessment	Degree Mark (R)	Unit
201	Spalling	Harmless	Harmless			
	Honeycombing	Inspect	Harmless	Reinforcement not visible	Light	
	Drumminess	Insufficient cover	Harmful	Reinforcement Visible	Heavy	sq.m or cu.m
	Poor Quality	Overloading	Harmful			
		Poor workmanship	Harmless			
		Pre-stressing force	Harmful			
		Volumetric expansion	Harmful			
		Chemical attack	Harmful	Visible leaking	Heavy	
202	Cracking	Overloading	Harmful	≤ 0,2 mm wide	Light	

Code	Appearance	Cause	Nature Marks (S)	Criteria for Assessment	Degree Mark (R)	Unit
				> 0,2 mm wide	Heavy	
				Visible leaking or seepage	Heavy	
		Carbonation	Harmless			
		Impact	Harmful			m or sq.m
		Foundation failure	Harmful			
		Pre-stressing force	Harmful			
		Shrinkage	Harmless	≤ 0,4 mm wide	Light	
		Vegetation	Harmful	> 0,4 mm wide	Heavy	
		Volumetric expansion	Harmful			
203	Corrosion of steel	Any	Harmful	≤ 10% of cross section	Light	m or sq.m
	Reinforcement			> 10% of cross section	Heavy	
204	Weathered or aged	Abrasion	Harmful			
		Aging		≤ Cover layer	Light	
		Chemical Attack		> Cover layer	Heavy	sq.m or cu.m
		Impact				
		Poor workmanship				
		Volumetric expansion				
205	Broken or missing material	Any	Harmful	Structural Element	Heavy	sq.m or cu.m
				Non-Structural Element	Light	
206	Deflection	Impact	Harmful	Slabs		
		Foundation failure		≤ 1 in 600	Light	
		Overloading		> 1 in 600	Heavy	sq.m
				Other Element		
				≤ 20 mm	Light	
				> 20 mm	Heavy	

According to the BMS'92 Manual, bridge consists of a number of elements which interacts one another as well as with their environment and surrounding. From the perspective of bridge structure constituent, their hierarchy is divided into several levels (the level of importance/risk), for example, the hierarchy for substructure as shown on **Figure 2-7** below.



(Sources: BMS'92 Bridge Inspection Manual)

Figure 2-7 Bridge element hierarchy

Level-1, BRIDGE: Overall.

Level-2, COMPONENTS: Super-structure, Sub-structure, Waterways.

Level-3, MAIN ELEMENT: Foundation, Abutment, or Pier.

Level-4, ELEMENT: Pile-cap, Abutment Wall, Wing Wall.

Level-5, LOCATION OF ELEMENT: Abutment Wall A1.

Table 2-8 shows a form for elements and defects condition for rating assessment of BMS '92.

Table 2-8 Filled up inspection form with list defects element BMS'92

Defective Element		Defect		Location				Level 5 Condition						Level 3 - 4 Condition					
Code	Description (optional)	Code	Description (optional)	A/P/B	X	Y	Z	S	R	K	F	P	NK	S	R	K	F	P	NK
4.462	BOTTOMCHORD	302	CORROSION																
4.461	TOP CHORD	302	CORROSION																
4.463	DIAG.NORMAL	302	CORROSION																
4.612	BEARINGS	712	DEFORMATION																
3.210	WATERWAY	503	SCOUR																

(Sources: BMS'92 Bridge Inspection Manual)

2.7.4 Maintenance issue

Poor bridge maintenance represents of issues in Bridge Management System. District may not conduct routine and periodic bridges maintenance due to no binding technical policy, including special budget allocation for such activities.

Under decentralized government, the road and bridge administration is separated based on the authority according to Article 14, Article 15, and Article 16 Law No.38 year 2004 on Road, namely:

1) Article 14 Clause (1). Central Government Authority responsible for general and national roads.
2) Article 15 Clause (1). Provincial Government Authority responsible for provincial roads.
3) Article 16 Clause (1). District Government Authority responsible for district and rural roads.
4) Article 16 Clause (2). Municipal/City Government Authority responsible for urban roads.

Therefore, road and bridge maintenance programs including technical policy generally represents authority of central government, provincial government and district/municipal government for each road level. Accordingly the policy and budgeting are responsibility by each government level.

2.7.5 Budget allocation

Central Government and Local Government as road administrator as mandated in Article13, Law No. 38 year 2004 on Road has obligation in maintenance, repair and inspection of roads (including bridges) periodically, to maintain service level as the minimum service level set forth. Hence, financing of the activities will be allocated by Central Government (through National Funds/APBN) and Local Government (through Regional Funds/APBD).

For financing from APBN/APBD it is stipulated in law on State's Budget, law on Financial Balance between Central Government and Local Government, and Government Regulation (PP) on Financial Balance. The budget is provided from State/Local revenues as well as foreign loans or grants. Central Government allocates APBN for infrastructure, especially roads and bridges, covering development, improvement and maintenance. For Local Government, budget for roads and bridges development is allocated in each APBD, as stipulated in Article 85 Clause (1) of Government Regulation (PP) No. 34 year 2006 on Roads, provided that:

> "Administration in the implementation of roads network maintenance program represents activity requiring budget allocation to realize the target".

If Local Government is not able to finance roads development fully, then Central Government will assist as stipulated in Article 85 Clause (2) and (3) of PP No. 34 year 2006 which mentioned:

> "(2) In case of local government is not able to finance fully development of roads under their authority, Central Government may assist as prevailing laws and regulations.(3) Further stipulation on procedure and requirement for the financing support to local government as mentioned in Clause (2) set forth in Ministerial Regulation."

In order to support Local Government to realize development, improvement, and maintenance of roads and bridges, therefore Central Government provides financing support through Special Allocation Fund (DAK) for Infrastructure or Non Reforestation Special Allocation Fund for Infrastructure. DAK represents type of specific fund transfer from Central Government to districts. Determination of allocation and guideline on DAK for Infrastructure and Non Reforestation DAK in Infrastructure, generally stipulated with Regulation of Minister of Finance.

From technical aspect, DAK utilization is stipulated in Regulation/Decree of Minister of Public Work and Housing (PUPR), where DAK is allocated for periodical road maintenance of minimum 70% and road improvement of maximum 30%. The activities of routine road maintenance and development cannot be funded by the DAK financing scheme. As already mentioned the DAK is especially allocated for periodical maintenance of roads officially designated as district (Kab./Kota) roads. For its utilization, Minister of PUPR establishes coordination team and technical team at ministerial level, and provides special fund for the operational activities of the teams. At provincial level, governors also establish operation team consisting of elements of Local Government Planning Board (BAPPEDA), related technical agencies, and central working unit at the district (Road and Bridge Planning and Supervision/P2JJ).

In order to implement activities at district level funded by DAK, regent/mayor establishes operation team consisting of elements of BAPPEDA and related agencies. Head of SKPD who deals with road responsible for physical and financial matters upon the implementation of activities funded by DAK.

In the regulation of Minister of PUPR above, there are articles on sanction for DAK operators who do not implement their duties as this ministerial regulation. Upon the DAK there will be performance evaluation which will be stipulated in minister's report to Minister of Finance, Minister of National Development Planning (BAPPENAS), Minister Home Affairs (Mendagri), and Legislative (DPR). In order to provide evaluation, minister requires report on DAK implementation for each beneficiary district. Reporting on DAK implementation carried out as its hierarchy by Head of Local Development Working Unit (SKPD), Head of District, and Minister. Article 102 of Law No. 33/2004 on Balance Budget of Government and Local Government, provides authority to Minister of Finance to enforce sanction in form of suspension of financial balance, including DAK, for Head of District who do not deliver information. As consequence this suspension of fund channel to district will affect to people economy in the district.

2.7.6 Bridge development policy

Policy on bridge development is discussed in this subchapter especially on how the role of the public implementation policy applied in provincial and district level administrator.

According to Law No. 38 year 2004 on Road, bridge represents one part of road supporting structure, which located at the ground surface, above ground surface, underground surface and/or water, and above water surface, except railways, lorry, and cable way. Article 86 Clause (3) Government Regulation No.

34 year 2006 on Road, mention that bridge represents road which located above water surface and/or ground water.

Based on Law No. 38 year 2004 on Road Article 30 Clause (1) point b, mention that road operator shall prioritize road maintenance, repair and inspection periodically to maintain service level as the minimum standard set forth.

In Law No. 22 year 2009 on Traffic and Road Transport, mention that road operator shall immediately and properly repair deteriorated road that may lead to traffic accident. In addition, the law also mentioned that preservation as activity to keep road condition, including road maintenance, rehabilitation, and reconstruction.

According to Government Regulation No. 34 year 2006 on Road, in Article 97, road operator shall maintain the road as their authority, which covers routine maintenance, periodical maintenance, and rehabilitation. Based on several prevailing regulations, bridge maintenance shall be implemented by operators, therefore fund allocation for the activities need to be provided by each district as their authority. **Figure 2-8** shows the pipeline proccess of bridge project delivery in or operational stage, it has not regulated in detail yet. While for Planning stage and Construction stage, it has been regulated by Decree of Minister of Public Work No. 19 year 2011 stipulates on Technical Specification and Design Criteria and Construction Service of Law No. 18 year 1999.

Law No. 12 year 2011on States Law and Regulation (Policy) has grouped policies in Indonesia into four levels, namely:

- Highest policies, which includes state constitution,
- Public policies, which includes law, government regulation,
- Special policies, which includes presidential decree, ministerial decree, and
- Technical policies, which includes procedure, and technical guidance.

According to management stage which is ruled by those policies, **Table 2-9** shows some of the staging in bridge development governed by Laws, Government Regulation, etc. As shown in **Table 2-9** the activities related to the inspection of the bridge condition does not yet have specific policies, especially for field data collection activities, programming and budgeting, and maintenance program even though the manual and guideline were available and have been applied.

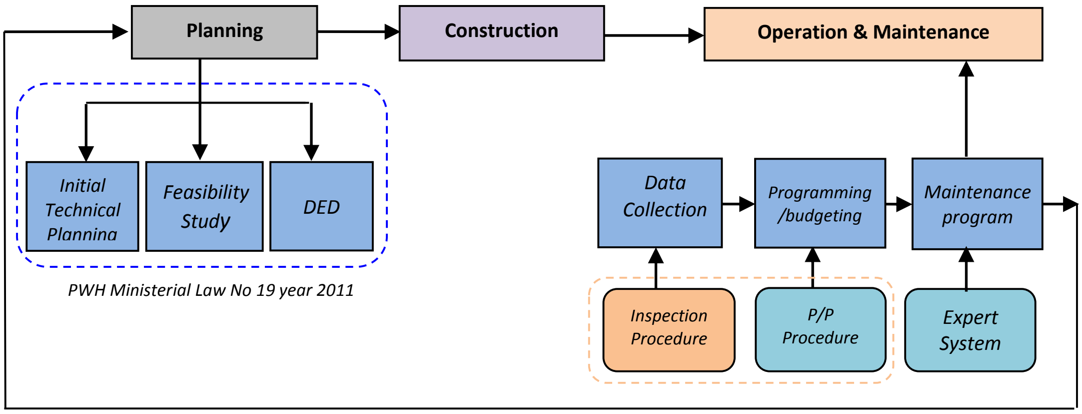


Figure 2-8 Policy on bridge asset management

Based on the activities ruled by those policies, **Table 2-9** shows the activities in bridge management governed by Laws, Government Regulation, etc. As shown in **Table 2-9** the activities related to the inspection of the bridge condition does not yet have specific policies, especially for field data collection activities, programming and budgeting, and maintenance program. All of the policy groups related to one another when the activities need to be drafted into a policy.

The readiness of planning stage will determine the success level of bridge construction. Completed and detailed of bridge establishment, the lower risk will be faced. The imperfection in construction detail potentially creates a slow failure until catastrophic sudden failure. Bridge failure could also happen due to wrong procedure and environmental condition. If the collapse occurs in the construction stage, it is easy to identify the responsible parties which involves such as designer, contractor and consultant supervision. Those parties engage in the project and have clear responsibility as it is still in the construction stage. In this case the bridge owners have no liability.

Table 2-9 Bridge policy govern for bridge development stage

	Law and regulation	Planning Stages					Construction Stages		Operational and Maintenance Stages			
		Initial Technical Planning	Feasibility Study	Environmental	Detail Engineering Design	Road Safety	Construction Failure	Collapse during service life	Road Operational Performance	Data Collection	Programming/ Budgeting	Maintenance Program
Mandatory to all road administration authorities	Environmental Law, No. 32/2009	n/a	Yes	Yes	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Road Law, No. 38/2004	General guidance for road and bridge development										
	Construction Services Law, No. 18/1999	n/a	n/a	n/a	n/a	n/a	Yes	Yes	n/a	No mandatory road/bridge policy covered for whole road administraton authorities		
	Government regulation on Road No. 34/2006	Yes	Yes	n/a	Yes	Yes	n/a	n/a	Yes			
	Government regulation on Construction Services No. 29/2000	n/a	n/a	n/a	n/a	n/a	Yes	Yes	n/a			
	Ministerial Regulation No. 10/2011*	Yes	Yes	Yes	Yes	n/a	n/a	n/a	n/a			
	Ministerial Regulation No. 19/2011**	n/a	n/a	n/a	n/a	Yes	n/a	n/a	Yes			
Non mandatory	Procedures***	Yes	Yes	Yes	Yes	Yes	n/a	n/a	Yes	Yes	Yes	Yes

Note: *) Road Safety, **) Technical Specification & Design Criteria, ***) Include: Code & Spesification, n/a is not available.

This condition will be different, if the collapse happens several years after Final Hand Overs (FHO). According to Law No. 18 year 1999 on Construction Services, if the Bridge Failure occurs before 10 years, this condition categorized as a construction failure and each related party could be asked for their responsibility including the user.

If the collapse happens after 10 years, the roles of Designer, Contractor, and Supervision related to the bridge construction is not prominent, because there are other factors involved such as improper usage of the bridge structure. Several events might trigger of bridge collapse including mistakes in bridge maintenance etc.**Figure 2-9** shows dissimilarity of Construction Failure and Service Collapse (Vaza, H., 2014).

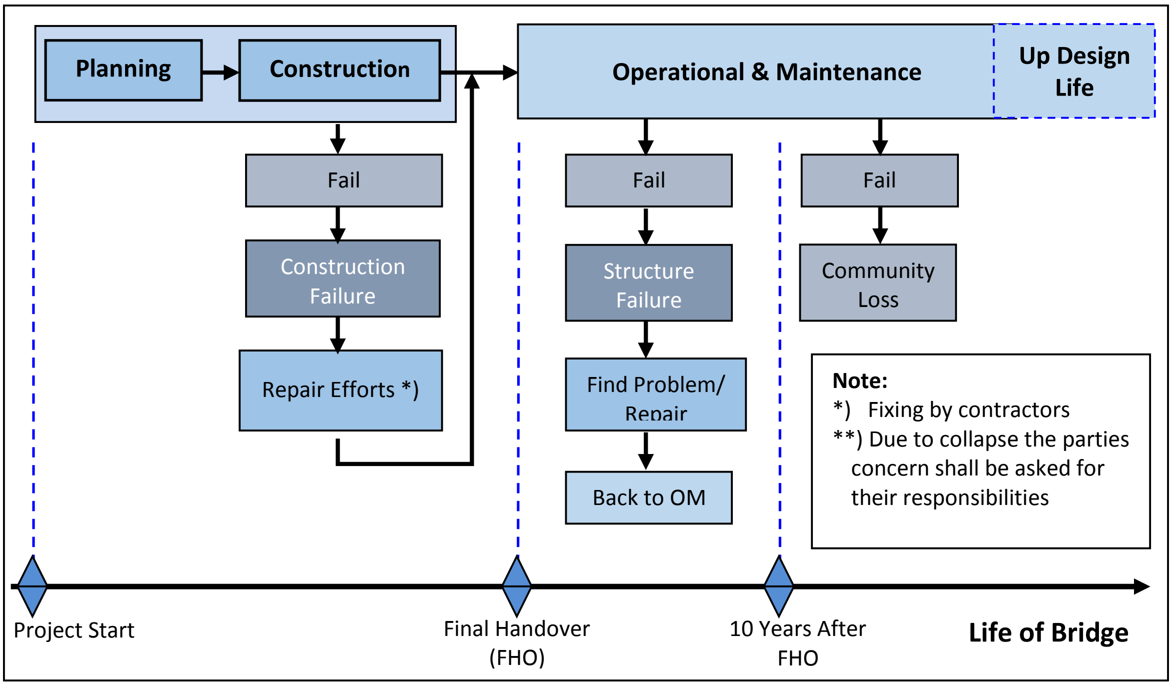


Figure 2-9 Construction Failure and Serviced Collapse

2.8 Instrumented bridge inspection and rating

In this research, results from visual inspection will be proved and correlated to instrumented inspection rating. This instrumented inspection is aimed to make inspection results carried out visually produce absolute rating of bridge condition. In addition, it is expected to be reference in determining bridges condition by only using a simple device that cost effective and more accurate as well as reduce subjectivity factor of inspectors. **Figure 2-10** shows the steps of using the devices in bridge condition inspection and rating assessment.

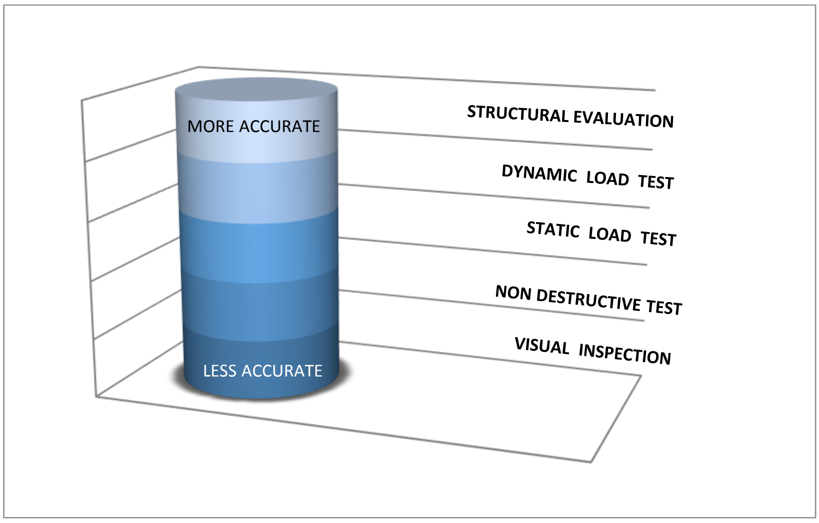


Figure 2-10 Diagnostic Instruments in Structural Evaluation

For this purpose, there will be carried out bridge geometry measurement and collection/testing of bridge properties for those become object of this research. For several non destructive test (NDT) methods, degree of accuration related to condition state (Sanford,1999) as shown in **Table 2-10.**

Table 2-10 Accuration of several Non-Destrcutive Tests

Integrated Condition State					
Parameters	1 (Protected)	2 (Exposed)	3 (Vulnerable)	4 (Attacked)	5 (Damaged)
Electrical Resistance	High	Low			
Specific Ion Probe	Low Cl		High Cl		
Corrosion Current	Low			High	
Radar Sounding	No Damage				Damage

Subsequently testing will be carried to collect bridge's elastic response by using static load. The response is measured by displacement due to the static loading. Other testing, i.e., dynamic loading, at the same bridge to collect dynamic response conducted by acceleration measurement of structural vibration response as function of time (Islam,A.A,et al, 2014). From this inspection, there will be determined and measured condition rating of the bridge from difference of natural frequency of several measurements in different period. The natural frequency contains information on bridge stiffness. Therefore, decrease of frequency value is considered correlate to decrease of bridge condition (Mekjavic,I.,2013, Siringoringo,D.M., et al., 2013, Salgado, R., 2014, Islam, A.A.,et al, 2014 and Vaza, H., et al., 2015), which usually determined by visual.

Inspection with dynamic response measurement method has advantage in term of rapid field data collection, consistency of collected data and more cost effective for long term inspection condition (Mekjavic, I., 2013,, Salgado, R., 2014 and Islam, A.A.,et al 2014).

2.8.1 Structure performance

The performance of structures such as bridges under operational and environmental conditions may decrease because of the deterioration/aging of its materials/elements. Visual inspection has been widely conducted to detect damage and evaluate the condition of existing structures. However, it is subjective and inefficient for large and complex structures. To overcome such limitation of visual inspection, vibration-based damage detection has been widely studied, because of its cost-effectiveness and objectiveness, (Jin, S., Cho, S., & Jung, H. 2015).

Vibration analysis one of the most common techniques used in predictive maintenance for mechanical equipment, (Carnero, M. C., 2005). Other example of structures which utilize vibration for condition monitoring is pipeline installation, which is a simple and effective approach of analyzing pipeline vibration is to treat a pipeline as an elongated beam due to the typical large span length of pipeline segments between end supports, (Horizon, D., 2014).

Bridge structures have most similarities with common mechanical equipment using modal analysis method. A research states that generated vibration signals is able to identify the structural defects of element, (El-thalji, I., & Jantunen, E., 2015). In the case of rolling elements, vibration monitoring techniques is often used to predict when the maintenance or replacement activities are required, (Orhan, S., & Aktu, N., 2006). Based on the research on bearing vibration monitoring, (Orhan, S., & Aktu, N., 2006), failure level will increase significantly when bearing condition measured by vibration has reach specific point, as shown in **Figure 2-11**.

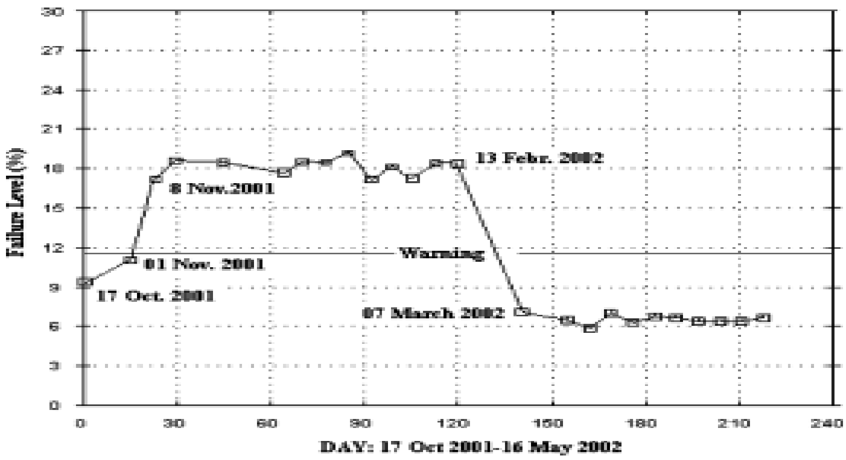


Figure 2-11 Overall vibration level trend of the pump inner bearing

An intelligent conditions base on the maintenance standard for rotation technologies developed by Tran, V. T., & Yang, B. (2012) as shows **in Figure 2-12**. The hazard rate gradually increases with respect to time. Start the certain point, the hazard rate significantly changes due to the rapid growth of RMS values. Thus, the more the hazard rate increases, the less the reliability. In the case of bridge structures, the philosophy of vibration monitoring and analysis are appropriate to applied.

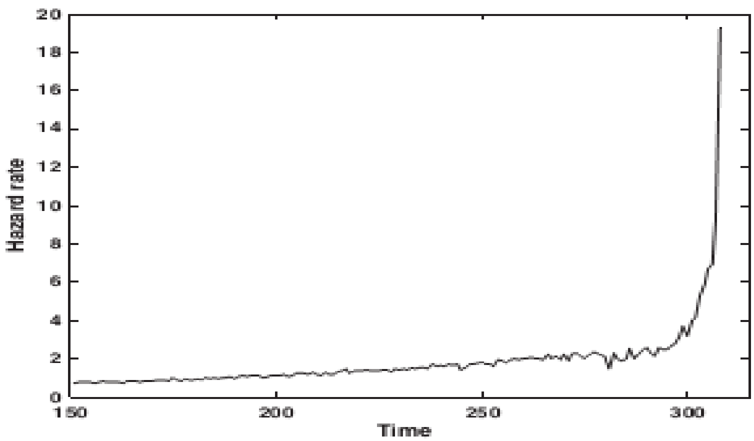


Figure 2-12 Hazard rate estimation

2.8.2 Numerical analysis

In order to set up rating of bridge condition by domain frequency approach, time series measurement required. Earlier measurement considered as *finger print* and become reference rating for further analysis.

For that reason, there will be determined frequency rating of newly built bridges with numeric approach, i.e., elastic modal analysis. The modal analysis of the research object carried out using structural software package such as; SpaceGass V6, by using 2 modeling approaches, namely: 1) make model for overall geometry and properties of bridges, including consideration of its boundary layer; and 2) make model of artificial bridge as beam element with geometry and properties recorded from bridges elastic response from results of static loading test.

The second numeric approach is more accurate since the *boundary layer* and detail *geometry* as well as *properties* of the bridge covered in elastic response information recorded from static load testing. The difference of both modal are analyzed to get an ideal structural modeling approach, therefore static loading test can be represented by using results of measurement and testing of properties only and frequency obtained from the first modal analysis approach.

2.8.3 Field measurement and analysis

Measurement results of structural vibration response acceleration from dynamic testing is continued by analysis and determination of peak vibration response that represent bridges under study, proceeded by eliminating noise and following vibration recorded in device reading.

Subsequently results of this field measurement will be analyzed by using *Fast Fourier Transform* (FFT) method (Dewetron, 2011). The analysis will result several peak frequency of bridges. Natural frequency represents the lowest frequency with small energy excitation and represent simple sinusoidal harmonic wave that contain information on properties and stiffness of the bridges under study.

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \tag{2.1}$$

Where:

f is frequency of bridge

k is stiffness of bridge

m is mass of bridge

2.8.4 Bridge rating based on frequency

Natural frequency of simple supported beam in form of simple sinusoidal harmonic wave obtained from field measurement, containing information on bridges properties and stiffness, hence bridge or structure healthy of current state. Series data of those will lead to determining the bridge condition rating based on frequency (Tristanto,L., 2002, Mekjavic, I., 2013, Siringoringo.D.M., et al., 2013, Salgado, R., 2014 and Islam, A.A.,et al, 2014).

Natural frequency requires defining bridge condition rating, consisting of two parameters, namely theoretical natural frequency and actual natural frequency. Theoretical natural frequency can be obtained from modal analysis of an ideal bridge modeling where the bridge is in good condition state. It can be also defined through instrumented field measurement just before bridge is readyopen for traffic. While actual natural frequency can be obtained from field measurement. Both values compare to obtain the ratio, *K*. The ratio *K* is a relative estimate of defect rate. Based on *K* value and defect rate ratio, bridge condition rating can be classified.

In the case of this research, comparison is also done to the results of elastic modal analysis. When the parameter inputs are as the as-built drawing documents (design specification) than the modal analysis results represent the condition state of new built bridge (represent a finger print condition). Subsequently set up numeric modeling procedure by using modal analysis, can be used to correlate the rating of bridge condition obtained from visual inspection.

From visual inspection results carried out at several bridges then determine several bridges with different rating that represent variation of bridges condition in which static and dynamic load test is still possible carried out, i.e.: bridges with rating of visual inspection range of 0, 1, 2, and 3. Subsequently, instrumentation testing on the representative bridges are carried out. The results of the instrumented inspection will be correlated to the rating from visual inspection, the results will be used as basis for determining condition rating of frequency approach.

After all processes and iteration carried out there will be produced a bridge inspection and rating assessment with several new proposed of inspection sequence, inspection technique, and correlation of frequency domain related to rating of bridge condition. Therefore, to determine bridge condition rating in thefuture can be carried out through two different approaches i.e.: through visual inspection and vibration measurement of bridge structure

2.9 Issues related to bridge inspection

Based on the results of the above study can be concluded several issues related to Bridge Management System, especially related to current bridge inspection:

a. Bridge Management System BMS'92 have never evolved since it was first launched in 1992, meaning that the system is 23-year-old without any improvement to meet current state of the art of information technology as well as issues raise in using of BMS’92 for more than 20 years of application.
b. The development of bridge condition assessment methods in the international sphere is quite advanced, following the developments in information technology so that Indonesia as a developing country needs to undertake the development of the system of inspection of the condition of the bridge gradually and continuously.
c. Some countries have implemented expert systems which enable the inspection results of the bridge more valid according to expert experiences, as well as can generate output such as estimated cost of repairs/ maintenance to be budgeted by bridge managers.

d. The largest population of bridges in Indonesia is dominated by simply supported bridges in the form of standardized I-Girder bridge and standardized steel truss, as a result of government policies in accelerating road and bridge construction in early 1970s - 1990s.
e. Maintenance is the main issue in the management of the bridge in Indonesia, which is not performing well, especially during the decentralization era. Law on roads in Indonesia has been published which stated that the management of the bridge as part of the road assigned to each person in charge (Minister of Public Works and Housing for the national, regional heads of provincial and district). However, less applicable regulations to guide the operation at the field and even some are still not legitimate.
f. The use of the instrumented test for screening bridges need visual inspection is worthy and save cost and time consuming. The use of vibration principle as a quantitative measure in determining the condition of a general structure has been developed, especially for the purposes of predictive maintenance in industry sectors. The use of the vibration principle in the bridge structure need to be developed in Indonesia, by comparing the natural frequency at the time of initial bridge opening to traffic (new bridge condition) with the current state condition.

CHAPTER 3

REVIEW OF BRIDGE INSPECTION AND RATING ASSESSMENT OF BMS'92

3.1 General

This chapter provides critical review of the existing Indonesian Bridge Management System with respect to the weakness and problem by using the BMS'92 Bridge Inspection Manual. Inspection data which were collected by the inspectors consists of Bridge Administration data, Bridge Dimensioning Data, Bridge Structural Data, and Bridge Condition Data which was carried out by visual observation. To make those data are reliable then strategy in collecting data should consider the perspective of sustainable concepts, so collected data will always up-to-date for Decision Support System within bridge administrator in Indonesia.

For purpose of assessment bridge rating based on the BMS '92 Bridge Inspection Manual than data on bridge condition should be collected from basic level of bridge i.e.: bridge elements level where the defects discovered. Those Bridge Elements in hierarchy level constitute a bridge. From bridge element condition data collected than element rating assessment is carried out for each element at fourth level (Level-5 in the case defect happen in only part of Level-4). Assessment on bridge rating than move forward to third level (Level-3). According to BMS'92 Bridge Inspection Manual, the bridge rating (Level-1) is calculated based on available formula.

The facts and portraits of the weakness and barrier of using BMS '92 Bridge Inspection Manual will be rationalized from secondary data related to inspection of bridge condition which was carried out by Directorate General of Highways (DGH), Ministry of Public Works and Housing and Institute of Road Engineering (IRE), Ministry Public Works and Housing which were carried out in 2008 on Pantura Highway (North Java Corridor) as seen on **Figure 3-2**. Those data had not collected in the same time.

In addition, to determine study area and improvement of inspection manual as well as assessment of bridge rating system, than polling and analysis responses of bridge's users or operators through questionnaire are carried out. The respondent were selected who has related to bridge administrator through all level bridge authorities including provincial and district level, as well as city administrator.

Further critical review was focused on direction of improvement of bridge inspection areas as well as improvement of assessment rating system, than simulation of field inspection were carried out by 10 personnel of Candidate Master Inspector (CMP), who represent researchers and engineers within IRE with classification expert on bridge inspections. Simulation of inspection will be done to one selected composite I-Girder concrete bridge (PC-beams). The procedure, 10 personnel before inspection will have coaches from the senior experts, this is intended to make the same perception on the BMS '92 Bridge Inspection Manual – Visual Procedure among inspectors. Those 10 inspectors during inspection were asked to working independently.

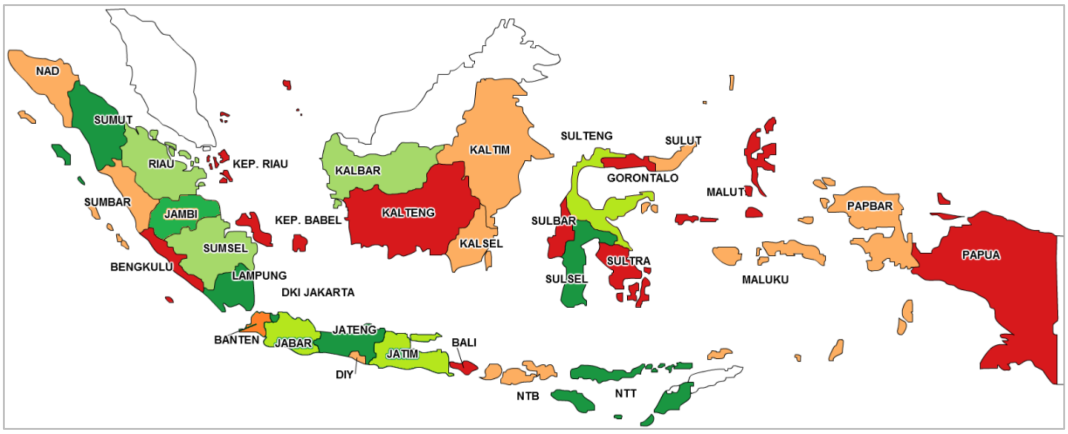


Figure 3-1 Republic of Indonesia

3.2 Bridges in Pantura Highway

3.2.1 Bridge inspection of BMS '92

The procedure of visual bridge inspection in Indonesia as seen on the sub chapter 2.7.3 is used for inspection and assessment the bridge rating of Pantura Highway bridges. Inspection of bridges in Pantura Highway have done by the

Directorate of Highways (DGH) and Institute of Road Engineering (IRE) in year 2008 and the result is exceptional and inconsistent where there is a different perspective regarding the bridge rating condition amongst the different institution.

