Australian Earthquake Engineering Society
2023 National Conference, 23-25 November 2023
Brisbane, Queensland, Australia

Structural Monitoring of Bumbu and Butibam Bridges of Lae City, Papua New Guinea

[1]Grace Wantepe and [2]Mirzi L Betasolo[*], [3]Nicholas Lambrache
Department of Civil Engineering Papua New Guinea University of Technology
[1]grace.wantepe@pnguot.ac.pg
[3]nicholas.lambrache@pnguot.ac.pg

[*]*Corresponding author:* [2]*mirzi.betasolo@pnguot.ac.pg*

Abstract

Bridge inspection and condition assessment are essential in any Bridge Management System (BMS), particularly for aged and deteriorated bridges. The majority of the bridges of Papua New Guinea (PNG) have exceeded their design lives and are at risk of collapse, knowing that the country is tectonically active. Bridge condition assessment and management are crucial to maintaining and preserving them from deteriorating. A significant part is bridge condition rating and simulation, an essential aspect in their service lives to forecast bridge durability and their need for repair and maintenance. The study establishes three levels of bridge inspection and condition assessment forms for the steel girder bridges for Bumbu and Butibam Bridges of Lae City in the Morobe Province of PNG. The bridge evaluation and condition assessment emanate from visually recorded inspection data. Three critical factors in evaluating bridge element structural index condition assessment are structural importance, material vulnerability, and casual factors such as road class, age, environment, and inspection. These parameters were adopted, and the causal factors were implemented as a coefficient to the overall structural index, which illustrates the capability of the developed forms. Moreover, the results from the developed forms are applied and used to evaluate the current stage of the steel girder bridges of Bumbu and Butibam of Lae City. The results reflect the actual condition of the bridges.

Keywords: earthquake, risk, bridge health monitoring, inspection forms, infrastructure

1 Introduction

The road network system in Papua New Guinea (PNG) is playing a significant role in the economic growth of the country. PNG is a country known for its rugged physical topography and landscape, where roads comprise most of the land transport system. Given the country's rough terrain, it is challenging to travel any distance without crossing a bridge structure. As stated by Badran (2013), the health and prosperity of transportation infrastructures are essential tools for measuring national growth, where transportation networks play a pivotal role in

the movement of people, goods, and services. Hence, bridges provide linkages for moving people, goods, and services from production areas to markets and ensure efficient service delivery between centers. According to Cardno Emerging Markets (2011), most of the bridge stock in PNG along the major roads or highways was constructed before Independence in 1975 by the Australian Government. Even more new bridges have been built under the 'Yumi Yet' Bridge Project after the Independence of the Government of PNG (GoPNG).

Steel Girder Bridges are common on national roads and highways of PNG because girders are efficiently designed and constructed to carry the maximum T44 (44 tonnes) vehicle load (AS 5100 (2004)). However, in the remote areas and districts of PNG, depending on road use, bridges are designed for the appropriate loading conditions (vehicle loads). Nevertheless, due to lack of proper maintenance, the steel girders of a bridge suffer different degrees of damage at different positions of a bridge as they are exposed to environmental influences, where fatigue due to corrosion remains a significant concern for safety and durability, especially for those located close to marine environments. For instance, the Bumbu and Butibam bridges are located at a lower altitude and very close to the sea, which requires constant monitoring of bridge steel components. Figure 1 shows the location of the Bumbu and Butibam bridges in the industrial heart of Lae City at an altitude of 55m and close to the sea. These bridges were constructed in 1973 and 1997, respectively, and the Bumbu bridge is the oldest at 47 years old.

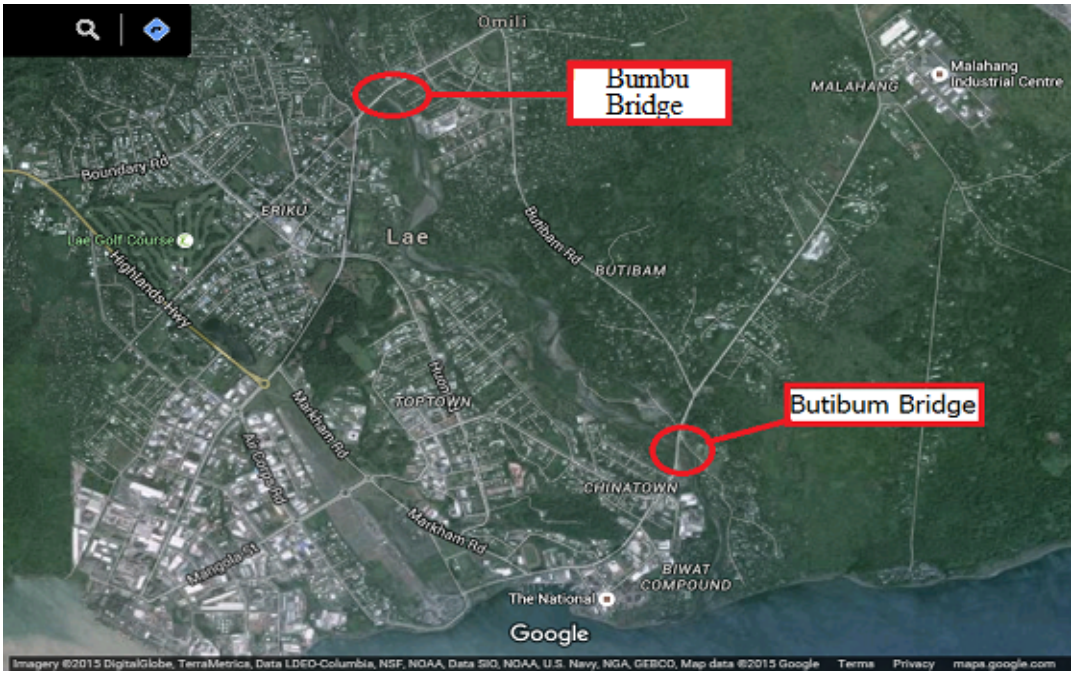

Figure 1. Satellite view showing the location of Bumbu and Butibam Bridge of Lae City

Lae City is undergoing increased developments in infrastructure, which is mainly influenced by the operation of mine sites, the establishment of significant

mackerel and tuna manufacturing plants, the recently completed new Lae Port (Tidal Basin), and the construction of the four-lane road from Lae to Nadzab Airport. There are about 3.5 billion Kina worth of goods moving every day at the Lae Port. Industrial activities in Lae City are high, and the province is leading PNG with many industries and manufacturing companies. These projects are having a significant impact on the existing road system, and there is a high use of heavy commercial vehicles on roads and bridges. Employment in Lae is 10% from freight transportation and warehousing and 30% from manufacturing (Konzang, 2013). According to Konzang (2013), every day, more than 600 vehicles cross the Bumbu and Butibam, including heavy vehicles with six axles. Moreover, the recent developments are having a significant impact on the road network system, with traffic congestion due to the increasing number of people in the city. Bumbu and Butibam Bridge are on the primary road network of the city and link residential, industrial, commercial, and the university to the city Centre. Hence, monitoring the safe performance of a bridge is essential for the smooth and effective movement of people, goods, and services.

Moreover, PNG is located in a seismically active region due to its position along the Pacific Ring of Fire, making it prone to earthquakes and tectonic activities. Seismicity in PNG varies across different regions, and Lae City, being situated in the Morobe Province, experiences its share of seismic events. The seismic hazard in this area is influenced by the tectonic plate boundaries and geological features. In Lae City, the seismicity is primarily associated with the Pacific Plate subducting beneath the Indo-Australian Plate. This subduction zone, known as the New Britain Trench, is a significant source of seismic activity in the region. Earthquake in this area vary in magnitude and depth, leading to potential ground shaking and ground deformation.

Specific seismic hazard values for bridges in Lae City, such as Bumbu and Butibam Bridges, would require detailed seismic hazard assessments. These assessments would involve analyzing historical earthquake data, local geological conditions, fault lines, and ground motion predictions to estimate the seismic forces that bridges may experience during an earthquake event.

Bridge infrastructures are designed for a maximum service life. Hence, the design of bridges in PNG is for a maximum life span of 50 years and a 1 in a 100-year flood according to Australian and PNG Bridge Design Standards and codes. Most PNG bridges were constructed in colonial times and need more inspection and maintenance. Monitoring a bridge improves knowledge and understanding of in-situ structural behavior, detects damage at its onset, assures owners of the structure's strength and serviceability, reduces downtime, and results in improved maintenance practices and management of limited resources.

2 Materials & Methods

The conceptual framework for the development of the Steel Girder Condition Assessment Forms (SGBCAF) is presented below in Figure 2.

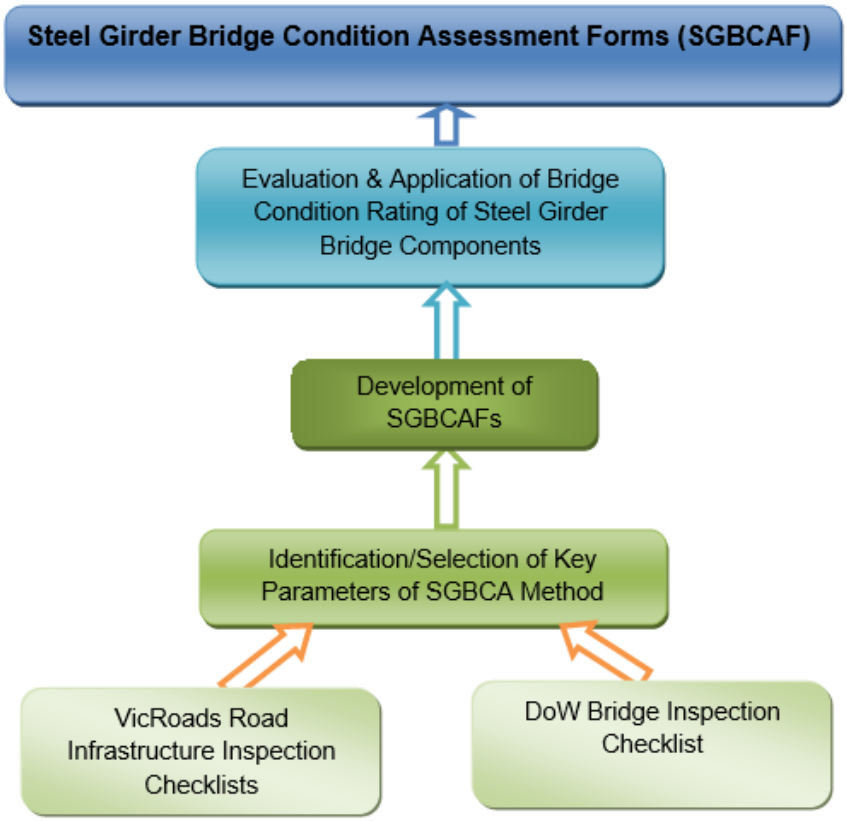

Figure 2. Conceptual Framework of SGBCAF Assessment Form

2.1 Steel Girder Condition Assessment (SGBCA) Method

The SGBCA study workflow in Figure 3 is categorized into three levels: Level 1 Routine Inspection and Condition Assessment, Level 2 Bridge Structure Detailed Inspection and Condition Rating, and Level 3 Engineering Analysis and Safety Evaluation. The SGBCA levels were adopted and implemented after the Australian State Bridge Inspection Manuals literature review, including the VicRoads Roads Structures Inspection Manual (2011).

5

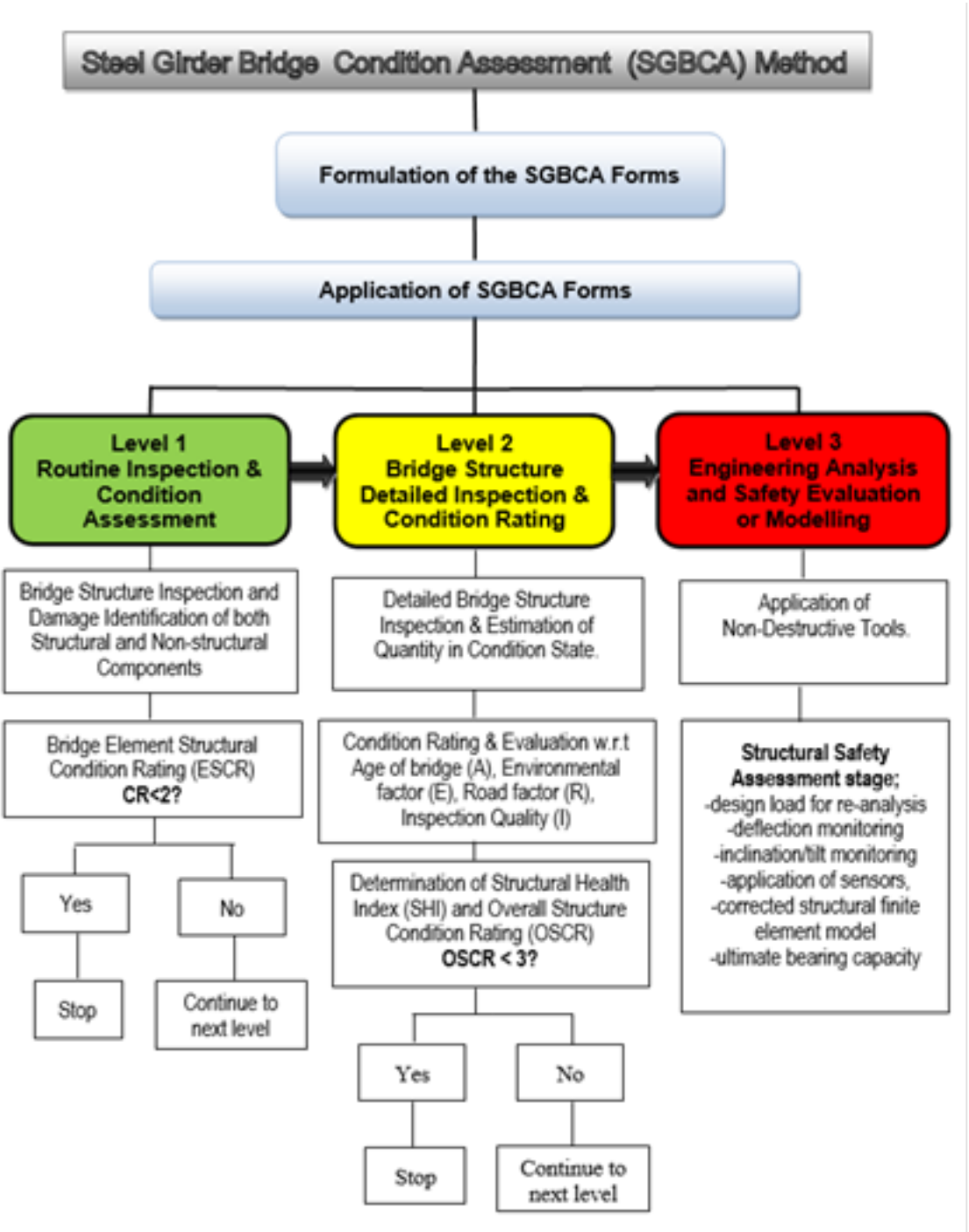

Figure 3. Conceptual Framework

The authors developed new condition assessment forms that include key parameters identified in the VicRoads Road Infrastructure Inspection Manual and the DOW Bridge Inspection Data Collection Form. The newly developed forms incorporate all the desired parameters as outlined, but most importantly, the document includes several new features for bridge condition rating. These new parameters are the Overall Structural Condition Index (OSCI), Structural Health

Index (SHI), and Priority Index (PI). The authors adopted the new parameters used in the study from Rashidi and Gibson (2011), which illustrates a sound methodology for developing an element-based structural index where the OSCI value would help decision-makers understand and compare the conditions of bridges in a network. Moreover, that kind of bridge condition assessment is most applicable to bridges under this study as well as all other bridges in Lae City and PNG.

3 Results & Discussion

The forms developed for this study are most reliable and applicable for steel girder bridge elements in PNG because of three critical parameters considered in developing the forms. The first important parameter incorporated in the evaluation is the material vulnerability factor, which ranges between 1 (steel) and 4 (precast concrete), including 5 (other materials. The other significant parameter is the structural significance factor. For instance, a minor component with a worse condition may unreasonably raise the rating value of that element. This kind of problem was dealt with through the introduction of element structural significance, which the prevailing condition of components was not dependent on (Samal & Ramajaneyulu, 2008). The third parameter incorporated in the forms is the causal factor, which contributes to the structural efficiency of the steel girder bridge. The structural elements of a steel girder bridge deteriorate over time, and the rate of deterioration depends on various parameters. These parameters include the environment the structure is located in, the number of years in service (Age), the function the structure is required to perform (Road Class), and the quality of inspection and assessment. The developed form is shown in Figure 4, Level 1-Bridge Inspection & Condition Assessment Form.

There were two condition-level assessment forms developed for Level 1: bridge condition assessment and condition rating. The first form was used to collect general information on the two bridges since no bridge data was available. The second form was used to rate the condition of the identified states of the bridge component using the condition rating criteria. The Level 1 forms were used to check out the initial condition status of structural and non-structural bridge components, and any visible damages such as cracks, material deterioration, and foundation settlement were recorded. The condition checklist results from this

7

L1 ROUTINE MONITORING INSPECTION & CONDITION ASSESSMENT DATA COLLECTION FORM — **LEVEL 1 BRIDGE MONITORING**

BRIDGE LOCATION		**General Bridge Information**	
Bridge Name:	Bridge ID:	Bridge construction type:	Year of construction:
Road Name:	Road Number:	Inspection Type:	
Latitude:	Longitude:	Overall Length (m):	Number of Spans:
Altitude:	Map Reference:	Waterway Clearance (m):	
Province:	District:	Kerb to kerb width (m):	
Weather:	Date:	Clear Vehicle Width (m):	Walkway Width (m):
Inspector's Name:		Estimated Vehicles per day:	
SPAN DATA		**ABUTMENT DATA:**	
Main Member Type:		Abutment Type:	
Secondary Member Type:		Abutment Material:	
Other Member Type:		Abutment Foundation:	
Deck Material:		Bearing Type - Abutment:	
Deck Wearing Surface (DWS):		Restraint Type - Abutment:	
Deck Drainage:	Parapet:	Scour Protection - Abutment:	
Expansion Joint Type		Bank/Slope Protection:	
PIER DATA		**MISCELLANEOUS DATA**	
Pier Type:		Design Load (Tonnes):	Safe Speed Limit (km/h):
Pier Material:		Posted Load Limit (Tonnes):	
Pier Foundation Type:		Guardrailings:	
Piers Bearing Type:		River Training Type:	
Piers Restraint Type:		Soil Type:	
PIER Scour Protection:		Embankment/Riverbed (erosion/ scour/landslid):	Yes / No / DNK

BRIDGE CONDITION CHECKLIST

Condition of Steel Girders
- ☐ Satisfactory
- ☐ Minor Corrosion Deterioration
- ☐ Major Corrosion Deterioration
- ☐ Requires Level 2 Inspection

Condition of Concrete
- ☐ Satisfactory
- ☐ Minor Deterioration
- ☐ Major Deterioration - Level 2 Inspection Required

Condition of Piers, Abutments and Wings
- ☐ Satisfactory
- ☐ Back Slabs Gaping
- ☐ Requires Minor Repairs
- ☐ Requires Major Repair or Correction (give details)

Condition of Handrail and Kerbs
- ☐ Satisfactory
- ☐ Requires Tightening or Straightening
- ☐ Requires Painting
- ☐ Requires Minor replacement (give details).
- ☐ Requires Major Replacement (give details).

Condition of Guard Fencing or Guardrails
- ☐ Satisfactory
- ☐ Requires Painting
- ☐ Requires Repairs
- ☐ Requires Replacement

Condition of Ground Around Footings
- ☐ Satisfactory
- ☐ Fire Hazard
- ☐ Debris Requires Removal
- ☐ Scour (give details)

Debris on Deck Surface
- ☐ Satisfactory
- ☐ Debris/Rubbish Removal
- ☐ Requires Sweeping/Cleaning

Condition of Expansion Joints
- ☐ Satisfactory
- ☐ Requires Cleaning
- ☐ Not Applicable

Conditon of D.W.S (drive way surface)
- ☐ Satisfactory
- ☐ Requires Patching
- ☐ Requires Major Replacement (give details).
- ☐ Nil
- ☐ Requires Tingling and replacement

Condition of Nameboards/Signs/Depth Markers
- ☐ Satisfactory
- ☐ None
- ☐ Requires Replacement
- ☐ Required

Condition of Vegetation
- ☐ Satisfactory
- ☐ Requires Spraying
- ☐ Requires Removal

Condition of Scuppers
- ☐ Satisfactory
- ☐ Blocked Requires Cleaning
- ☐ Requires Replacement

Condition of Bearings
- ☐ Satisfactory
- ☐ Requires Level 2 Inspection
- ☐ Requires Repair
- ☐ Not Applicable

Conditon of Approaches
- ☐ Satisfactory
- ☐ Requires Premix
- ☐ Requires Repairs (give details)

Traffic Damaged Members
- ☐ Yes (give details)
- ☐ No

Level 1 Condition Rating of the whole structure by inspection?
- ☐ **1** Generally in good condition
- ☐ **2** Minor defects
- ☐ **3** Moderate defects
- ☐ **4** Critical condition

Remarks:

Requires Further Detailed Condition Monitoring Inspection?
- ☐ Yes
- ☐ No

Remarks:

PHOTO LOG

No.	*Photo Description*	*File Name*

L2 ACTION REQUIRED

Detailed Structural Evaluation Required?
- ☐ Yes, construction details not available
- ☐ Yes, condition rating more than cut-off
- ☐ Yes, other hazards present

Detailed Nonstructural Evaluation Required?
- ☐ Yes, nonstructural hazards indentified that should be evaluated
- ☐ No, nonstructural hazards exist that may require mitigation, but a detailed evaluation is not necessary
- ☐ No, no nonstructural hazards identified
- ☐ DNK

Where information cannot be verified, Inspector shall note the following: EST = Estimated or unrealiable data OR DNK = Do Not Know

Figure **Error! No text of specified style in document.**: Level 1 – Bridge Inspection & Condition Assessment Form

form was able to tell if a repair, replacement, or maintenance (minor or major) was required or not with the assistance of the second form, as shown in Figure 4, Level 1 Bridge Structural Condition Rating (ESCR) Form.

Moreover, depending on the visible defects and maintenance issues, the bridge structure was assigned a condition rating of 1 (generally in good condition) to 4 (critical condition). The Level 1 inspection forms were intended for use at a frequency of 6 months.

The new parameters introduced in the forms provided reliable results for both the Bumbu and Butibam bridges. As indicated in the results presented below, the Butibam bridge was recently reconstructed, and most of the bridge elements are below the ESCR value of 2, which confirms, according to the form, that it stopped at Level 1 and did not proceed into the next stage of the condition assessment. On the other hand, the Bumbu bridge had the majority of the bridge elements of ESCR value more than 2, with an overall condition rating of 2.11. Hence, the Bridge was recommended for the next stage of assessment. Therefore, the validity of the proposed assessment forms was proved by the results obtained from the condition assessment forms that the parameters are reliable for the steel girder bridge of Bumbu and Butibam Bridge of Lae City.

Bridge Structure Evaluation and Condition Rating Form. This form was used to further evaluate and assess in detail the defects identified in Level 1 condition assessment forms. In the second level, the bridge components were measured, and the number of elements in each condition state was determined. The second level of inspection also verified the causes of defects and vulnerability of the assessed Bridge based on known hazards like floods or earthquakes. The Level 2 evaluation and condition rating is critical and essential for this study because it determines the Overall Structural Condition Index (OSCI) for each bridge component, including the provision of a Structural Health Index (SHI) and Priority Index (PI) that could be utilized in bridge asset management. The Level 2 monitoring form is shown in Figure 6.

9

BRIDGE COMPONENT				CONDITION STATE FOR BRIDGE ELEMENTS				
Element No.	Description of Element	Total Quantity	Units of Measurements	Estimated Quantity in Condition State				Element Structural Condition (ESCR)
				1	2	3	4	
	SUPERSTRUCTURE/DECK							
1	Steel - Beam/Girder (Load Bearing)		ea					
2	Concrete-Deck Slab		m^2					
3	Steel - Diaphragm/Bracing/Secondary Members		m^2					
	SUBSTRUCTURE							
4	Concrete-Pier (Diaphragm/Headstock)		m^2					
5	Concrete - Pier (excl. any Headstock or Piles)		m^2					
6	Concrete-Abutment and Wingwalls		m^2					
	FOUNDATIONS							
7	Piles & Footings		item					
8	Ground around footings		item					
	ACCESSORIES							
9	Expansion Joints		m					
10	Deck Drains		ea					
	Bearings:							
11	Elastomeric Bearing Pad		ea					
12	Metal Fixed Bearing		ea					
	Parapets (kerbs/rails & barriers):							
13	Metal Railing		m					
14	Miscellaneous Railing including Guardfence		m					
15	Railing Paint work		m					
	MISCELLANEOUS & OTHERS							
16	Bridge Approach Road/Carriageway		item					
17	Bridge Approach Barriers		m					
18	Signs		item					
19	Embankment Erosion		m^2					
20	Riverbed Scour		item					
21	General Cleaning		ea					

L1 CONDITION RATING: Note: See further condition rating criteria.

1 In good condition
2 Minor defects
3 Moderate defects.
4 Critical Condition

Overall Condition Rating:
(without condition factors)
∑ ESCR)/n = 0.00

RECOMMENDATION

Status of Bridge Health Monitoring?