Figure 3-2 Red Line is Pantura Highway (North Java Corridor Highway)

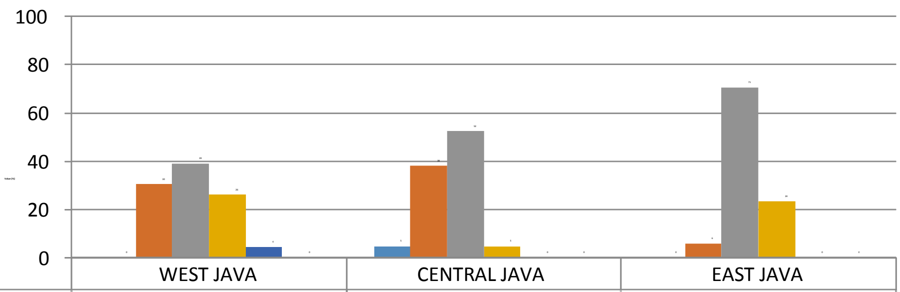
3.2.2 Result on the Pantura bridge condition assessment

From secondary data collected by IRE, which describes name of bridges, year of construction, date of inspection, Super-structure type, Sub-structure type and Bridge (Level-1) condition rating. Number of superstructure type of the I-Girder bridges around 85% which is greater than steel truss bridge and others around 15% (Vaza, 2013).

Furthermore, in nationwide, from existing bridge database collected by DGH, number of steel truss bridge (warren-truss) is relatively large, i.e., 40% of bridges at national and provincial roads (Vaza, 2014), remain simply supported I-Girder bridge. In addition, steel truss bridges are less applied for heavy loaded and populated traffic which is normally designed with high standard principle since 100 years ago (Zhao, J. J., & Tonias, D. E., 2014).

Those facts become the basic consideration to developing recent model of Bridge Inspection Manual that focus for I-Girder type bridges including voided slab bridges. This is also the fact that the bridges in local road mostly dominated by an average short span bridge which span length is less than 7.4 meter, where normally constructed by simple-supported bridge structure. Therefore, it is most strategic solution to improve the Bridge Inspection Manual with focus I-Girder bridges, particularly also to support decentralization era of government of Indonesia.

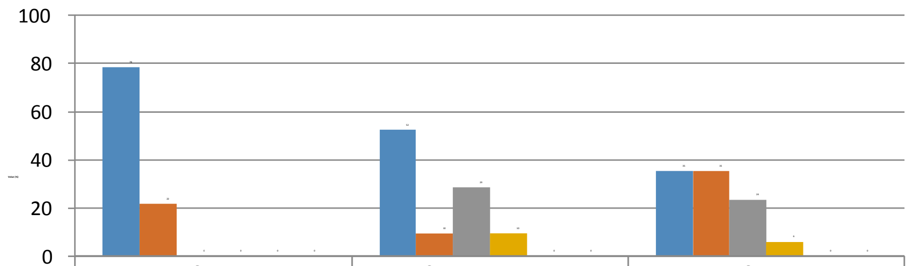
Moreover, when we consider the accuracy of data collected by two authorities, i.e., IRE and DGH then by using similar instrument inspection tool as stated in Bridge Inspection Manual of BMS’92 from similar secondary data collected, it shows the bridge condition rating in three provinces in Java Islands as in **Figure 3-3** and **Figure 3-4**. Those figures show the variation on bridge condition rating and compromise ratio of its discovered defects between inspectors from IRE and DGH.



	WEST JAVA	CENTRAL JAVA	EAST JAVA
Rating= 0	0	5	0
Rating= 1	30	38	6
Rating= 2	39	52	71
Rating= 3	26	5	24
Rating= 4	4	0	0
Rating= 5	0	0	0

Figure 3-3 Bridge condition rating at Pantura Highway (by IRE)

Further investigation of those data, disagreement ratio on bridge condition rating from each province can be presented in graph as shown in **Figure 3-5**. When the condition rating of Level-1 (bridge level) is used for this assessment, it is concluded that the disagreement ratio between DGH and IRE is 70% and only 30% are confirmed each other. This shows a great inconsistency ratio, therefore it is necessary further studies find the factors influence the bridge condition rating based on current Bridge Inspection Manual, BMS ‘92.



	WEST JAVA	CENTRAL JAVA	EAST JAVA
Rating= 0	78	52	35
Rating= 1	22	10	35
Rating= 2	0	29	24
Rating= 3	0	10	6
Rating= 4	0	0	0
Rating= 5	0	0	0

Figure 3-4 Bridge condition rating at Pantura Highway (by DGH)

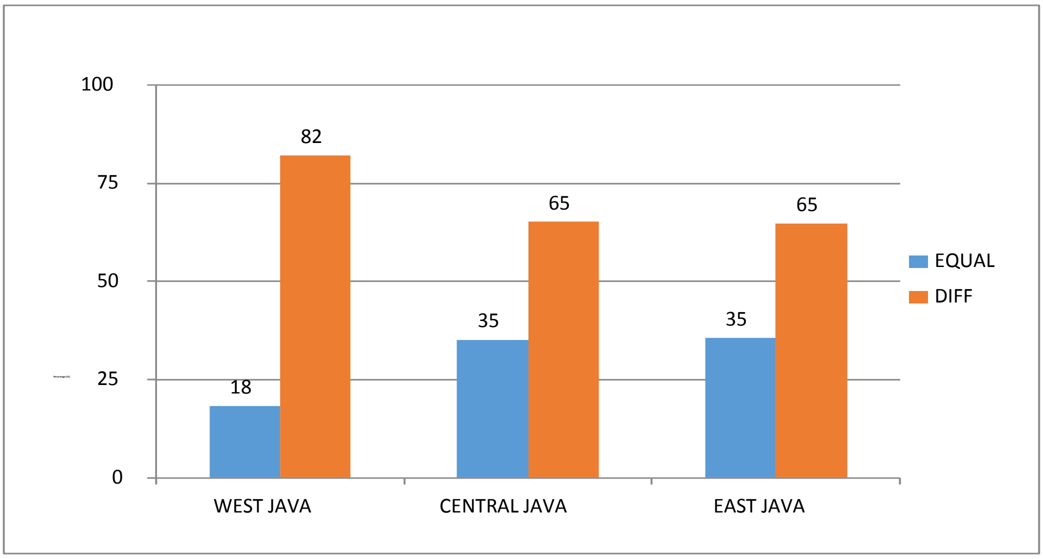


Figure 3-5 Ratio of identical in classify bridge condition rating by DGH vs. IRE

Further discussion on bridges data collected in West Java Province and Central Java Province as well as East Java Province which is highway of northern Java coastal road (Pantura) and subsequent assessment, the results are presented in form of frequencies of defect events that often emerging at Level-3 (bridge elements) as shown in Figure 3-6. Those data are firstly normalized to figures which do not directly effect to bridge condition rating that directed to sudden collapse, although from bridge users perspective it is very important.

In order to identify the magnitude and quantity of defect at the existing bridges, data collection shall be carried out, both for primary and secondary data, than data classification and assessment were done. Data collection may be collected through inspection to objects, information from various sources, internet and social media, as well as collection of inspection data from government institutions and local bridge operator. This activity carried out to obtain accurate data on degree or quantity of bridges defect in Indonesia.

Subsequently, from these data, frequency of event is arranged from the most frequent on the top rows of **Figure 3-6** and so on until the less frequent on the lower part of figure. Furthermore, based on frequency of defects as shown in **Figure 3-6**, it is worthy for most inspectors to perform field inspection if they are provided with Defects Catalogue that can be used as a reference in finding the defects and defects rate.

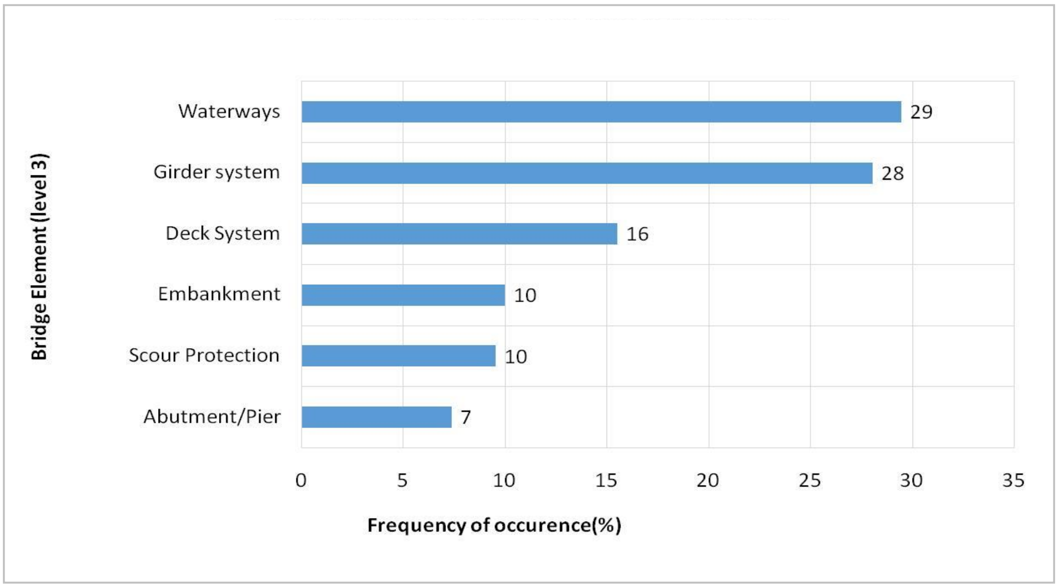


Figure 3-6 Frequent defect of bridge element

3.2.3 Review on the bridge accident

In addition to investigation on secondary data of Pantura Highway that has done in previous sub-chapter, further evaluation is carried out based on information collected from literature study, mass media, social media, i.e., where subsequently validation was carried out by inspecting bridge condition by using prevailing system.

Bridge as part of land transportation infrastructure play important role in supporting safety of road networks as consequence national economy development. Bridge also becomes important element of a road segment, since it determines maximum vehicle load allowed to pass through the road segments. A bridge might degrade due to several factors, among others environmental and physical impact factors. In addition, number of users and loads that exceed bridge's capacity also affect to structural element of bridge in accepting traffic loads. The degradation of bridge condition, if does not manage in timely, it may trigger and lead to worse condition, and even the greatest defect lead to bridge collapse.

In case of Indonesia, there are several cases of bridges collapse in recent years. The most popular case is the collapse of Kutai Kartanegara Bridge (Vaza 2014), which located at Tenggarong, East Kalimantan. Based on data collected from 2004 to 2014 there are 71 cases of bridge collapse in Indonesia. This happen were mostly occurred in 2013 with 25 cases where government system who will manage the bridge assets has been decentralized to district level. This situation proves that in decentralization government era started in 2000, responsibility to manage the bridges in their regional was not well organized by many reasons. **Figure 3-7** shows the number of bridges collapsed between 2004 and 2014.

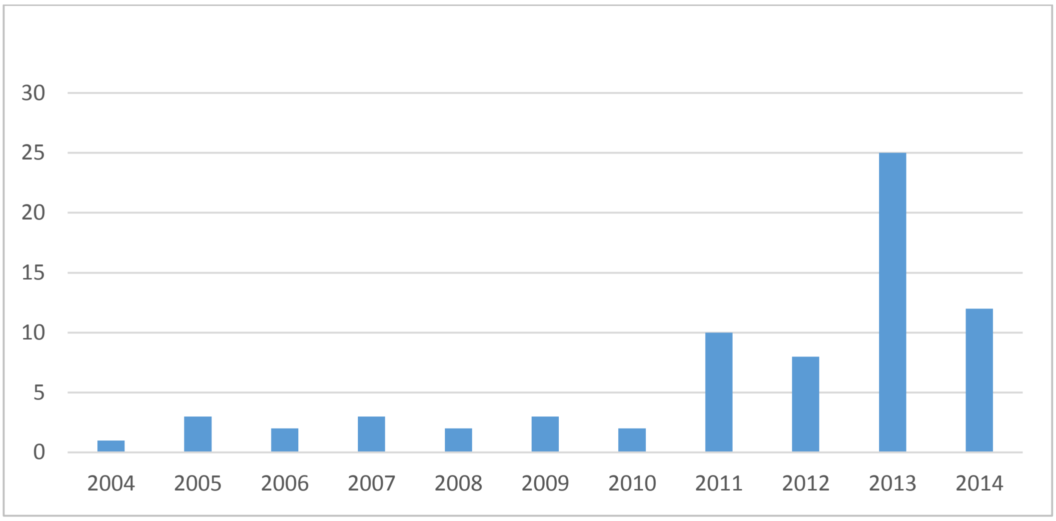


Figure 3-7 Number of bridge collapse in Indonesia between year 2004-2014

One of the bridge development objectives highlights the safety of bridge user. For that reason, bridge shall able to control the loads on the bridge. Improper in designing may choose type and dimension of bridge below the strength limit allowed. The bridge built will collapse since the structure cannot hold the load, either due to bridge's dead-load, live-load, wind-load, seismic-load and environment load or combination of those (Vaza, 2013). There are several factors in designing the bridge which responsible for bridge collapse. Based on data of the studies, bridge collapse is primarily caused by natural factors.

In order to quantify and factor causes bridge collapse, a descriptive method is used. This method is applied by collecting, classifying, analyzing, and presenting data that the final results can describe factors and quantity of bridges collapse in Indonesia. In order to determine the cause, accurate data collection is required. The collected data can be secondary and primary data.

These conditions happen as the inspection procedure have not been optimally utilized as regular agenda as an input for tool in managing bridge asset especially in decentralized government era. Furthermore, the BMS '92 bridge inspection Manual also contributes to that problem as collected information does not always reflect the actual condition in the field. Moreover, from bridge condition rating perspective, even though the bridge rating are considered as reference or relative to the condition of other bridges. This situation is reflected when Comal Bridge in Pantura collapsed in July 2014, while in bridge management system of BMS '92 recorded that the Comal Bridge was relatively in good condition (Direktorat Bina Teknik, 2014). **Figure 3-8** shows the factors involved in bridge collapse recently in Indonesia.

Further discussion from that figure, as the bridges are generally not protected and directly contacted to surrounding environments, therefore the environmental factors most contribute to various types of defects of the bridges. The defect occurs at bridges due to environment primarily causes corrosion on bridge materials. Finally the bridge condition will accelerated deterioration. In order to ensure, its services maintenance required both routine and periodic maintenance.

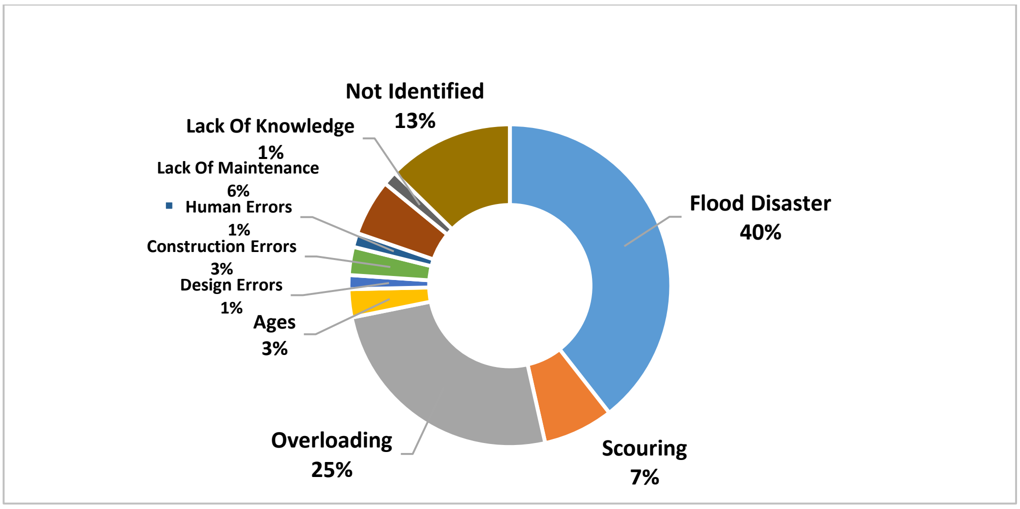


Figure 3-8 Causes of bridge collapse in Indonesia

3.3 Questionnaire survey

In this sub-chapter questionnaire survey is discussed. The objective, the results of pooling from respondent are used to support more objective conclusion as additional information are also collected through questionnaire. Feedback from respondents become additional input that real demand for inspection system become closes to the users or inspector therefore accurate results more easy to achieved. Sampling of questionnaire carried out through bridge's managers both at central and local government.

3.3.1 Survey methodology

a) Design questionnaire

In preparing questionnaire several questions asked to collect information on characteristics of respondents, number of bridges, bridges inspection, bridges inspector, budget, bridges inspection system and BMS' 92. In order to obtain accurate information, the questionnaires filled by respondents shall be witnessed by chief of the institution and stamped. Example of questionnaire used in this research presented in attachment-A.

b) Define sample

Sampling frame in this research are name of institutions and its address. Sampling of samples (respondents) carried out randomly (*probability sampling*), namely object of research has equal opportunity to be selected as sample. Random sampling used in this research, namely stratified random sampling. A stratified random sample is one obtained by separating the population elements into non-overlapping groups, called strata, and then selecting a simple random sample from each stratum (Scheaffer et al, 1990).

c) Determining the amount of samples

Population in this research covers public works office of all provinces and district in Indonesia. Number of samples in this research collected by using Slovin formula, as follows:

$$n = \frac{N}{1+Ne^2} \qquad (3.1)$$

Where:

n is number of samples

N is number of population

e is error tolerance

Population in this research covers 548 consists of 34 provincial Public Works and 514 district Public Works level. By using Slovin formula with error tolerance of 10%, obtained number of samples 85 consisting of 5 Provincial Public Works and 80 District Public Works office.

d) Data collection

Data collection carried out by sending questionnaire to address of respondents. In order to avoid non-response, “callbacks” carried out.

3.3.2 Survey results

From diagram Figure 3-10 given that activity of bridges inspection in several districts in Indonesia has different period, and even some districts do not conduct the inspection or never carry out the bridge inspection. There are 37% districts which conduct bridge inspection every year and 36% conduct the inspection occasionally as shown in **Figure 3-9**.

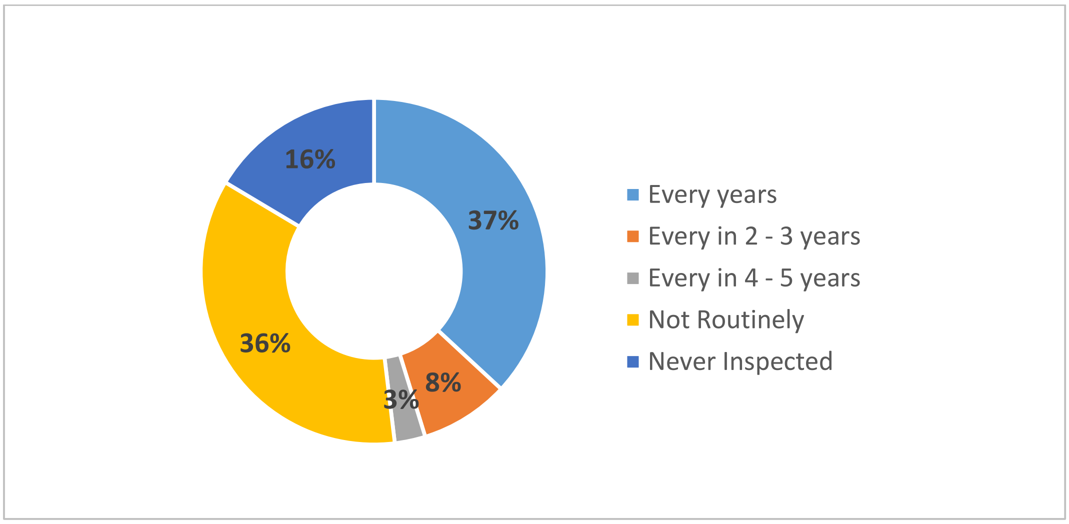


Figure 3-9 Consistency of bridge inspection

Based on the analysis result of questionnaire, there are 69% districts which have regulation on bridge inspection. In this case, they are not supported with assistance for intensive bridge inspection, proved from figure of 53% districts which never receive assistance as shown in **Figure 3-10**.

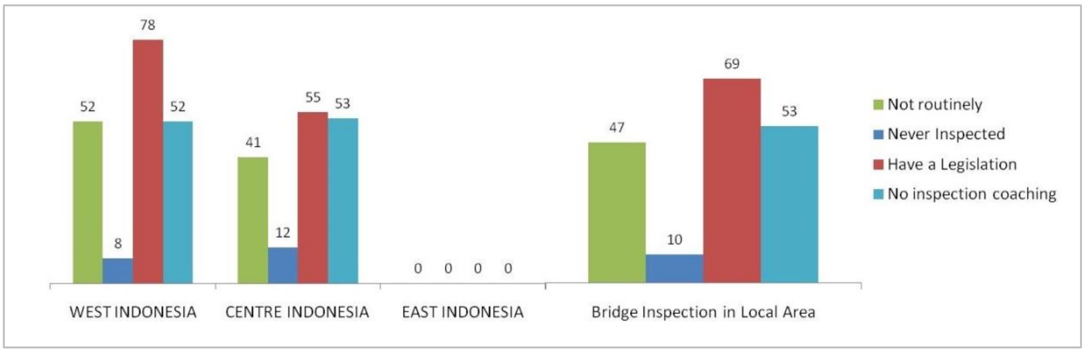


Figure 3-10 Consistency between legislation and training

There are several reasons expressed in questionnaire why the districts do not conduct bridge inspection routinely or even no inspection. The figure shows that 40% do not carry out inspection due to limited fund; 27% do not carry out inspection due to limited human resource; and 11% do not carry out inspection due to no assistance on periodic bridge inspection as shown in **Figure 3-11**.

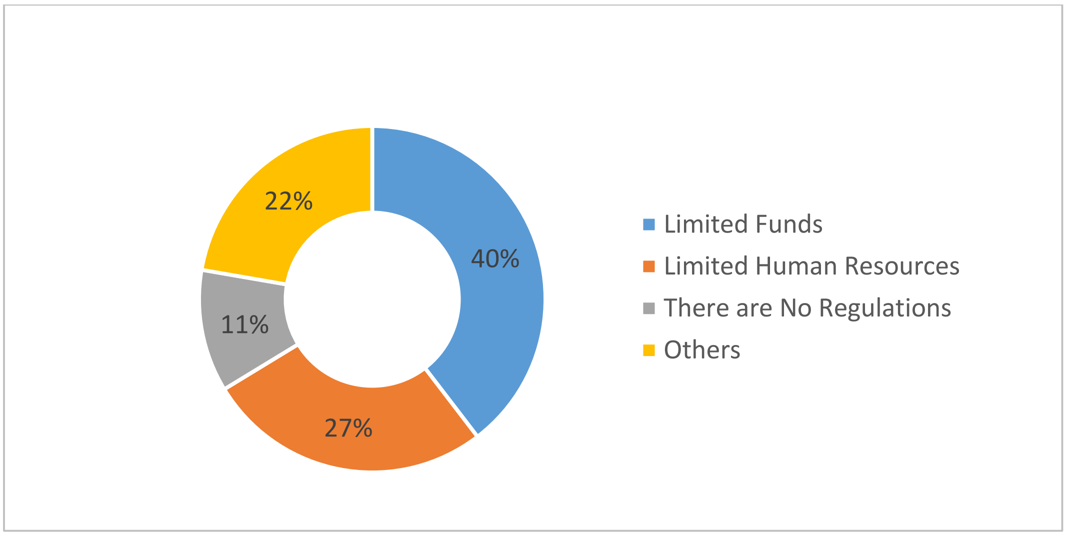


Figure 3-11 Issue in routine inspection agenda

Further investigation shows, BMS’92 has been recognized in several districts in Indonesia, but only 63% make use of BMS’92 as guidance in bridge inspection and according 36% respondents BMS’92 is considered complicated. From the inspection results already carried out, 95% districts refer the results as guidance to maintain the bridges further as shown in **Figure 3-12**.

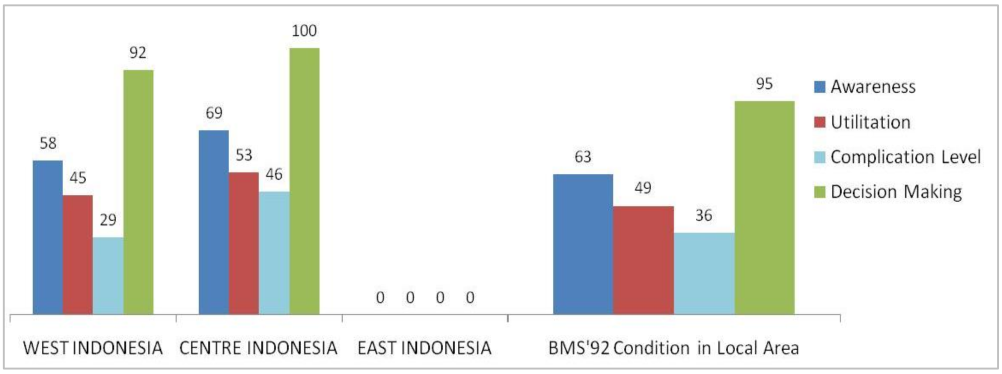


Figure 3-12 Application of BMS'92 in several level bridge administrators

There are 65% districts have bridge's inspectors, but only 8% districts which inspectors meet standard competence. While 17% districts acknowledge on inspector's standard competence issued by Ministry of Public Work and Housing.

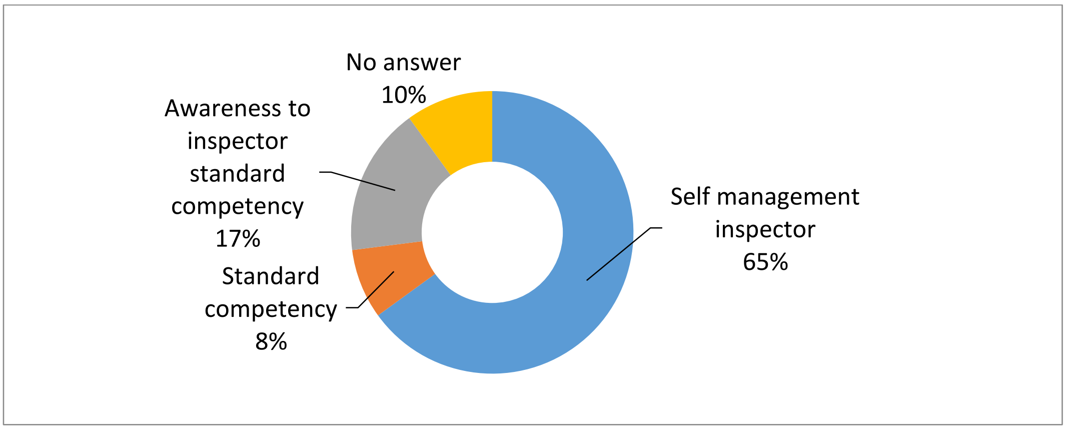


Figure 3-13 Inspector competency

Sequence of field inspection as described in BMS '92 shown in **Figure 2-2** is rather difficult to implement in case bridge crosses over large river which requires supported equipment as well as a narrow space and even requires special equipment. This is the reason why every inspector can find defect on bridge elements differently.

It is confirmed from questionnaire results as shown in **Figure 3-14** where most respondents (35%) stated that they have difficulty in finding defects on bridge elements. While 31% respondents stated that they are lack of experience.

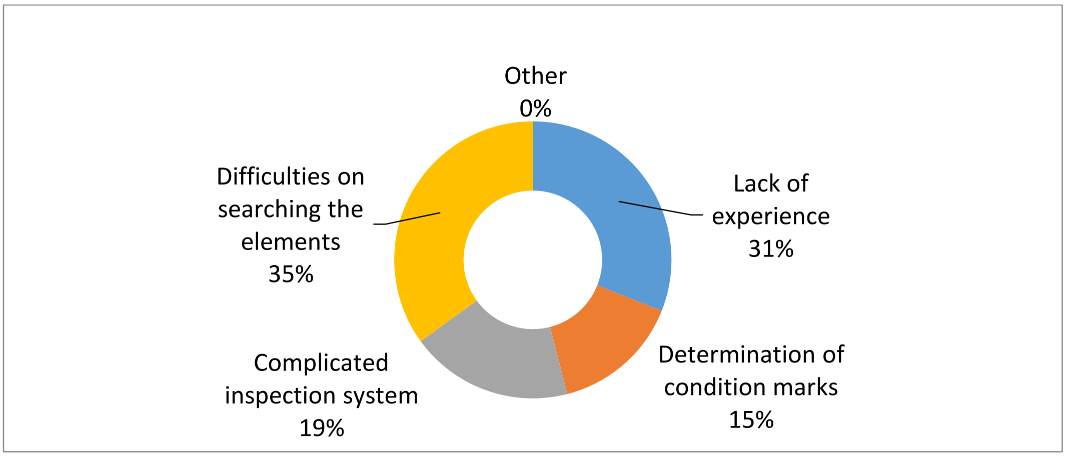


Figure 3-14 Bridge inspection problems

Inaccurate in determine bridge elements rating may occur as result of the difficulty in carrying out an inspection. There are many reasons to answer the issue as shown in **Figure 3-15**. This might occur to find the defects. This situation may happen due to lack of supporting equipment or difficulties in understanding bridge rating parameter.

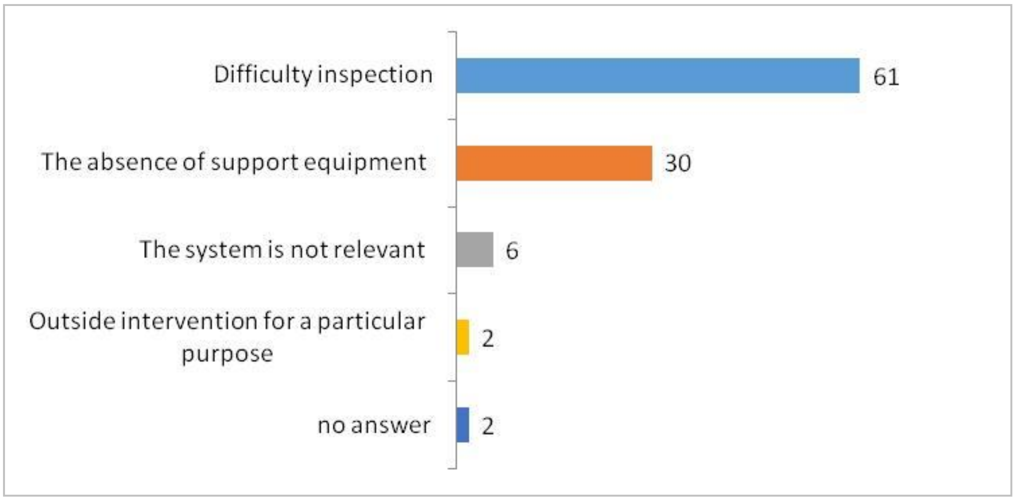


Figure 3-15 Inaccuracy in identifying bridge condition

Further discussion in carry out an bridge inspection, where there is a certain sequence to inspect bridges as described in previous section, which follow risk level of bridge elements of level 3 (bridge element). This is the strategy to focus inspection on elements with high risk level against bridge collapse and it does not follow procedure as set forth in current practice of BMS '92. It is expected that every inspector will find target of uniform defects and later to uniform in classifying defect rating. Alternatively, evaluate the defect elements as directed in recommended check list from routine inspection which is filled up during routine maintenance works.

In addition to secondary data results above, the following supported information is summarized from respondent's feedback to questionnaire. **Figure 3-17** shows compiled of 3 graphs from questionnaire: Bridge Management in decentralized government era with different focuses. On the lower part of graph, presents bridge type population according to respondent's feedback, where more than 49% agree that bridges in Indonesia are mostly I-Girder type, while 35% state that they are steel truss bridges type. While in middle part of graph describes difficulties in perform bridge inspection, where 34% agree that the truss bridge is most difficult to inspected and only 23% agrees that I-Girder type bridge is difficult to inspect.

Furthermore, on the top parts of graph in **Figure 3-16** shows difficulty level in evaluating the bridge element condition, where 82% of respondents agree that truss bridge is most difficult to define the bridge elements rating, while for I-Girder bridge type only 8% respondents agree it is the most difficult to define the bridge elements rating.

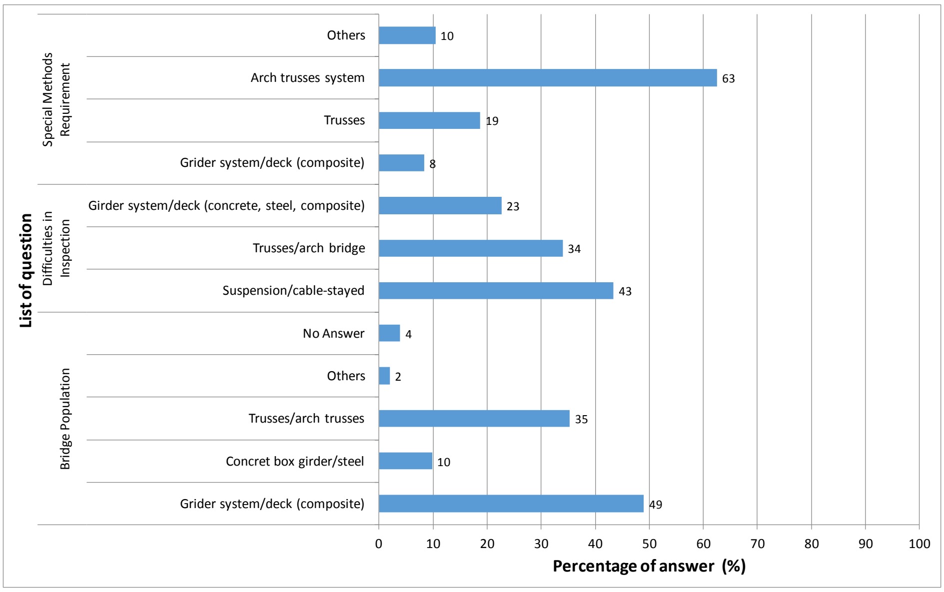


Figure 3-16 Bridge population and complexity in evaluating bridge condition

Necessity of BMS as a guide in assessing the condition of bridges is very important. The level of awareness in using Bridge Management System as a bridge inspection guide according to the analysis of questionnaire as shown in the **Figure 3-17** shows that in general most respondents aware of BMS as an important Manual as a basis for determining the condition of the bridge. But most of respondents do not aware on the use of BMS as a guide in assessing the condition of the bridge.