☐ Green — Green = 1 - 2 — If Green then STOP at L1.
☐ Yellow — Yellow = 2.1 - 3 — If Yellow then proceed on to Next Bridge Monitoring Level.
☐ Red — Red = 3.1 - 4 — If Red then proceed on to Next Bridge Monitoring

L2 DETAILED INSPECTION REQUIRED? : ☐ **YES** ☑ **NO**

L2 ACTION REQUIRED

Detailed Structural Evaluation Required?
- ☐ Yes, construction details not available
- ☐ Yes, condition rating more than cut-off
- ☐ Yes, other hazards present

Detailed Nonstructural Evaluation Required?
- ☐ Yes, nonstructural hazards indentified that should be evaluated
- ☐ No, nonstructural hazards exist that may require mitigation, but a detailed evaluation is not necessary
- ☐ No, no nonstructural hazards identified ☐ DNK

Where information cannot be verified, Inspector shall note the following: EST = Estimated or unrealiable data OR DNK = Do Not Know

CONDITION RATING CRITERIA

Condition State	Description of defects
1 (0%<d<25%)	The element shows no distress/deterioration. There may be discolouration, efflorescence and/or superficial cracking but without effect on strength and/or serviceability.
2 (26%<d<50%)	Minor rust/damage in the steel elements and require minor work. Concrete elemets has minor cracks and spalls may be present but there is no evidence of corrosion of non-prestressed reinforcement or
3 (51%<d<75%)	Major rust and minor structural damage in steel components. Some delaminations and/or spalls may be present including wide cracks at critical locations. No evidence of deterioration of the prestress system. Corrosion of non-prestressed reinforcement may be present both loss of section is minor and does not significantly affect the
4 (76%<d<100%)	Major structural damage and missing parts to steel parts. Delaminations, spalls and corrosion of non-prestressed reinforcement are prevalent. There may be also be exposure and deterioration of the prestress system (manifested by loss of bond, broken strands or wire, failed and anchorages, etc). There is sufficient concern to warrant an analysis to ascertain the impact on the strength and/or serviceability of either the element or the bridge.

Note: Qty (%) This is quantity measured as percentage (%) of the component requiring the specified major maintenance.

Figure 5: Level 1 Bridge Element Structural Condition Rating (ESCR) Form

L2 BRIDGE STRUCTURE EVALUATION & CONDITION RATING DATA COLLECTION FORM — **LEVEL 2 BRIDGE MONITORING**

BRIDGE COMPONENT				CONDITION STATE FOR BRIDGE ELEMENTS							
Element No.	Description of Element	Total Quantity	Units of Measurements	Estimated Quantity in Condition State 1	2	3	4	(Refer Condition Rating Ciriteria) ESCR	Si	Mi	ESCR*Si*Mi
	SUPERSTRUCTURE/DECK										
1	Steel - Beam/Girder (Load Bearing)		m^2					0.00			0.00
2	Concrete-Deck Slab		m^2					0.00			0.00
3	Steel - Diaphragm/Bracing/Secondary Members		m^2					0.00			**0.00**
	SUBSTRUCTURE										
4	Concrete-Pier (Diaphragm/Headstock)		m^2					0.00			0.00
5	Concrete - Pier (excl. any Headstock or Piles)		m^2					0.00			0.00
6	Concrete-Abutment and Wingwalls		m^2					0.00			0.00
	FOUNDATIONS										
7	Piles & Footings		m					0.00			0.00
8	Ground around footings		m^2					0.00			0.00
	ACCESSORIES										
9	Expansion Joints		m					0.00			0.00
10	Deck Drains		ea					0.00			0.00
11	Bearings (Elastomeric/Metal Fixed)		ea					0.00			0.00
12	Parapets (kerbs/rails & barriers):		m					0.00			0.00
13	Railing Paint work		m					0.00			0.00
	MISCELLANEOUS & OTHERS										
14	Bridge Approach Road/Carriageway		ea					0.00			0.00
15	Bridge Approach Barriers		m					0.00			0.00
16	Signs		item					0.00			0.00
17	Embankment Erosion		m^2					0.00			0.00
18	Riverbed Scour		item					0.00			0.00
19	General Cleaning		item					0.00			0.00
	∑(ESCR*Si*Mi)										**0.00**
	CF = 0.411A + 0.120E + 0.107R + 0.3621			**A= 3**	**E = 4**	**R = 3**	**I = 3**				**3.10**

Parameters: Adapted from Rashindi & Gibson 2011
A - Age of bridge **E**- Environmental factor **R**- Road factor **I**- Inspection

Table of Casual Factors

	A	R	E	I
1	Recently Built	Minor	Low	Very High
2	New	Local access	Medium	High
3	Old	Collectors	High	Medium
4	Very Old	Arterials	Very High	Low

STRUCTURAL HEALTH INDEX (SHI):
SHI = CF *∑(ESCR*Si*Mi)/n — **0.00**

L2 OVERALL STRUCTURE CONDITION RATING (OSCR):
OSCI = 1, when SHI = 1
OSCI = 2, when 1<SHI≤ 16
OSCI = 3, when 16<SHI≤81
OSCI = 4, when 81<SHI≤256
=

RECOMMENDATION
Status of Bridge Health Monitoring?

☐	Green	Green = 1 - 2	If Green then STOP at L1.
☐	Yellow	Yellow = 2.1 - 3	If Yellow then proceed on to Next Bridge
☐	Red	Red = 3.1 - 4	If Red then proceed on to Next Bridge Monitoring Level.

L3 DETAILED INSPECTION REQUIRED? :
☐ **YES**
☐ **NO**

L1 OVERALL CONDITION RATING? ☐ **YES** ☐ **NO**

L3 ACTION/OR FURTHER ANALYTICAL INVESTIGATION REQUIRED
What general properties of the bridge would you like to monitor?

☐ Climatic Conditions (e.g. wind speed/humidity, temperature, air pressure
☐ Displacements - Using what type of sensor/system?
☐ Scour (using pneumatic tubes & filters)
☐ Acceleration/Vibration (using accelerometers)
☐ Tilt/Slope (using tiltmeters or slope indicators)
☐ Ground Velocity
☐ Load
☐ DNK

What properties of the concrete bridge components would you like to monitor?

☐ Strain (e.g., in concrete, steel reinforcing bar, etc)
☐ Concrete Cracking (e.g., flexural, shear, shrinkage, D-cracking or spalling/crushing)
☐ Corrosion (e.g., in concrete and
☐ Locating Rebar/Voids or Delaminations
☐ Concrete Strength (Thermistor or Schid

What properties of the steel bridge components would you like to monitor?

☐ Strain (e.g., in plates, rolled sections, connections, etc.
☐ Fracture (e.g., brittle, ductile, or fatigue)
☐ Crack Growth
☐ Corrosion (portable ultrasonic gusset plate thickness measurements)
☐ Others? specify
☐ DNK

Where information cannot be verified, Inspector shall note the following: EST = Estimated or unrealiable data OR DNK = Do Not Know

Figure 6: Level 2 - Bridge Structure Evaluation and Condition Rating Form

3.1 Application of Steel Girder Bridge Condition Assessment (SGBCA) form

The newly developed SGBHMFs were applied in the case study of the Butibam and Bumbu Bridge of Lae City. As per the study workflow, the SGBHM was undertaken in three (3) different Levels, where the forms were used in the first and second Levels. The Level 1 inspection was done 11 times, and the Level 2 inspection was conducted six times (once a year) during the period from December 2014 to August 2020, excluding the year 2016. The results obtained from the forms in both Levels 1 and 2 were then verified by structural analysis and solid works modeling and simulation software in Level 3. The results from the first and second levels of SGBHMFs for Butibam and Bumbu Bridge are presented in the sub-sections below.

3.1.1 Results of Steel Girder Bridge Condition Assessment (SGBCA) - Butibam Bridge

Butibam Bridge was recently reconstructed in 1997 and is approximately 23 years old. According to PNG and Australian bridge design codes, bridges can be in service for 60 or 75 years. Even though the Bridge is not close to its effective life span, it was monitored because it is part of the primary road network connection of industrial centers located at the northern end of Lae City. The results obtained in Level 1 and Level 2 for Butibam Bridge are shown below.

Figure 7: Butibam Bridge: Aerial View on Left, Side View from Southern End on Right

12

3.1.2 Results of Steel Girder Bridge Condition Assessment (SGBCA) - Butibam Bridge

L1 ROUTINE MONITORING INSPECTION & CONDITION ASSESSMENT — **LEVEL 1**
DATA COLLECTION FORM — **BRIDGE MONITORING**

BRIDGE NAME & LOCATION

Bridge Name: BUTIBAM BRIDGE **Bridge ID:** B_ND 4201_060
Road Name: BUTIBAM **Road Number:** DNK
Latitude: 6.53'44" **Longitude:** 147.0'56"
Altitude: 55 m **Map Reference:** DNK
Province: MOROBE **District:** LAE CITY
Weather: FINE/SUNNY **Date:** 3/12/2014
Inspector's Name: G. WANTEPE

General Bridge Information

Bridge construction type: STANDARD Year of construction: 1997
Inspection Type: L1 Routine Monitoring Inspection
Overall Length (m): 81.5 m Number of Spans: 3
Waterway Clearance (m): 9.4 m
Kerb to kerb width (m): 12.1 m
Clear Vehicle Width (m): 10.8 m Walkway Width (m): 1.5 m
Estimated Vehicles per day: 201 - 1000

SPAN DATA

Main Member Type: Girder
Secondary Member Type: Girder
Other Member Type: Bracing
Deck Material: Concrete
Deck Wearing Surface (DWS): Bitumen
Deck Drainage: Deck Crossfall Parapet: Rails/posts
Expansion Joint Type: Rubber extrusion

ABUTMENT DATA:

Abutment Type: Reinforced Earth
Abutment Material: Concrete
Abutment Foundation: DNK (assumption - driven piles)
Bearing Type - Abutment: Steel plate/Elastomeric
Restraint Type - Abutment: Not Known
Scour Protection - Abutment: Gabions
Bank/Slope Protection: Concrete/ Gabions

PIER DATA

Pier Type: Multiple Columns
Pier Material: Concrete
Pier Foundation Type: DNK (assumption - driven piles)
Piers Bearing Type: Not Known
Piers Restraint Type: Not Known
PIER Scour Protection: None

MISCELLANEOUS DATA

Design Load (Tonnes): 44 T Safe Speed Limit (km/h): **DNK**
Posted Load Limit (Tonnes): **DNK**
Guardrailings: Rails/Posts
River Training Type: None
Soil Type: Stiff Soil
Embankment/Riverbed (erosion/ scour/landslid): Yes/ No /DNK

BRIDGE CONDITION CHECKLIST

Condition of Steel Girders
- [ ] Satisfactory
- [ ] Minor Corrosion Deterioration
- [ ] Major Corrosion Deterioration
- [ ] Requires Level 2 Inspection

Condition of Concrete
- [√] Satisfactory
- [ ] Minor Deterioration
- [ ] Major Deterioration - Level 2 Inspection Required

Condition of Piers, Abutments and Wings
- [√] Satisfactory
- [ ] Back Slabs Gaping
- [ ] Requires Minor Repairs
- [ ] Requires Major Repair or Correction (give details)

Condition of Handrail and Kerbs
- [√] Satisfactory
- [ ] Requires Tightening or Straightening
- [√] Requires Painting
- [ ] Requires Minor replacement (give details).
- [ ] Requires Major Replacement (give details).

Condition of Guard Fencing or Guardrails
- [√] Satisfactory
- [ ] Requires Painting
- [ ] Requires Repairs
- [ ] Requires Replacement

Condition of Ground Around Footings
- [√] Satisfactory
- [ ] Fire Hazard
- [√] Debris Requires Removal
- [ ] Scour (give details)

Debris on Deck Surface
- [ ] Satisfactory
- [√] Debris/Rubbish Removal
- [√] Requires Sweeping/Cleaning

Condition of Expansion Joints
- [√] Satisfactory
- [ ] Requires Cleaning
- [ ] Not Applicable

Conditon of D.W.S (drive way surface)
- [√] Satisfactory
- [ ] Requires Patching
- [ ] Requires Major Replacement (give details).
- [ ] Nil
- [ ] Requires Tingling and replacement

Condition of Nameboards/Signs/Depth Markers
- [ ] Satisfactory
- [√] None
- [ ] Requires Replacement
- [√] Required

Condition of Vegetation
- [√] Satisfactory
- [ ] Requires Spraying
- [ ] Requires Removal

Condition of Scuppers
- [√] Satisfactory
- [ ] Blocked Requires Cleaning
- [ ] Requires Replacement

Condition of Bearings
- [√] Satisfactory
- [ ] Requires Level 2 Inspection
- [ ] Requires Repair
- [ ] Not Applicable

Conditon of Approaches
- [√] Satisfactory
- [ ] Requires Premix
- [√] Requires Repairs (give details)

Traffic Damaged Members
- [√] Yes (give details)
- [ ] No

Damaged guard fencing and rails damaged and requires repair.

Level 1 Condition Rating of the whole structure by inspection?
- [√] **1** Generally in good condition
- [ ] **2** Minor defects
- [ ] **3** Moderate defects
- [ ] **4** Critical condition

Remarks:
Generally in good condition with only routine mainenance issues.

Requires Further Detailed Condition Monitoring?
- [√] Yes.
- [ ] No.

Remarks:
A further Level 2 condition rating is required for this study.

PHOTO LOG

No.	*Photo Description*	*File Name*
	Damaged guard rails	L1 Butibam Bridge - 03-12-2014

L2 ACTION REQUIRED

Detailed Structural Evaluation Required?
- [√] Yes, construction details not available
- [ ] Yes, condition rating more than cut-off
- [ ] Yes, other hazards present
- [ ] No,

Detailed Nonstructural Evaluation Required?
- [ ] Yes, nonstructural hazards indentified that should be evaluated
- [√] No, nonstructural hazards exist that may require mitigation, but a detailed evaluation is not necessary
- [ ] No, no nonstructural hazards identified
- [ ] DNK

Where information cannot be verified, Inspector shall note the following: EST = Estimated or unrealiable data OR DNK = Do Not Know

Figure 8: Level 1 SGBCA Result for Butibam Bridge 3rd December, 2014

BRIDGE COMPONENT				CONDITION STATE FOR BRIDGE ELEMENTS				
Element No.	Description of Element	Total Quantity	Units of Measurements	Estimated Quantity in Condition State				Element Structural Condition (ESCR)
				1	2	3	4	
	SUPERSTRUCTURE/DECK							
1	Steel - Beam/Girder (Load Bearing)	8	ea	8	0	0	0	1.00
2	Concrete-Deck Slab	985	m^2	900	0	0	0	0.91
3	Steel - Diaphragm/Bracing/Secondary Members	780	m^2	780	0	0	0	1.00
	SUBSTRUCTURE							
4	Concrete-Pier (Diaphragm/Headstock)	20	m^2	20	0	0	0	1.00
5	Concrete - Pier (excl. any Headstock or Piles)	38.4	m^2	4	2	0	0	0.21
6	Concrete-Abutment and Wingwalls	70	m^2	70	0	0	0	1.00
	FOUNDATIONS							
7	Piles & Footings	48	item	48	0	0	0	1.00
8	Ground around footings	4	item	4	0	0	0	1.00
	ACCESSORIES							
9	Expansion Joints	16.5	m	16.5	0	0	0	1
10	Deck Drains	10	ea	5	5	0	0	1.5
	Bearings:							
11	Elastomeric Bearing Pad	8	ea	8	0	0	0	1.00
12	Metal Fixed Bearing	8	ea	8	0	0	0	1.00
	Parapets (kerbs/rails & barriers):							
13	Metal Railing	400	m	140	110	150	0	2.03
14	Miscellaneous Railing including Guardfence	1020	m	500	500	20	0	1.53
15	Railing Paint work	1200	m	0	800	400	0	2.33
	MISCELLANEOUS & OTHERS							
16	Bridge Approach Road/Carriageway	160	item	90	50	20	0	1.56
17	Bridge Approach Barriers	40	m	30	10	0	0	1.25
18	Signs	4	item	0	0	2	2	3.50
19	Embankment Erosion	985	m^2	905	80	0	0	1.08
20	Riverbed Scour	2	item	0	2	0	0	2.00
21	General Cleaning	3	ea	0	3	0	0	2.00

L1 CONDITION RATING: Note: See further condition rating criteria.

1 In good condition
2 Minor defects
3 Moderate defects.
4 Critical Condition

Overall Condition Rating:
(without condition factors)
∑ ESCR)/n = 1.44

Figure 9: Level 1 Butibam Bridge Element Structural Condition Rating (ESCR)

Figure 10: Photos of Butibam Bridge

According to the Level 1 results, the general assessment of the Bridge is reasonable, where most conditions of the components are satisfactory or require minor maintenance and repair or painting. The majority of the bridge components' conditions were satisfactory, as shown below in Table 1, and an overall bridge structure condition rating of 2, as shown in the graph in Figure , which means the Bridge is generally in good condition.

Table 1: Level 1 Condition Assessment of Butibam Bridge

Component Name	Condition of Components
Steel Girders	Satisfactory
Handrails & Kerbs	Satisfactory, requires painting
Expansion Joints	Satisfactory
Bearings	Satisfactory
Concrete	Satisfactory
Driveway surface	Satisfactory
Ground around footings	Satisfactory; debris requires removal
Piers, Abutments, Wings	Satisfactory
Debris on the Deck Surface	Debris/rubbish removal requires sweeping/cleaning
Scuppers	Satisfactory
Nameboards, signs	None, required
Guard Fencing or Guardrails	Satisfactory, requires painting
Vegetation	Satisfactory
Approaches	Satisfactory, requires repairs
Traffic Damaged Members	Yes, requires repair

As mentioned earlier, the level 1 monitoring was conducted at a frequency of 6 months, and from the results presented, it can be noted that the bridge condition is generally good throughout monitoring except for minor maintenance and repair of road approaches and guard fencing or railings.

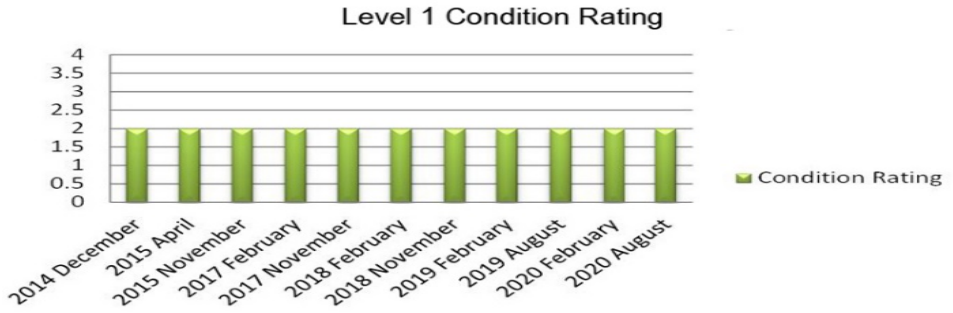

Figure 11: Level 1 - Butibam Bridge Overall Structure Condition Rating from December 2014 to August 2020.

The graph in Figure 11 shows the summary of the Level 1 overall condition rating for Butibam during the period of inspection and assessment from December 2014 to August 2020. During that period of inspection and assessment, it was noted that the results improved when there was a repair and maintenance of the miscellaneous components. It was also concluded that these maintenance practices can have an impact on the overall bridge structure condition rating. The overall condition rating for Butibam Bridge was below 2 during the assessment period, as shown in Figure 12, Level 2 SGBCA Result for Butibam Bridge on 10th December 2014. This result shows that only a slight deterioration or damage was done to the Bridge except for minor routine maintenance, repair, and replacement works.

16

L2 BRIDGE STRUCTURE EVALUATION & CONDITION RATING DATA COLLECTION FORM — **LEVEL 2 BRIDGE MONITORING**

BRIDGE NAME: BUTIBAM BRIDGE WEATHER: FINE/ SUNNY
INSPECTION(S) NAME: GRACE WANTEPE DATE: 10/12/2014

Element No.	Description of Element	Total Quantity	Units of Measurements	Estimated Quantity in Condition State 1	2	3	4	(Refer Condition Rating Ciriteria) ESCI	Si	Mi	ESCI*Si*Mi
	SUPERSTRUCTURE/DECK										
1	Steel - Beam/Girder (Load Bearing)	8	m^2	8.0	0.0	0.0	0.0	1.00	4	1	4.00
2	Concrete-Deck Slab	880.2	m^2	792.2	88.0	0.0	0.0	1.10	3	2	6.60
3	Steel - Diaphragm/Bracing/Secondary Members	780	m	780.0	0.0	0.0	0.0	1.00	**4**	**1**	4.00
	SUBSTRUCTURE										
4	Concrete-Pier (Diaphragm/Headstock)	25	m^2	25.0	0.0	0.0	0.0	1.00	4	2	8.00
5	Concrete - Pier (excl. any Headstock or Piles)	47.5	m^2	47.5	0.0	0.0	0.0	1.00	4	2	8.00
6	Concrete-Abutment and Wingwalls	30	m^2	18.0	12.0	0.0	0.0	1.40	2	2	5.60
	FOUNDATIONS										
7	Piles & Footings	48	m	38.4	9.6	0.0	0.0	1.20	2	2	4.80
8	Ground around footings	4	m^2	4.0	0.0	0.0	0.0	1.00	2	2	4.00
	ACCESSORIES										
9	Expansion Joints	22	m	19.8	2.2	0.0	0.0	1.10	1	3	3.30
10	Deck Drains	16	ea	16.0	2.0	0.0	0.0	1.25	3	3	11.25
11	Bearings (Elastomeric/Metal Fixed)	16	ea	16.0	0.0	0.0	0.0	1.00	3	3	9.00
12	Parapets (kerbs/rails & barriers):	163	m	114.1	48.9	0.0	0.0	1.30	1	1	1.30
13	Railing Paint work	1400	m	700.0	700.0	0.0	0.0	1.50	1	3	4.50
	MISCELLANEOUS & OTHERS										
14	Bridge Approach Road/Carriageway	2	ea	1.4	0.6	0.0	0.0	1.30	1	3	3.90
15	Bridge Approach Barriers	40	m	20.0	20.0	0.0	4.0	1.90	1	1	1.90
16	Signs/Nameboards	4	ea	0.0	0.0	2.0	2.0	3.50	1	3	10.50
17	Embankment Erosion	2	m^2	1.4	0.4	0.2	0.0	1.40	1	1	1.40
18	Riverbed Scour	2	ea	1.2	0.4	0.4	0.0	1.60	1	5	8.00
19	General Cleaning	7	ea	0.0	6.3	0.0	0.7	2.20	1	3	6.60
	∑(ESCI*Si*Mi)					Average ESCI		**1.41**	**∑(ESCI*Si*Mi)**		**106.65**
	CF = 0.411A + 0.120E + 0.107R + 0.362I			**A= 2**	**E = 3**	**R = 3**	**I = 3**				**2.59**

Parameters: Adapted from Rashindi & Gibson 2011
A - Age of bridge **E**- Environmental factor **R**- Road factor **I**- Inspection Quality

Table of Casual Factors

	A	R	E	I
1	Recently Built	Minor	Low	Very High
2	New	Local access	Medium	High
3	Old	Collectors	High	Medium
4	Very Old	Arterials	Very High	Low

STRUCTURAL HEALTH INDEX (SHI): **14.53**

SHI = CF *∑(ESCI*Si*Mi)/n

L2 OVERALL STRUCTURE CONDITION INDEX (OSCI):

OSCI = 1, when SHI = 1
OSCI = 2, when 1<SHI≤16
OSCI = 3, when 16<SHI≤81
OSCI = 4, when 81<SHI≤256

OSCI = **2**

RECOMMENDATION

Element Structural Condition Index (ESCI) or Average ESCI of Bridge Health Monitoring? **1.41**

- [√] Green — Green = 1 - 2 — If Green then STOP.
- [ ] Yellow — Yellow = 2.1 - 3 — If Yellow then proceed on to Next Bridge Monitoring Level.
- [ ] Red — Red = 3.1 - 4 — If Red then proceed on to Next Bridge Monitoring Level.

L3 ENGINEERING ANALYSIS REQUIRED? :

- [√] **YES**
- [ ] **NO**

L3 ACTION/OR FURTHER ANALYTICAL INVESTIGATION REQUIRED

What general properties of the bridge would you like to monitor?

- [ ] Climatic Conditions (e.g. wind speed/humidity, temperature, air pressure
- [√] Displacements - Using what type of sensor/system?
- [ ] Scour (using pneumatic tubes & filters)
- [√] Acceleration/Vibration (using accelerometers)
- [√] Tilt/Slope (using tiltmeters or slope indicators)
- [ ] Ground Velocity
- [√] Load
- [ ] DNK

What properties of the concrete bridge components would you like to monitor?

- [ ] Strain (e.g., in concrete, steel reinforcing bar, etc)
- [√] Concrete Cracking (e.g., flexural, shear, shrinkage, D-cracking or spalling/crushing)
- [ ] Corrosion (e.g., in concrete and reinforcing
- [ ] Locating Rebar/Voids or Delaminations
- [ ] Concrete Strength (Thermistor or Schid Hammer)

What properties of the steel bridge components would you like to monitor?