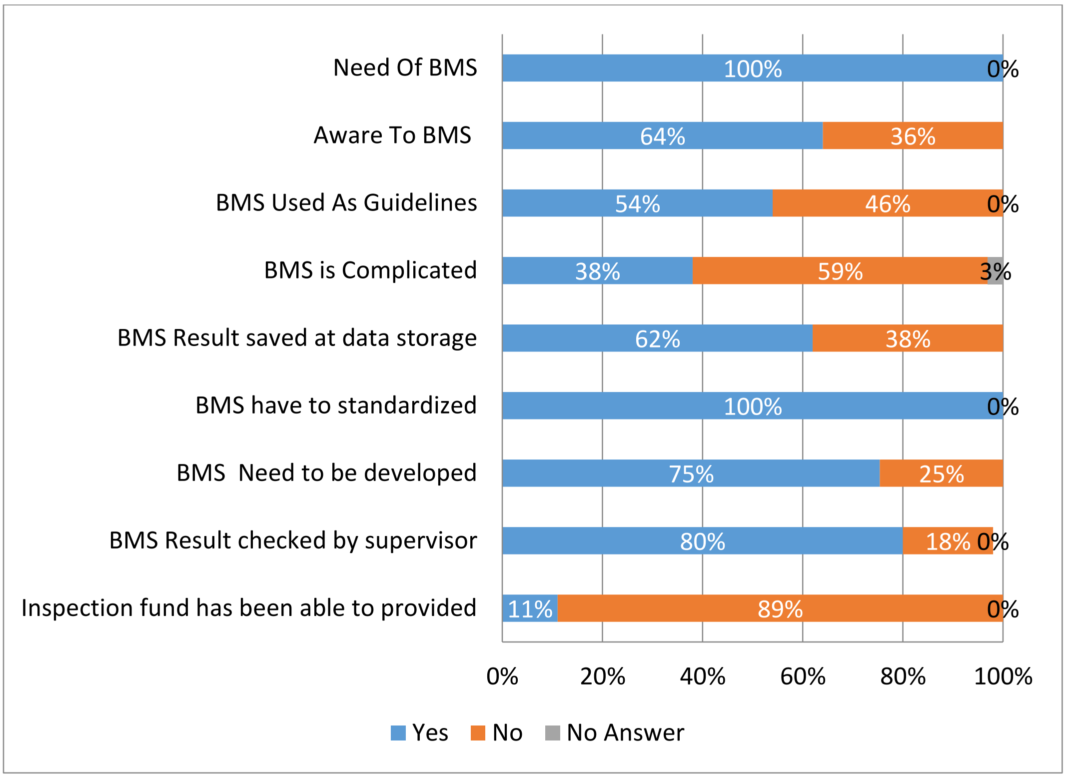


Figure 3-17 BMS'92 evaluation from questioners survey perspective

Approximately half of the respondents agree to use the existing BMS as bridge inspection manual. While, certain respondents, states that bridge inspection conducted according to BMS'92 have considerable level of complexity. Not all local bridge managers perform bridge condition data storage, both for the existing bridge as well as for the newly constructed bridge.

Based on some of those problems, it is necessary to standardize the system and the system needs to be developed, so that each region has the same responsibility in conducting the data management process of bridge condition so that it can be used optimally. In practice, the results of bridge inspection were rechecked by the immediate supervisor, so that the results of the inspection should have been verified.

Inspection of the bridge is an important part in the Bridge Management System, as a basis in determining the condition of the bridge, and the need for repair/action on the bridge. But the majority of regions in Indonesia still do not have sufficient funds to carry out inspection activities and also repair bridges either regularly or periodically.

Based on the provisions set forth, bridge inspection should be performed regularly, based on the type of inspection, such as routine inspection and detailed inspection. Period of inspection under based on BMS'92 shown in the following **Figure 3-18**.

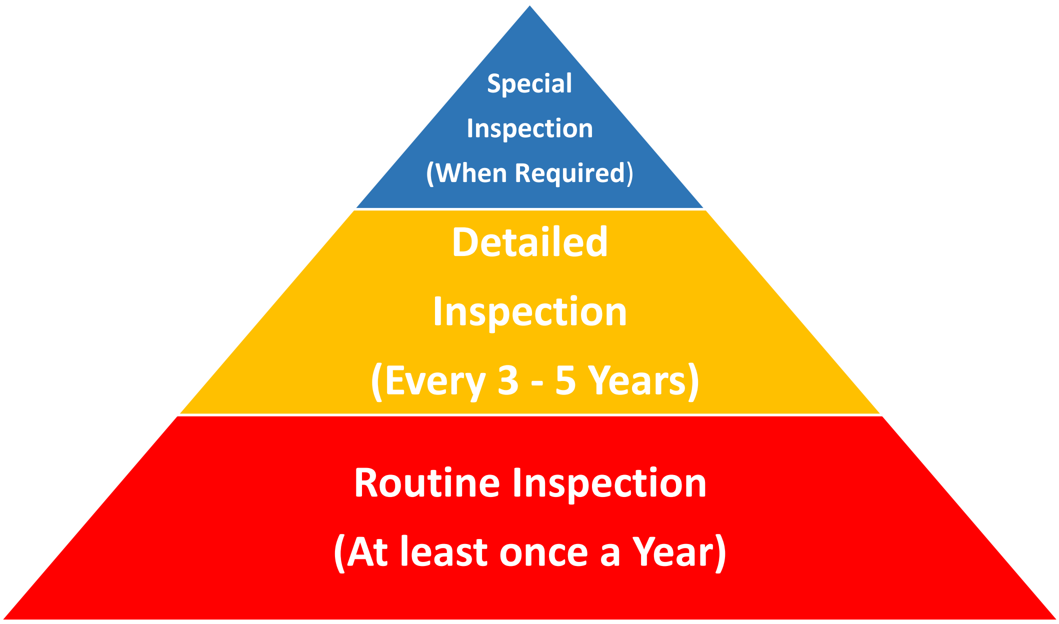


Figure 3-18 BMS’92 bridge inspection schedule

The needs of bridge inspectors in bridge condition assessment activity are very high, considering the number of bridge experts are still limited and tend to decrease. One of the factors cause to reduce number of experts including bridge inspection is the unavailability of competency standards for bridge inspectors.

This sort of thing causes interest as a bridge inspector slowly diminished. According to the survey, 91% of inspectors are unqualified, only 9% are qualified.

According to the survey, a special training, field training, and experience should be the benchmark that determines an inspector in his or her expertise to perform bridge inspection, see **Figure 3-20**.

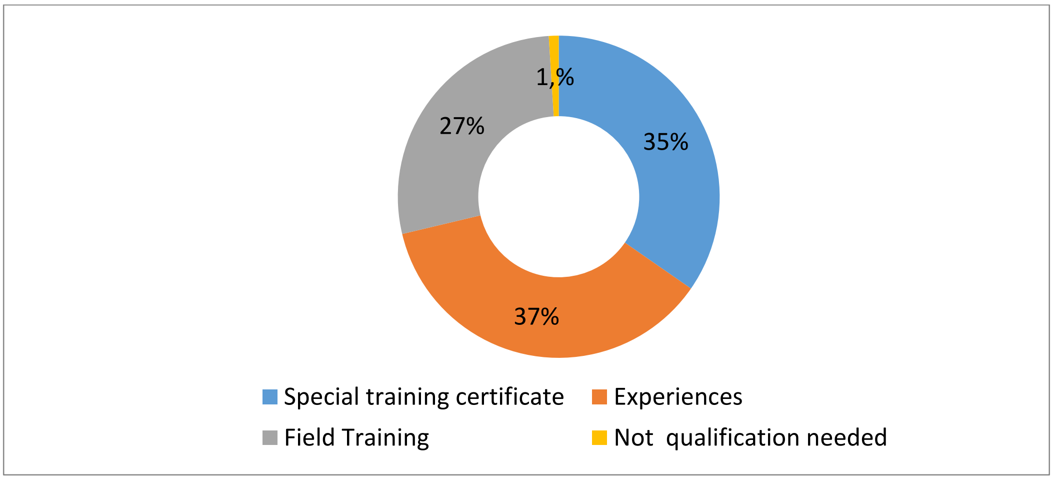


Figure 3-19 Qualification of inspector

Based on discussion above, there are some important issues relating to the results of the questionnaire, that might practical for improvement of currents inspection system i.e.:

a) Data is highly required in the bridge management system for preparing bridge maintenance program, however in some districts the human resource still not ready.
b) The inspection program is not routinely performed, mostly due to the limited fund.
c) Bridge inspector in most area still not have a qualification or standard competency.

3.4 Simulation of visual bridge condition inspection

Further investigation to focusing the area of improvement of current inspection system is discussed. The report from field inspection simulation and the results together with others important issues, than analysis is carried out.

Based on these analyses, improvement of inspection model and rating assessment is formed. Furthermore, based on the improvement inspection model then re-inspection is performed, the results are compared to the existing.

Detail field inspection simulation is discussed where simulation of field inspection were carried out by 10 personnel of Candidate Master Inspector (CMP), who represent researchers and engineers within IRE with classification expert on bridge inspection. Simulation of inspection will be done to one selected composite I-Girder bridge. The mechanism, 10 personnel before inspection will have coaches from the prominent experts, this is intended to make the same perception on the BMS '92 Bridge Inspection Manual – Visual Procedure among inspectors. Those 10 inspectors during inspection were asked to working independently.

Bridge inspectors assigned to CMP are selected from the assessment of several researchers and engineers of Bridge and Structure Experimental Station, Institute of Road Engineering (IRE) as many as 10 persons with portfolio show in **Table 3-1**.

Table 3-1 Portfolio candidate bridge inspector of IRE (CMP)

No	Name	Age	Graduate	Department	Expe-rience	Bridge inspection training	Bridge inspection certificate	Vision impaired	Information
1	I	40	S1	Civil Eng.	8	Yes	Yes	Yes	Myopi
2	II	37	S1	Civil Eng.	7	Yes	No	No	-
3	III	36	D3	Civil Eng.	4	Yes	No	No	-
4	IV	35	S1	Civil Eng.	7	Yes	Yes	No	-
5	V	29	D3	Civil Eng.	2	Yes	No	No	Myopi
6	VI	28	S1	Civil Eng.	3	Yes	No	No	Myopi
7	VII	28	S1	Civil Eng.	4	Yes	No	No	-
8	VIII	28	S1	Civil Eng.	4	Yes	No	Yes	Myopi
9	IX	27	S1	Civil Eng.	4	Yes	No	No	-
10	X	27	S1	Civil Eng.	3	Yes	No	No	-

Inspection data collected by CMP represents bridge data condition which collected by Candidate Master Inspector of IRE's engineers. Assignment of 10 CMP to perform inspections on one selected bridge on national highway at Padalarang, around Plered, Purwakarta, West Java Province, namely Cilalawi

Bridge-A. The bridge structure is concrete I-Girder composite with span length about 36 m and width 9.2 m. Photographs are presented in attachment-B.

Assessment of the inspection results carried out on 3 principles namely, number of defects, type of defect and rating of defects at level 4 and level 3. Assessment carried out by comparing results of each inspector. From these assessments, the results are given on rating of bridge element which mostly inspected. In addition to that results, the different perceptions on type of defect, rating of defected element as well as different assessment on rating parameter of S, R, F, K and P are presented. The assessment shows percentage of subjectivity and dissimilar perception among inspectors.

Reports from bridge inspection experiment performed by 10 CMPs then analyzed and evaluated with focuses on practicality in finding defects and uniformity to determine the rating condition. The results only few elements of bridge can be detected among the inspectors who agree that there are defects. The reason is only few defects easy to find out and reaching i.e., bridge railing, and pavement surface. The report on bridge inspection conducted by 10 CMP is reviewed than level-3 bridge element was evaluated. The analysis results show inconsistency found in condition rating. As shown in **Figure 3-20** each level-3 element has 3 or more different condition rating as shown **Figure 3-21**.

Furthermore, the evaluation 10 inspectors are intended to determine deviation that may occur and the recommendation to obtain concurrent results for all 10 inspectors. An agreement of result of 10 CMP inspectors then set up as result of IRE's Master Bridge Inspector (MBI) and later on is used as the benchmark or standard for basis to evaluate the achievement so far of proposed inspection, i.e., model of an updated BMS '92 bridge inspection manual.

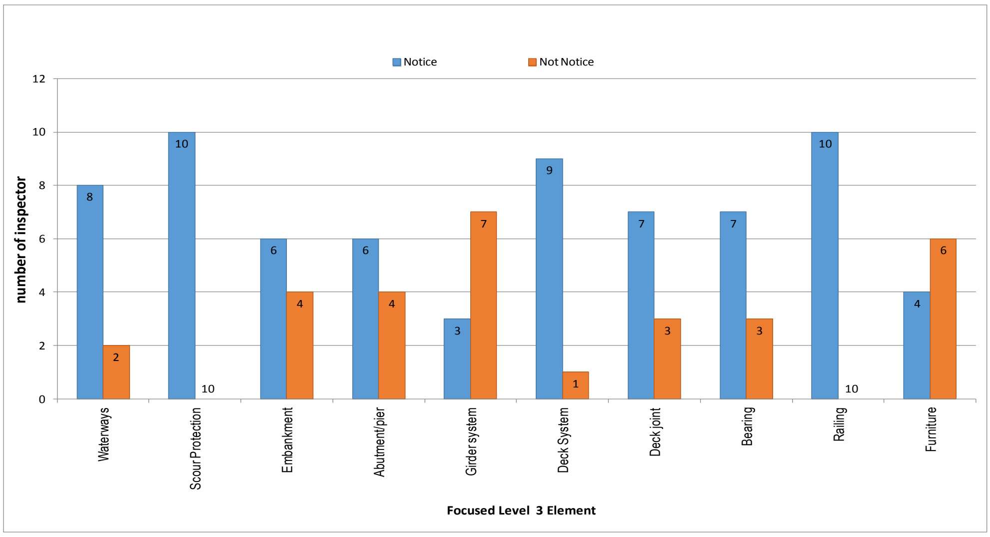
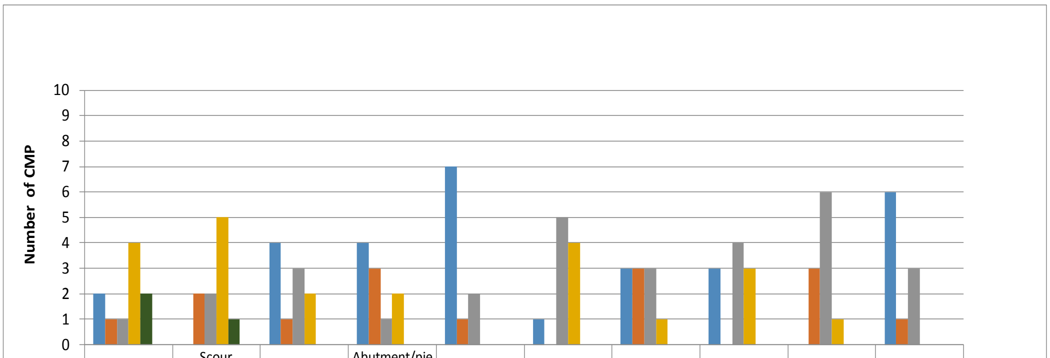


Figure 3-20 Focus CMP inspectors to the defect elements (level-3)



	Waterways	Scour Protection	Embankment	Abutment/pier	Girder system	Deck System	Deck joint	Bearing	Railing	Furniture
Score = 0	2	0	4	4	7	1	3	3	0	6
Score = 1	1	2	1	3	1	0	3	0	3	1
Score = 2	1	2	3	1	2	5	3	4	6	3
Score = 3	4	5	2	2	0	4	1	3	1	0
Score = 4	2	1	0	0	0	0	0	0	0	0
Score = 5	0	0	0	0	0	0	0	0	0	0

Figure 3-21 Perception of CMP inspectors on bridge condition rating (level-3)

Figure 3-22 shows an aggregate in classifying bridge elements rating as results of 10 CMP inspectors for Cilalawi-A bridge. An appropriate manner of inspection simulation will produce a uniform results and magnitude of bar lead to 1 variation only.

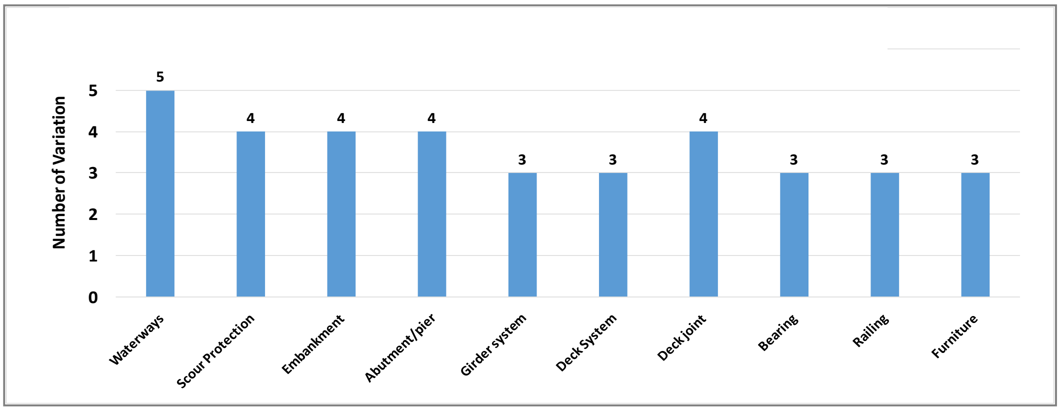


Figure 3-22 Variation of CMP inspector's opinion on bridge condition

Furthermore, from experimental visual inspection on Cilalawi-A bridge by using current BMS'92 bridge condition inspection manual, the results of the assessment on parameter rating S, R, K, F and P shown in **Figure 3-23**. The largest disparity found in parameter rating R, which manual for evaluation is already available. While the parameter rating F have not a manual and shows the least discrepancy. This leads to study more detail or more practice required before carrying out an inspection.

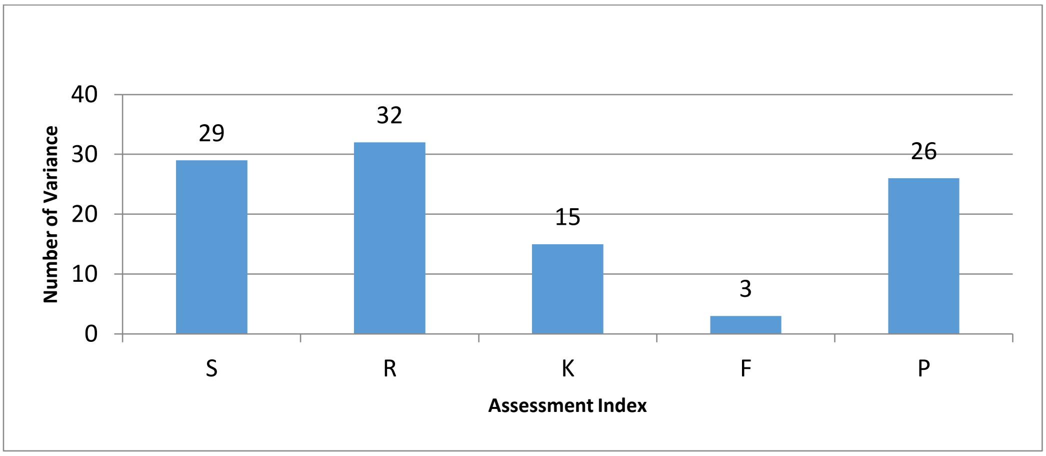


Figure 3-23 Disparity of CMP inspectors in characterized rating parameter

When results of inspection carried out by 10 CMP who independently evaluated on rating parameter set forth, then potential deviation in determining element rating can be minimized. Subsequently, select possible combinations in determining elements rating. Deviation on rating parameter S, R, K, F, and P can be focused so the accurate rating parameter can be generated by providing proposed matrix validation of rating that may guide virtually by directing of bridge experts.

In order to have more accurate inspection results, the participation matrix of each bridge element to overall bridge rating would be strategic solutions. In addition, based on this CMP inspection results, several issues can be formulated and subject for improvement and set in proposed model of bridge inspection Manual as follows:

a) During visual inspection sometimes it is impossible to find several defects elements without special inspection tools.
b) Unclear procedure on sequences to investigate the defect elements.
c) Insufficient information in defects assessment manual, where out of 5 defect rating parameter only 2 criteria have assessment guideline i.e., parameter S and parameter R.
d) It is clear, based on technical approach of BMS'92 to fill the detailed inspection forms during field inspection with guided manual for determination of bridge elements rating in order to achieve accurate and objective results. Thompson and Shepard, 2000, and Shirato M., and Tamakoshi, T., 2013, stated the best approaches to identify the defect based on elements level required for maintenance program. Bridge condition rating is carried out at bridge element level which express through 'real' Family Tree approach. However, **Table 3-2** shows family tree of bridge element hierarchy based on BMS'92 which does not represent 'real' Family Tree approach, where level-2 (superstructure) braking down to level 3 into type of superstructure rather than elements (level-3) which forming the components of bridge (superstructure/level-2).

Table 3-2 Bridge hierarchy element mix with type of bridge components

Code	Level 1	Code	Level 2	Code	Level 3	Code	Level 4
1.00	Brdge	2.40	Sprstructure	3.41	I-Girder	4.41	I-Girder (main)
						4.41	Cross Beam (I Girder)
						4.41	Diaphragm (I Girder)

Code	Level 1	Code	Level 2	Code	Level 3	Code	Level 4
						4.41	Connection
						4.41	Bearing
				3.42	Flat Slab	4.42	Slab
				3.43	Arch Stone	4.43	Barrel
						4.43	Spandrel wall
				3.44	Beam Arch	4.44	I-Girder (Arch Beam)
						4.44	Arch Beam
						4.44	Vertical (Beam Arc)
						4.44	Cross Beam (Beam Arc)
						4.44	Lateral Bracing (Beam
						4.44	Connection (Beam Arc)
				3.45	Trusses	4.45	Truss Panel
						4.45	Chord reinforcement
						4.45	Bracing Frame
						4.45	Rake
						4.45	Clamp
						4.45	Chord Top
						4.45	Chord Bottom
						4.45	Diagonal
						4.45	Vertical Truss
						4.46	Lateral Bracing (Truss)
						4.46	Lateral Bracing Bottom
						4.46	Diaphragm (Truss)
						4.46	Cross Beam (Truss)
						4.46	Connection (Truss)
						4.46	Chord middle

e) Bridge rating is made canonically stratified at top of pyramid systematically as shown in **Figure 3-24**. As consequence, if defects occur at elements or part of elements, the bridge is considered have defects. This include for the defects occur at non-structural elements which technically will not affect to bridge safety (failure). According to that system, the defects will come up to Level-2 and Level-1 in tiers manner. This condition leads to bias if the defects occurred at elements does not structurally lead to bridge collapse, such as defects on railing were caused impacts of vehicle’s collision.

Code	Level 1	Code	Level 2	Code	Level 3	Code	Level 4
1.00	Bridge	2.20	Wway/Emb	3.21	Waterway	4.21	Stream Bank
						4.21	Main Channel
						4.21	Flood Plain
				3.22	Scour	4.22	Groyne
						4.22	Gabion
						4.22	Concrete Lining
						4.22	Rock Breaching
						4.22	Sheet Pilling
						4.22	Fender System
						4.22	Retaining Wall
						4.22	Riverbed Controller
				3.23	Embankment	4.23	Approach
						4.23	Embankment
						4.23	Pavement
						4.23	Approach Slab

Figure 3-24 BMS'92 assessment bridge condition rating

f) Maintaining detailed defects up to elements Level-5 of bridge elements to determine location of defects, which considered less practical. Under BMS'92 bridge inspection manual, bridge elements hierarchy is not purely derived from family tree concepts. The hierarchy still agglomerates with elements of different bridge type. This causes data collected is relatively large as the consequences of data collection until Level-5 (bridge sub-sub-element). **Table 3-2** shows bridge component i.e., superstructure divided into types of superstructure component, i.e.: I-Girder, Flat Slab, Arch Beam, Trusses, therefore, hierarchy of bridge elements move down one step lower, which is actually not true.

g) Based on the simulation show that every inspector has a variation result on the assessment bridge rating according to the BMS'92 Manual. Furthermore, many inspectors did not notice the defect elements occur in the bridge. The variation is shown on the defect elements finding, and the assessment of each defect parameter criteria of S, R, K, F, and P.

3.5 Bridge condition assessment

Assessment of bridge condition with BMS ‘92 conducted through several stages, among others element assessment at level-5 to level-3, subsequently concluded by identifying the highest value among the elements in level-3. From the value of element level-3 can be concluded for each element at level-2 which represent element group of superstructure, sub-structure, and river basin/bridge. Subsequently from the element group can be concluded condition for level-1, namely bridge at whole.

- $NK_{2.200} = MAX\ (NK_{3.210}, NK_{3.220}, NK_{3.230})$
- $NK_{2.300} = MAX\ (NK_{3.310}, NK_{3.320})$

  $NK_{2.400} = MAX\ (NK_{3.410}, NK_{3.420}, NK_{3.430}, NK_{3.440}, NK_{3.450}, NK_{3.480}, NK_{3.500}, (NK_{3.600} - 3), NK_{3.610}, (NK_{3.620} - 2))$
- $NK_{1.000} = MAX\ ((NK_{2.200} - 2), NK_{2.300}, NK_{2.400}, (NK_{3.500} - 2))$

Figure 3-25 Equation for calculation of level-1 bridge condition rating

Formula above demonstrates that bridge rating assessment (**Figure 3-25**), structural element such as river flow/soil embankment (2.200) less significant to the bridge rating condition. This is probably the case why Comal Bridge collapses while the condition relatively good compared to the other adjacent bridges. The collapse of Comal Bridge due to underestimate in rating the soil embankment element which becomes main cause of bridge failure.

3.6 Findings on existing bridge inspection Manual of BMS’92

Based on secondary inspection data and questionnaire as discussion made above, several general issue on policy on bridge condition inspection and rating assessment of BMS’92, can be explained as follows:

a) The bridge condition inspection and rating assessment of BMS’92 creates disparity results between IRE and DGH about the bridge rating.

b) The demand of developing the methods of bridge inspection is very high. It is also shored up by the requirement to simplify the inspection system in conjunction with limited budget available for inspection.

c) Skilled bridge inspectors are highly needed, but the availability of the inspector is still limited.

Inaccurate results as consequence of inspector’s opinion in using BMS’92 bridge inspection manual as guidance in inspecting bridge condition may occur due assessment system, which has not been properly quantified for each type of defect elements. Moreover, as there is no weighting system at the bridge’s elements level that affect to bridge collapse, therefore the greater weight, then the most possible the element leads to failure.

Any weakness and limitation in utilizing of BMS’92 bridge condition inspection Manual will lead as issues that can create collected data and given assessment rating beyond from absolute rating, even though the reference is still accountable for use of general planning purposes and based on the discussion in this chapter, there are some of critical issues need to solve in order to improve the quality of results of using bridge condition inspection and rating assessment as follows:

a) Difficulty to find the defects on bridge elements, resulting bridge condition rating is less accurate. This situation represents when Comal Bridge in Pantura collapsed in July 2014, therefore it is worthy for most inspectors to carry out field inspection provided with Defects Catalogue that can be used as a reference in finding the defects and defects rate and pre defect information recorded by maintenance team.

b) Inconsistency in breaking down bridge element hierarchy. As consequence, it leads to element hierarchy break down up to level-5. This condition make data collected huge and insignificant for bridge rating condition.

c) The bridge elements which contribute to the bridge structural condition are not separated from the secondary elements (non-structural elements/Accessories). For purpose of bridge condition rating, it should focus on structural bridge elements only that will affect to bridge failure.

e) Complicated assessment method in characterized bridge condition rating parameters i.e.: S, R, K, F, and P, also need qualified inspectors such as professional engineers has trained and certificate as inspectors. These indicates, where out of 5 rating parameters only 2 parameter have assessment manual i.e., parameter S and parameter R.

d) Importance of contribution bridge elements to overall bridge rating condition does not clearly define.

e) As accumulation of above mentioned issues lead to the bridge condition rating does not always represent actual condition on the field.

These weakness and obstacle are needed further study and analysis to obtain more ideal bridge inspection manual. To solve these issues and come up with better solution, expert experiences consensus in conjunction with a focused group discussion (FGD) with relevant parties is used as the strategic approach. In addition by comparing to similar international bridge inspection system and rating assessment.

CHAPTER 4

PROPOSED IMPROVEMENT OF BRIDGE INSPECTION AND RATING ASSESSMENT OF BMS'92

4.1 General

An accurate bridge condition database in associated to road database such as road data and traffic information, play an important roles in Bridge Asset Management's well as for Bridge Management Information System (B-MIS). Generally, bridge administrator requires those data to support decision-making on road development. Hence, bridge condition data together with others data should be collected in appropriate manner and detailed of data require depending on its importance. They are collected for certain period of time regularly and systematically.

Moreover, the updated database will also serves and accurate database that will use to improve quality and capacity of recommendation, as well as for early warning system and also basis for bridge planning and programming which is a part of asset management system. Accurate data will determine performance of existing management system. Indonesian Bridge Management Systems (BMS '92) uses rating system where bridge condition embedded in elements of bridge where in hierarchy order as bridge constituent.

Moreover, the bridge elements hierarchy system shows irregularity approach and sequences of field inspection should follow such rule which is independent to defect which frequent happen in case of Indonesia condition. As consequence, the assessment results indicate high subjectivity. Furthermore, the collected information also bias since they are not segregated between bridge structural risk and bridge user safety. As the hierarchy of element shows irregular pattern therefore the collected condition data more complicated and become inaccurate results.

The strategic approaches are used for bridge data collection for Indonesian Bridge Management System through Bridge Inspection as stated in Bridge

Inspection Manual of BMS '92 as described in Chapter-2. The data collected consists of administration data, bridge geometries data, types of superstructure and substructure data, bridge elements condition data as well as historical data on maintenance woks.

Based on study in Chapter-3, several findings related to applying of BMS'92 so far can be categories such as: a) Difficult to finding defect on bridge elements; b) Inconsistency in breaking down bridge element in hierarchy manner; c) Complicated assessment method in characterized bridge condition parameters i.e., S, R, K, F, and P; d) Difficult to defining bridge condition rating when evaluate bridge/elements structural condition; e) The bridge rating does not always represent actual condition on the field; f) Importance of bridge elements to overall bridge condition does not clearly define.

4.2 Proposed improvement

As results of analysis and evaluation of the data collected in previous chapter and literature reviews, development of a proposed model of bridge inspection and rating system as an updated of BMS '92 is suggested. The development includes the following areas of the current BMS '92 system Bridge Inspection Manual:

a) Improve the sequences of bridge inspection which focus on element defects.
b) Improvement on bridge hierarchy system follows the real family tree approach in which bridge is built from their constituent (elements).
c) Establish matric of validation of rating parameters (S, R, K, F, and P) of existing BMS'92 rating system to control inspectors when filling uncommon combination of rating parameter S, R, K, F, and P.
d) Improvement bridge elements hierarchy which do not directly affect to bridge condition that lead to catastrophic collapse or reduce bridge performance then classified as the elements which only require routine maintenance. It can be done by evaluating the bridge elements which affect to the bridge performance. Review number of defects from

bridge database which often emerges as reference to evaluate importance of the bridge elements.

e) Weigh bridge elements that combine feedback from questionnaire and then evaluate through technical design approaches.

f) Improvement of bridge data collecting strategy and proposed an updated model of inspection.

4.3 Inspection sequence

Information used for this evaluation taken from data collected from bridges in West Java Province and Central Java Province as well as East Java Province from northern Java coastal road (Pantura). Subsequently evaluation results are presented in form of frequency of defects event that often emerging at level-3 (L-3). Firstly, data are normalized to data that do not directly effect to bridges structural rating which lead to sudden collapse although from bridge users' perspective it is very important.

From these data, subsequently frequency of event is arranged from the most frequent on the top rows of **Table 4-1** and so on until the least frequent on the lower part of the table.

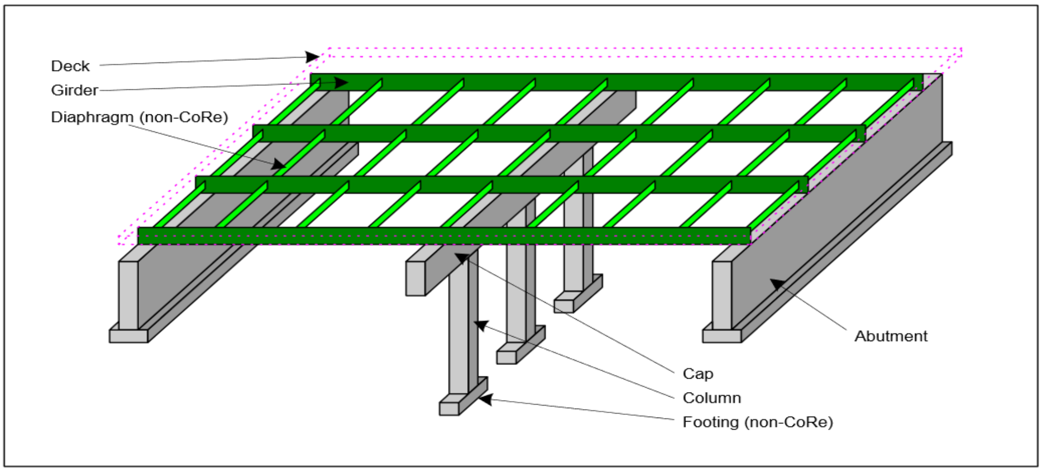
Table 4-1 A model proposed inspection sequence

Priority Checked	Major Elements or Components	External	Internal
1	Waterways, Vegetation, Debris	1	
2	Flat Slab/ Girders/ Arch/ Truss System		1
3	Deck System		2
4	Embankment	2	
5	Protection Structure	3	
6	Abutment/Pier		3

4.4 Bridge elements hierarchy

Basic principle of bridge inspection Manual BMS ’92 is hierarchy of bridge element as the bridge condition is related to the elements of bridge. Therefore evaluation of bridge elements hierarchy of BMS '92 system by reviewing each type of bridge in Indonesia with family tree approaches is key issue.