- [√] Strain (e.g., in plates, rolled sections, connections, etc.
- [√] Fracture (e.g., brittle, ductile, or fatigue)
- [ ] Crack Growth
- [ ] Corrosion (portable ultrasonic gusset plate thickness measurements)
- [ ] Others? specify
- [ ] DNK

Where information cannot be verified, Inspector shall note the following: EST = Estimated or unrealiable data OR DNK = Do Not Know

ADDITIONAL COMMENTS ON REQUIRED ACTIONS & LOCATIONS ON STRUCTURE

Structural Health Index (SHI) is **14.53**
L2 Overall Structure Condition Index (OSCI) is **2**
Further analyze the structure using Structural Analysis Software and Modelling.

Figure 12: Level 2 SGBCA Result for Butibam Bridge on 10th December 2014

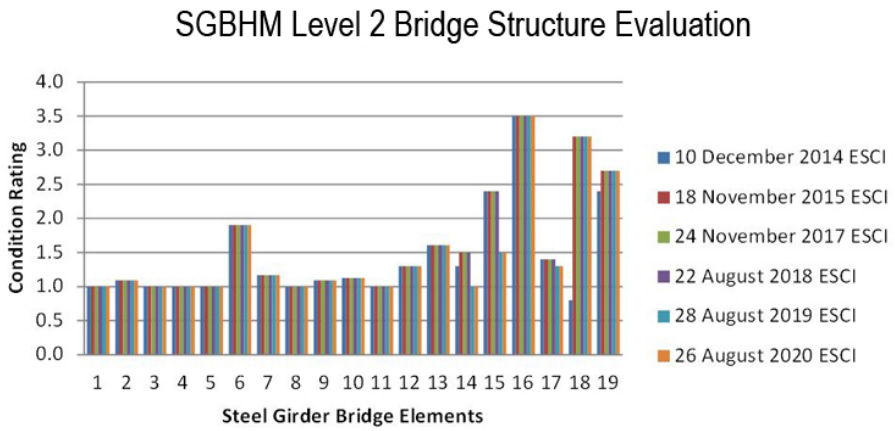

Figure 13: Level 2 Butibam Bridge Structure Evaluation & Condition Rating

To find the priority vector of the contributed factors, an Analytical Hierarchy Process developed by Saaty (1980) was adopted in this study. According to Rashidi and Gibson (2011), a casual factor ranging from 1 to 4 is calculated as follows:

To determine the SHI for the Bridge, the CF value 2.59 was multiplied by the sum (of the result obtained from ESCI*Si*Mi), which is 106.65. The CF value was calculated from this equation:

$$CF = 0.411A + 0.120E + 0.107R + 0.362I$$

Where:

- *A* - Age Factor
- *E* - Environmental Factor
- *R* - Road Type Factor
- *I* - Inspection factor

and the SHI was calculated using the equation;

$$SHI = \frac{CF \sum S_i \cdot M_i \cdot ESCI_i}{n}$$

Where:

- *CF* - Causal Factor
- S_i - Structural Importance Factor
- M_i - Material Vulnerability Factor
- $ESCI_i$ - Element Structural Condition Index
- *n* - Number of Element Types

The SHI value for the Butibam Bridge is 14.53, where the values range from 1 to 256. This index may be applied for the prioritization of bridge remedial actions. The priority of remedial actions increases as the number rises. However, an entire structural element is introduced as OSCI, where the Level 2 OSCI value for Butibam Bridge is 2 since the SHI value 14.53 falls in the range of OSCI 2**.** This validates that the Bridge is still new. All the Level 2 bridge structure evaluation and condition assessment results for the Butibam Bridge from December 2014 to August 2020 are presented in Table 2.

The SHI value ranges from 1 to 256, where the index may be applied to prioritize bridges in a network, and the priority of remedial actions increases as the number rises. The identical upper limit (4) and lower limit (1) of all parameters and the uniformity of quantity ranges according to the condition of an entire structural element are introduced as the Overall Structural Condition Index, OSCI, which has been re-rated based on SHI and defined as:

- *OSCI* = 1, when *SHI* = 1
- *OSCI* = 2, when 1< *SHI*≤ 16
- *OSCI* = 3, when 16< *SHI*≤ 81
- *OSCI = 4 when* 81< *SHI*≤ 256

The re-rated rating number for OSCI is applicable for prioritization and selecting the major remedial strategies such as repair, strengthening, and replacement.

Table 2: Level 2 SGBCA Evaluation of the Overall Structural Condition Index (OSCI) for Butibam Bridge

		L2 Element Structural Condition Index (ESCI)																							
		10 December 2014				18 November 2015				24 November 2017				22 August 2018				28 August 2019				26 August 2020			
		ESCI	Si	Mi	ESCI*Si*Mi	ESCI	Si	Mi	ESCI*Si*Mi	ESCI	Si	Mi	ESCI*Si*Mi	ESCI	Si	Mi	ESCI*Si*Mi	ESCI	Si	Mi	ESCI*Si*Mi	ESCI	Si	Mi	ESCI*Si*Mi
No.	Description of Bridge Element																								
1	Steel - Beam/Girder	1.0	4	1	4.0	1.0	4	1	4.0	1.0	4	1	4.0	1.0	4	1	4.0	1.0	4	1	4.0	1.0	4	1	4.0
2	Concrete-Deck Slab	1.1	3	2	6.6	1.1	3	2	6.6	1.1	3	2	6.5	1.1	3	2	6.5	1.1	3	2	6.5	1.1	3	2	6.5
3	Steel - Bracing	1.0	4	1	4.0	1.0	4	1	4.0	1.0	4	1	4.0	1.0	4	1	4.0	1.0	4	1	4.0	1.0	4	1	4.0
4	Concrete-Pier (Diaphragm/Headstock)	1.0	4	2	8.0	1.0	4	2	8.0	1.0	4	2	8.0	1.0	4	2	8.0	1.0	4	2	8.0	1.0	4	2	8.0
5	Concrete - Pier (excl. any Headstock or Piles)	1.0	4	2	8.0	1.0	4	2	8.0	1.0	4	2	8.0	1.0	4	2	8.0	1.0	4	2	8.0	1.0	4	2	8.0
6	Concrete-Abutment and Wingwalls	1.4	2	2	5.6	1.4	2	2	5.6	1.9	2	2	7.6	1.9	2	2	7.6	1.9	2	2	7.6	1.9	2	2	7.6
7	Piles & Footings	1.2	2	2	4.8	1.2	2	2	4.8	1.2	2	2	4.7	1.2	2	2	4.7	1.2	2	2	4.7	1.2	2	2	4.7
8	Ground around footings	1.0	2	2	4.0	1.0	2	2	4.0	1.0	2	2	4.0	1.0	2	2	4.0	1.0	2	2	4.0	1.0	2	2	4.0
9	Expansion Joints	1.1	1	3	3.3	1.1	1	3	3.3	1.1	1	3	3.3	1.1	1	3	3.3	1.1	1	3	3.3	1.1	1	3	3.3
10	Deck Drains	1.3	3	3	11.3	1.3	3	3	11.3	1.1	3	3	10.1	1.1	3	3	10.1	1.1	3	3	10.1	1.1	3	3	10.1
11	Bearings (Elastomeric/Metal Fixed)	1.0	3	3	9.0	1.0	3	3	9.0	1.0	3	3	9.0	1.0	3	3	9.0	1.0	3	3	9.0	1.0	3	3	9.0
12	Parapets (kerbs/rails & barriers):	1.3	1	1	1.3	1.3	1	1	1.3	1.3	1	1	1.3	1.3	1	1	1.3	1.3	1	1	1.3	1.3	1	1	1.3
13	Railing Paint work	1.5	1	3	4.5	1.5	1	3	4.5	1.6	1	3	4.8	1.6	1	3	4.8	1.6	1	3	4.8	1.6	1	3	4.8
14	Bridge Approach Road/Carriageway	1.3	1	3	3.9	1.3	1	3	3.9	1.5	1	3	4.5	1.5	1	3	4.5	1.0	1	3	3.0	1.0	1	3	3.0
15	Bridge Approach Barriers	1.9	1	1	1.9	1.9	1	1	1.9	2.4	1	1	2.4	2.4	1	1	2.4	1.5	1	1	1.5	1.5	1	1	1.5
16	Signs	3.5	1	3	10.5	3.5	1	3	10.5	3.5	1	3	10.5	3.5	1	3	10.5	3.5	1	3	10.5	3.5	1	3	10.5
17	Embankment Erosion	1.4	1	1	1.4	1.4	1	1	1.4	1.4	1	1	1.4	1.4	1	1	1.4	1.3	1	1	1.3	1.3	1	1	1.3
18	Riverbed Scour	1.6	1	5	8.0	1.6	1	5	8.0	3.2	1	5	16.0	3.2	1	5	16.0	3.2	1	5	16.0	3.2	1	5	16.0
19	General Cleaning	2.2	1	3	6.6	2.2	1	3	6.6	2.7	1	3	8.1	2.7	1	3	8.1	2.7	1	3	8.1	2.7	1	3	8.1
	Agerage ESCI	1.41	∑(ESCI*Si*Mi)		106.65	1.41	∑(ESCI*Si*Mi)		106.65	1.58	∑(ESCI*Si*Mi)		118.23	1.58	∑(ESCI*Si*Mi)		118.23	1.50	∑(ESCI*Si*Mi)		115.73	1.50	∑(ESCI*Si*Mi)		115.73
	CF = 0.411A + 0.120E + 0.107R + 0.362I	A=2, E=3, R=3, I=3			2.589	A=2, E=3, R=3, I=3			2.589	A=2, E=3, R=3, I=3			2.589	A=2, E=3, R=3, I=3			2.589	A=2, E=3, R=3, I=3			2.589	A=2, E=2, R=3, I=3			2.589
	SHI = CF *∑(ESCI*Si*Mi)/n	SHI = 3.12*106.65/(19)			14.532	SHI = 3.12*106.65/(19)			14.532	SHI = 3.12*118.23/(19)			16.110	SHI = 3.12*118.23/(19)			19.414	SHI = 3.12*115.73/(19)			15.769	SHI = 3.12*115.73/(19)			15.770
	OSCI = 1, when SHI = 1 OSCI = 2, when 1<SHI≤ 16 OSCI = 3, when 16<SHI≤81 OSCI = 4, when 81<SHI≤256	16<SHI≤81			OSCI = 2	16<SHI≤81			OSCI = 2	16<SHI≤81			OSCI = 3	16<SHI≤81			OSCI = 3	16<SHI≤81			OSCI = 2	16<SHI≤81			OSCI = 2

3.2 Results of Steel Girder Bridge Condition Assessment (SGBCA) -Bumbu Bridge

Bumbu Bridge is one of the three bridges along the Bumbu River built in 1973. According to Atkins and Walsh (1985), a major flood occurred in the Bumbu River in September 1983, affecting the peaceful coexistence of the river and Lae City. The Bumbu River drains an area of approximately 100 km2. The river's catchment is 22 km long, and urban development has occurred over the past four decades along the lower 10 km. It is close to the end of its life span and requires close inspection and monitoring.

Figure 14: Photos of Bumbu Bridge in August 2020: Aerial View on Left, Longitudinal View on Right

Figure 14, Photos of Bumbu Bridge in August 2020: Aerial View on Left, Longitudinal View on Right shows the aerial view and longitudinal view of the Bumbu Bridge. The pile caps are already exposing the piles due to the happening in the Bumbu River.

Figure 15, Level 1 SGBCA Result for Bumbu Bridge in December 2014, shows the result of the routine inspection using the Condition Assessment Level 1 Form. Figure 16, Bumbu Bridge Element Structural Condition Rating (ESCR), shows the condition rating of the Bumbu bridge per condition assessment on its structural health.

3.2.1 Routine Monitoring Inspection & Condition Assessment Level 1

L1 ROUTINE MONITORING INSPECTION & CONDITION ASSESSMENT DATA COLLECTION FORM — **LEVEL 1 BRIDGE MONITORING**

BRIDGE NAME & LOCATION

Bridge Name: BUMBU BRIDGE **Bridge ID:** B_NI 4201_080
Road Name: MILFORHAVEN ROAD **Road Number:** DNK
Latitude: 6.42'23" **Longitude:** 146.59'56"
Altitude: 55 m **Map Reference:** DNK
Province: MOROBE **District:** LAE CITY
Weather: FINE/CLOUDY **Date:** 3/12/2014
Inspector's Name: G. WANTEPE

General Bridge Information

Bridge construction type: STANDARD Year of construction: 1973
Inspection Type: L1 Routine Monitoring Inspection
Overall Length (m): 50 m Number of Spans: 2
Waterway Clearance (m): 7.3 m
Kerb to kerb width (m): 8.2 m
Clear Vehicle Width (m): 7.5 m Walkway Width (m): 1.5 m
Estimated Vehicles per day: 201 - 1000

SPAN DATA

Main Member Type: Girder
Secondary Member Type: Girder
Other Member Type: Bracing
Deck Material: Concrete
Deck Wearing Surface (DWS): Bitumen
Deck Drainage: Scuppers Parapet: Rails/posts
Expansion Joint Type: Steel (Open)

ABUTMENT DATA:

Abutment Type: Reinforced Earth
Abutment Material: Concrete
Abutment Foundation: DNK (assumption - driven piles)
Bearing Type - Abutment: Steel plate/Elastomeric
Restraint Type - Abutment: Lateral
Scour Protection - Abutment: Steel Sheets
Bank/Slope Protection: Steel Pile/Sheets

PIER DATA

Pier Type: Single Columns
Pier Material: Concrete
Pier Foundation Type: DNK (assumption - driven piles)
Piers Bearing Type: Not Known
Piers Restraint Type: Not Known
PIER Scour Protection: None

MISCELLANEOUS DATA

Design Load (Tonnes): 44 T Safe Speed Limit (km/h): **DNK**
Posted Load Limit (Tonnes): **DNK**
Guardrailings: Rails/Posts
River Training Type: None
Soil Type: Avg. Rock
Embankment/Riverbed (erosion/ scour/landslide): (Yes) / No / DNK

BRIDGE CONDITION CHECKLIST

Condition of Steel Girders
- ☐ Satisfactory
- ☑ Minor Corrosion Deterioration
- ☐ Major Corrosion Deterioration
- ☑ Requires Level 2 Inspection

Condition of Concrete
- ☐ Satisfactory
- ☑ Minor Deterioration
- ☐ Major Deterioration - Level 2 Inspection Required

Condition of Piers, Abutments and Wings
- ☐ Satisfactory
- ☐ Back Slabs Gaping
- ☑ Requires Minor Repairs
- ☐ Requires Major Repair or Correction (give details)

Condition of Handrail and Kerbs
- ☐ Satisfactory
- ☐ Requires Tightening or Straightening
- ☑ Requires Painting
- ☑ Requires Minor replacement (give details).
- ☐ Requires Major Replacement (give details).

Condition of Guard Fencing or Guardrails
- ☐ Satisfactory
- ☐ Requires Painting
- ☑ Requires Repairs
- ☐ Requires Replacement

Condition of Ground Around Footings
- ☐ Satisfactory
- ☐ Fire Hazard
- ☑ Debris Requires Removal
- ☑ Scour (give details)

Debris on Deck Surface
- ☐ Satisfactory
- ☑ Debris/Rubbish Removal
- ☑ Requires Sweeping/Cleaning

Condition of Expansion Joints
- ☐ Satisfactory
- ☑ Requires Cleaning
- ☐ Not Applicable

Conditon of D.W.S (drive way surface)
- ☐ Satisfactory
- ☐ Requires Patching
- ☐ Requires Major Replacement (give details).
- ☐ Nil
- ☑ Requires Tingling and replacement

Condition of Nameboards/Signs/Depth Markers
- ☐ Satisfactory
- ☑ None
- ☐ Requires Replacement
- ☑ Required

Condition of Vegetation
- ☐ Satisfactory
- ☑ Requires Spraying
- ☐ Requires Removal

Condition of Scuppers
- ☐ Satisfactory
- ☑ Blocked Requires Cleaning
- ☐ Requires Replacement

Condition of Bearings
- ☐ Satisfactory
- ☑ Requires Level 2 Inspection
- ☐ Requires Repair
- ☐ Not Applicable

Conditon of Approaches
- ☑ Satisfactory
- ☐ Requires Premix
- ☐ Requires Repairs (give details)

Traffic Damaged Members
- ☑ Yes (give details)
- ☐ No

Damaged guard fencing and rails damaged and requires repair.

Level 1 Condition Rating of the whole structure by inspection?
- ☐ **1** Generally in good condition
- ☑ **2** Minor defects
- ☐ **3** Moderate defects
- ☐ **4** Critical condition

Remarks: *A lot of routine maintenance works required*

Requires Further Detailed Condition Monitoring?
- ☑ Yes.
- ☐ No.

Remarks: *A Level 2 condition rating is required to further assess its condition.*

PHOTO LOG

No.	Photo Description	File Name
	Longitudinal view from upstream	L1 Bumbu Bridge - 03-12-2014
	Corrosion of steel girders	L1 Bumbu Bridge - 03-12-2014
	Damaged guard rails	L1 Bumbu Bridge - 03-12-2014

L2 ACTION REQUIRED

Detailed Structural Evaluation Required?
- ☑ Yes, construction details not available
- ☐ Yes, condition rating more than cut-off
- ☐ Yes, other hazards present

Detailed Nonstructural Evaluation Required?
- ☐ Yes, nonstructural hazards indentified that should be evaluated
- ☑ No, nonstructural hazards exist that may require mitigation, but a detailed evaluation is not necessary
- ☐ No, no nonstructural hazards identified
- ☐ DNK

Where information cannot be verified, Inspector shall note the following: EST = Estimated or unrealiable data OR DNK = Do Not Know

Figure 15: Level 1 SGBCA Result for Bumbu Bridge in December 2014.

BRIDGE COMPONENT				CONDITION STATE FOR BRIDGE ELEMENTS				
Element No.	Description of Element	Total Quantity	Units of Measurements	Estimated Quantity in Condition State				Element Structural Condition (ESCR)
				1	2	3	4	
	SUPERSTRUCTURE/DECK							
1	Steel - Beam/Girder (Load Bearing)	4	m	60	40	0	0	1.4
2	Concrete-Deck Slab	555	m^2	300	150	105	0	9.15
3	Steel - Diaphragm/Bracing/Secondary Members	27	m	80	20	0	0	1.2
	SUBSTRUCTURE							
4	Concrete-Pier (Diaphragm/Headstock)	12	m^2	66	33	1	0	1.35
5	Concrete - Pier (excl. any Headstock or Piles)	1	m^2	70	30	0	0	1.3
6	Concrete-Abutment and Wingwalls	20	m^2	40	30	30	0	1.9
	FOUNDATIONS							
7	Piles & Footings	17	item	25	35	20	20	2.35
8	Scouring of foundations	3	item	15	30	25	30	2.7
	ACCESSORIES							
9	Expansion Joints	33	m	60	40	0	0	1.4
10	Deck Drains	8	ea	25	50	25	0	2
11	Bearings (Elastomeric/Metal Fixed Bearings)	8	ea	10	25	25	40	2.95
12	Parapets (kerbs/rails & barriers):	8	ea	80	20	0	0	1.2
13	Railing Paint work	700	m	25	50	25	0	2
	MISCELLANEOUS & OTHERS							
14	Bridge Approach Carriageway	2	item	20	30	50	0	2.3
15	Bridge Approach Barriers	40	m	20	30	40	10	2.4
16	Signs (Miscellaneous attachments)	4	item	0	0	50	50	3.5
17	Embankment Erosion	985	m^2	80	20	0	0	1.2
18	Riverbed Scour	2	item	0	10	60	30	3.2
19	General Cleaning	3	item	0	40	50	10	2.7

L1 CONDITION RATING: Note: See further condition rating criteria.

1 In good condition
2 Minor defects
3 Moderate defects.
4 Critical Condition

Overall Condition Rating:
(without condition factors)
∑ ESCR)/n = 2.43

RECOMMENDATION

Status of Bridge Health Monitoring?

☐	Green	Green = 1 - 2	If Green then STOP at L1.
√	Yellow	Yellow = 2.1 - 3	If Yellow then proceed on to Next Bridge Monitoring Level.
☐	Red	Red = 3.1 - 4	If Red then proceed on to Next Bridge Monitoring

L2 DETAILED INSPECTION REQUIRED? : √ **YES** ☐ **NO**

Figure 16: Bumbu Bridge Element Structural Condition Rating (ESCR)

The general assessment of the Bridge is fair, with most components requiring minor maintenance, repairs, or painting. Most of the bridge components need to be more satisfactory, as shown in Table 3, Level 1 condition assessment of Bumbu Bridge below.

Table 3: Level 1 condition assessment of Bumbu Bridge

Component Name	Condition of Components
Steel Girders	Requires Level 2 Inspection
Handrails & Kerbs	Requires Painting and Minor Replacements
Expansion Joints	Requires Cleaning
Bearings	Requires Level 2 Inspection

Concrete	Minor Deterioration
Driveway surface	Requires Replacement
Ground around footings	Requires Debris Removal
Piers, Abutments, Wings	Requires Minor Repairs
Deck Surface	Debris/Rubbish Removal, Sweeping/Cleaning
Scuppers	Blocked Requires Cleaning
Nameboards, signs	None Required
Guard Fencing or Guardrails	Requires Repairs
Vegetation	Requires Cutting/Spraying
Approaches	Requires Repairs
Traffic Damaged Members	Requires Handrails/Guard Fencing on Both Sides

During the inspection on 3rd December 2014, most of the elements of the Bridge were not in good condition. Handrails and guard fencing on both sides of the Bridge were damaged by traffic, as shown in Figure 17 below.

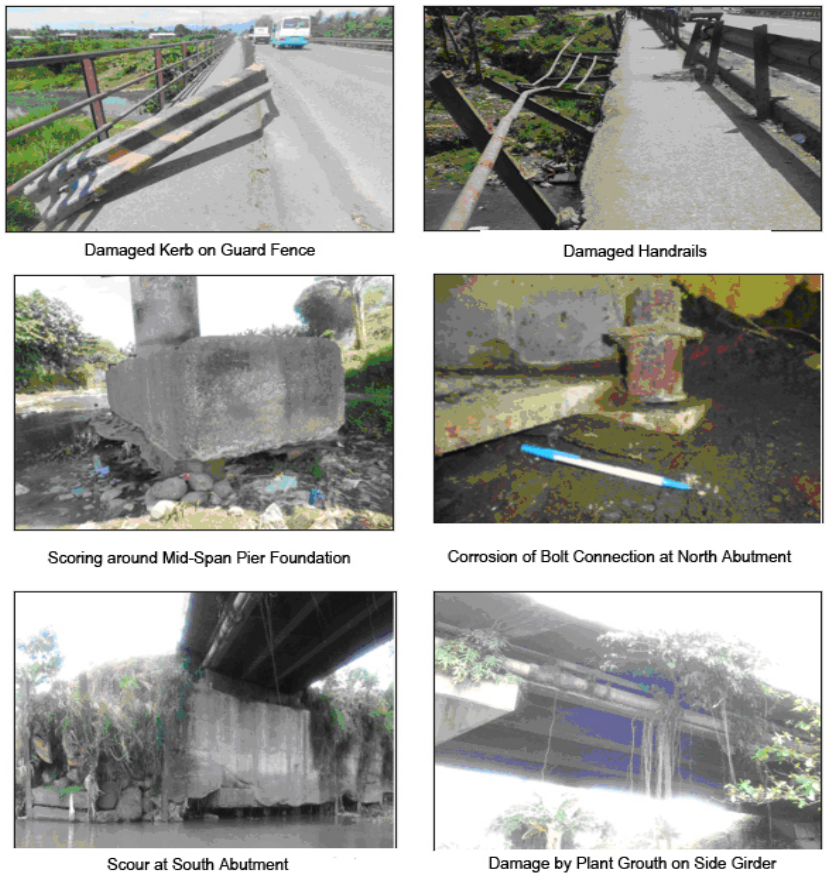

Figure 17: Photos showing the condition of Bumbu Bridge in 2015

The level 1 inspection and condition assessment were conducted at a frequency of approximately 6 months.

The graph below shows the results of level 1 routine inspection and condition assessment between December 2014 and August 2020 at Bumbu Bridge. The

overall bridge structure condition rating is 2. Some maintenance work is required for minor repairs, including non-loading bridge elements.

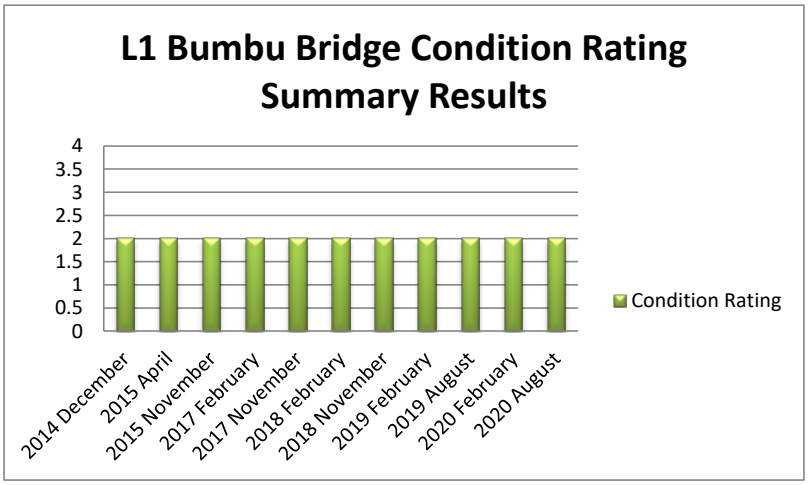

Figure 18: Summary Results for Bumbu Bridge Level 1 Condition Rating

3.3 Bridge Structure Evaluation and Condition Rating Level 2

Similar to the Butibam Bridge, the elemental structural condition index for the Bumbu Bridge has been evaluated. Figure 18 presents the result of the first Level 2 inspection on 10th December 2014. The CF value for Bumbu Bridge is 3.00, and when multiplied by 172.20 - the sum of the result obtained from ESCI*Si*Mi, it gives an SHI value of 27.27. Again, an entire structural element is introduced as OSCI, where the Level 2 OSCI value for Bumbu Bridge is 3 since the SHI value 27.27 falls in the range of OSCI 3 when 16< SHI≤ 81. This result validates that the Bridge is quite old and requires further attention.