For that reason, prepare sketch (**Figure 4-1**) of main elements and bridge forming components, based on flow force flow or force transfer (transfer of load) from traffic load and environmental load to bridge foundation. Subsequent from the force flow concept determine bridge elements that affect to collapse.



(Source: Thomson and Shepard, 2000)

Figure 4-1 Co-Re elements in AASTHO Bridge Inspection Manual

Moreover, evaluate whether those elements, such as bridge railing is not harmful to bridge structure in case unforeseen failure. Although from user’s perspective, railing is very important and indispensable, but defects on railing are simple issue and can be repaired immediately. Similar to bridge railing, running surface and drainage pipes, their presence are important but not directly affect to the integrity of bridge structure.

Table 4-2 shows family tree of bridge elements hierarchy applied at bridge-object selected as inspection samples by 10 candidates of master inspector of IRE experts. The bridge is a single span I-Girder bridge. From

Table 4-3, and after carrying out field investigation, there are some bridge's elements indirectly determine bridge defects, although technically there are defects at the elements. This can be explained in **Figure 3-24** where bridge rating is determined hierarchically streamlined to the top of pyramid.

Table 4-2 Element hierarchy for I-Girder bridge

L-1 Bridge	L-2 Component	L-3 Main Element	L-4 Element	Level-5 Sub Element
I-Girder Bridge	Superstructure	Deck	Deck-xx	N/A
		I Girder	I Girder-xx	N/A
		Diaphragm	Diaphragm-xx	N/A
		Expansion Joint	ExpJoint-xx	N/A
		Bearing	Bearing-xx	N/A
	Abutment/Pier	Pile-cap	Pile-cap-xx	N/A
		Abutment/pier-Wall	Abutment/pier-Wall-	N/A
		Wing Wall	WingWall-xx	N/A
		Column Bracing	ColumnBracing-xx	N/A
		Cross Head	Cross Head-xx	N/A
		Pedestal	Pedestal-xx	N/A
	Foundation	Pile/Well	Pile/Well-xx	N/A
	Scouring Protect.	Scour Protection	Scour Protection	N/A
	Embankment	Approach Slab	ApprSlab-xx	N/A
		Embank Wall	EmbkWall-xx	N/A
		Embank Drainage	EmbkDrainage-xx	N/A
	Waterway	Stream Bank	Stream Bank-xx	N/A
		Main Channel	Main Channel –xx	N/A
		Flood Plain	Flood Plain-xx	N/A

Note: -xx define as location of defects. Level-4 is the lowest level of hierarchy element where the condition rating will directly contribute to the bridge rating.

Defects of elements that indirectly determine bridge condition is recommended to be putting into routine maintenance program such as defects on bridge surface pavement. **Table 4.3** shows bridge element hierarchy model where the bridge elements defects can lead the bridge to failure. While **Table 4-4** shows bridge element hierarchy model where the bridge elements defect is indirectly causes the failure of the bridge if the defect is not maintained routinely.

Figure 4-2 shows proposed model bridge hierarchies in which most of bridge elements are divided into level 3 element while for determining location of defect start on level-4 (L-4).

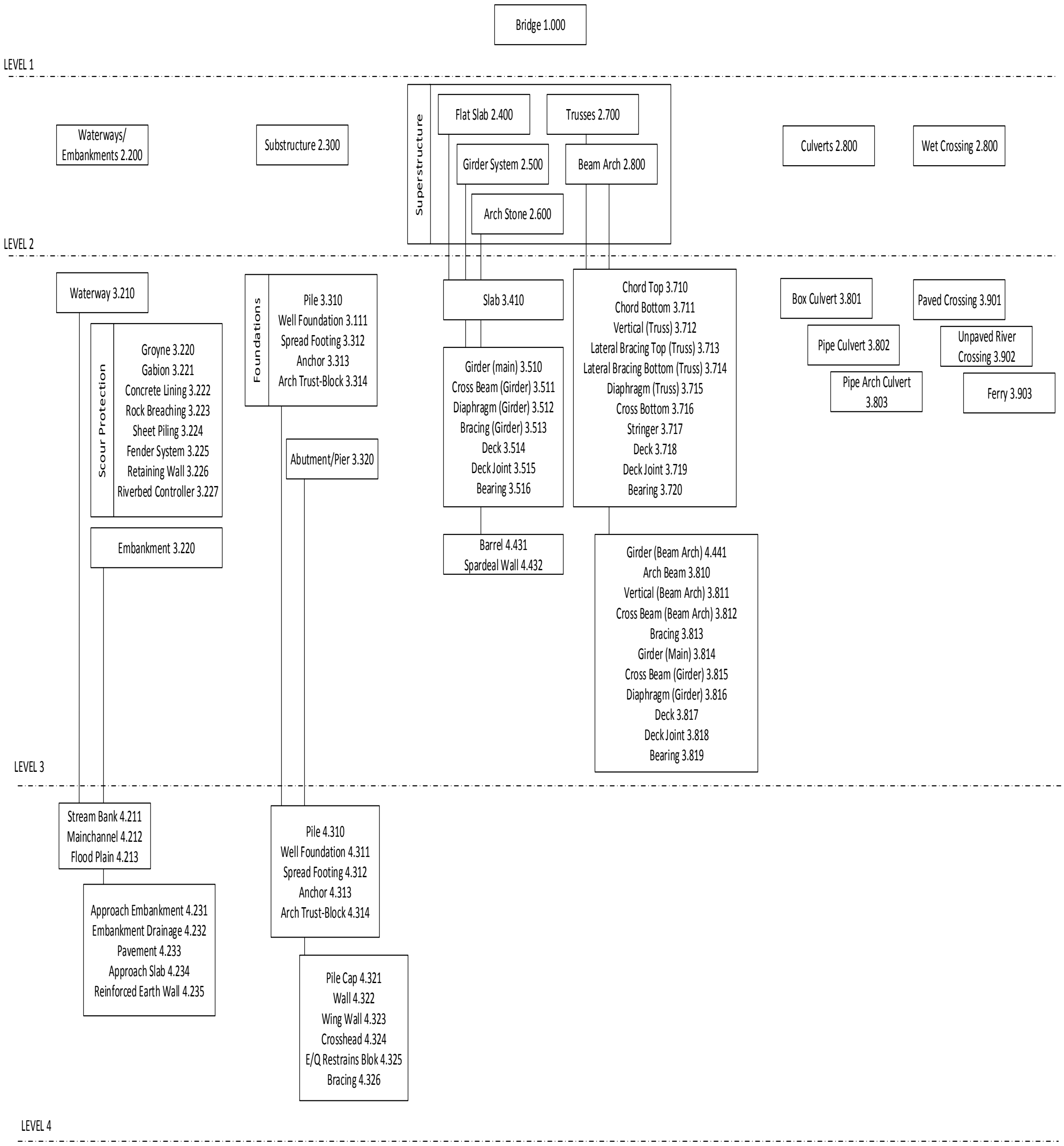


Figure 4-2 Model of family tree of bridge elements

It can be done by evaluating the bridge elements which affect to the bridge performance. Review number of defects from bridge database which often emerges as reference to evaluate importance of the bridge elements.

Table 4-3 Model of bridge element hierarchy leads to bridge condition

CODE	LEVEL 1	CODE	LEVEL 2		CODE	LEVEL 3	CODE	LEVEL 4
1.000	Bridge	2.200	Waterway		3.211	Stream Bank	4.211	Stream Bank -xx
					3.212	Main channel	4.212	Main channel -xx
					3.213	Flood Plain	4.213	Flood Plain -xx
		2.221	Scour Protection Type	Groyne	3.221	Groyne -xx		
		2.222		Gabion	3.222	Gabion -xx		
		2.223		Concrete Lining	3.223	Concrete Lining -xx		
		2.224		Rock Beaching	3.224	Rock Beaching -xx		
		2.225		Sheet Pilling	3.225	Sheet Pilling -xx		
		2.226		Fender System	3.226	Fender System -xx		
		2.227		Retaining Wall	3.227	Retaining Wall -xx		
		2.228		Riverbed Controller	3.228	Riverbed Controller -xx		
		2.230	Embankment		3.231	Approach Embankment	4.231	Approach Embankment -xx
					3.232	Embankment Drainage	4.232	Embankment Drainage -xx
					3.233	Pavement	4.233	Pavement -xx
		2.310	Foundation	Pile	3.310	Pile -xx		
		2.311		Well foundation (Caisson)	3.311	Well foundation (Caisson) -xx		
		2.312		Spread Footing	3.312	Spread Footing -xx		
		2.313		Anchor	3.313	Anchor -xx		
		2.314		Arch Thrust-Block	3.314	Arch Thrust-Block -xx		
		2.320	Abutment/Pier		3.321	Pile Cap	4.321	Pile Cap -xx
					3.322	Abutment Wall/Pier-Column Wall	4.322	Abutment Wall/Pier-Column Wall -xx
					3.323	Wing Wall	4.324	Wing Wall -xx
					3.324	Crosshead	4.325	Crosshead -xx
					3.326	Bracing (Column)	4.327	Bracing (Column) -xx
					3.327	Weep hole	4.328	Weep hole -xx
		2.400	Superstructure	Flat Slab	3.410	Slab		
		2.500		Girder	3.510	Girder (member)	4.510	Girder (main) -xx
					3.511	Cross Beam (Girder)	4.511	Cross Beam (Girder) -xx
					3.512	Diaphragm (Girder)	4.512	Diaphragm (Girder) -xx
					3.513	Bracing (Girder)	4.513	Bracing (Girder) -xx
					3.514	Deck	4.514	Deck -xx
					3.515	Deck Joint	4.515	Deck Joint -xx
					3.516	Bearings	4.516	Bearings -xx
		2.600		Arch Stone	3.610	Barrel		
					3.611	Spandrel Wall		
		2.700		Trusses	3.710	Chord Top	4.710	Chord Top -xx
					3.711	Chord Bottom	4.711	Chord Bottom -xx
					3.712	Vertical (Truss)	4.712	Vertical (Truss) -xx
					3.713	Lateral Bracing Top (Truss)	4.713	Lateral Bracing Top (Truss) -xx
					3.714	Lateral Bracing Bottom (Truss)	4.714	Lateral Bracing Bottom (Truss) -xx
					3.715	Diaphragm (Truss)	4.715	Diaphragm (Truss) -xx
					3.716	Cross Bottom	4.716	Cross Bottom -xx
					3.717	Stringer	4.717	Stringer -xx
					3.718	Deck	4.718	Deck -xx
					3.719	Deck Joint	4.719	Deck Joint -xx
					3.720	Bearings	4.72	Bearings -xx
		2.800		Beam Arch	3.810	Arch Beam	4.81	Arch Beam -xx
					3.811	Vertical (Beam Arch)	4.811	Vertical (Beam Arch) -xx
					3.812	Cross Beam (Beam Arch)	4.812	Cross Beam (Beam Arch) -xx
					3.813	Bracing	4.813	Bracing -xx
					3.814	Girder (Main)	4.814	Girder (Main) -xx
					3.815	Cross Beam (Girder)	4.815	Cross Beam (Girder) -xx
					3.816	Diaphragm (Girder)	4.816	Diaphragm (Girder) -xx
					3.817	Deck	4.817	Deck -xx
					3.818	Deck Joint	4.818	Deck Joint -xx
					3.819	Bearings	4.819	Bearings -xx
		2.910	Culvert	Culverts	3.911	Box Culvert		
					3.912	Pipe Culvert		
					3.913	Pipe Arch Culvert		
		2.920	Wet Crossing		3.921	Paved Crossing		
					3.921	Unwed River Crossing		
					3.922	Ferry		

Table 4-4 A model of bridge element hierarchy need routine maintenance works

Code	Main Element	Code	Element
3.110	Deck Pavement	4.111	Deck running surface
		4.112	Footway/Curb
		4.113	Scupper
3.120	Railing	4.121	Post
		4.122	Horizontal railing
		4.123	Railing support
		4.124	Parapet
3.130	Furniture	4.131	Gauge
		4.132	Road Sign
		4.133	Road Marking
		4.134	Name/Number Plate
		4.135	Status
		4.136	Lighting
		4.137	Lighting Post
		4.138	Power Conduit
		4.139	Utilities

4.5 Possible combination of rating indicators

Bridge inspection is carried out by Candidate Master Inspector of IRE experts (CMP) on 29 August 2014 and 5 September 2014. The bridge visited is Cilalawi-A on national road between Purwakarta-Padalarang. It is I-Girder beam bridge, details on the bridge can be seen in photograph on attachment-B.

Evaluation is carried out for the feedback of self-inspection results. There are 10 forms filled by CMP inspectors. From 10 respondents (CMP) received, accuracy level of bridges rating was reviewed and considered necessary to prepare Validation Matrix of Elements Rating by Experts, which may be used as cross-checking reference to parameters in determining bridges element rating carried out by inspector. Validation matrix of bridge element rating developed at level-3 (L-3) hierarchy of BMS ’92 shown in **Table 4-5.**

Table 4-5 provided as example for an I-Girder bridge. Combination of Experts’ opinion presented in the table, where no rating 3 shown. This matrix can be used as ideal bridge maintenance program. Routine maintenance is intended for elements that do not deteriorate further, while rehabilitation maintenance is required for corrective works of the elements so the bridges rating become better (with lower rating). Replacement maintenance consists of elements replacement, component or part of whole.

Table 4-5 Possible matrix combination of condition rating (I-Girder type)

Major element of superstructure	S	R	K	F	P	C-Mark	Possible Corrective action
Deck	0	0	0	0	0	0	-
	1	0	0	0	0	1	Routine
	1	1	0	0	0	2	Rehabilitation
	1	0	1	0	0	2	Routine
	1	1	1	0	0	3	Rehabilitation
	1	1	1	0	1	4	Replacement
	1	1	1	1	1	5	Replacement
Girder Members	0	0	0	0	0	0	-
	1	0	0	0	0	1	Routine
	1	1	0	0	0	2	Rehabilitation
	1	0	1	0	0	2	Routine
	1	1	1	0	0	3	Rehabilitation
	1	1	1	0	1	4	Strengthening
	1	1	1	1	1	5	Replacement
Diaphragm	0	0	0	0	0	0	-
	1	0	0	0	0	1	Routine
	1	1	0	0	0	2	Rehabilitation
	1	0	1	0	0	2	Routine
	1	1	1	0	0	3	Rehabilitation
	1	1	1	1	0	4	Replacement
Expansion Joint	0	0	0	0	0	0	-
	1	0	0	0	0	0	Routine
	1	0	0	0	1	2	Rehabilitation
	1	1	0	0	1	3	Rehabilitation
	1	1	1	0	1	4	Rehabilitation
	1	1	1	1	1	5	Replacement
Bearing	0	0	0	0	0	0	-
	1	1	0	0	1	3	Rehabilitation
	1	1	1	0	1	4	Rehabilitation
Pile-cap	0	0	0	0	0	0	-
	1	0	1	0	o	2	Rehabilitation
	1	1	0	0	0	2	Rehabilitation
	1	0	1	0	0	2	Routine
	1	1	1	0	0	3	Rehabilitation
Abutment/pier-Wall	0	0	0	0	0	0	-
	1	0	0	0	0	1	Routine
	1	0	1	0	0	2	Routine
	1	1	0	0	0	2	Routine
	1	1	1	0	0	3	Rehabilitation
	1	1	1	1	0	4	Rehabilitation
	1	1	1	0	0	3	Rehabilitation

Major element of superstructure	S	R	K	F	P	C-Mark	Possible Corrective action
Wing Wall	0	0	0	0	0	0	-
	1	0	1	0	0	2	Routine
	1	1	0	0	0	2	Routine
Column Bracing	0	0	0	0	0	0	-
	1	0	1	0	0	0	Routine
	1	1	0	0	0	2	Routine
	1	1	1	0	0	3	Rehabilitation
	1	1	1	0	0	3	Rehabilitation
Cross Head	0	0	0	0	0	0	-
	1	0	1	0	0	2	Routine
	1	1	0	0	0	2	Routine
	1	1	0	0	0	3	Rehabilitation
Pedestal	0	0	0	0	0	0	-
	1	1	0	0	0	2	Routine
	1	1	0	0	0	2	Routine
Pile/Well	0	0	0	0	0	0	-
	1	1	0	0	0	2	Routine
	1	0	1	0	0	2	Routine
	1	1	1	0	0	2	Routine
	1	1	1	0	0	3	Rehabilitation
	1	1	0	1	0	3	Rehabilitation
	1	1	1	0	0	3	Rehabilitation
Scour Protection	0	0	0	0	0	0	-
	1	0	1	0	0	2	Routine
	1	1	0	0	0	2	Routine
	1	1	1	0	0	3	Rehabilitation
Approach Slab	0	0	0	0	0	0	-
	1	1	0	0	0	2	Routine
	1	0	1	0	0	2	Routine
Embankment Wall	0	0	0	0	0	0	-
	1	0	1	0	0	2	Routine
	1	1	1	0	0	3	Rehabilitation
	1	1	1	1	0	4	Rehabilitation
Embankment Drainage	0	0	0	0	0	0	-
	1	0	0	0	0	1	Routine
	1	1	0	0	0	1	Routine

4.6 The importance level of bridge elements

Risk level of bridge elements to failure is discussed. For this purpose, it is necessary to evaluate each type of bridge comprehensively. Evaluation can be carried out by using technical design approach as well as through polling with consultant experts and resource persons from academia or practitioner. For the polling purpose, it is designed questionnaire. From these two approaches it is expected to propose risk weight of bridge element/major-element to failure or collapse of the bridge catastrophically. Risk weight in **Table 4-6** is proposed by evaluating from perspective of bridge technical design according to regulation of Minister of Public Work, Indonesia No. 19/2010 on Technical Planning and Planning Criteria and later will be tuned from polling results.

To define level of importance bridge elements,weight system is used by introducing MCUA (*Multiple Criteria Utility Assessment*) method (Communities and Local Government Publications, 2009). In this method, several criteria are defined based on Indonesian Bridge Design Code which represents level of importance of bridge elements. Weigthing of these criteria are defined by discussion, argumentation and justification.

Referring to above regulation, there are 5 important criteria in bridge planning which may correlate for the importance of each bridge element to the bridge itself. The criteria consist among others; strength, comforts, durability, replace-ability, and mode of collapse.

Strength means that the element shall be designed so they able to hold load both dead load and running load. An element shall meet these criteria if they have important function to bridge or if the failure of this element makes the bridge cannot be used.

Service capacity (serviceability) means the element shall be designed so they meet structural function required, related to shape, stability and resilience, deal with loading, deflection, vibration, permanent deformation, crack and corrosion, as well as other design requirements.

Durability means the element able or resist to traffic and climate condition in certain period. Similar with strength criteria, durability shall be met by important elements of bridge where failure to meet the requirement make the bridge cannot be used.

Subsequently, it is difficulty level in repair if the element damaged. This criterion is important since if the repair of damaged element difficult, it will affect to cost, time, and alternative access for road users.

The last criteria deal with harmful impact or fatality caused by bridge structure if the element damaged. Without the fatality criteria, the bridge cannot be used. Bridge element assessment of each criterion is presented in **Table 4-6**, where bridge that meets the criteria scored with value "1" and value "0" for otherwise.

Table 4-6 I-Girder Bridge – Single Span

Element Level-3 or Level-4	Ultimate/ Strength	Serviceability/ Displacement	Durability/ Deterioration	Remedial Action	Mode of Collapse	Sco-re	M_{par} %
Deck	1	1	1	0	0	3	12
Girder Members	1	1	1	1	0	4	16
Diaphragm	0	0	1	0	0	1	4
Expansion Joint	1	0	1	0	0	2	8
Bearing	1	0	1	0	0	2	8
Pile-cap	0	0	1	1	0	2	8
Abut-Wall/Pier-	0	0	1	0	1	2	8
Wing Wall	0	0	1	0	0	1	4
Pedestal	0	0	0	0	0	0	0
Column Bracing	1	0	0	0	0	1	4
Cross Head	1	0	0	0	0	1	4
Foundation	1	0	1	1	1	4	16
Embankments	1	0	0	0	0	1	4
Scour Protection	0	0	1	0	0	1	4
Waterway	0	0	0	0	0	0	0
Total						25	100

4.7 Bridge condition rating

Based on its element hierarchy, bridge rating (B-Mark) is the representative of defects recorded in level 3, which proposed by combining rating of each evaluation and multiplying with importance weight (M-Participation) of the level 3 elements as shown in Formula 4.1. While the proposed maintenance plan is derived from maintenance recommendation as explained in **Table 4-6** above.

$$B_{Mark} = \sum_{1}^{n} T_{Mark} x M_{Par} \qquad (4.1)$$

Where:

B_{mark} is Bridge condition rating Level-1

T_{mark} is Total rating

B_{part} is Level-3 rating

Table 4-7 shows an example of spreadsheet calculation in determining the bridge condition rating based on the condition collected from field on level-3 by using Formula 4.1.

Table 4-7 Bridge condition mark

Element Level-3	S	R	K	F	P	T_{Mark}	M_{par}	B_{Mark}
Deck	1	1	0	0	0	2	12	0.24
Girder Members	1	1	0	0	0	2	16	0.32
Diaphragm	2	2	2	0	0	2	4	0.08
Expansion Joint	1	1	0	0	1	3	8	0.24
Bearing	1	0	1	0	0	2	8	0.16
Pile-cap	1	1	0	0	0	2	8	0.16
Abut-Wall/Pier-Col	1	1	0	0	0	2	8	0.16
Wing Wall	1	0	1	0	0	2	4	0.08
Pedestal	0	0	0	0	0	0	0	0.00
Column Bracing	1	0	1	0	0	2	4	0.08
Cross Head	1	0	1	0	0	2	4	0.08
Foundation	1	0	1	0	0	2	16	0.32
Embankments	1	1	1	0	1	4	4	0.16
Scour Protection	1	1	1	0	1	4	4	0.16
Waterway	0	0	0	0	0	0	0	0.00
Brd. Condition (Level-1)								2.24

4.8 A model of bridge condition inspection manual

A proposed Model of Bridge Condition Inspection Manual as an updated Bridge Inspection Manual BMS ’92 is provided in attachment-C. This model is intended to be used to replace the original existing manual of BMS ’92.

4.9 Model test and discussion

Re-inspection of existing Cilalawi-A bridge by 10 CMP inspectors using proposed new model of Bridge Condition Inspection Manual is accomplished. The result from this re-inspection was written in the inspection reports attached. The summarized results of the inspection are presented in the same format as previous discussions, so make the comparison is more simple and easy to check whether there any significant improvement from previous system.

Bridge inspection experiment will be analyzed and evaluated with focuses on practicality in finding defects and uniformity to determine the rating condition. **Figure 4-3** shows the perception of CMP inspectors to find out the defects element of bridge inspected. Most inspectors agree that defects occur or do not happen on the bridge elements as the each elements show single bar. Others do not agree, the reason is difficult to find out and reaching the objects.

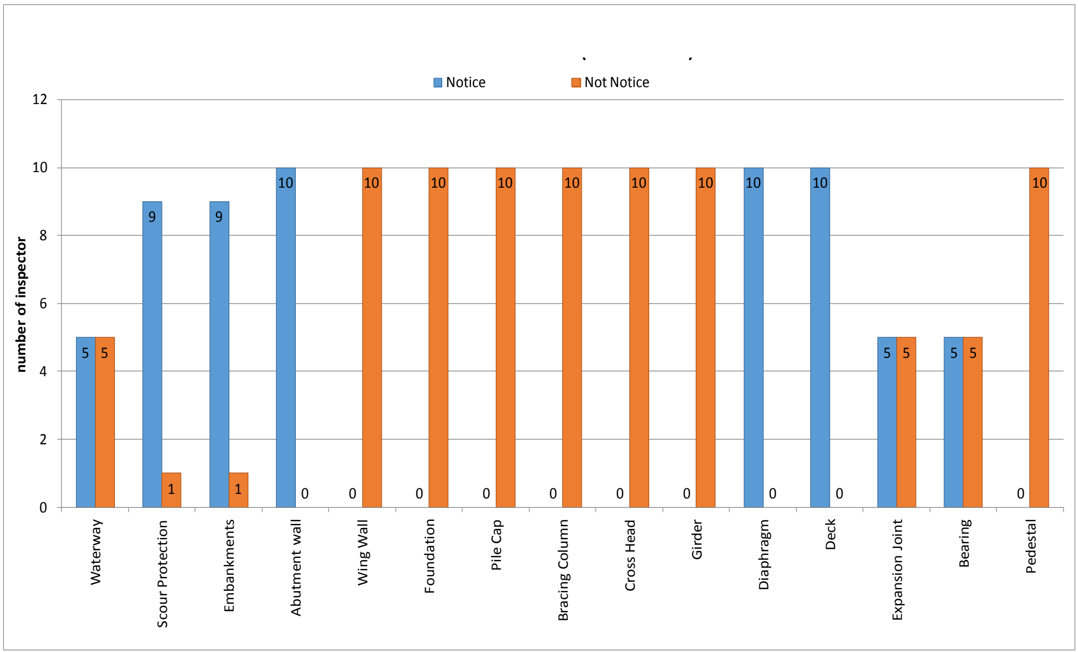
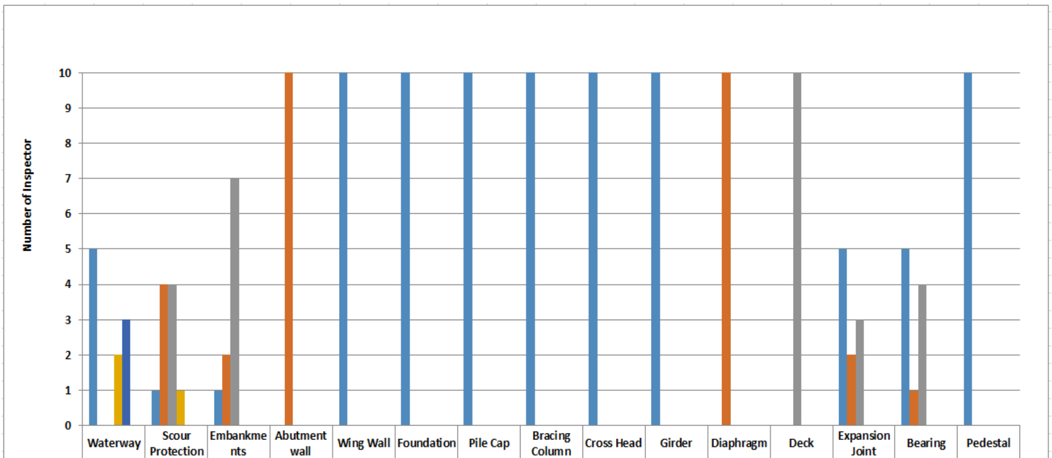


Figure 4-3 Focus CMP inspector to the defects element (New model)

Figure 4-4 shows bridge condition results where most of CMP inspectors agree that there were defects on several level-3 elements.



	Waterway	Scour Protection	Embankments	Abutment wall	Wing Wall	Foundation	Pile Cap	Bracing Column	Cross Head	Girder	Diaphragm	Deck	Expansion Joint	Bearing	Pedestal
Rating = 0	5	1	1	0	10	10	10	10	10	10	0	0	5	5	10
Rating = 1	0	4	2	10	0	0	0	0	0	0	10	0	2	1	0
Rating = 2	0	4	7	0	0	0	0	0	0	0	0	10	3	4	0
Rating = 3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Rating = 4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rating = 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 4-4 Perception of CMP inspectors on bridge rating level-3 (New model)

As shown in **Figure 4-3** and compared to **Figure 4-5** an aggregate in classifying bridge element rating as results of 10 CMP inspectors for Cilalawi-A bridge with new proposed model produces an uniform magnitude where mostly lead to only 1 variation. Only few elements of level-3 still have big inconsistency as they are slight difficult to investigate without provided inspection tools.

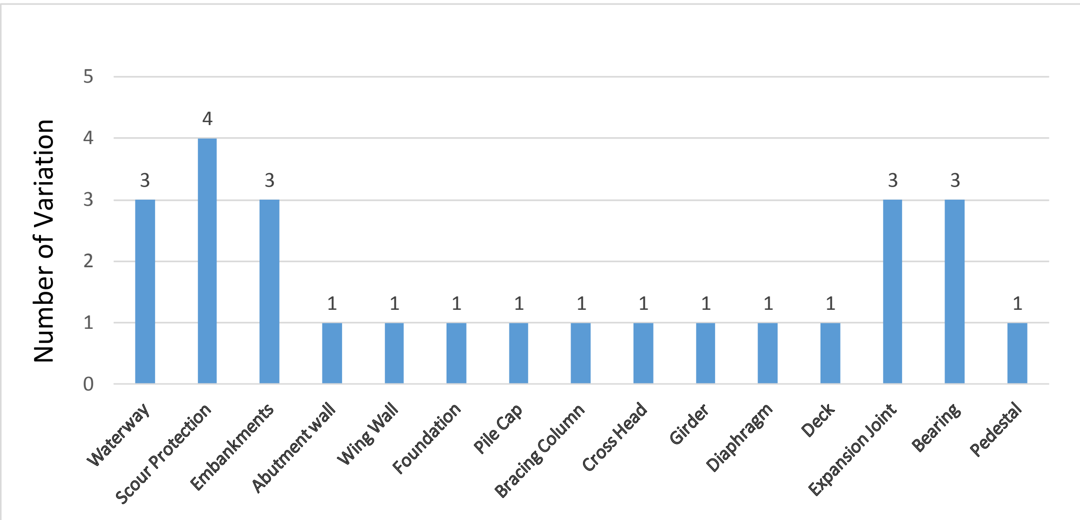


Figure 4-5 Variation of CMP opinion on bridge condition level-3 (New model)

The condition rating observed on level-3 elements by inspectors also show quite uniform. The difference ratio between the assessment on rating parameters of S, R, K, F and P is shown on **Figure 4-6**. The largest difference moves to parameter K, which actually is not provided in the Manual. While parameter F shows a good result, even though a Manual is not provided.

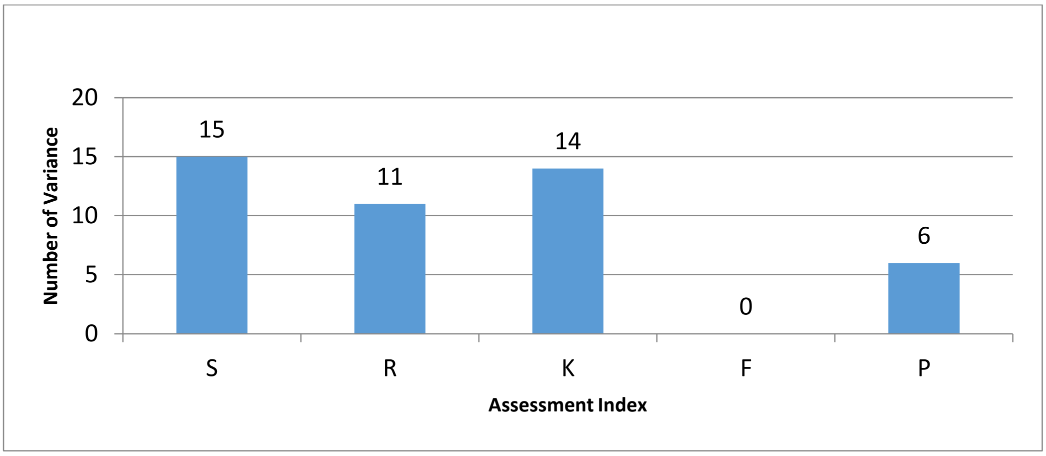
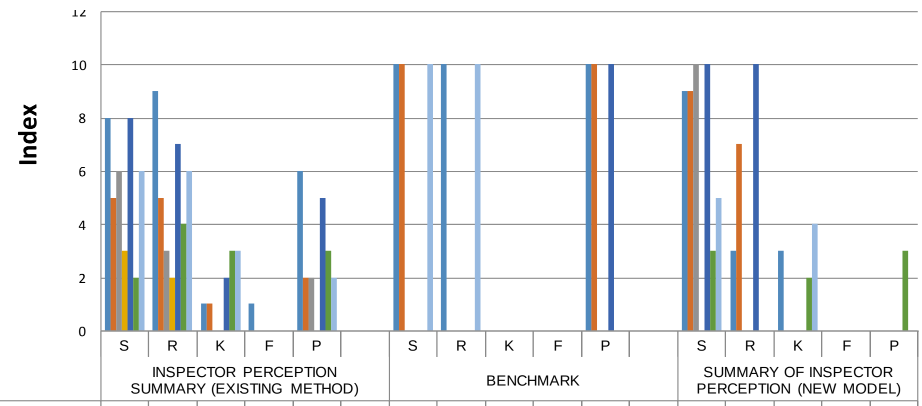


Figure 4-6 Disparity of CMP inspectors in characterized rating parameter (New model)

Figure 4-7 and **Figure 4-8** show profile of assessment index for Cilalawi-A bridge. The basis used for the index calculation is benchmark rating. This benchmark rate is defined by normalizing and compromising the results from first inspection on Cilalawi-A bridge by using existing Bridge Inspection Manual.

As we can see from **Figure 4-8** the index of inspector perception for Cilalawi-A bridge is significantly improved by using new model of inspection and only one out of seven elements of bridge shows disagreement, i.e., Scour Protection.