L2 BRIDGE STRUCTURE EVALUATION & CONDITION RATING — **LEVEL 2**
DATA COLLECTION FORM — **BRIDGE MONITORING**

BRIDGE NAME: BUMBU BRIDGE WEATHER: FINE/ SUNNY
INSPECTION(S) NAME: GRACE WANTEPE DATE: 10/12/2014

BRIDGE COMPONENT				CONDITION STATE FOR BRIDGE ELEMENTS							
Element No.	Description of Element	Total Quantity	Units of Measurements	Estimated Quantity in Condition State				(Refer Condition Rating Criteria)			ESCI*Si*Mi
				1	2	3	4	ESCI	Si	Mi	
	SUPERSTRUCTURE/DECK										
1	Steel - Beam/Girder (Load Bearing)	185	m^2	101.8	55.5	27.8	0.0	1.60	4	1	6.40
2	Concrete-Deck Slab	555	m^2	305.3	166.5	83.3	0.0	1.60	3	2	9.60
3	Steel - Diaphragm/Bracing/Secondary Members	37.8	m	20.8	11.3	5.7	0.0	1.60	**4**	**1**	6.40
	SUBSTRUCTURE										
4	Concrete-Pier (Diaphragm/Headstock)	12	m^2	8.4	1.8	1.2	0.6	1.50	4	2	12.00
5	Concrete - Pier (excl. any Headstock or Piles)	14	m^2	9.8	2.8	1.4	0.0	1.40	4	2	11.20
6	Concrete-Abutment and Wingwalls	20	m^2	10.0	6.0	4.0	0.0	1.70	2	2	6.80
	FOUNDATIONS										
7	Piles & Footings	17	m	7.7	4.3	3.4	2.6	2.15	2	2	8.60
8	Ground around footings	3	m^2	1.2	0.6	0.6	0.6	2.20	2	2	8.80
	ACCESSORIES										
9	Expansion Joints	33	m	0.0	16.5	9.9	6.6	2.70	1	3	8.10
10	Deck Drains	8	ea	0.0	2.8	1.6	3.6	3.10	3	3	27.90
11	Bearings (Elastomeric/Metal Fixed)	8	ea	2.0	2.4	2.0	1.6	2.40	3	3	21.60
12	Parapets (kerbs/rails & barriers):	140	m	28.0	42.0	42.0	28.0	2.50	1	1	2.50
13	Railing Paint work	700	m	175.0	210.0	175.0	140.0	2.40	1	3	7.20
	MISCELLANEOUS & OTHERS										
14	Bridge Approach Road/Carriageway	2	ea	0.8	0.5	0.4	0.3	2.10	1	3	6.30
15	Bridge Approach Barriers	40	m	18.0	12.0	10.0	0.0	1.80	1	1	1.80
16	Signs/Nameboards	4	item	0.0	0.8	1.2	2.0	3.30	1	3	9.90
17	Embankment Erosion	985	m^2	443.3	246.3	197.0	147.8	2.15	1	1	2.15
18	Riverbed Scour	2	item	0.9	0.6	0.5	0.0	1.80	1	5	9.00
19	General Cleaning	3	item	1.4	0.8	0.6	0.5	2.15	1	3	6.45
	∑(ESCI*Si*Mi)							2.11			172.70
	CF = 0.411A + 0.120E + 0.107R + 0.362I			**A= 3**	**E = 3**	**R = 3**	**I = 3**				3.00

Parameters: Adapted from Rashindi & Gibson 2011
A - Age of bridge **E**- Environmental factor **R**- Road factor **I**- Inspection Quality

Table of Casual Factors

	A	R	E	I
1	Recently Built	Minor	Low	Very High
2	New	Local access	Medium	High
3	Old	Collectors	High	Medium
4	Very Old	Arterials	Very High	Low

STRUCTURAL HEALTH INDEX (SHI):
SHI = CF *∑(ESCI*Si*Mi)/n — **27.27**

L2 OVERALL STRUCTURE CONDITION INDEX (OSCI):
OSCI = 1, when SHI = 1
OSCI = 2, when 1<SHI≤ 16
OSCI = 3, when 16<SHI≤81
OSCI = 4, when 81<SHI≤256
OSCI = **3**

RECOMMENDATION
Element Structural Condition Index (ESCI) or Average ESCI of Bridge Health Monitoring? **2.11**

- ☐ Green — Green = 1 - 2 — If Green then STOP.
- ☑ Yellow — Yellow = 2.1 - 3 — If Yellow then proceed on to Next Bridge
- ☐ Red — Red = 3.1 - 4 — If Red then proceed on to Next Bridge

L3 ENGINEERING ANALYSIS REQUIRED? :
- ☑ YES
- ☐ NO

L3 ACTION/OR FURTHER ANALYTICAL INVESTIGATION REQUIRED
What general properties of the bridge would you like to monitor?
- ☐ Climatic Conditions (e.g. wind speed/humidity, temperature, air pressure
- ☑ Displacements - Using what type of sensor/system?
- ☐ Scour (using pneumatic tubes & filters)
- ☑ Acceleration/Vibration (using accelerometers)
- ☑ Tilt/Slope (using tiltmeters or slope indicators)
- ☐ Ground Velocity
- ☑ Load
- ☐ DNK

What properties of the concrete bridge components would you like to monitor?
- ☐ Strain (e.g., in concrete, steel reinforcing bar, etc)
- ☑ Concrete Cracking (e.g., flexural, shear, shrinkage, D-cracking or spalling/crushing)
- ☐ Corrosion (e.g., in concrete and reinforcing bar, etc)
- ☐ Locating Rebar/Voids or Delaminations
- ☐ Concrete Strength (Thermistor or Schid Hammer)

What properties of the steel bridge components would you like to monitor?
- ☑ Strain (e.g., in plates, rolled sections, connections, etc.
- ☑ Fracture (e.g., brittle, ductile, or fatigue)
- ☐ Crack Growth
- ☐ Corrosion (portable ultrasonic gusset plate thickness measurements)
- ☐ Others? specify
- ☐ DNK

Where information cannot be verified, Inspector shall note the following: EST = Estimated or unrealiable data OR DNK = Do Not Know

ADDITIONAL COMMENTS ON REQUIRED ACTIONS & LOCATIONS ON STRUCTURE

Structural Health Index (SHI) is **27.27**
L2 Overall Structure Condition Index (OSCI) is **3**
Further analyze the structure using Structural Analysis Software and Modelling.

Figure 19: SGBCA Level 2 Result for Bumbu Bridge December 2014

Moreover, the graph below summarizes the condition index results from 2014 to 2020.

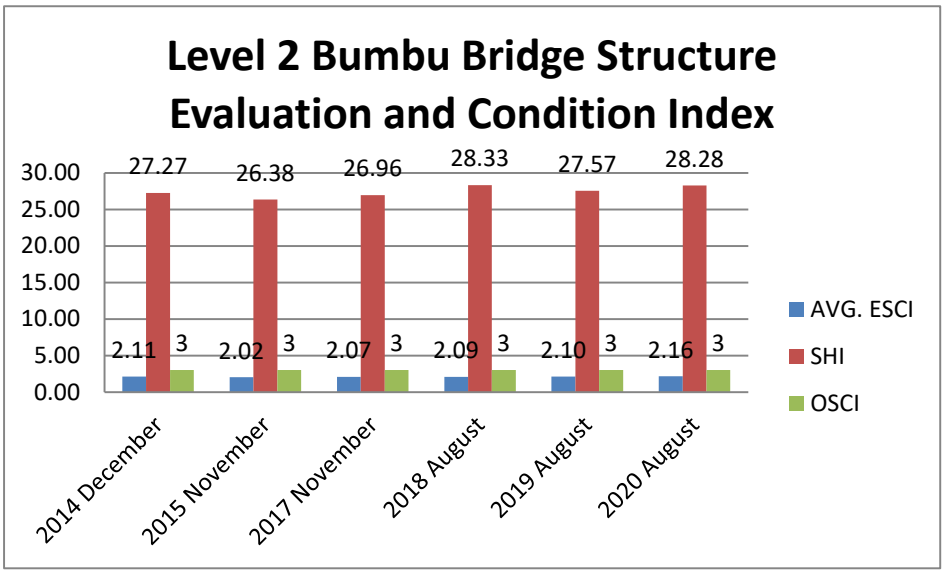

Figure 20: Graph showing the summary of the condition index of the Bumbu Bridge

According to the inspection and condition assessment results, Bumbu Bridge had an average ESCI value of 2 for all years of inspection, a low SHI of 26.38, and a high SHI of 28.33. However, an OSCI is 3, which means that the Bridge requires further attention to evaluate its structural integrity, repair, and maintenance requirements. All Level 2 bridge structure evaluations and condition assessment results for Butibam Bridge from December 2014 to August 2020 are shown in Table 4, Level 2 SGBCA Evaluation of the Overall Structural Condition Index (OSCI) for Bumbu Bridge.

Table **Error! No text of specified style in document.**: Level 2 SGBCA Evaluation of the Overall Structural Condition Index (OSCI) for Bumbu Bridge

		L2 Element Structural Condition Index (ESCI)																							
		10 December 2014				18 November 2015				24 November 2017				22 August 2018				28 August 2019				26 August 2020			
		ESCI	Si	Mi	ESCI*Si*Mi	ESCI	Si	Mi	ESCI*Si*Mi	ESCI	Si	Mi	ESCI*Si*Mi	ESCI	Si	Mi	ESCI*Si*Mi	ESCI	Si	Mi	ESCI*Si*Mi	ESCI	Si	Mi	ESCI*Si*Mi
No.	Description of Bridge Element																								
1	Steel - Beam/Girder	1.6	4	1	6.4	1.6	4	1	6.4	1.6	4	1	6.4	1.6	4	1	6.4	1.7	4	1	6.8	1.7	4	1	6.8
2	Concrete-Deck Slab	1.6	3	2	9.6	1.6	3	2	9.6	1.8	3	2	10.8	2.1	3	2	12.6	2.1	3	2	12.6	2.1	3	2	12.6
3	Steel - Bracing	1.6	4	1	6.4	1.6	4	1	6.4	1.6	4	1	6.4	1.6	4	1	6.4	1.6	4	1	6.4	1.6	4	1	6.4
4	Concrete-Pier (Diaphragm/Headstock)	1.5	4	2	12.0	1.5	4	2	12.0	1.5	4	2	12.0	1.5	4	2	12.0	1.5	4	2	12.0	1.5	4	2	12.0
5	Concrete - Pier (excl. any Headstock or Piles)	1.4	4	2	11.2	1.4	4	2	11.2	1.4	4	2	11.2	1.4	4	2	11.2	1.6	4	2	12.8	1.6	4	2	12.8
6	Concrete-Abutment and Wingwalls	1.7	2	2	6.8	1.7	2	2	6.8	1.7	2	2	6.8	1.7	2	2	6.8	1.7	2	2	6.8	1.7	2	2	6.8
7	Piles & Footings	2.2	2	2	8.6	2.2	2	2	8.6	2.2	2	2	8.8	2.2	2	2	8.8	2.3	2	2	9.0	2.3	2	2	9.0
8	Ground around footings	2.2	2	2	8.8	2.2	2	2	8.8	2.2	2	2	8.8	2.2	2	2	8.8	2.2	2	2	8.8	2.2	2	2	8.8
9	Expansion Joints	2.7	1	3	8.1	2.7	1	3	8.1	2.7	1	3	8.1	2.7	1	3	8.1	2.7	1	3	8.1	2.7	1	3	8.1
10	Deck Drains	3.1	3	3	27.9	3.1	3	3	27.9	3.1	3	3	27.9	3.1	3	3	27.9	3.1	3	3	27.9	3.4	3	3	30.2
11	Bearings (Elastomeric/Metal Fixed)	2.4	3	3	21.6	2.4	3	3	21.6	2.4	3	3	21.6	2.4	3	3	21.6	2.4	3	3	21.6	2.4	3	3	21.6
12	Parapets (kerbs/rails & barriers):	2.5	1	1	2.5	2.5	1	1	2.5	2.5	1	1	2.5	2.5	1	1	2.5	2.5	1	1	2.5	2.5	1	1	2.5
13	Railing Paint work	2.4	1	3	7.2	2.4	1	3	7.2	2.5	1	3	7.4	2.5	1	3	7.4	2.5	1	3	7.4	2.5	1	3	7.4
14	Bridge Approach Road/Carriageway	2.1	1	3	6.3	2.1	1	3	6.3	2.2	1	3	6.6	2.2	1	3	6.6	2.2	1	3	6.6	2.5	1	3	7.5
15	Bridge Approach Barriers	1.8	1	1	1.8	1.8	1	1	1.8	1.8	1	1	1.8	1.8	1	1	1.8	1.8	1	1	1.8	1.8	1	1	1.8
16	Signs	3.3	1	3	9.9	1.4	1	3	4.2	2.0	1	3	6.0	2.0	1	3	6.0	2.0	1	3	6.0	2.0	1	3	6.0
17	Embankment Erosion	2.2	1	1	2.2	2.3	1	1	2.3	2.3	1	1	2.3	2.3	1	1	2.3	2.3	1	1	2.3	2.3	1	1	2.3
18	Riverbed Scour	1.8	1	5	9.0	1.8	1	5	9.0	1.8	1	5	9.0	1.8	1	5	9.0	1.8	1	5	9.0	1.8	1	5	9.0
19	General Cleaning	2.2	1	3	6.5	2.2	1	3	6.5	2.2	1	3	6.5	2.2	1	3	6.5	2.1	1	3	6.3	2.6	1	3	7.7
	Agerage ESCI	2.11	∑(ESCI*Si*Mi)		172.70	2.02	∑(ESCI*Si*Mi)		167.10	2.07	∑(ESCI*Si*Mi)		170.75	2.09	∑(ESCI*Si*Mi)		172.55	2.10	∑(ESCI*Si*Mi)		174.60	2.16	∑(ESCI*Si*Mi)		179.10
	CF = 0.411A + 0.120E + 0.107R + 0.362I	A=3, E=3, R=3, I=3			3	A=3, E=3, R=3, I=3			3	A=3, E=3, R=3, I=3			3	A=3, E=3, R=3, I=3			3	A=3, E=3, R=3, I=3			3	A=3, E=3, R=3, I=3			3
	SHI = CF *∑(ESCI*Si*Mi)/n	SHI = 3.12*106.65/(19)			27.268	SHI = 3*167.1/(19)			26.384	SHI = 3*170.75/(19)			26.961	SHI = 3*172.55/(19)			28.335	SHI = 3*174.6/(19)			27.568	SHI = 3*179.10/(19)			28.279
	OSCI = 1, when SHI = 1 OSCI = 2, when 1<SHI≤16 OSCI = 3, when 16<SHI≤81 OSCI = 4, when 81<SHI≤256	16<SHI≤81			OSCI = 3	16<SHI≤81			OSCI = 3	16<SHI≤81			OSCI = 3	16<SHI≤81			OSCI = 3	16<SHI≤81			OSCI = 3	16<SHI≤81			OSCI = 3