	Existing S	Existing R	Existing K	Existing F	Existing P	Benchmark S	Benchmark R	Benchmark K	Benchmark F	Benchmark P	New model S	New model R	New model K	New model F	New model P
Scour Protection	8	9	1	1	6	10	10	0	0	10	9	3	3	0	0
Embankment	5	5	1	0	2	10	0	0	0	10	9	7	0	0	0
Abutment/pier	6	3	0	0	2	0	0	0	0	0	10	0	0	0	0
Girder system	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Deck System	8	7	2	0	5	0	0	0	0	10	10	10	0	0	0
Deck joint	2	4	3	0	3	0	0	0	0	0	3	0	2	0	3
Bearing	6	6	3	0	2	10	10	0	0	0	5	0	4	0	0

Figure 4-7 Profiles of assessment index for Cilalawi-A bridge

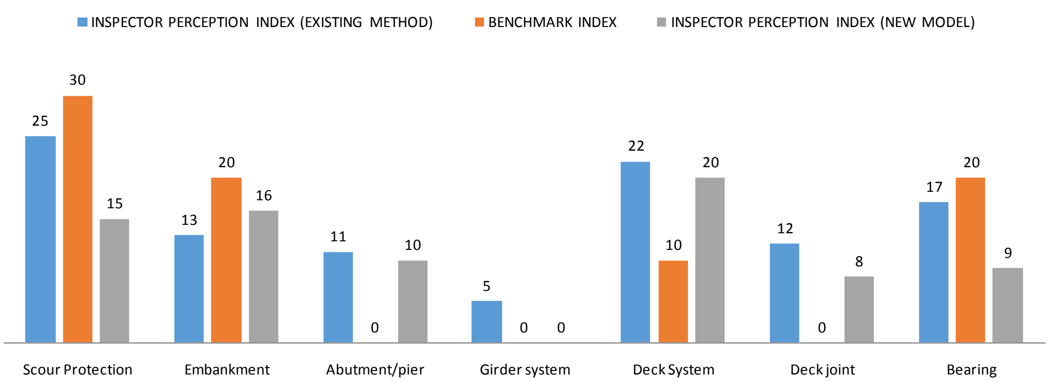


Figure 4-8 Index of inspector perception for Cilalawi-A bridge

The index of inspector perception shows that 5/7 (71 percent) of inspectors agree that bridge condition marking using new model are closer to the benchmark, while by using existing method, it is only 2/7 (29 percent) of inspectors. This also confirm that the new model resulting more focused and uniform result between inspectors as shown of **Figure 4-9**.

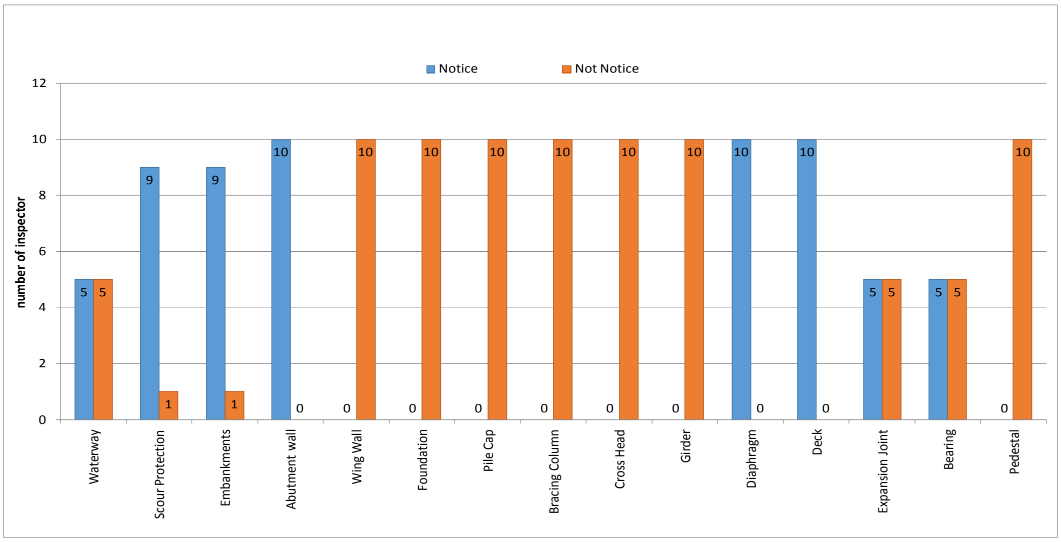


Figure 4-9 Inspector observation on level-3 bridge element defect for Cilalawi-A

For new model, the bridge condition rating level-1 can be calculated according formula 4.1 and the result shown on **Table 4-9** while bridge rating according existing procedure as shown in **Table 4-8**.

Table 4-8 Bridge condition rating for Cilalawi-A Bridge (existing system)

Code	Elements (L-3)	Rating
3.210	Waterway	3
3.220	Scour Protection	3
3.230	Embankment	0
3.320	Abutment / Pier	0
3.410	Girder Members	0
3.500	Deck System	2
3.600	Deck Joint	1
3.610	Bearing	2
3.620	Railing	2
3.700	Furniture	0
	Components (L-2)	
2.200	Waterway & Embankment	3
2.300	Substructure	0
2.400	Superstructure	2
	Bridge (L-1)	
1.000	Bridge	2

Table 4-9 Bridge condition rating for Cilalawi-A Bridge (New Model)

No	Elements L-3	T_{Mark}	M_{par} (%)	B_{Mark}
1	Waterway	3	0	0.00
2	Scour Protection	2	4	0.08
3	Embankments	2	4	008
4	Abutment Wall	1	8	0.08
5	Wing Wall	0	8	0.00
6	Foundation	0	16	0.00
7	Pile Cap	0	8	0.00
8	Bracing Column	0	4	0.00
9	Cross Head	0	4	0.00
10	Girder Members	0	16	0.00
11	Diaphragm	1	4	0.04
12	Deck	2	12	0.24
13	Expansion Joint	0	8	0.00
14	Bearing	2	8	0.16
15	Pedestal	0	0	0.00
	Bridge Rating Level-1			**0.68**

Level-1 bridge condition rating based on the existing system shows “2” with explanation that bridge with defects require monitoring, while the “round-up” bridge condition rating of the same bridge with new model shows “1”, bridge with minor defects no repair required but routine maintenance.

Field facts of the bridge concern based on inspection report and photograph shown in attachment-B, some defects exist on the bridge deck, however according to the new model inspection system, this element is classified as non-structural element where it can be secured by routine maintenance, as the defects does not directly lead to bridge collapse. Based on the updated inspection system by using Formula 4.1, the bridge condition rating level-1 is 0.68. **Table 4-10**, shows the rating classification associate to defects and repairs relationship between existing BMS’92 and proposed model.

Table 4-10 Proposed description of bridge rating

New Model		Existing BMS'92	
Rating	Description	Rating	Description
4 – 5	Bridge/Components/elements broken or no longer Function (Replacement apart/New Bridge)	5	Component broken or no longer functioning
3 – 4	Critical condition (Rehabilitation)	4	Critical condition
2 – 3	Defects require attention soon (Repair)	3	Defects which require attention soon
1 – 2	Defects require monitoring (Preventive repair)	2	Defects require monitoring or maintenance in the future
0 – 1	Minor defects, no immediate repair needed (routine only)	1	Very minor defects
0	No defects exist (routine only)	0	As new with no defects

4.11 Updated bridge condition procedure

Strategic updated bridge condition data is discussed. Data collection mechanism follows procedure as stated in BMS ’92 Bridge Inspection Manual. However, collecting of bridge condition data after major repair/rehabilitation or bridge geometric alteration is suggested to be updated by Provision Handover/Final Handover (PHO/FHO) team, due to these teams as the projects acceptance team set forth under project delivery mechanism.

Certainly, when routine maintenance of bridge is carry out and state as completed then subsequent routine inspection is also made (Henriksen, A., 1999). Along with routine inspection, the requirement of routine/rehabilitation for the next events will be recorded and reported to the system management. Furthermore, routine maintenance crews can also recommend critical defects found that need to be followed up by detailed inspection team, see **Figure 4-10**.

The procedure to up-dated data as an effort to obtain currently bridge database and ease of collection is proposed by the conveying to the FHO team and the expertise, minimum required by maintenance personnel bridges including the recording of the current findings in routine inspections, would make it easier to find the damage and at the same time, and ensure the bridge database is always up-to-date.

In order to looking for bridge condition accurately, recommended defects that exist and found during the routine maintenance become precedence for next detailed inspection agenda and Elements and Material Defects Catalogue become important issues to support the routine inspectors knowledge.

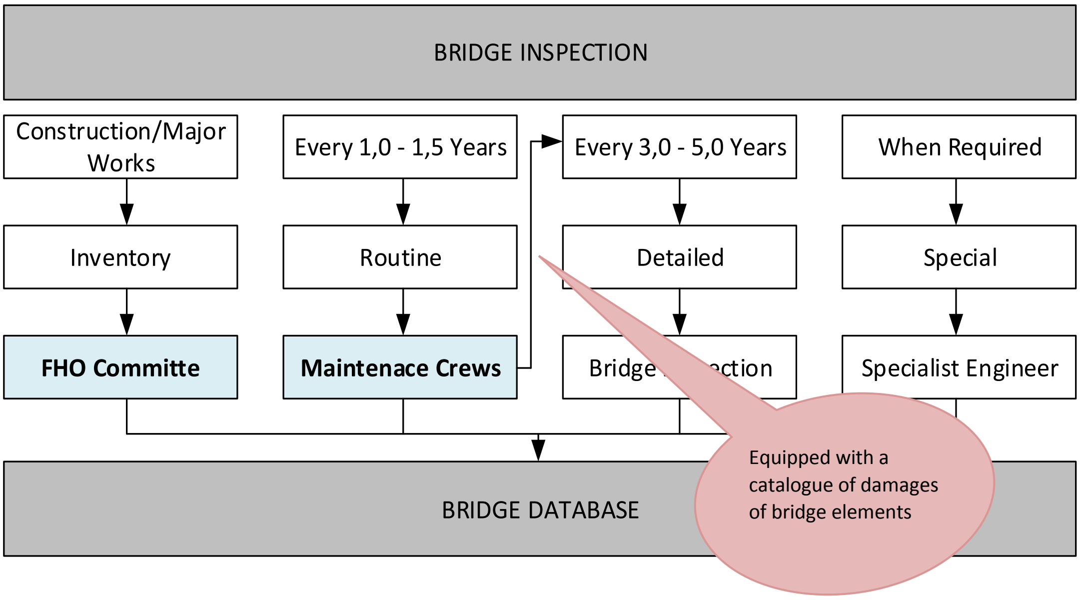


Figure 4-10 Proposed update procedure of bridge condition

4.12 Further development

The process of developing the bridge condition assessment system in Indonesia needs to be carried out. This associated with the requirement to achieve more accurate, and objective results. Some of the results that have been done through the development of these activities include:

a) Improvement in bridge condition assessment to eliminate the subjectivity issues.

b) Optimization works in the field, in order to reduce the assessment duration.

c) List of the important elements that must be checked to make it easier for inspectors to assess defects of the bridge.

d) Ease to perform the assessment based on the type of the elements that only contribute to the overall bridge condition.

e) Minimize errors in discovering the damage or defected element by utilizing the role of maintenance crews to record defects soon after maintenance completed.

Moreover, the assessment rating of the bridge condition by using a new model of visual inspection Manual shows the result is appropriate manner and the influence of inspector opinion can be controlled.

Further improvement on bridge condition inspection manual is needed to be developed, to suit current Indonesia and to support decentralization government era with main issue is limited human resources in collecting data, fast, accurate, and to reduce human errors. One of the key points which can be used as a strategic approach to achieve accurate results is by proposing an instrumented inspection. By using instrumented inspection, the bridge condition result is more reliable, reduced time consuming, and human resources.

CHAPTER 5
FURTHER IMPROVEMENT ON BRIDGE CONDITION INSPECTION

5.1 General

Damage to the bridge keeps increase as the escalation of the economy of the countries. The land transportation is normally used for economy development. This economic transportation used normally heavy trucks that will initiates the defect of the bridge exist. This growth leads to cause early damage of bridges, so their service life shorter than planned. This condition is more obvious in case the composition of heavy vehicles passing the bridge exceeds the number of planned vehicles specified in the bridge code on fatigue design provision (Directorate General of Highway, Bridge Design Code, 1992).

Furthermore, from the condition above, the damage of bridges are also affected by environmental condition where the bridges concerned exist. Therefore, safety of bridge becomes the main concern for bridge managers and bridge authorities as well as researchers. The assessment of the bridge rating by using new visual bridge inspection manual shows the results are relatively sufficient and the influence of inspector opinion reduced compared to existing procedure, however further enhancement other than the accuracy of data results, such as ease, speed up of data collection and retrieval as well as considering the limitations of the technical human resources which is exist in the districts and provinces level in particularly in the decentralization era in government of Indonesia is very important.

In parallel, the development of instrumentation for non-destructive test nowadays is more advance in field to support the bridge inspection. Some methods to evaluate the bridge structure can be used to determining the condition and damage rate in more accurate way. Selection of the methods depends on complexity level of parameters will be evaluated. Therefore, one of the strategic solutions to this condition is by introducing non-destructive testing.

In addition to the population of bridge type in Indonesia, I-Girder with simple supported beam construction will be used as experimental objects for this research. The selected bridges will be examined through visual inspection by using updated BMS '92 Bridge Inspection Manual. Furthermore, there will be performed instrumented testing, i.e., static and dynamic testing and following up with structural analysis by numerical approach, including capacity analysis of the bridge structure as well as modal analysis to determine dynamic properties of the bridge, (Plachý, T., & Polák, M.,2004)

In this research, the advantage of natural frequencies as dynamic response to Bending Mode of bridge structure are examined and evaluated to use for screening bridge database for certain defect/damage classification rather than to assess damage rate and damage location. For this propose, the correlation is made through the degree of maintenance required with associated with defects/damage elements discovered. As the bridge condition rating relates to certain “ideal” bridge maintenance and along to those bridges have their own natural frequency collected, therefore the range of degradation of natural frequencies related to the similar maintenance required can be defined.

Accordingly, by using instrumented test to screening bridge database for certain visual rating classification, i.e.: “no defects” or “minor defects” where the bridges visually by definition in the chapter-4 in good condition rating “0” and “1” can be skip for next visual inspection agenda. This procedure will create of inspection results more reliable, reduced time consuming, and human resources and save bridge inspection budget allocation.

5.2 Natural frequency

The natural circular frequency of vibration ω (rad/sec) and the natural cyclic frequency of vibration *f* (cycles/sec or Hz) are related to the natural period of vibration T (sec) of the structure as follow:

$$T=2\pi/\omega \quad (5.1)$$

$$f=1/T=\omega/2\pi \quad (5.2)$$

The natural period of vibration T (sec) of the structure is the time required for one cycle of free vibration. The term 'natural' is used to qualify each of the above quantities to emphasize the fact that these are natural properties of the structure when it is allowed to vibrate freely without any external excitation. Because the structure is linear, these properties are independent of the initial displacement and velocity. If mathematically solved the equation of motion governing free vibration of an un-damped structure have shown that: $\omega = \sqrt{(k/m)}$. Thus the free vibration properties ω, T, and f depend only on the mass and stiffness of the structure, (Chopra,K., 2012).

The natural frequency is one of dynamic characteristic of bridge to excited loads. It is related to stiffness of the structure that influenced by changes in mechanical and physical condition of the bridge structure. The stiffness of the bridge will decline along with the operating life of bridge or deteriorated. The natural frequency can be determined by several methods as describe in the subsequent sub-chapter.

5.2.1 Natural frequency from general formula

General formula is applied for simple supported bridge. This formula is according to mathematically solved of free vibration of an un-damped structure that shown as: $\omega = \sqrt{(k/m)}$, hence $f = 1/2\pi\sqrt{(k/m)}$. It is depend on the mass and stiffness of the structure. The natural frequency for simple supported beam is shown in **Figure 5-1**. The value depends on the type of beam or bridge support (Paz, M., 2012 and Islam A.A.,et al, 2014).

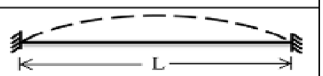
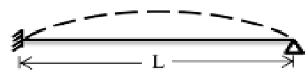
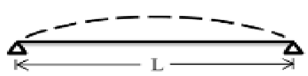
Support Condition	Fundamental frequency, Hz	Mode shape
Fixed-Fixed	$f = 3.5608\sqrt{\frac{EI}{mL^4}}$	
Fixed-Hinged	$f = 2.4529\sqrt{\frac{EI}{mL^4}}$	
Simply Supported	$f = 1.5708\sqrt{\frac{EI}{mL^4}}$	

Figure 5-1 Fundamental frequency

5.2.2 Natural frequency from empirical formula

Empirical natural frequency formula is discussed in this sub-chapter. For reference, empirical formula is normally used to determining natural frequency of typical bridge structures. According to the empirical formula adopted from Report No. 211, "Dynamic Load Tests on Highway Bridges in Switzerland", EMPA, Dubendorf (Catieni, R 1983, and Burdett, O & Corthay S, 1995) for simple span simply-supported bridges which is determined based on statistical regression, the natural frequency is around 100/L, where L is span length.

In addition, based on Institute of Road Engineering (IRE) field test research's reports for the case of Indonesian bridges, the natural frequency is around 125/L with condition applied as in the Report No. 211 above. The graph and the formula based on the IRE's experiment as shown in **Figure 5-2.**

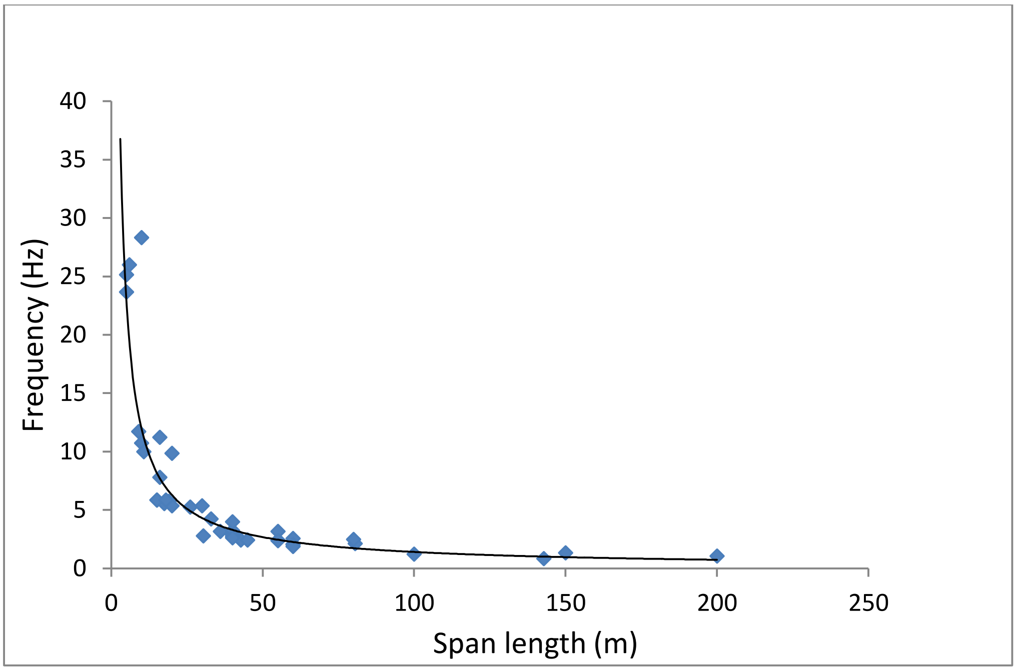


Figure 5-2 Graph of empirical formula of natural frequency based on bridge span

5.3 Natural frequency based on numerical computation

Modal analysis is a numerical approach for determining the natural frequency of bridge structure. In this procedure, the bridge structure is modeled as detail as possible by using structural analysis package software. The numerical model is made in accordance to the desired performance, e.g.: the ideal condition is based on as-built drawing document and design specification parameter or from the actual condition which is based on results of bridge investigation. The output of this analysis is the natural frequencies for each mode shape.

In this research, two modeling will be used, i.e.: firstly, full bridge structure is modeled in computer program where each element and bridge boundary layer behavior is considered detail in the model. The second, the artificial member stiffness is used in modal analysis, where the artificial member stiffness is defined by using correlation to displacement of bridge which is measured under static load test. This second approach was considered all the boundary layer and behavior of elements that constitute the bridge structure. The natural frequency results are independently to precision in modeling, therefore the results is more accurate as long as the measured displacement was accurate.

5.4. Natural frequency from dynamic load test

The dynamic load test is proposed to identify parameters such as natural frequencies, damping ratio, dynamic amplification and dynamic load amplification factor (Islam,A.A.,et al, 2014). This experiment proposed to use Ambient Vibration Test, where normal traffic moves on the bridge deck excited the bridge to vibrate, and then the responses recorded in time series with significant accurate results for various speed of moving truck between 10-50 km/h (Institute of Road Engineering, 2014).

A simple arrangement of dynamic load test is considered as a procedure for determining the resonance (natural) frequencies of a structure. To identify vibration mode shape for each natural frequency corresponds to the deflected shape when the structure is vibrating at that frequency. Each vibration mode is associated with a damping value, which is a measure of energy dissipation. From the measured dynamic response, induced by ambient or forced excitation, modal parameters (natural frequencies, mode shapes and modal damping values) and system parameters (stiffness, mass and damping matrices) can be obtained. These identified parameters can be used to characterize and monitor the performance of the bridge structure.

Moreover, the existing bridge natural frequency can be determined directly from field test by measuring dynamic response of a bridge under loading by using acceleration transducers. Based on the data collected, vibration parameters are evaluated from time domain (m/s^2) to frequency domain in hertz (Hz) through Fast Fourier Transformation. The result of peak frequency represents the characteristic of dynamic properties of bridge (Siringoringo.D.M., et.al, 2013) as shown in **Figure 5-3**.

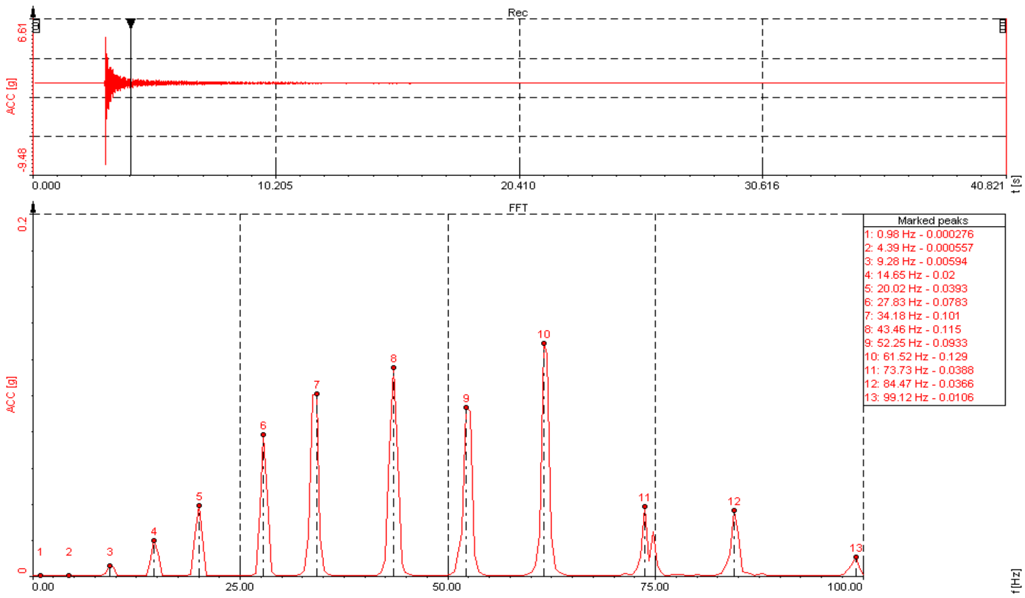


Figure 5-3 Fourier transformation

The procedure of ambient vibration testing is straightforward a seen in **Figure 5-4**. First a computational model of the structure under surveillance is carried out and its natural frequencies and corresponding mode shapes are determined. Location of measurement points are selected in accordance with geometric layout of the structure, i.e.: at the center points of a span. Accelerometers are used for the simultaneous measurement of vertical vibration of the structure.

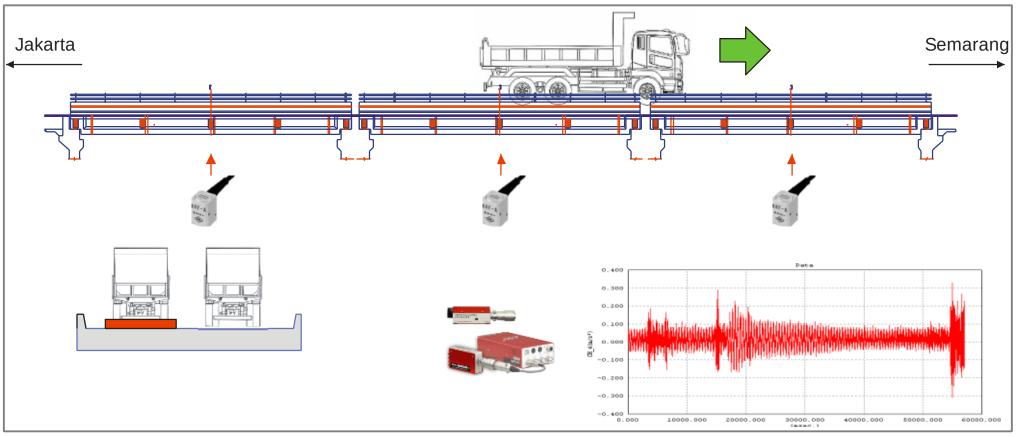
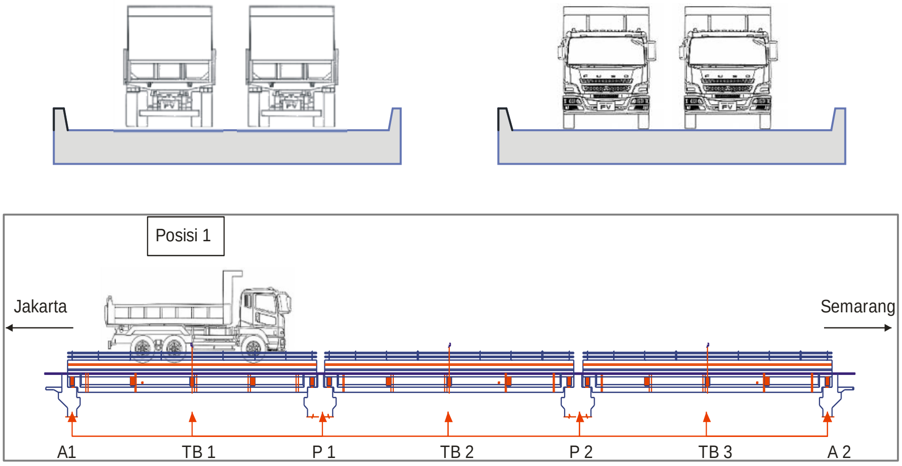


Figure 5-4 Moving vehicles on the bridge deck (Ciberes Bridge)

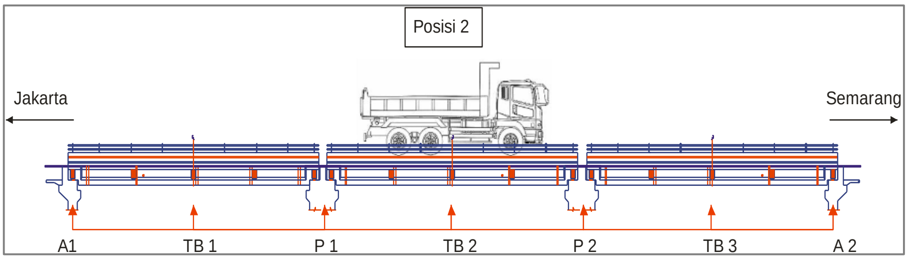
5.5 Natural frequency from static deflection measurement

A loading test involves the process of loading and observation of the related reactions of an existing structure or a part of it, for the purpose of assessment of its load bearing safety and serviceability. The load test is essentially designed to investigate structural response under short-term loading. The load test involves the application of physical test loads to a structure or parts of it, measurement of the response of the structure under the influence of the loads and interpretation of the results to make recommendations for future courses of action.

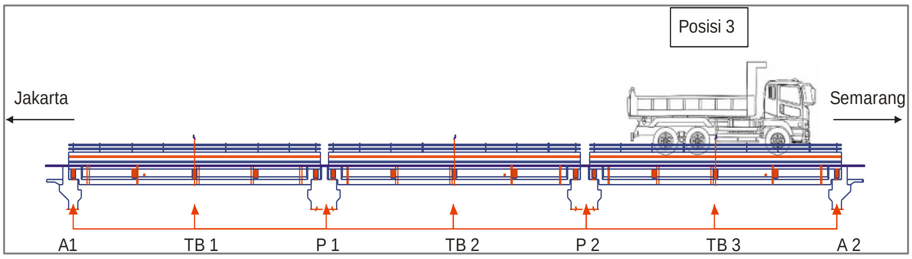
Load may be applied using dead weight or by mechanical means and consideration need to be given to any effect the loading method may have on the observed behavior. Materials, which can be used, included building materials, water, cast-iron weight and loaded vehicles combination as seen in **Figure 5-5**.



2nd Combination



3rd Combination



4th Combination

Figure 5-5 Scheme of load combination (Ciberes Bridge)

In this case, loading test is conducted to measure the deflection of structure. Relationship between load and deflection represent the stiffness of the structure as equation below:

$$k = \frac{P}{\delta} \tag{5.3}$$

$$k = \frac{48\,EI}{L^3} \tag{5.4}$$

Where:

k is Stiffness, (kN/m)

E is Elastic modulus, (kN/m^2)

P is Static load, (kN)

I is Inertia, (m^4)

δ is Deflection, (m)

L is Length, (m)

When bridge stiffness is known, then natural frequency can be calculated by using formula as seen on **Figure 5-1** or can be determined through modal analysis by applying artificial member with the stiffness properties given from static relationship above.

5.6 Field experiments and results

5.6.1 General

Matani Bridge is simple span simply supported concrete I-Girder bridge. It is selected to demonstrate field test procedure of this research. **Figure 5-6** (a) shows photographs of front view and long view with underneath channel without water flows, as shown in **Figure 5-6** (b). Matani Bridge consists of single span with length of 16.6 m. The width of bridge carriage way is 6.8 m. Superstructure is made of reinforced concrete for I-Girder and deck. While substructure consists of reinforced concrete abutment on each sides.

(a)

(b)

Figure 5-6 Matani Bridge: (a) front view; (b) long view

The bridge construction start on 2011 and open for traffic on late September 2014, therefore it can be assumed and classified as newly built bridge. The experiment field test carried out on 19–24 November 2014. Bird view and detailed information on this Matani Bridge is shown in **Figure 5-7** and **Table 5-1**.

Figure 5-7 Matani Bridge bird view

Table 5-1 Detail of Matani Bridge

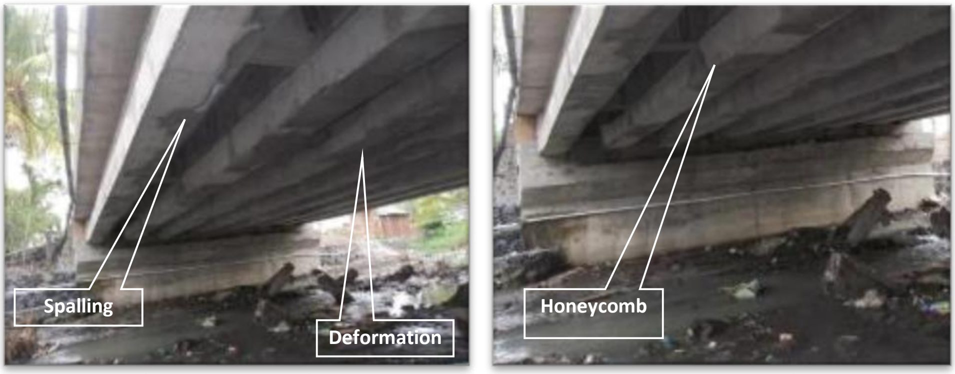
Bridge Name	:	Matani
ID	:	50.036 027 0
Construction	:	2011, open traffic on late September 2014
Corridor	:	Trans-Sulawesi Highway, Tumpaan–Batas Kota Manado Section KM 47+600
GPS Coordinate		
Start	:	01° 15’15,93’’ LS 124° 36’ 43,67’’ BT
End	:	01° 15’ 15,42’’ LS 124° 36’ 44,02’’ BT
Type	:	Girder I-Type
Deck System	:	Reinforced Concrete
Length	:	16,65 m
Width	:	9,0 m (1,0 m + 7,0 m + 1,0 m)
Number of Span(s)	:	1
Abutment	:	Reinforced Concrete
Support	:	Elastomeric Bearing
Inspector & Crew	:	IRE Team, Led by G. Sukmara & Herry Vaza
Test Type	:	Dynamic and Static Load Test
Date Test	:	19-27 November 2014

For the field test, the first step is to retrieve data by performing visual inspection according to Bridge Inspection Manual (by using an updated version of BMS, 1992). Second step is to conduct homogeny concrete test by using non-destructive method as well as measuring dimensions of each element of the bridge. Third step is to conduct bridge vibration test by measuring bridge response to the traffic load. Forth step is to conduct static test by measuring bridge deflection under static load test trucks.

5.6.2 Visual inspection

There are some defects on elements of Matani Bridge as results of improper construction stage. Furthermore, the defects may be also caused by traffic load as bridge is entered into operation and as they interacts one another to its surrounding environment. This can be seen from results of visual bridge condition inspection as shown in **Figure 5-8**.

Figure 5-8 (a) shows concrete I-Girder and diaphragm which has some spalling concrete, honeycomb and deformation. The concrete defects on I-Girder and diaphragm cause reduction of stiffness and strength of bridge, which then lead to reduction of structure capacity and reduce of the deck capacity to carry vehicle loads. While bridge abutment is in good condition even it was found some spalling and deformation as shown in **Figure 5-8** (b). From visual bridge inspection manual (updated model), where the defect condition is classified as rating 1 (range: 0-5), meaning that the bridge needs only routine maintenance.



(a) (b)

Figure 5-8 Matani Bridge element condition:

(a) Damage on I-Girder and diaphragm; (b) Abutments cracks

5.6.3 Bridge dimension and properties

a) Concrete crack and homogeny

Ultrasonic Pulse Velocity device is used to measure crack and homogeny of concrete. Two transducers are attached in parallel at object surface and by moving the other transducer to measure the travelled velocity as shown in **Figure 5-9**. Test result shows the concrete homogeny can be classified as middle criteria as shown in **Table 5-2**.

Figure 5-9 Concrete investigation

(a) Crack depth evaluation; and (b) concrete homogeny

Table 5-2 Concrete homogeny

Bridge Element	Points	T_1 (μsec.)	T_2 (μsec.)	V (μ/sec.)	Criteria
Abutment	1	32.1	56.4	4115	Excellent
	2	18.9	63.4	2247	Bad
	3	22.9	62.9	2500	Bad
	4	24.4	63.7	2545	Bad
	5	31.6	60.4	3472	Fair
Deck bridge	1	31.7	71.9	2488	Bad
	2	41.6	73.1	3115	Fair
	3	41.4	86.4	2222	Bad
	4	42.1	74.7	3096	Fair
	5	38.2	74.7	2740	Bad
I-Girder Y_2	1	42.1	72.9	3247	Fair
	2	36.7	70.4	2967	Bad
	3	35.9	70.9	2857	Bad
I-Girder Y_5	1	40.9	65.4	4082	Excellent
	2	43.4	76.9	2985	Bad
	3	41.9	67.6	3891	Good

Note: Concrete velocity (m/sec.) V > 4000: Excellent; 3500< V < 4000: Good; 3000< V < 3500: Fair; and V < 3000: Bad.

Further investigation on concrete I-Girder, cracks with 0.15 mm width and varies in depth from 3 mm to 72 mm were discovered as shown in **Table 5-3**.

Table 5-3 Concrete crack and depth

Bridge Element	Point	T_1 (µsec.)	T_2 (µsec.)	Crack depth (mm)	Crack width (mm)
Preloading					
I-Girder Y_2	1	56.2	112.2	3	0.15
	2	57.9	113.9	11	0.15
I-Girder Y_5	1	59.7	92.6	53	0.15
	2	66.4	93.4	73	0.15
Post loading					
I-Girder Y_2	1	35.4	53.7	57	0.15
	2	57.9	66.4	58	0.15
I-Girder Y_5	1	39.7	61.7	64	0.15
	2	66.1	86.9	63	0.15

b) Concrete cover

For this purpose, Concrete Cover devices are used to evaluate concrete cover on the bridge I-Girder, **Figure 5-10**. From the results show that concrete cover has varies in thickness from 33mm to 44mm as shown in **Table 5-4**.

Figure 5-10 Concrete cover assessment

Table 5-4 Concrete cover

No.	Elements	Concrete cover (mm)
1	Deck bridge	44.00
2	I-Girder Y_4	35.75
3	I-Girder Y_5	33.00

c) Bridge camber

Initial bridge camber is used to evaluate increment bridge displacement under static load test. The measured position and marks as shown in Figure **5-11** and **Figure 5-12**. The result of camber measurement is shown in **Table 5-5**. These figure shows the bridge has negative camber or sagging state.

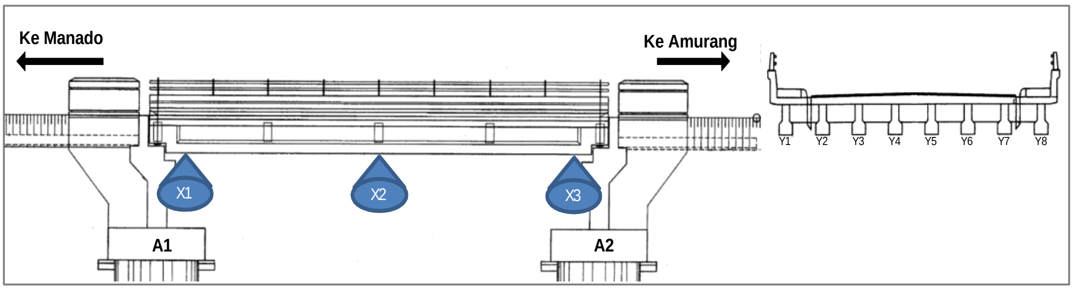


Figure 5-11 Camber measured position

Figure 5-12 Camber measurement

Table 5-5 Bridge camber

Measured position	Bridge I-Girder position from left (mm)							
	G_1	G_2	G_3	G_4	G_5	G_6	G_7	G_8
X_1	0.297	0.296	0.296	0.293	0.278	0.257	0.260	0.244
X_2	0.222	0.227	0.226	0.229	0.218	0.223	0.237	0.233
X_3	0.258	0.243	0.262	0.265	0.260	0.273	0.265	0.270
Max Camber	-56	-43	-53	-50	-51	-42	-26	-24

5.7 Static experiment

The main device used in field experiment for either static or dynamic load test is Dewetron - universal data logger as shown in **Figure 5-13**.

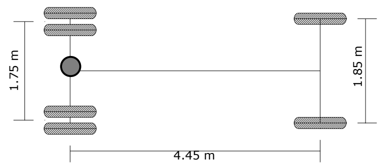
Figure 5-13 Main device use in field experiment

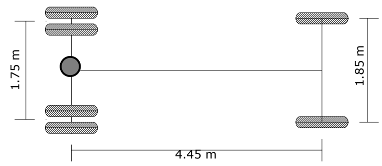
5.7.1 Load and load configuration

Static load test uses trucks as external loads. Two 2 axles' trucks are used for field experiment. The weight of each truck is shown in **Table 5-6**.

Table 5-6 Truck weight

Truck #1: DB 8821 AC			Truck #2: DB 8821 AU		
Unit in kN	**Rare wheel**	**Front Wheel**	**Unit in kN**	**Rare wheel**	**Front Wheel**
Left side	87.20	29.05	Left side	85.55	23.90
Right side	87.20	29.05	Right side	85.55	23.90
Total wheel	174.40	58.10	Total wheel	171.10	47.80
Total truck	232.50		Total truck	218.90	

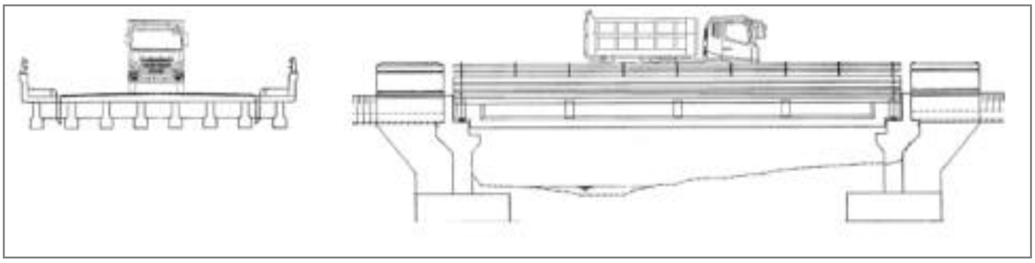




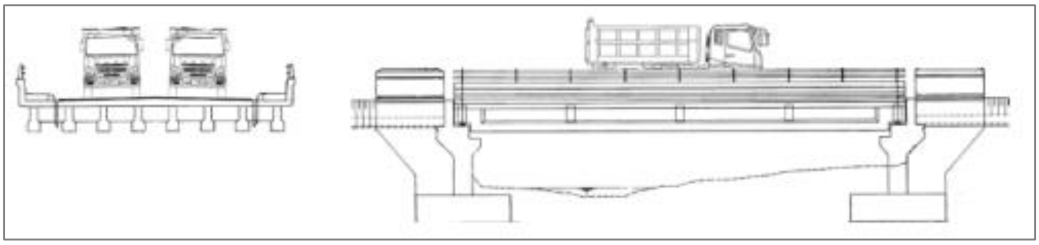
There are 5 steps of load combination as shown in **Table 5-7**. The scheme of load step is shown on **Figure 5-14**.

Table 5-7 Load configuration

No.	Combination	Remarks
1	1st Configuration	Initial
2	2nd Configuration	1 truck - middle
3	3rd Configuration	unload
4	4th Configuration	2 truck - middle
5	5th Configuration	unload



(a)



(b)

Figure 5-14 Scheme of load combination

5.7.2 Instrumentation setup

There are two types of sensor used for static load testing, i.e.: Strain Gauge which is used and attached to reinforced bars and bottom surfaces of concrete; and Linear Variable Differential Transformer (LVDT) to measure displacement. The instrumentation setup is shown on **Figure 5-15** where red marking and green marking are strain gauge transducer to measure forces, while blue marking represent LVDT transducer to measure bridge I-Girders displacement.

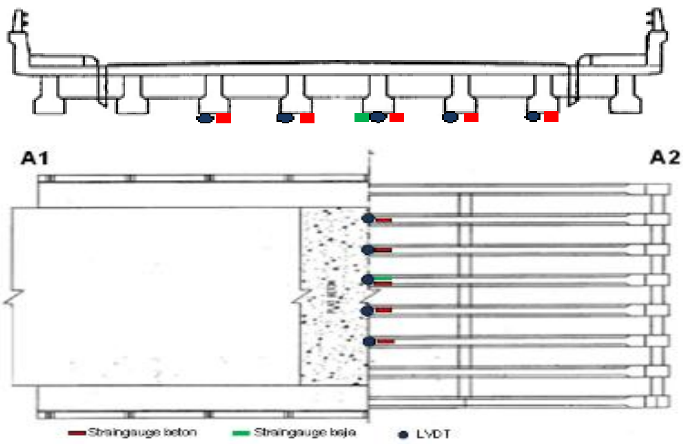


Figure 5-15 Instrumentation setup

5.7.3 Static strain measurement

Results of static strain measurement to the load steps refer to load configuration is shown in **Table 5-8**. The bridge response to load scheme is presented graphically in local orientation as shown in **Figure 5-16**.

Table 5-8 Static strain measurement

No.	Combination	Strain (με)						
		Concrete					Steel	
		Stg01	Stg02	Stg03	Stg06	Stg07	Stg04	Stg05
1	1st Conf.	0	0	0	0	0	0	0
2	2nd Conf.	14	50	30	6	2	36	36
3	3rd Conf.	0	5	0	2	1	0	2
4	4th Conf.	69	124	72	33	22	85	86
5	5th Conf.	2	-11	-12	-17	-20	-13	-14

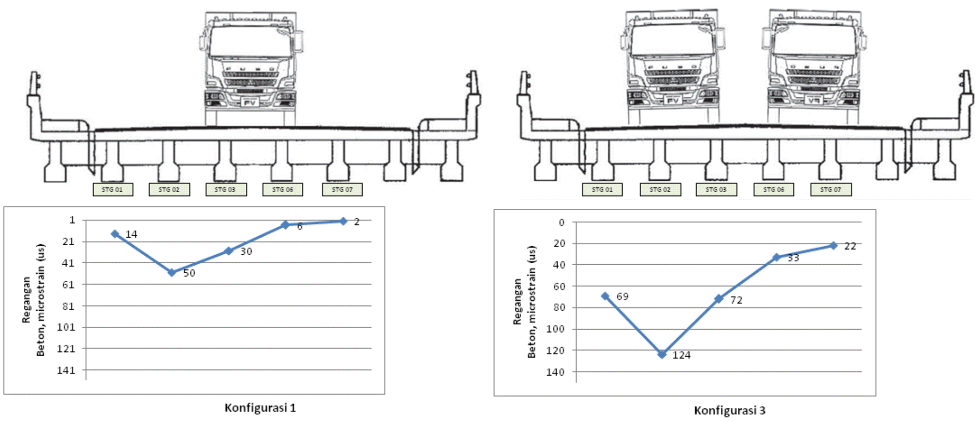


Figure 5-16 Section load scheme

5.7.4 Displacement measurement

Table 5-9 shows the bridge I-Girder deflection associated to load steps as stated in load configuration **Table 5-7**. The figure presents maximum value of -2.04 mm for truck load to simulate 45% equivalent of actual live load or equivalent 4.53 mm for full live load. This value is lower than limit of 20 mm (L/800 for service condition). The bridge response to load scheme is presented graphically in local orientation as shown in **Figure 5-17**.

Table 5-9 Bridge mid-span displacement

No.	Combination	Bridge I-Girder displacement (mm)				
		Y_2	Y_3	Y_4	Y_5	Y_6
1	1st Conf.	0	0	0	0	0
2	2nd Conf.	-0.67	-0.72	-0.95	-1.13	-0.82
3	3rd Conf.	-0.07	-0.17	0	-0.26	-0.05
4	4th Conf.	-1.79	-1.76	-1.92	-2.04	-1.72
5	5th Conf.	-0.13	-0.33	-0.21	-0.38	-0.06

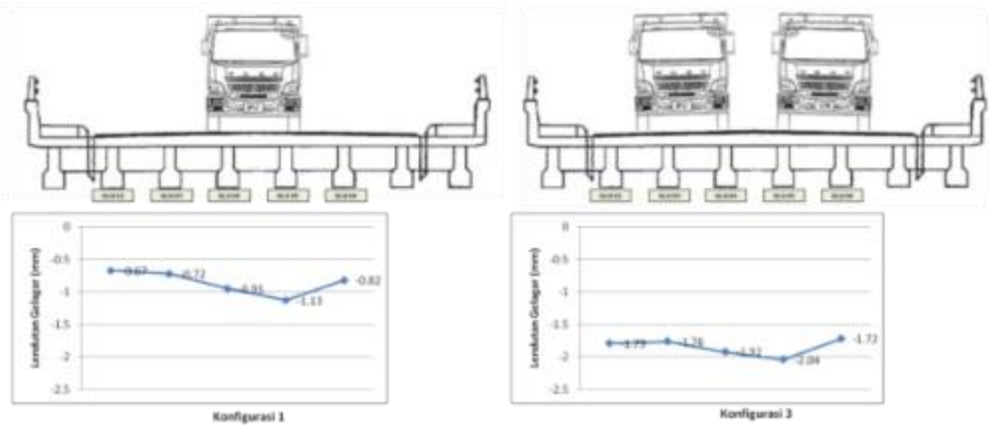


Figure 5-17 Truck position for test

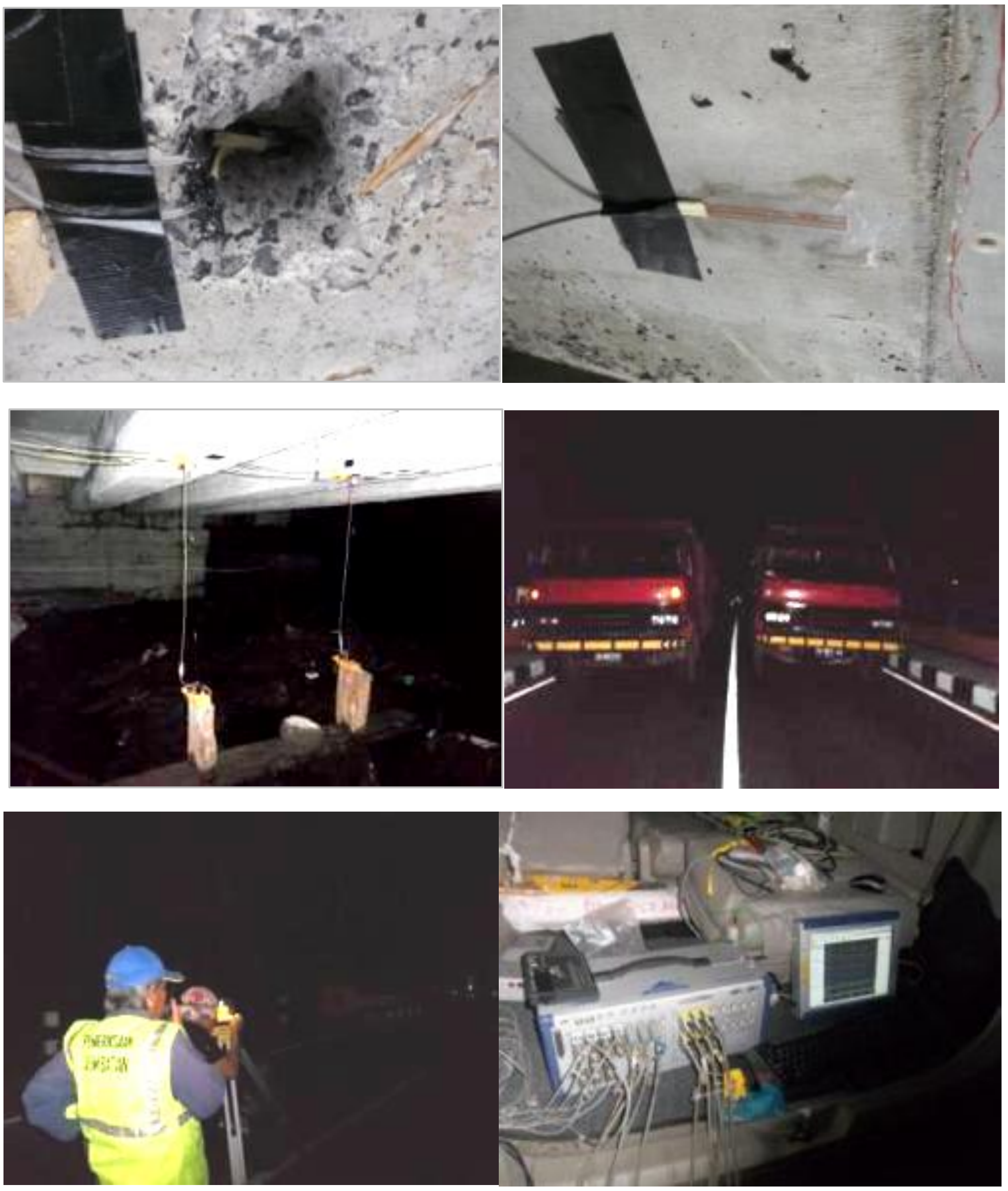


Figure 5-18 Static loading test documentation

5.8 Dynamic experiment

Dynamic load test is non-destructive test (NDT) and propose to identify dynamic parameters such as natural frequencies, damping ratio, dynamic amplification factor and dynamic load amplification factor (Salgado, R., 2014 and Siringoringo.D.M.,et al, 2013). Truck move on the bridge deck to exciting vibration and recorded in time series as function of truck speed. The experiment test setup is shown in **Figure 5-19**.

5.8.1 Fundamental natural frequency

The experimentation shows that the natural frequency of first bending mode has peak 7.810 Hz. This figure does not change for different truck speed as shown in **Table 5-10** and **Figure 5-19**. It can be concluded that the test procedure and the results are approved for a basis parameter of the research. Mekjavic,I, 2013, Islam, A.A.,et al, 2014 and Vaza, et al 2015 claims that different placement of vibration sensors or accelerometer do not give significant affect to the measured frequencies. Only displacement amplitude was affected.

For reference purpose, if the empirical formulas are applied to Matani Bridge then the natural frequency is 7.508Hz where span length of 16.65m (measure end to end). This value closely agrees with natural frequency which directly measure for field test with excited vibration by moving truck between 10km/h to 50km/h. The result shows within reasonable error with less than 3.879%.

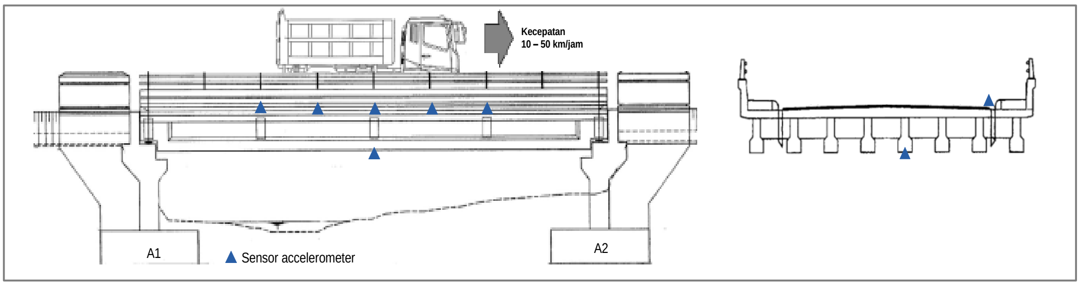


Figure 5-19 Acceleration sensors with moving truck

Table 5-10 Natural frequency of the 1st mode

No.	Configuration	Frequency (Hz)	
		Peak 01	**Peak 02**
1	Truck #1 (V 10km/h)	7.810	46.880
2	Truck #2 (V 10km/h)	7.810	-
3	Truck #1 (V 25km/h)	7.810	-
4	Truck #2 (V 28km/h)	7.810	15.630
5	Truck #1 (V 35km/h)	7.810	15.630
6	Truck #2 (V 40km/h)	7.810	-
7	Truck #2 (V 50km/h)	7.810	-

Based on the static load test result and by using displacement and loading relationship Formula 5.3, then the artificial equivalent beam stiffness can be easily obtained. From static load experiment bridge response can be calculated as follows:

P = 451 kN (Two trucks loaded symmetrically)

δ = 2.62 E-3 m (Displacement due to two trucks)

M = 140 ton (Bridge mass)

k = 172 316 kN/m

Recall Formula 5.2 then the natural frequency:

$f = 0.159 \text{ x } (172\ 316/140)^{0.5} = 7.940$ Hz.

When natural frequency calculated based on formula refer to Structural Dynamic by Mario Paz, then frequency for simply supported beam should be, f = 7.959Hz. The results from both natural frequencies formula close with an error less than 1%.

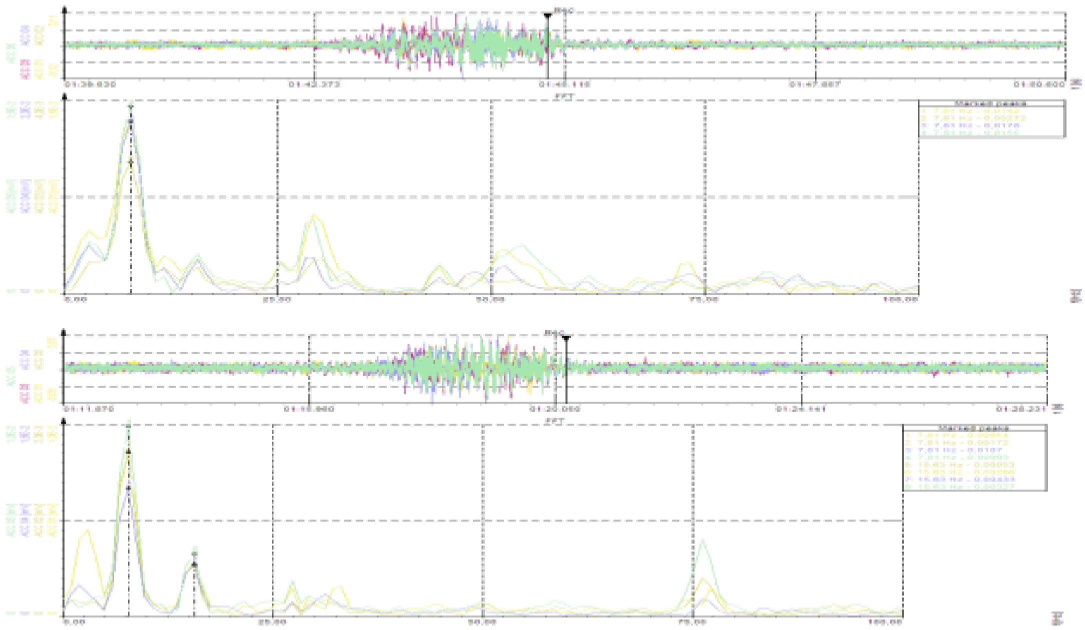


Figure 5-20 Frequency spectrum of the bridge

5.8.2 Dynamic load amplification

The experiment uses ± 225 kN truck load which moves over the bridge to give strain and displacement responses. From the Strain Dynamic recorded shows that the amplification factor is 1.1 and from Displacement Dynamic is 1.01. The response of dynamic measurement shows in **Figure 5-21** for Dynamic Strain–Displacement and collected on **Table 5-11** for all the measurement series that have average value 1.14 for concrete strain and 1.03 for reinforcement strain.

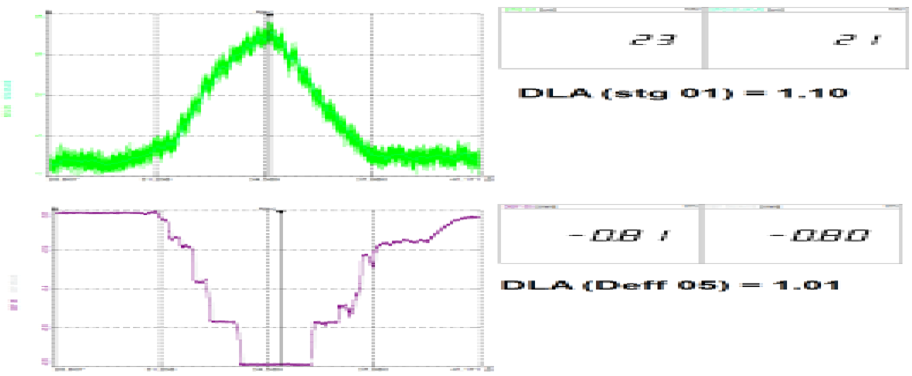


Figure 5-21 Strain dynamic and displacement dynamic

Table 5-11 Dynamic load amplification (DLA)

Test Num.	DLA strain							DLA Displacement				
	Concrete					Steel		Defl 01	Defl 02	Defl 03	Defl 04	Defl 05
	Stg 01	Stg 02	Stg 03	Stg 06	Stg 07	Stg 04	Stg 05					
#1: 23ton Truck, V 10 km/h	1.05	1.03	1.03	1.07	1.00	1.00	1.00	1.03	1.00	1.01	1.00	1.01
			1.04			1.00				1.01		
#2: 22ton Truck, V 10 km/h	1.00	1.00	1.00	1.06	1.20	1.02	1.00	1.02	1.01	1.01	1.00	1.01
			1.05			1.01				1.01		
#3: 23ton Truck, V 25 km/h	1.05	1.04	1.05	1.00	1.00	1.04	1.02	1.04	1.01	1.01	1.02	1.02
			1.03			1.03				1.02		
#4: 22ton Truck, V 28 km/h	1.00	1.02	1.00	1.00	1.00	1.02	1.02	1.00	1.00	1.01	1.01	1.00
			1.00			1.02				1.00		
#5: 23ton Truck, V 35 km/h	1.00	1.03	1.03	1.00	1.200	1.08	1.08	1.00	1.00	1.01	1.01	1.01
			1.05			1.08				1.01		
#6: 22ton Truck, V 40 km/h	1.06	1.02	1.03	1.08	1.20	1.07	1.02	1.03	1.03	1.01	1.01	1.05
			1.08			1.05				1.03		
#7: 23ton Truck, V 50 km/h	1.00	1.05	1.00	1.00	1.00	1.02	1.07	1.02	1.02	1.00	1.04	1.01
			1.01			1.05				1.02		
#8: 22ton Truck, V 50 km/h	1.06	1.04	1.05	1.20	1.33	1.03	1.03	1.00	1.02	1.02	1.03	1.06
			1.14			1.03				1.03		
				1.04						1.02		

The Dynamic Load Amplification Factor is the ratio between magnitude occurs from high speed moving vehicles (>15 km/hour) and magnitude from low speed moving vehicles lower than 15 km/hour (AASTHO, 2010). The value set to be up from 1.33. The experiment result shows that the DLFA in ratio ranging from 1.68 to 2.14.

5.8.3 Damping

Critical damping can be calculated based on the test result of time series data shown on **Figure 5-22**.

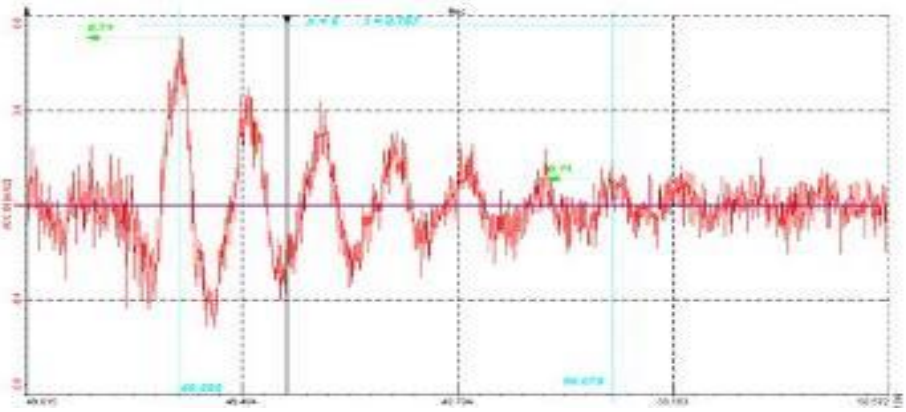


Figure 5-22 Time series of vibration

The critical damping calculation according Formula 5.6:

$$h = \frac{\delta}{2\pi} = \frac{1}{6} \cdot \frac{1}{2\pi} . ln\left(\frac{0.71}{0.11}\right) x\ 100\% \qquad (5.5)$$

$$h = 4.496$$

The value approximate to the reference of the critical damping.

5.9 Numerical analysis

5.9.1 Full model analysis of Matani Bridge

Based on geometries and properties measure of Matani Bridge then numerical model can be made as shown in **Figure 5-23**.

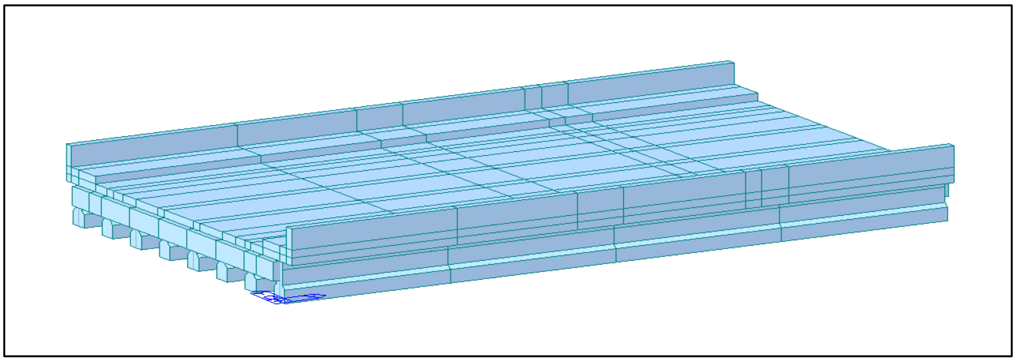


Figure 5-23 Geometry of the model

Structure properties as an inputs of model (refer to design specification) such as: concrete strength K-350 (fc' 30MPa) and mass density of bridge need to be inputted as well as Young's modulus of concrete which has correlation to given concrete strength is $E_c = 4700\sqrt{fc'}$.

Natural frequency of Matani Bridge can be obtained by using modal analysis, i.e., 7.986 Hz in first bending mode shape. This frequency is close to field result of 7.810 Hz, with an error of 2.20%. **Figure 5-24** shows mode shape of first bending and association to natural frequency.

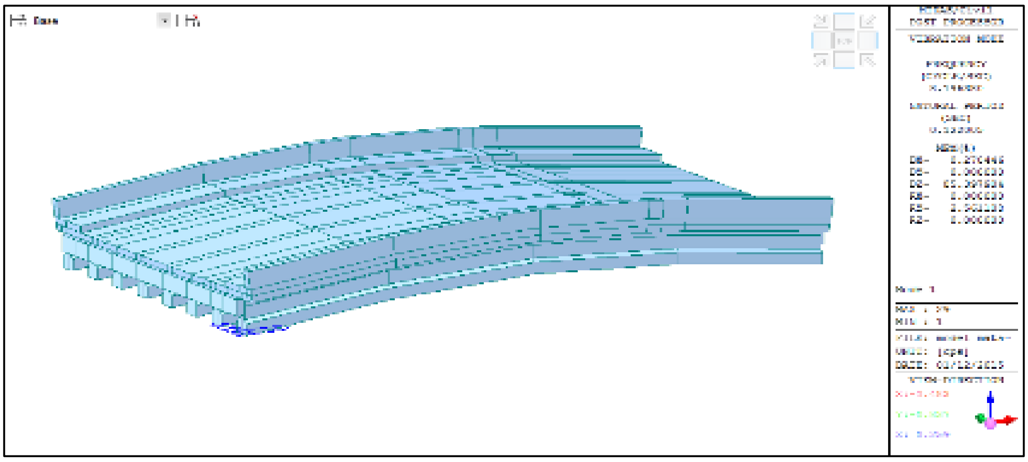


Figure 5-24 Natural frequency of modal analysis

5.9.2 Artificial model analysis of Matani Bridge

Natural frequency of Matani Bridge can be also obtained by using result of static load test in combination with modal analysis. From static load test, an equivalent stiffness of beam member can be obtained by using Formula 5.4. Based on this stiffness by using modal analysis of simple span simply supported beam as shown in **Figure 5-25** natural frequency of an artificial beam can be determined.