4 Conclusion & Recommendation

This thesis aims to develop bridge condition assessment forms to improve the condition assessment of steel girder bridges through three main goals. The first task was to create a reliable and effective steel girder bridge condition assessment rating criteria that considered common factors contributing to bridge damage and deterioration. A thorough review of the current concepts, methods, and technologies in developed countries such as Australia was considered. The developed forms are unique because of the vital parameters and factors incorporated into evaluating the Bridge's structural components. Hence, this case study developed bridge inspection and condition assessment forms for steel girder bridges. The forms were developed for three levels. There were two forms developed for Level 1 since no bridge information and data were available at the time of research.

Visual inspection and assessment of damages or defects of bridges at the earliest possible stage are vital because it is costly to replace a bridge. Hence, the second objective of this paper was to apply the bridge condition inspection and assessment form on steel girder bridges, Bumbu and Butibam, of Lae City, to validate the reliability of the developed forms. The two bridges have been chosen because both are on institutional roads where they connect major institutions and industries in the northern part of the city to the main city center. The study applied the forms in three levels as specified in the conceptual framework in Figure 3 and required data collected during inspections. The final results obtained from applying the steel girder condition assessment forms indicated the overall condition state of the bridges. The OSCI was expressed as numbers 1 to 4 to understand the condition and compare it with each other. An OSCI value of 4 indicates the worst condition of a bridge that might require urgent attention, and an OSCI value of 1 represents a new bridge. The conclusions of the application of these forms are compelling. The condition rating for each bridge element eventually led to the overall bridge structure condition index, which can be utilized for planning and maintenance purposes. A list of significant results obtained is provided below.

- The first inspection results of the Butibam bridge showed the majority of the components to be satisfactory, with an ESCR value of 1.41 and an SHI value of 14.53. Since the SHI value was below 16, it was categorized under the OSCI value of 2. This result was reliable because the Butibam bridge was recently reconstructed in 1997 and has been in service for 23 years. The value was in the same range throughout the inspection and evaluation period.
- It was also observed from the results of the Butibam bridge that the ESCR value falls between the range of 1.41 to 1.58. Moreover, it had a 4 times SHI value below 16 with an OSCI value of 2 and a high 2 times SHI value more than 16 OSCI value of 3. It was also noted that during that period, the OSCI value of 3 was because of maintenance that happened.
- During the first inspection of the Bumbu bridge, most of the bridge components required minor maintenance or repairs. There was corrosion all over the steel girders and deep scouring of the bridge center pier. The ESCI value was 2.11 from the first condition assessment. Even throughout the inspections and evaluations, the ESCI values were all above 2, with a low ESCI of 2.02 to 2.06.

- Bumbu Bridge had a low SHI value of 26.38 to a high SHI value of 28.34, which implied that the Bridge had an OSCI value of 3 throughout the inspection and assessment period. This shows that the Bridge requires further attention, and the identified issues need to be rectified soon.
- According to the Level 1 inspection results, a recently constructed bridge like Butibam (23 years in service) does not pose much risk to the safety of the public and the risks are minor, as no structural integrity issues have been identified. However, Bumbu Bridge, being the oldest with almost 49 years of operation, has more structural integrity issues. This is due to proper routine maintenance, which is neglected for bridges in PNG.
- Bridge condition assessment and condition rating are vital to evaluate the structure's strength and serviceability, thus reducing downtime and resulting in improved maintenance practices and management of limited resources.
- According to the results, the member stiffness of the two bridges is okay, however, Bumbu Bridge is currently undergoing excessive vibration during normal traffic. The deflection values for Bumbu Bridge are below the maximum values of 197.8 mm for the whole Bridge and 98.8 mm for the respective spans as per the general formula of length divided by 250 (L/250).

5 References

AASHTO. The Manual for Bridge Evaluation, Third Edition, Washington, DC: American Association of State Highway and Transportation Officials, USA, 2018.

Atkins, G.P., and Walsh, B., J. (1985). "Monitoring of the Bumbu River in the vicinity of Butibam Bridge to Monitor the performance of the bridge and to observe its effect on the river channel and other environs." Lae City Roads Upgrading Project (Phase 2) – Butibam Bridge Project Completion Report, Lae City, Papua New Guinea, 2002.

Austroads (2004), "Guidelines for Bridge Management: Structure Information", Published by Austroads Incorporated.

Al Badran, M. S. (2013). *Structural Reliability Analysis of Corroded Steel Girder Bridge, Civil Engineering Theses, Dissertations, and Student Research, Paper 65.* Lincoln, Nebraska.

Cardno Emerging Markets (Australia) Pty Ltd. (2011). *Papua New Guinea: Bridge Replacement for Improved Rural Access.* Asian Development Bank.

Department of Works. (2003). *Bridge Assessment Management System (BAMS).*

Department of Works. (2003). *Environmental Impact Assessment Guidelines for Roads and Bridges. Road Maintenance and Rehabilitation Project.*

Department of Works. (2011). *Initial Environmental Examination, PNG: Bridge Replacement for Improved Rural Access Sector Project.* Port Moresby: ADB TA-7594 (PNG).

Department of Works. (2014). *Presentation to PNG Advantage 2014 Investment and Infrastructure Summit.*

Farrar, C. R., & Keith, W. (2007, 15th February). An introduction to structural health monitoring. p. DOI: 10.1098/rsta.2006.1928.

Figueiredo, E., Moldovan, I., Marques, M. B., (2013). Condition Assessment of Bridge: Past, Present and Future, A Complementary Approach, Faculty of Engineering, Catholic University of Portugal

Fisher, J.W. *Fatigue and Fracture in Steel Bridges*; Wiley-Interscience: Hoboken, NJ, USA, 1984.

Fontana, M., & Green, N. (1978). *Corrosion Engineering, McGraw-Hill Inc, p. 314.* New York.

Ghasemi, H, J Penrod and JM Hooks (2009) Developing advanced methods of assessing bridge performance. Public Roads 73, no.3: 2.

Holemba GA. (2019). Flood-induced Bridge Failures in Papua New Guinea

Kekare, A., Huddedar, P., & Bagde, R. (2014). Bridge Health Monitoring System. *IOSR Journal of Electronics and Communication Engineering (IOSR-JECE), Volume 9, Issue 3*, 08–14.

Konzang M. M. (2013). "An evaluation of the Lae City Road network improvement project: Development of the Lae port and construction of four-lane roads,"

Kulak, G. (1990). Discussion of fatigue strength of riveted bridge members, by J.W. Fisher, B.T. Yen, D. Wang. *Journal of Structural Engineering, vol. 116, no.11,* 2968–2981.

Kulkarni S. R. (2004). Bridge Deterioration and its Impact on Bridge Rating – A Parametric Study, Transportation Research Forum

Miki, C. Ito, Y. Sasaki, E. (2003). Fatigue-Prone Details in Steel Bridges – Fatigue and Repair Cases in Steel Bridges, Tokyo Institute of Technology of Civil Engineering, Tokyo, Japan, 2003.

Muruganandam, M. N., Maheswaran, M. T., & Huynh, C. (2012). Structures Inspections - VicRoads Experience. *25th ARRB Conference - Shaping the future: Linking policy, research, and outcomes.* Perth, Australia: ARRB Group Ltd.

Ontario Bridge Inspection Manual (OBIM), Pg. 28

PNG Department of Works. (2011). *Bridge Replacement for Improved Rural Access Projects: Initial Environmental Examination Ramu Highway.* ADB TA-7594.

Queensland Bridge Inspection Manual (2004).

Rashidi M and Gibson. P (2011), Proposal of a Methodology for Bridge Condition Assessment, Australia Transport Research Forum

Rashidi M & Lemass B (2011). "Holistic decision support for bridge remediation". The 4th International Conference on Construction Engineering and Project Management" ICCEPM, S2-4

Road & Traffic Authority of New South Wales (2007), RTA Bridge Inspection Procedure, RTA, Sydney, NSW.

Sang Hyo Kim, Won Ho Heo, Dong Woo You, Jae Gu Choi. (2017). "Vehicle loads for assessing the required load capacity considering the traffic environment," Department of Civil and Environmental Engineering, Journal: Applied Sciences (Switzerland), Volume 7, 2017.

Sharifi, Y. Paik, J.K. (2010). Environmental Effects on Ultimate Strength Reliability of Corroded Steel Box Girder Bridges, Tech Science Press, SL, Vol. 2, No. 2, Page 81–101, 2010.

Sasmal, S. and K. Ramanjaneyulu (2008). "Condition evaluation of existing reinforced concrete bridges using fuzzy based analytic hierarchy approach." Expert Systems with Applications 35(3): 1430-1443.

Sikorsky, C. (1999). Development of a Health Monitoring System for Civil Structures Using a Non-Destructive Damage Evaluation Method. *Proceedings of the 2nd International Structural Health Monitoring 2000,* (pp. 68–81). Stanford University, CA, USA.

Sohn, H., Farrar, C. R., Hemez, F. M., Czarnecki, J. J., Shunk, D. D., Stinemates, D. W., et al. (2004). *A Review of Structural Health Monitoring Literature: 1996-2001.* Los Alamos National Laboratory Report, LA-13976-MS.

Valenzuela et., al (2010). "Proposal of an integrated index for prioritization of bridge maintenance," Journal of Bridge Engineering, Volume 15, Issue 3.

VicRoads. (2011). *Road Structures Inspection Manual.*

X. W. Ye et al (2014). A State-of-the-Art Review on Fatigue Life Assessment of Steel Bridges, Department of Civil Engineering, Zhejiang University, Hangzhou 310058, China.

Yanev, B. (2007). "Bridge Management" published by John Wiley & Sons, Inc., Hoboken, New Jersey.

Yoon-Si, Lee, “Development of a structural health monitoring system for bridges and components.” A dissertation submitted to the graduate faculty in partial fulfillment of the requirements for the degree of Doctor of Philosophy, Iowa State University, Ames, Iowa, 2007.