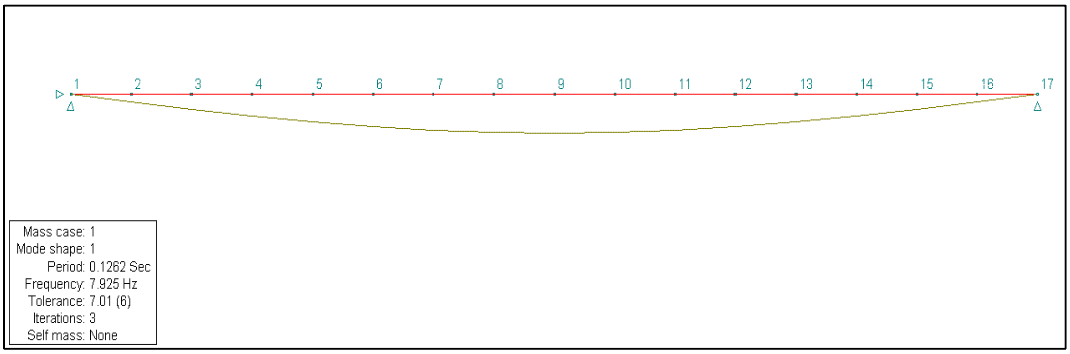


Figure 5-25 Geometry of artificial beam model

SECTION PROPERTIES (m,m^2,m^4,deg)

Sect	Area of Section	Torsion Constant	Y-Axis Mom of In	Z-Axis Mom of In	Y-Axis Shr Area	Z-Axis Shr Area	Princ Angle
2	3.4340E+00	1.0000E-04	1.0000E-03	5.1400E-01	INFINITE	INFINITE	0.00

MATERIAL PROPERTIES (kPa,Kg/m^3)

Matl	Material Name	Young's Modulus	Poisson's Ratio	Mass Density	Coeff of Expansion	Concrete Strength
2	CONCRETE-40	3.2000E+07	0.15	2.4500E+03	1.0000E-05	40000.00

LUMPED MASSES (T,Tm^2)

Load Case	Node	X Trans Mass	Y Trans Mass	Z Trans Mass	X Rot'n Mass	Y Rot'n Mass	Z Rot'n Mass
1	1	0.000	4.375	0.000	0.000	0.000	0.000
	2	0.000	8.750	0.000	0.000	0.000	0.000
	3	0.000	8.750	0.000	0.000	0.000	0.000
	4	0.000	8.750	0.000	0.000	0.000	0.000
	5	0.000	8.750	0.000	0.000	0.000	0.000
	6	0.000	8.750	0.000	0.000	0.000	0.000
	7	0.000	8.750	0.000	0.000	0.000	0.000
	8	0.000	8.750	0.000	0.000	0.000	0.000
	9	0.000	8.750	0.000	0.000	0.000	0.000
	10	0.000	8.750	0.000	0.000	0.000	0.000
	11	0.000	8.750	0.000	0.000	0.000	0.000
	12	0.000	8.750	0.000	0.000	0.000	0.000
	13	0.000	8.750	0.000	0.000	0.000	0.000
	14	0.000	8.750	0.000	0.000	0.000	0.000
	15	0.000	8.750	0.000	0.000	0.000	0.000
	16	0.000	8.750	0.000	0.000	0.000	0.000
	17	0.000	4.375	0.000	0.000	0.000	0.000

```
  DYNAMIC NATURAL FREQUENCIES (Sec,Hz,T)
Mass  Mode    Natural    Natural
  Case Shape     Period  Frequency  Tolerance Iterations  Self Mass

     1     1     0.1262      7.925   7.01 (6)         3       0.00
           2     0.0315     31.699   6.87 (6)        12       0.00
           3     0.0140     71.317   7.07 (6)         5       0.00

DYNAMIC MODE SHAPES
 Mass case 1, Mode shape 1, Period 0.1262 Sec, Frequency 7.925 Hz

         X-Axis     Y-Axis     Z-Axis     X-Axis     Y-Axis     Z-Axis
  Node   Transl'nTransl'nTransl'n   Rotation   RotationRotation

     1                                                           0.189
     2      0.000      0.195      0.000      0.000      0.000      0.185
     3      0.000      0.383      0.000      0.000      0.000      0.174
     4      0.000      0.556      0.000      0.000      0.000      0.157
     5      0.000      0.707      0.000      0.000      0.000      0.133
     6      0.000      0.831      0.000      0.000      0.000      0.105
     7      0.000      0.924      0.000      0.000      0.000      0.072
     8      0.000      0.981      0.000      0.000      0.000      0.037
     9      0.000      1.000      0.000      0.000      0.000      0.000
    10      0.000      0.981      0.000      0.000      0.000     -0.037
    11      0.000      0.924      0.000      0.000      0.000     -0.072
    12      0.000      0.831      0.000      0.000      0.000     -0.105
    13      0.000      0.707      0.000      0.000      0.000     -0.133
    14      0.000      0.556      0.000      0.000      0.000     -0.157
    15      0.000      0.383      0.000      0.000      0.000     -0.174
    16      0.000      0.195      0.000      0.000      0.000     -0.185
    17      0.000                                                -0.189
```

5.9.3 Summary of natural frequencies

Table 5-12 shows the comparison values of natural frequency from various sources both from experimental field test which is directly measured from dynamic bridge response under moving loads as well as based on formulas and numerical analysis.

Table 5-12 Summary of the Matani bridge natural frequencies

Method assessment	Symbol	Value (Hz)	Condition State
IRE's natural frequency empirical formula	$f_{empirical}$	7.508	As reference
Dynamic field test	$f_{dynamic}$	7.810	Benchmarks/ Current state
Static loading test: Formula 5.2	f_{static}	7.940	As current state
Mario Paz	f_{static}	7.959	As current state
Modal Analysis: Full bridge model	f_{model}	7.986	As new bridge
Artificial beam model	f_{beam}	7.925	As current state

5.10 Bridge rating based on frequency ratio

Bridge condition properties can be defined by using natural frequency. In previous sub-chapter is already explained on methods to determine natural frequency, namely by using general formula, empirical formula, and modal analysis, which can prove the condition state of new bridge (Islam,A.A., et al, 2014). While, direct measurement at field with accelerometer transducers for dynamic experiment and static load test which needed correlate to bridge stiffness, the current state condition of existing bridge structure can be determined.

$$K = \frac{|f_{actual} - f_{theory}|}{f_{theory}} \quad (5.6)$$

Where:

K is frequency ratio [%]

f_{actual} is actual frequency [Hz]

f_{theory} is theoretical frequency [Hz]

From **Table 5-12** above, assume if natural frequency obtained from modal analysis of full bridge model represents as a new built bridge, this also conducted by Islam, A.A., (2014), as they are calculated based on the actual properties of the bridge and bridge standard specification, and if the dynamic field test result represents as current state condition of the bridge (this result is also reflected by the natural frequencies which are calculated based on the formulas as well as from artificial beam model within an error of 1.5%), then Formula 5.6, K = |7.810-7.896|/7.896 = 2.20%. Mekjavic, I. (2013), stated the ratio of natural frequency for bridge with 5 years in operation in Croatia is around 3%, while Islam, A.A.,et al (2014) finds, the ratio of natural frequency of bridge with 25 years in operation is 37 %. It is quite similar to the result of this research, as defects are discovered on the field test bridge.

The investigation at several bridges of this research object which carried out, both visual and instrumented inspection is shown in **Table 5-13**.

Table 5-13 Ratio of natural frequency, *K* (%)

No	Bridge/Location/Span	As New Bridge (Hz)	Empirical Formula (Hz)	Current Condition (Hz)	*K* (%)
1	Matani Bridge/North Sulawesi/16.35 meter	7.986	-	7.810	2.200
2	Ciberes-A Bridge/West Java/10 meter	12.500	-	10.250	18.000
3	Ciberes-B Bridge/West Java/10 meter	12.500	-	9.760	21.920
4	Ciberes-C Bridge/West Java/ 8 meter	16.000	-	11.720	26.750
5	Cilalawi-A Bridge/West Java/36 meter	3.145	-	3.173	0.890
6	Sario Bridge/North Sulawesi/20.8 meter	5.419	-	5.370	0.904
7	Ciherang Bridge/West Java/70 meter	-	1.786	1.950	9.183
8	Ciasem Bridge/West Java/70 meter	-	1.786	1.560	12.650
9	Cimanuk Bridge/West Java/90 meter	-	1.136	1.170	3.539
10	Cimuja II Bridge/West Java/15.5 meter	7.763	-	7.200	7.250
11	Cibereum Bridge/West Java/16 meter	11.831	-	11.110	6.090
12	Cipeles Bridge/West Java/30 meter	3.421	-	3.360	1.780
13	Underpass KM.15+408 A/West Java/12.5 m (Tol Jagorawi)	-	8.000	7.810	2.375
14	Underpass KM.15+408 A/West Java/15 m (Tol Jagorawi)	-	6.667	5.860	12.104
15	Underpass KM.23+225 A/West Java/12 m (Tol Jagorawi)	-	8.333	7.810	6.276
16	Underpass KM.23+225 A/West Java/15 m (Tol Jagorawi)	-	6.667	5.860	12.104
17	Tinalun Bridge/Center Java/40.6 meter (Tol Semarang-Bawean)	-	3.079	3.300	7.177

Table 5-14 Relationship of natural frequency ratio to visual inspection Assessment rating

No.	Bridge/Location/Span	*K* (%)	Photograph	Visual Inspection Rating
1	Matani Bridge/North Sulawesi/16.35 meter	2.200		Bridge in good condition, there are defects on elements but no repair required (routine maintenance only).This confirms to visual inspection with new manual with rating "0". Bridge is open to traffic on Sept. 2014.
2	Ciberes-A Bridge/West Java/10 meter	18.000		RC-beams with condition rating "3", corrosion in reinforcement and concrete spalling. Steel plate covers and injected grout had done during rehabilitation in the past. Now, new bridge is constructed nearby.
3	Ciberes-B Bridge/West Java/10 meter	21.920		RC-beams with condition rating "4", Spall in reinforced I-Girder with steel plate bonding repaired. During inspection some plates are unfastened. Now, new bridge is constructed nearby.
4	Ciberes-C Bridge/West Java/ 8 meter	26.750		Bridge deck has severe structural cracks and corrosion in reinforcement. Some spalls in concrete deck and beams. Injected grout had done during strengthening work in the past. The new bridge was constructed nearby. Bridge rating is " 4"
5	Cilalawi-A Bridge/West Java/36 meter	0.890		PC-beams, bridge in good condition, some elements with minor defects no repair required (routine maintenance only). It confirms to visual inspection with new manual with rating "1"

No.	**Bridge/Location/Span**	***K* (%)**	**Photograph**	**Visual Inspection Rating**
6	Sario Bridge/North Sulawesi/20.8 meter	0.904		Precast PC-Girder with cast in-situ deck. It is new bridge, open to traffic on December 2014. Visual inspection rating is “0”, (routine maintenance only)
7	Ciherang Bridge/West Java/70 meter	9.183		Composite steel I-Girder bridge. The beams trapezoidal shape with reinforced concrete deck. Visual inspection rating “1” and routine maintenance is required to secure bridge condition.
8	Ciasem Bridge/West Java/70 meter	12.650		Composite steel I-Girder bridge I-shape with reinforced concrete deck, visual rating “2” Preventive repair required.
9	Cimanuk Bridge/West Java/90 meter	3.539		Composite steel I-Girder bridge I-shape with reinforced concrete deck. Visual condition rating is “1”. Preventive repair required.
10	Cimuja Bridge/West Java/15.5 meter	7.250		The bridge is RC-beams, corrosion on beams and decks reinforcement. Bridge condition rating is “2”, Preventive repair required.

No.	Bridge/Location/Span	*K* (%)	Photograph	Visual Inspection Rating
11	Cibereum Bridge/West Java/16 meter	6.090		Composite steel I-Girder, corrosion in steel beam closed to support. Visual inspection rating is “3”, repair required soon. Defects found closed to support due to environmental corrosion. The system less accurate to this shear mode, so less *K* reported
12	Cipeles Bridge/West Java/30 meter	1.780		Composite steel I-Girder, good condition, no defects, only corrosion at drainage pipes and bumping on running surface. Visual inspection rating “0”. No immediate repair required
13	Underpass KM.15+408 A/West Java/12.5 meter (Tol Jagorawi)	2.375		Voided slab pre-casted concrete Indonesia. Pre-casted concrete plate cracked (Rating = 1), No immediate repair required
14	Underpass KM.15+408 A/West Java/15 meter (Tol Jagorawi)	12.104		Bridge type of voided slab pre-casted concrete Indonesia. Pre-casted concrete plate cracked (Rating = 1), Preventive repair required.
15	Underpass KM.23+225 A/West Java/12 meter (Tol Jagorawi)	6.276		Bridge type of voided slab pre-casted concrete Indonesia. Pre-casted concrete plate cracked. (Rating =1), Preventive repair required.

No.	Bridge/Location/Span	*K* (%)	Photograph	Visual Inspection Rating
16	Underpass KM.23+225 A/West Java/15 meter (Tol Jagorawi)	12.104		Bridge type of voided slab pre-casted concrete Indonesia. Pre-casted concrete plate cracked (Rating = 2), Preventive repair required.
17	Tinalun Bridge/Center Java/40.6 meter (Tol Semarang-Bawen)	7.177		PC-beams (GPI). There are honeycombs at the diaphragm due to imperfect compaction, exposed reinforcement, visual inspection rating “1”. No immediate repair required.

Table 5-15 Ratio *K* vs Visual inspection rating and maintenance program

No.	Bridge Name	Visual Inspection Rating	Maintenance Requirement	*K* (%)
1	Matani bridge	0	No repair required	2.200
2	Ciberes-A bridge	3	Repair (Rehabilitation)	18.000
3	Ciberes-B bridge	4	Replacement	21.920
4	Ciberes-C bridge	4	Replacement	26.750
5	Cilalawi-A bridge	1	No immediate repair required	0.890
6	Sario bridge	0	No repair required	0.904
7	Ciherang bridge	1	No immediate repair required	9.183
8	Ciasem bridge	2	Preventive repair	12.650
9	Cimanuk bridge	1	No immediate repair required	3.539
10	Cimuja bridge	2	Preventive repair	7.250
11	Cibereum bridge	3	Repair (Rehabilitation)	6.090
12	Cipeles bridge	0	No repair required	1.780
13	Underpass KM.15+408 A	1	No immediate repair required	2.375
14	Underpass KM.15+408 A	2	Preventive repair	12.104
15	Underpass KM.23+225 A	2	Preventive repair	6.276
16	Underpass KM.23+225 A	2	Preventive repair	12.104
17	Tinalun Bridge	1	No immediate repair required	7.177

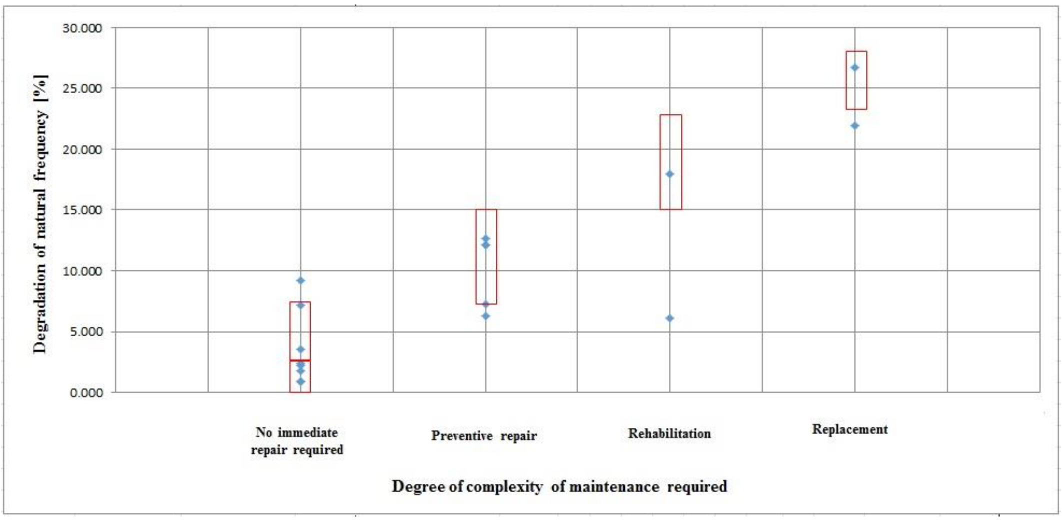


Figure 5-26 Maintenance program vs. Ratio *K*

5.11 Instrumented bridge inspection & rating based frequency

Inspection with instrumentation method carried out to obtain data on bridges frequency, which subsequently compared with bridge initial frequency (empirical). From both frequencies there will be difference which indicated with *K* (%).

For the bridges which will be inspected, field inspectors shall look for historical data. This is important to be carried out to see any difference of bridge frequency. If there is any difference of frequency, ratio *K* (%), the value can be correlated with description of defect as shown in **Table 5-16**.

According to Tristanto,L., (2002), Mekjavic,I (2013), and Islam, A.A.,et al (2014), ratio of natural frequency (*K*) can be correlated with bridge condition rating which is obtained from visual bridge condition inspection. In this research, the correlation made based on how the maintenance needed for defects at bridge elements or components as whole as shown in **Table 5-16.**

Table 5-16 Rating based on frequency ratio

No.	Visual defect description	Visual rating	Maintenance program	Frequency ratio K (%)
1	Elements of bridge in good condition and no defect exist require routine maintenance.	0	No repair required (routine only)	$0 < K \leq 2.5$
2	Elements of bridge with minor defects and require routine maintenance.	0 - 1	No immediate repair required (routine only)	$2.5 < K \leq 7.5$
3	Elements of bridge with defects that require preventive repair (within 12 months)	1 - 2	Preventive repair	$7.5 < K \leq 15.0$
4	Elements of bridge with defects that require attention soon or special repair.	2 - 3	Repair (Rehabilitation)	$15.0 < K \leq 22.5$
5	Elements of bridge in critical condition, that require immediate attention, need replacement.	3 - 4	Replacement	$22.5 < K \leq 27.5$
6	Element of bridge is not functioning, broken, or collapsed.	4 - 5	Replacement	-

5.12 Summary of proposed model of bridge rating assessment

5.12.1 Bridge Database

Results of bridge inspection represent digital data from input entered into database. The database as shown **Figure 5-27**, subsequently becomes a basis for sustainable bridge inspection updating. For bridges which have not initial data on it, the inspection shall be carried out directly in field with visual and instrumented bridge inspection. This is required so the bridge has significant historical data which useful for future inspections and assessment in defining bridge condition rating and maintenance program. This is very useful for bridge asset management.

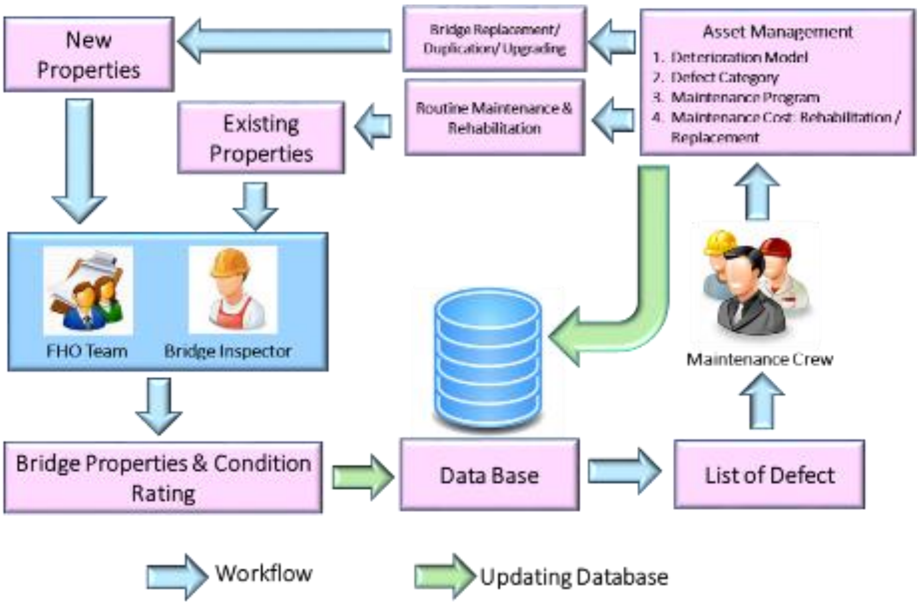


Figure 5-27 Database updating process

5.12.2 Hybrid inspection procedures

Based on the database, general bridge inspection procedure is carried out for preliminary examination of bridge condition in the database, subsequently the inspection carried out according to instrumented bridge inspection procedure. Instrumented test performs by setting up accelerometer transducers to records natural frequencies for bridge response to a dynamic impact. As recorded responds are associated to bending rigidity of structure and less to shear rigidity, therefore in this procedure prior to carry out test, probable shear defects or damage which normally happens at vicinity of supports should be investigated. From this inspection, rating of the bridge condition is classified based on its degradation of natural frequencies.

Furthermore, if the results of instrumented inspection show bridge condition rating of “0”, and “1”, which is associated to “no defects” and “minor defects” then the next visual inspection for these bridges can be skipped. While if the results show rating “2”, “3”, and “4”, the bridge requires visual inspection, because the defects and defect level and location needs to be defined. Based on the results, the bridge inspection cycle is proposed as shown in **Figure 5-28**.

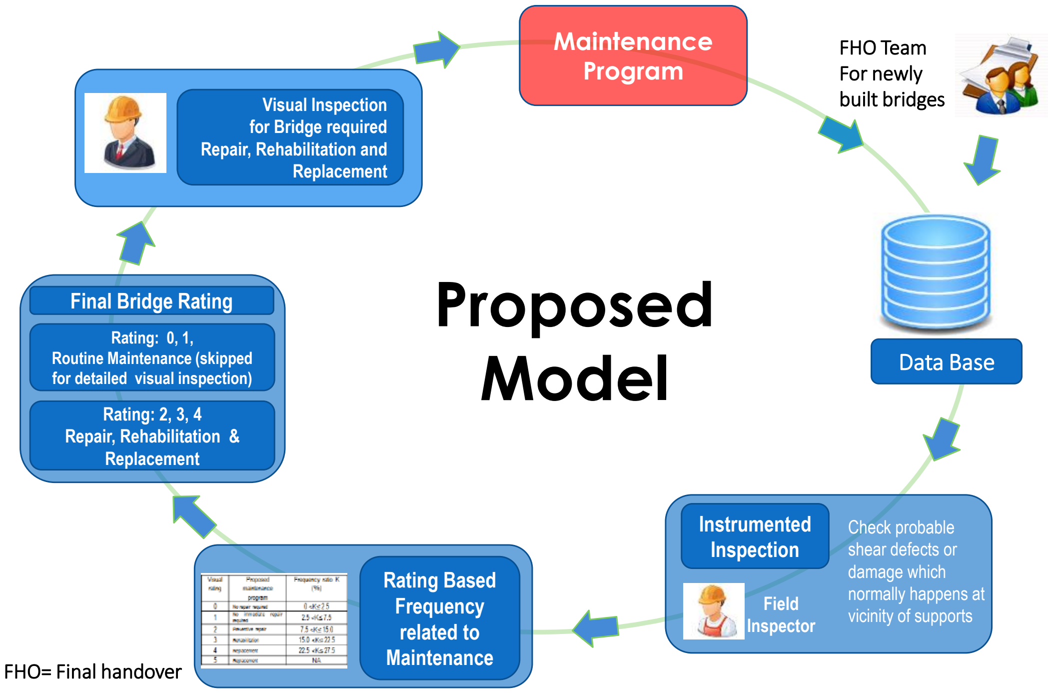


Figure 5-28 Hybrid bridge inspection of visual and instrumentation

5.12.3 Bridge maintenance decision making

Bridge maintenance program related to bridge condition rating, either in element level or component level of bridge. The bridge condition rating from visual or instrumented inspection shall be used as basis for bridge asset management system. For example, bridges with rating “0” to “1” are classified no defects and requiring routine maintenance only. While bridges with rating “2” to “4” are classified require visual inspection to define the location and volume of existing defects in more detail, which subsequently may be included into repair list to be carried out, see **Figure 5-29**.

It is an obligation to conduct the proper asset management activities that binds the stake holders (bridge administrator) to inspect bridge with consideration of bridge maintenance by law (Shirato, M., Tamakoshi, T., 2013). Such case is still doesn’t apply in Indonesia’s bridge asset management.

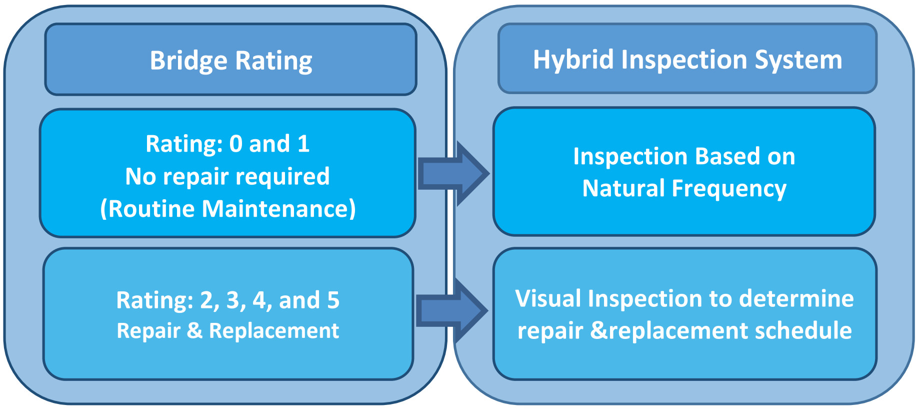


Figure 5-29 Bridge maintenance decision policy

5.12.4 The resource necessity for proposed model

The advantage of the proposed inspection model is discussed here. This advantage seem quite significant in respect to time consuming, cost, and human resources for carrying out field inspection by using proposed model bridge inspection rather than the existing. Visual inspection will require more personnel than the instrumented inspection, as the result, direct cost of personnel for instrumented inspection become less.Table 5-17 shows the benefits of proposed model which is combined between visual and instrumented bridge condition inspection and rating assessment.

Table 5-17 Comparison of instrumented bridge inspection and visual inspection

Description	Visual Based Inspection	Instrumented Inspection
Time for data collection at field	30 Minutes/Span	5 Minutes/Span
Personnel Requirement	3-4 Persons/Bridge	1-2 Persons/Bridge
Cost (Span) According to Regulation No 38 – 2012 PNBP	IDR 15 to 23 Million / Span	IDR 8 Million/Span
Requirement for data processing (on desk evaluation)	Yes	Yes

CHAPTER 6
CONCLUSION AND RECOMMENDATION

Learning from a series of research activities that covers literatures review, survey and analysis, the conclusion and recommendation can be drawn as follows:

6.1 Conclusion

1. Existing system of Indonesian BMS'92 was developed in 1990, and needs to be updated to meet dynamic advance of information technology and current advance of bridge structural knowledge, including the decentralization of government. Indicators already used in bridge inspection according to BMS'92 are detail enough to deliver accurate description of bridge condition, so the development of inspection system carried out by observing a particular element where the damage commonly happen.
2. Inspectors from local government require sufficient competency to deliver good bridge inspection data, by providing periodic courses on bridge inspection organized by central government.
3. Reducing complexity level during field inspection will deliver more objective inspection data, by reducing factors that influence the inspector's subjectivity and determining certain focused area of inspection such as separating element of structural members and non-structural members during inspection. Validation matrix is used to control the consistency of inspection logic.
4. Instrumented bridge inspection by vibration measurements produce rating which equal to the rating generated using updated visual inspection of the BMS 92 by employing correlation factor of vibration analysis of bridge spans. Vibration measurement for bridges provide advantages in term of low costs and ease of implementation such as:

- A vibration excitation does not require special equipment or vehicles, instead it uses ordinary traffic vehicles pass the bridge deck.
- Vibration measurement can be carried out by using any common equipment brands and types and still produce accurate results.
- Location of vibration sensor placement is not always necessary in the middle of span. Measurements at other points of location still produce consistency results.
- Vibration test reduce the inspection cost up to 50%, compared to the detailed visual inspection method. Especially, when the population of bridge with condition rating “0” to “1” is dominating with around 68%.

5. For bridges with “2” to “4” condition mark, they still require (detailed) visual inspection to find the rate and location of damage where rehabilitation actions to be taken.
6. Several difference (benefits) between BMS’92 and the proposed new model of bridge inspection is shown in the **Table 6-1** below:

Table 6-1 Comparison of BMS’92 and New Bridge Inspection Models

Parameter	BMS’92	New Model
Bridge Element Hierarchy	Complex, the structural elements is mixed with the non-structural elements	Less complex, only priority elements considered which lead to the bridge failure
Inspected Element	Not listed on the form	Priority element listed in the inspection form
Data Updating	Standard based on inspection budget	Sustainable data updating, with the Final Hand Over Committee acceptance reports as back-up.
Assessment Method	Hierarchical assessment, from level 4 or 5 (structural member elements) to level 1 (overall bridge)	Group of elements weighing system to define bridge rating
Reliability of results	No quantitative measures, high subjectivity	Correlation with results of vibration measurements

6.2 Recommendation

1. Improvement of this inspection model needs to be proven in the field with other I-Girder bridges including bridges under management of other local governments.
2. Level of importance for each bridge elements which contribute to overall bridge condition rating should developed further for other type of structures, as well as the matrix of possible combination of condition rating (S,R,K,F,P).
3. For optimum inspection result, Damage Catalogue for each bridge element should be developed.The research in this dissertation is limited to single span I-Girder bridge which represent the majority of bridge population in Indonesia. Further research for steel truss, continuous span bridges, and bridge sub-structure are required.
4. Vibration analysis discussed in this dissertation, is limited utilization of natural frequency, where condition rating related to bending mode, further exploration of bridge natural frequencies such as amplification and damping ratio correlated with damage detection (types and locations) and structural assessment are recommended.
5. Certification and standardized competency of inspectors should be endorsed by government regulation.
6. Existing manual for bridge condition updating should be modified by involving bridge inspector in a FHO Team to automatically record the newly built bridge inventory data into the bridge database and routine inspections should be done by maintenance crew as an input for detailed bridge inspection carried out every 3 to 5 years.
7. Manual of bridge inspection needs to be endorsed by policy such as government policy to engage bridge administrators to obligate with responsibility to ensure that the bridge management activity carried out according to the policy.

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ATTACHMENT

ATTACHMENT-A

QUESTIONAIRE FORM

INSTITUTE OF ROAD ENGINEERING

CODE

QUESTIONNAIRE

The Development Of Bridge Management System

Case Study : Bridge Management in Decentralized Government Era

In decentralized government era, some central authorities delegated to districts, one of them is the responsibility for infrastructure management, especially bridge. In some extent, the road condition in various districts in Indonesia are affected by asset management pattern after the adoption of local autonomy. For that reason, filling of this questionnaire is expected to provide valuable inputs and description on system, program, policy and strategy need to be implemented to maintain bridges for sustainable service as planned.

RESPONDENT'S DATA

1.	**Name of Respondent :**
2.	**Contact Number :**
3.	**E-mail :**
4.	**Institution : …….** (mention) □ **Ministry** □ **Province** □ **City** □ **District**
5.	**Position : …….** (mention) □ **Echelon III** □ **Echelon IV**

………………………, ………………………………………2015

Approved by,	Filled by,
Leader	**Respondent**
signature & stamp	signature
(………………………………………………………)	(………………………………………………………)
NIP. ………………………………………………	NIP. ………………………………………………

Confidentiality of respondent's identity is strictly respected and this questionnaire will be only used for analysis purpose.

Questionnaire Of Bridge Management In The Desentralized Era

<u>Filling Instruction :</u> **Please select one answer that best suits the conditions in your area . The information contained in this questionnaire is expected to represent actual conditions**

1. **How many bridges are there in your area? .... Bridge.**
(Please attach the list of bridge)

2. **How about the consistency of bridge inspection in your local area?**
(a) Every years
(b) Every in 2 - 3 years
(c) Every in 4 - 5 years
(d) Not routinely
(e) Never Inspected

3. **If inspection of the bridge is not routinely or never made, select a reason below! (allowed to answer more than one)**
(a) Limited funds
(b) Limited human resources
(c) There are no regulations
(d) Others (mention) ……

4. **Does the lack of legislation on the bridge inspection to be one of the reasons the bridge inspection is not conducted?**
(a) Yes
(b) Not

5. **Who did the bridge inspection training in your local area?**
(a) Center - Directorate General of Highways
(b) Center - Other institutions
(c) Province - Department of Public Works
(d) No coaching

6. **Are you aware of any (Bridge Management System 1992) BMS'92 used as guidelines for bridge inspection?**
(a) Yes
(b) Not

7. **Whether BMS'92 been used as guidelines for bridge inspection in your local area?**
(a) Yes
(b) No, we use (mention) ……..

8. **Whether BMS'92 use as guidelines bridge inspection is considered complicated?** (If at no.6 questions you answered "no " , go to question no.9)
(a) Yes
(b) Not

9. **Whether the results of an inspection bridge in your local area evaluated by the direct supervisor?**
(a) Yes
(b) Not

10. **Whether the results of an inspection bridge in your local area is used as the base for further action (required maintenance or handling)?**
(a) Yes
(b) Not

11. **Who is charge as inspector (inspector) bridge?**
* Technical staff (self-management) .... person.
* Consultant ………………… person.

12. **Whether bridge inspector in your local area already has a sufficient competency standards?**
(a) Already
(b) Not yet

13. **What qualifications must be owned by a bridge inspector in your local area? (the answer could be more than one)**
(a) Special training certificate
(b) Experience
(c) Trained directly in the field
(d) Do not need qualification

14. **Whether you already know the inspector competency standards that have been published by the Ministry of Public Works?**
(a) Yes
(b) Not

15 **Whether Qualification owned by bridge inspectors (self-management and consultants) in your area?**
(a) ≤ junior high school .... person.
(b) Senior High / Vocational School .... person.
(c) Diploma (D3) ....person.
(d) Bachelor (S1) .... person.

16. **When was the last bridge inspection training conducted?**
(a) in ≤ 1 years
(b) in 1 - 3 years
(c) in 3 - 5 yars
(d) in > 5 years
(e) Has never been

17. **Whether bridge inspection data storage results in your local area is well done? (the answer could be more than one)**
(a) Yes
(b) Not

18. **inspection result data is stored in what format?**
(a) *Hardcopy*
(b) *Softcopy* (word/excel/pdf*)
(c) Computer System on-line

19. **Whether new bridge inspection result data contained in the database?**
(a) Yes
(b) Not
(c) No assessment

20. **in what year bridge inspection database updates conducted………**

21. **In the period 2010 up to now, how many bridges in your area that collapsed?**
* Due to excess load .... Bridge
* Due to scouring .... Bridge
* Due to flooding .... Bridge
* Due to corrosion .... Bridge
* Due to the earthquake .... Bridge
* Others (mention) ……………………………………………………………………………., number of bridge? ………….. Bridge

22. **How many bridges in the area you are currently in a state of disrepair and in need of treatment?**
………….. Bridge.

23. **What percentage of the budget allocated for bridge inspection in your local area? ....% region budget.**

24. **Whether the fund has been able to provide for the bridge inspection in your local area?**
(a) Yes
(b) Not

25. **What percentage of regional budget allocated for the maintenance and handling of the bridge in your local area?**
....% regional budget.

26. **Whether the fund has been able to provide for the maintenance and handling of the bridge in your local area?**
(a) Yes
(b) Not

27. **Do you think the bridge management system is needed?**
(a) Yes
(b) Not

28. **Do you think the system needs to be standardized?**
(a) Yes
(b) Not

29. Do you think BMS'92 need to be developed?

(a) Do not need, because it is still relevant.

(b) Necessary, related policies / HR development / appraisal system / other *).

Advice related to bridge management system update

………

………

………

ATTACHMENT-B

PHOTOGRAPHS OF CILALAWI BRIDGE

Photograph of Cilalawi-A Bridge

(GPS location: 06° 37’ 08.9’’ SL 107°24’ 16.6’’EL)

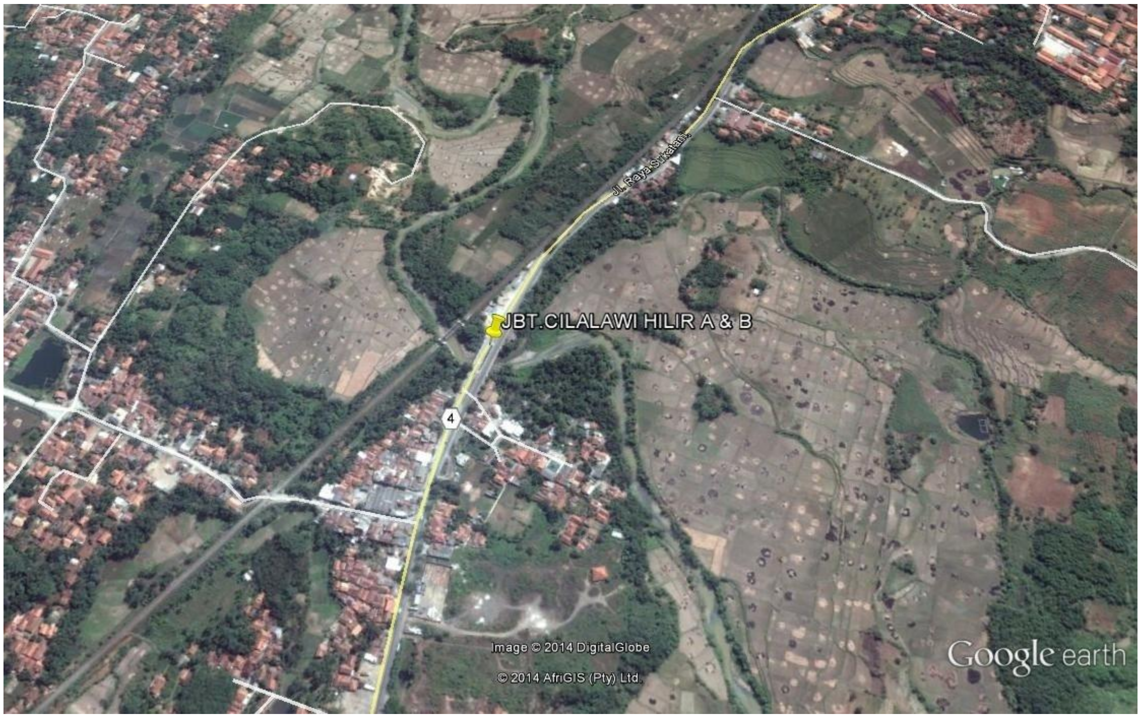

Figure B.1 Arial photograph of bridge location

Figure B.2 Front view of Cilalawi-A Bridge   **Figure B.3 Long view of Cilalawi-A Bridge**

Photographs of bridge element defects

Figure B.4 Waterways

Figure B.5 Scour Protection

Figure B.6 Embankment and channel

Figure B.7 Abutment

Figure B.8 Deck system

Figure B.11 Deck joint

Figure B.9 Bearing

Figure B.10 Railing

ATTACHMENT-C

NEW FORMS FOR BRIDGE INSPECTION

A Model Bridge Condition Inspection Forms

(Updated of BMS '92 Bridge Inspection Guideline)

Trial Test Form For:
I-Girder Bridge Structure

Bridge Condition Inspection Manual For I-Girder Bridge

(This form for single span only, used multiple forms for others)

Form C.1 Bridge Administration

Bridge Name		Bridge Number	
Road Name		Location Kilometer	
Inspected By		Latitude	
Inspection Date		Longitude	

Form C.2 Bridge Properties

<table>
<tr><th>Total Length (m)</th><th></th><th>Span Configuration (m)</th><th colspan="2"></th></tr>
<tr><td>Span Number of</td><td></td><td>Span Length (m)</td><td colspan="2"></td></tr>
<tr><td>Total Width (m)</td><td></td><td>Superstructure</td><td colspan="2"></td></tr>
<tr><td>Carriageway (m)</td><td></td><td>Abutmen/pier</td><td colspan="2"></td></tr>
<tr><td>Foundation</td><td></td><td rowspan="2">Vertical Clearance (m)</td><td>Navigation</td><td></td></tr>
<tr><td>Skew (rad)</td><td></td><td>Obstacle</td><td></td></tr>
</table>

Form C.3 Skecth/drawing

Form C.4 Level 4 element condition

Element code	Element type	Defect code	Defect type	S	R	K	F	P	Defect location
Superstructure:									
3.514	Deck-xx								
Abutment &/or Pier:									
3.321	Pile cap-xx								
Foundation:									
3.310	Pile-xx								
Embankment:									
3.231	Appr								
ScouringProtec.:									
3.225	Fender								

Form C.5 Level 3 element condition

Element code	Element type	Defect code	Defect type	S	R	K	F	P	$T_{\text{-Mark}}$
1	2	3	4	5	6	7	8	9	Σ (5–9)
Superstructure:									
3.514	Deck								
Abutment and/or Pier:									
3.321	Pile cap								
Foundation:									
3.310	Pile								
Embankment:									
3.231	Appr								
ScouringProtection.:									
3.225	Fender								

Form C.6 Bridge condition marks

Element Level-3	S	R	K	F	P	T_{-Mark}	%	B_{-Mark}
1	2	3	4	5	6	$7 = \Sigma\ (2\text{–}6)$	8	7 x 8
Superstructure:								
Deck							12	
Girder							16	
Diaphragm							4	
Expansion Joint							8	
Bearing							8	
Abutment and/or Pier:								
Pile-cap							12	
Abutment-wall/Pier-wall/column							8	
Wing Wall							4	
Pedestal							0	
Bracing Column							2	
Cross Head							2	
Foundation:								
Pile.Well							16	
Embarkment:								
Embankments							4	
Scour Protection:								
Scour Protection							4	
Waterway:								
Waterway							0	
General Bridge Mark (L-1)								

Attachments C1

Table C1.1 Bridge inspection sequence

Priority checked	Major Elements or Component	External	Internal
1	Waterways, Vegetation, Debris	1	
2	Flat Slab/Girder/Arch/Truss System		1
3	Deck system		2
4	Embankment	2	
5	Protection structure	3	
6	Abutment/Pier		3

Table C1.2 Element rating system

Parameter Evaluation	Criteria	Rating	
		No	Yes
S (Structure)	Are the defects harmful or otherwise?	0	1
R (Rating)	What is the level of defects, severe or mild?	0	1
K (Quantity)	Is the defect extensive (widespread) or localized? For example, the defect only affects to more less 50% of the length, width or volume of the element	0	1
F (Function)	Do these elements still function?	0	1
P (Effect)	Whether the elements defects seriously affect other elements or traffic flow?	0	1
Bridge Rating: Br = S + R + K + F + P		0	5

Table C1.3 Girder bridge element hierarchy (Level-1)

L-3 Main Element Code	Defect Code	S	R	K	F	P	L-4 Element	Defect Code	S	R	K	F	P	Defect location	Remarks
L-2 Superstructure:															Title L-2
Deck							Deck-xx								
Girder							Girder-xx								
Diaphragm							Diafragm-xx								
Expansion Joint							ExpJoint-xx								
Bearing							Bearing-xx								
L-2 Abutment &/or Pier:															Title L-2
Pile-cap							Pile-cap-xx								
Abutment-wall/pier-Wall							Abutment/pierWall-xx								
Wing-Wall							Wing Wall-xx								
Pedestal							Pedestal-xx								
Bracing Column							Column Bracing-xx								
Cross Head							Cross Head-xx								
L-2 Foundation:															Title L-2
Pile/Well							Pile/Well -xx								
L-2 Embankment:															Title L-2
Appr.Embank							Appr.Embank-xx								
Embank. Wall							Embank. Wall-xx								
Embank. Drainage							Embank. Drainage-xx								
L-2 ScouringProtection:															Title L-2
ScouringProtection							ScouringProtec.-xx								
Waterway:	**Defects on waterway are reflected to deteriorating of bridge elements**														**Title L-2**
Stream Bank							Stream Bank								
Main Channel							Main Channel								
Flood Plain							Flood Plain								

Note: -xx define as location of defects. Level 4 is the lowest level of hierarchy where the condition rating will directly contribute to the bridge marks.

Table C1.4 Element rating combination (Girder Bridge)

Major element of superstructure	S	R	K	F	P	C-Mark	Remedial action
Deck	0	0	0	0	0	0	-
	1	0	0	0	0	1	Routine
	1	1	0	0	0	2	Rehabilitation Minor
	1	0	1	0	0	2	Routine
	1	1	1	0	0	3	Rehabilitation
	1	1	1	0	1	4	Replacement
	1	1	1	1	1	5	Replacement
Girder	0	0	0	0	0	0	-
	1	0	0	0	0	1	Routine
	1	1	0	0	0	2	Rehabilitation Minor
	1	0	1	0	0	2	Routine
	1	1	1	0	0	3	Rehabilitation
	1	1	1	0	1	4	Strengthening
	1	1	1	1	1	5	Replacement
Diaphragm	0	0	0	0	0	0	-
	1	0	0	0	0	1	Routine
	1	1	0	0	0	2	Rehabilitation
	1	0	1	0	0	2	Routine
	1	1	1	0	0	3	Rehabilitation
	1	1	1	1	0	4	Replacement
Expansion Joint	0	0	0	0	0	0	-
	1	0	0	0	0	0	Routine
	1	0	0	0	1	2	Rehabilitation
	1	1	0	0	1	3	Rehabilitation
	1	1	1	0	1	4	Rehabilitation
	1	1	1	1	1	5	Replacement
Bearing	0	0	0	0	0	0	-
	1	1	0	0	1	3	Rehabilitation
	1	1	1	0	1	4	Rehabilitation
Pile-cap	0	0	0	0	0	0	-
	1	0	1	0	o	2	Rehabilitation
	1	1	0	0	0	2	Rehabilitation
	1	0	1	0	0	2	Routine
	1	1	1	0	0	3	Rehabilitation
Abutment/pier-Wall	0	0	0	0	0	0	-
	1	0	0	0	0	1	Routine
	1	0	1	0	0	2	Routine
	1	1	0	0	0	2	Routine
	1	1	1	0	0	3	Rehabilitation
	1	1	1	1	0	4	Rehabilitation
	1	1	1	0	0	3	Rehabilitation
Wing Wall	0	0	0	0	0	0	-

Major element of superstructure	S	R	K	F	P	C-Mark	Remedial action
	1	0	1	0	0	2	Routine
	1	1	0	0	0	2	Routine
Column Bracing	0	0	0	0	0	0	-
	1	0	1	0	0	0	Routine
	1	1	0	0	0	2	Routine
	1	1	1	0	0	3	Rehabilitation
	1	1	1	0	0	3	Rehabilitation
Cross Head	0	0	0	0	0	0	-
	1	0	1	0	0	2	Routine
	1	1	0	0	0	2	Routine
	1	1	0	0	0	3	Rehabilitation
Pedestal	0	0	0	0	0	0	-
	1	1	0	0	0	2	Routine
	1	1	0	0	0	2	Routine
Pile/Well	0	0	0	0	0	0	-
	1	1	0	0	0	2	Routine
	1	0	1	0	0	2	Routine
	1	1	1	0	0	2	Routine
	1	1	1	0	0	3	Rehabiliation
	1	1	0	1	0	3	Rehailitation
	1	1	1	0	0	3	Rehabilitaion
Scour Protection	0	0	0	0	0	0	-
	1	0	1	0	0	2	Routine
	1	1	0	0	0	2	Routine
	1	1	1	0	0	3	Rehabilitation
Approach Slab	0	0	0	0	0	0	-
	1	1	0	0	0	2	Rouine
	1	0	1	0	0	2	Routine
Embankment Wall	0	0	0	0	0	0	-
	1	0	1	0	0	2	Routine
	1	1	1	0	0	3	Rehabiiation
	1	1	1	1	0	4	Rehabiltaiton
Embankmentdrainag	0	0	0	0	0	0	-
	1	0	0	0	0	1	Routine
	1	1	0	0	0	1	Routine

Table C1.5 A model of bridge element hierarchy (leads to bridge condition)

ELEMENT CODES								
CODE	LEVEL 1	CODE	LEVEL 2		CODE	LEVEL 3	CODE	LEVEL 4
1,000	Bridge	2,200	Waterway		3,211	Stream Bank	4,211	Stream Bank -xx
					3,212	Main channel	4,212	Main channel -xx
					3,213	Flood Plain	4,213	Flood Plain -xx
		2,221	Scour Protection Type	Groyne	3,221	Groyne -xx		
		2,222		Gabion	3,222	Gabion -xx		
		2,223		Concrete Lining	3,223	Concrete Lining -xx		
		2,224		Rock Beaching	3,224	Rock Beaching -xx		
		2,225		Sheet Pilling	3,225	Sheet Pilling -xx		
		2,226		Fender System	3,226	Fender System -xx		
		2,227		Retaining Wall	3,227	Retaining Wall -xx		
		2,228		Riverbed Controller	3,228	Riverbed Controller -xx		
		2,230	Embankment		3,231	Approach Embankment	4,231	Approach Embankment -xx
					3,232	Embankment Drainage	4,232	Embankment Drainage -xx
					3,233	Pavement	4,233	Pavement -xx
		2,310	Foundation Type	Pile	3,310	Pile -xx		
		2,311		Well foundation (Caisson)	3,311	Well foundation (Caisson) -xx		
		2,312		Spread Footing	3,312	Spread Footing -xx		
		2,313		Anchor	3,313	Anchor -xx		
		2,314		Arch Thrust-Block	3,314	Arch Thrust-Block -xx		
		2,320	Abutment/Pier		3,321	Pile Cap	4,321	Pile Cap -xx
					3,322	Abutment Wall/Pier-Column Wall	4,322	Abutment Wall/Pier-Column Wall -xx
					3,323	Wing Wall	4,324	Wing Wall -xx
					3,324	Crosshead	4,325	Crosshead -xx
					3,326	Bracing (Column)	4,327	Bracing (Column) -xx
					3,327	Weephole	4,328	Weephole -xx
		2,400	Superstructures	Flat Slab	3,410	Slab		
		2,500		Girder	3,510	Girder (main)	4,510	Girder (main) -xx
					3,511	Cross Beam (Girder)	4,511	Cross Beam (Girder) -xx
					3,512	Diaphragm (Girder)	4,512	Diaphragm (Girder) -xx
					3,513	Bracing (Grider)	4,513	Bracing (Grider) -xx
					3,514	Deck	4,514	Deck -xx
					3,515	Deck Joint	4,515	Deck Joint -xx
					3,516	Bearings	4,516	Bearings -xx
		2,600		Arch Stone	3,610	Barrel		
					3,611	Spardeal Wall		
		2,700		Trusses	3,710	Chord Top	4,710	Chord Top -xx
					3,711	Chord Bottom	4,711	Chord Bottom -xx
					3,712	Vertical (Truss)	4,712	Vertical (Truss) -xx
					3,713	Lateral Bracing Top (Truss)	4,713	Lateral Bracing Top (Truss) -xx
					3,714	Lateral Bracing Bottom (Truss)	4,714	Lateral Bracing Bottom (Truss) -xx
					3,715	Diaphragm (Truss)	4,715	Diaphragm (Truss) -xx
					3,716	Cross Bottom	4,716	Cross Bottom -xx
					3,717	Stringer	4,717	Stringer -xx
					3,718	Deck	4,718	Deck -xx
					3,719	Deck Joint	4,719	Deck Joint -xx
					3,720	Bearings	4,720	Bearings -xx
		2,800		Beam Arch	3,810	Arch Beam	4,810	Arch Beam -xx
					3,811	Vertical (Beam Arch)	4,811	Vertical (Beam Arch) -xx
					3,812	Cross Beam (Beam Arch)	4,812	Cross Beam (Beam Arch) -xx
					3,813	Bracing	4,813	Bracing -xx
					3,814	Girder (Main)	4,814	Girder (Main) -xx
					3,815	Cross Beam (Girder)	4,815	Cross Beam (Girder) -xx
					3,816	Diaphragm (Girder)	4,816	Diaphragm (Girder) -xx
					3,817	Deck	4,817	Deck -xx
					3,818	Deck Joint	4,818	Deck Joint -xx
					3,819	Bearings	4,819	Bearings -xx
		2,910	Culvert Type	Culverts	3,911	Box Culvert		
					3,912	Pipe Culvert		
					3,913	Pipe Arch Culvert		
		2,920	Wet Crossing		3,921	Paved Crossing		
					3,921	Unowed River Crossing		
					3,922	Ferry		

Table C1.6 Material defect codes

Defect Code	Material and defect
	MASONRY
101	Deterioration and cracking
102	Bulging or change of shape
103	Broken or missing material
	CONCRETE
201	Defective concrete including spalling, honeycombing,drumminess,
202	Cracking
203	Corrosion of steel reinforcement
204	Worn, weathered, aged or deteriorated concrete
205	Broken or missing material
206	Deflection
	STEEL
301	Deterioration of corrosion protection
302	Corrosion
303	Deformation
304	Cracking
305	Broken or missing element
306	Incorrect element
307	Frayed cables
308	Loose connection
	TIMBER
401	Defective timber due to rot, insect attack, splitting,crookedness, knots
402	Broken or missing element
403	Shrinkage
404	Deterioration of surface protection
405	Loose element

Table C1.7 Element defect codes

Defect Code	Elements and defects
	WATERWAY
501	Siltation
502	Debris accumulation and obstruction of the waterway
503	Scour
504	Excess afflux
	SCOUR PROTECTION
511	Missing material
	EMBANKMENTS
521	Scour
522	Cracking/settlement/bulging of fill
	REINFORCED EARTH
531	Bulging of facing panels
532	Cracking/spalling/breaking of panels
	ANCHORS
541	Instability
	ABUTMENTS/PIERS
551	Movement

Defect Code	Elements and defects
	EARTHQUAKE RESTRAINT BLOCK
561	Loose or missing element
	BEARING
601	Loss of movement ability
602	Improper seating
603	Cracked or spalled mortar pad
604	Excessive movement or deformation
605	Defective material including aged, split torn, cracked or broken bearings
606	Loose parts
607	Dry metal bearing
	SLAB AND DECKING
701	Excess movement in longitudinal deck joint
702	Excessive deflection
	WEEP HOLES/SCUPPERS/DECK DRAINAGE
711	Blocked scuppers and weep holes
712	Missing Material
	RUNNING SURFACE
721	Slippery surface
722	Potholed/rough/cracked surface
723	Heaving/rutting of pavement
724	Excessive overlay
	FOOTWAY AND KERBS
731	Slippery footway
732	Potholed/rough/cracked footway
733	Missing Material
	DECK JOINTS
801	Rough/uneven joints
802	Loss of movement ability
803	Loose parts/loss of adhesion, Broken/Missing Parts, Cracked asphalt due to joint movement
	GAUGES
901	Damaged/Missing gauges
	ROAD SIGN AND MARKING
911	Aged or worn material
912	Missing Element
	LIGHTING, POLES AND CONDUITS
921	Aged or deteriorated materials
922	Missing materials
	UTILITIES
931	Malfunction

Table C1.8 Defect assessment guideline

DEFECTS IN MASONRY ELEMENTS						
Code	Appearance	Cause	Nature Mark S	Criteria for Assessment	Degree Mark R	Unit of Measurement
101	Deterioration	Aging Impact Erosion Poor material quality	Harmful	Stone/bricks Mortar ≤ 20 mm deep > 20 mm deep	Heavy Light Heavy	m^2
	Cracking	Foundation failure Movement Overload Vegetation Vibration	Harmful Harmful Harmful Harmful Harmful	Mortar ≤ 5 mm wide > 5 mm wide	Light Heavy	
102	Bulging and changing shape	Foundation failure Overloading	Harmful Harmful	> 40 mm outward movement of face and/or < 750 mm long > 750 mm long	Heavy Light Heavy	m^2
103	Broken or missing material	Any	Harmful	Non-structural element Structural element	Light Heavy	m^3

DEFECTS IN CONCRETE ELEMENTS (INCLUDING REINFORCEMENT)						Unit of Measurement
Code	Appearance	Cause	Nature Mark **S**	Criteria for Assessment	Degree Mark **R**	
201	Spalling Honeycombing Drumminess Poor quality	Carbonation Impact Insufficient cover Overloading Poor workmanship Prestressing force Volumetric expansion Chemical attack	Harmless Harmless Harmful Harmful Harmless Harmful Harmful Harmful	 Reinforcement not visible Reinforcement visible Visible leaching	 Light Heavy Heavy	m^2 or m^3
202	Cracking	Overloading	Harmful	≤ 0.2 mm wide > 0.2 mm wide Visible leaching or seepage	Light Heavy Heavy	m or m^2
		Carbonation Impact Foundation failure Prestressing force Shrinkage Vegetation Volumetric expansion	Harmless Harmful Harmful Harmful Harmless Harmful Harmful	Visible leaching or seepage ≤ 0.4 mm wide > 0.4 mm wide	Heavy Light Heavy	
203	Corrosion of steel reinforcement	Any	Harmful	≤ 10% of cross section > 10% of cross section	Light Heavy	m or m^2
204	Worn, weathered or aged (Deterioration)	Abrasion Aging Chemical attack Impact Poor workmanship Volumetric expansion	Harmful	≤ Cover layer > Cover layer	Light Heavy	m^2 or m^3
205	Broken or missing material	Any	Harmful	Structural element Non-structural element	Heavy Light	m^2 or m^3
206	Deflection	Impact Foundation failure Overloading	Harmful	Slabs ≤ 1 in 600 > 1 in 600 Other Elements ≤ 20 mm > 20 mm	 Light Heavy Light Heavy	m^3

DEFECTS IN STEEL ELEMENTS						Unit of Measurement
Code	Appearance	Cause	Nature Mark S	Criteria for Assessment	Degree Mark R	
301	Deterioration of Corrosion Protection	Aging Cracks Dampness Vandalism Wearing	Harmful Harmless Harmful Harmless Harmful	No visible steel surface Visible steel surface	Light Heavy	m^2
302	Corrosion	Any	Harmful	≤ 10% of dimension > 10% of dimension	Light Heavy	m^2
303	Deformation	Impact Foundation failure Heat Overloading	Harmful	For structural elements ≤ 20 mm > 20 mm For non-structural elements	Light Heavy Light	m of member
304	Cracking	Any	Harmful	Any	Heavy	m
305	Broken or Missing element	Any	Harmful	Non-structural element Structural element	Light Heavy	m of member
306	Incorrect element	Any	Harmful	Not undersized Undersized	Light Heavy	m of member
307	Frayed cables	Any	Harmful	≤ 5% of strands > 5% of strands	Light Heavy	m of member
308	Loose connection	Any	Harmful	Any	Heavy	no. of fixings

DEFECTS IN TIMBER ELEMENTS

Code	Appearance	Cause	Nature Mark S	Criteria for Assessment	Degree Mark R	Unit of Measurement
401	Rot	Dampness	Harmful	$\leq$ 15% of section affected > 15% of section affected	Light Heavy	m or m² or m³
	Insect attack	Infestation	Harmful			
	Splitting/ Splintering	Aging Drying out Imperfect material Overloading	Harmful Harmless Harmful Harmful	Splits < 10 mm wide and/or < 1 m long Otherwise	Light Light Heavy	
	Crookedness	(For compression) Imperfect material Overloading (For tension)	Harmful Harmless	Deviation $\leq$ 50 mm in 3m Deviation > 50 mm in 3m	Light Heavy	
	Knots, sloping grain	Imperfect material	Harmful	Knot dimension $\leq$ 15% of section Knot dimension > 15% of section Sloping grain $\leq$ 1 in 16 Sloping grain > 1 in 16	Light Heavy Light Heavy	
402	Broken or missing element	Any	Harmful	Non-structural elements Structural elements	Light Heavy	m or m³
403	Shrinkage	Poor quality	Harmless	$\leq$ 50 mm deflection in a truss > 50 mm deflection in a truss Any in other structure	Light Heavy Light	member or m³
404	Deterioration of surface protection	Aging Vandalism Wearing	Harmful	Non-structural element. No visible protection coating on timber surface on structural element	Light Heavy	m²
405	Loose element	Any	Harmful	Any	Heavy	no. fixings

DEFECTS IN PARTICULAR ELEMENTS: 3.210 - WATERWAY

Code	Appearance	Cause	Nature Mark S	Criteria for Assessment	Degree Mark R	Unit of Measurement
501	Siltation	Water current	Harmful	$\leq$ 20% reduction of waterway > 20% reduction of waterway	Light Heavy	m³
502	Debris accumulation and obstruction	Deposition	Harmful	< 20% reduction of waterway > 20% reduction of waterway and/or < 20% height at pier > 20% height at pier Otherwise	Light Heavy Light Heavy	m³
503	Scour	Water current	Harmful	$\leq$ foundation level or 6 times pile diameter Otherwise	Light Heavy	m² or m³
504	Excessive afflux	Rainfall Inadequate bridge length	Harmful	$\leq$ 250 mm > 250 mm	Light Heavy	m

DEFECTS IN PARTICULAR ELEMENTS: 3.220 - SCOUR PROTECTION, 3.230 - EMBANKMENTS AND 3.310 - FOUNDATIONS						Unit of Measurement
Code	Appearance	Cause	Nature Mark S	Criteria for Assessment	Degree Mark R	
511	Missing material	Any	Harmful	≤ 10% > 10%	Light Heavy	m³
521	Scour	Water current	Harmful	No undermining Undermining	Light Heavy	m³
522	Crack	Any	Harmless		Light	m³ or m² or Special Inspection
	Settlement	Any	Harmful	Surface lower than foundation level or 6 x pile dimension Otherwise	Heavy Light	
	Bulging	Any	Harmful	≤ 300 mm > 300 mm	Light Heavy	

DEFECTS IN PARTICULAR ELEMENTS: 4.235 - REINFORCED EARTH						Unit of Measurement
Code	Appearance	Cause	Nature Mark S	Criteria for Assessment	Degree Mark R	
531	Bulging facing panels	Anchorages pulling out	Harmful	Any	Heavy	m²
532	Cracking, spalling or breaking	Anhorages failing	Harmful	Any	Heavy	m²
		Impact Movement Vandalism	Harmless	> 3 panels or > 10% of facing defective Otherwise	Heavy Light	

DEFECTS IN PARTICULAR ELEMENTS: 4.314 - ANCHOR						Unit of Measurement
Code	Appearance	Cause	Nature Mark S	Criteria for Assessment	Degree Mark R	
541	Instability	Overloading Poor construction	Harmful	Any	Heavy	Special Inspection

DEFECTS IN PARTICULAR ELEMENTS: 3.320 - ABUTMENTS/PIERS						Unit of Measurement
Code	Appearance	Cause	Nature Mark S	Criteria for Assessment	Degree Mark R	
551	Movement	Overturning Rotation Settlement Tilting	Harmful Harmful Harmful Harmful	Rotation < 1 in 12 in vertical plane Settlement < 50 mm No noticiable transverse (sideways) tilting Otherwise	Light Light Light Heavy	Special Inspection

DEFECTS IN PARTICULAR ELEMENTS: 4.326 - EARTHQUAKE RESTRAINT BLOCK						Unit of Measurement
Code	Appearance	Cause	Nature Mark S	Criteria for Assessment	Degree Mark R	
561	Loose	Any	Harmful	Any	Heavy	M^3
	Missing	Any	Harmful	Any	Heavy	

DEFECTS IN PARTICULAR ELEMENTS: 3.610 - BEARINGS						Unit of Measurement
Code	Appearance	Cause	Nature Mark S	Criteria for Assessment	Degree Mark R	
601	Loss of movement ability	Any	Harmful	Any	Heavy	no.
602	Improper seating	Any	Harmful	< 2mm gap > 2 mm gap > ⅓ of correct bedding area < ⅓ of correct bedding area	Light Heavy Light Heavy	no.
603	Crack or spalling in mortar pad	Any	Harmful	≤ 15% defective > 15% defective	Light Heavy	no.
604	Excessive movement	Any	Harmful	≥ 30 mm still possible < 30 mm still possible	Light Heavy	no.
	Excessive deformation	Any	Harmful	≤ 20% of depth of bearing > 20% of depth of bearing	Light Heavy	
605	DEFECTIVE MATERIAL Aged	Any	Harmless	≤ 25% through section > 25% through section	Light Heavy	no.
	Split, torn or cracked rubber bearing	Any	Harmless	≤ 2 mm wide > 2 mm wide	Light Heavy	
	Broken or missing parts	Any	Harmful	Any	Heavy	
606	Loose parts	Any	Harmful	Any	Heavy	no.
607	Dry metal bearing	Poor lubrication	Harmful	Any	Heavy	no.

DEFECTS IN PARTICULAR ELEMENTS: 4.421 - SLAB AND 4.502 - DECKING						Unit of Measurement
Code	Appearance	Cause	Nature Mark **S**	Criteria for Assessment	Degree Mark **R**	
701	Excessive Movement in longitudinal deck joint	Any	Harmful	Any	Heavy	m
702	Excessive deflection	Any	Harmful	≤ span/200 > span/200	Light Heavy	m^2

DEFECTS IN PARTICULAR ELEMENTS: 4.329 - WEEP HOLE, 4.507 - SCUPPER						Unit of Measurement
Code	Appearance	Cause	Nature Mark **S**	Criteria for Assessment	Degree Mark **R**	
711	Blocked	Any	Harmful	Any	Heavy	no.
712	Missing material	Any	Harmful	Any	Heavy	no.

DEFECTS IN PARTICULAR ELEMENTS: 4.505 - RUNNING SURFACE						Unit of Measurement
Code	Appearance	Cause	Nature Mark **S**	Criteria for Assessment	Degree Mark **R**	
721	Slippery	Any	Harmful	Skidding on surface No skidding	Heavy Light	m^2
722	Potholed/Rough	Any	Harmless	≤ 20 mm deep > 20 mm deep	Light Heavy	m^2
	Crack	Any	Harmless	≤ 20 mm deep > 20 mm deep	Light Heavy	m^2
723	Heaving (rutting)	Any	Harmless	≤ 20 mm deep > 20 mm deep	Light Heavy	m^2
724	Excessive overlay	Any	Harmful	≤ 100 mm thick ≥ 100 mm thick	Light Heavy	m^2

DEFECTS IN PARTICULAR ELEMENTS: 4.506 - FOOTWAY/KERB						Unit of Measurement
Code	Appearance	Cause	Nature Mark S	Criteria for Assessment	Degree Mark R	
731	Slippery	Any	Harmful	Skidding on surface No skidding	Heavy Light	m^2
732	Potholed	Any	Harmless	≤ 20 mm deep > 20 mm deep	Light Heavy	m^2
733	Missing material	Any	Harmful	Any	Heavy	m^2

DEFECTS IN PARTICULAR ELEMENTS: 3.600 - DECK JOINTS						Unit of Measurement
Code	Appearance	Cause	Nature Mark S	Criteria for Assessment	Degree Mark R	
801	Uneven	Any	Harmless	≤ 30 mm variation in level > 30 mm variation in level	Light Heavy	m
802	Loss of movement ability	Any	Harmful	Span < 25 m Span > 25 m If pavement heaving at joint > 25 mm Otherwise	Light Heavy Heavy Light	m
803	Loose parts	Any	Harmful	Any	Heavy	m
	Loss of adhesion	Any	Harmless	≤ 25% of adhesion lost > 25% of adhesion lost	Light Heavy	
805	Broken or missing parts	Any	Harmful	Any	Heavy	m
806	Cracked asphalt due to joint movement	Any	Harmless	≤ 15 mm > 15 mm	Light Heavy	m

DEFECTS IN PARTICULAR ELEMENTS: 4.701 - GAUGE						Unit of Measurement
Code	Appearance	Cause	Nature Mark S	Criteria for Assessment	Degree Mark R	
901	Broken or missing parts	Any	Harmful	Any	Heavy	m

DEFECTS IN PARTICULAR ELEMENTS: 4.711 - ROAD SIGN, 4.712 - ROAD MARKING AND 4.713 - NO. PLATE						Unit of Measurement
Code	Appearance	Cause	Nature Mark S	Criteria for Assessment	Degree Mark R	
911	Wearing	Any	Harmless	> 25% non effective ≤ 25% non effective	Heavy Light	no. or m
912	Missing material	Any	Harmless	If bridge No. plate or statue Otherwise	Light Heavy	no. or m

DEFECTS IN PARTICULAR ELEMENTS: 4.721 - LIGHTING, 4.722 - LIGHTING POST AND 4.723 - POWER CONDUIT						Unit of Measurement
Code	Appearance	Cause	Nature Mark S	Criteria for Assessment	Degree Mark R	
921	Aged material Deterioration	Any	Harmless	> 25% deteriorated ≤ 25% deteriorated	Heavy Light	no. or m
922	Missing material	Any	Harmless	Danger of electrocution Otherwise	Heavy Light	no. or m

DEFECTS IN PARTICULAR ELEMENTS: 4.731 - UTILITIES						Unit of Measurement
Code	Appearance	Cause	Nature Mark S	Criteria for Assessment	Degree Mark R	
931	Malfunction	Any	Harmless	Dangerous	Heavy	m