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# Structural Review of a Bridge for Condition Assessment

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***Abstract:*** *The cost of performing a thorough bridge condition assessment is prohibitive, as it requires the installation of sensors, weigh-in-motion bridge facilities, load tests, destructive and non-destructive testing, and monitoring of the data they provide to estimate the bridge's durability. This study establishes the applicability of the structural review approach and demonstrates how it can be effectively utilized for assessing bridge conditions, particularly in developing countries such as Nigeria. Bridge inspection was performed on the Benin-Sagamu Overpass bridge to demonstrate this approach and condition rating of key bridge elements. Numerical appraisal equations were applied to the findings of the bridge inspection, which quantified the risks associated with the structure and its reliability. The decision on whether to embark on an intensive assessment scheme or not, and to determine the extent of assessment required if necessary, was arrived at based on the risk and reliability indices. The structural review tool proves to be less expensive and effective as the results it presents, reflect the actual physical conditions of the bridge. The cost of using the structural review tool for an assessment is only about 4% of the cost associated with a complete bridge structural assessment. The value of reliability deduced, which is 11.028, reflects the system reliability of the bridge, while the risk score of 333.33 reflects all the risks directly associated with the bridge and is a reliable tool for decision-making. The findings from the review on the bridge suggest there is no need for an inspection for assessment or a full-scale investigation for the durability of the bridge, and that the best decision regarding the bridge is to allow for another review after a certain number of years. It is recommended that the bridge authority perform a well-documented Principal Inspection on the facility for reference purposes in future reviews, and that this review tool be adopted to assess and document bridges across Nigeria in order to establish a database for the current condition of all bridges and start a bridge management program.*

***Keywords****: Bridge Inspection, Bridge Assessment, Condition Assessment, Condition Rating, Structural Health, Structural Review*

## 1. INTRODUCTION

The assessment of the current conditions of bridge structural members is essential to bridge engineers and officials when making decisions on how to fix, maintain, or replace a bridge [1]. Bridge failures may become disastrous and catastrophic, as regards human life and economic loss; therefore, efficient bridge condition assessment is vital in estimating its future performance and in optimizing its maintenance, rehabilitation, and replacement needs [2].

### 1.1 Bridge Condition Assessment

Bridge condition assessment (BCA) requires only visual inspection [3]; however, the results can be quantified to aid in bridge management and in making critical decisions concerning the bridge's well-being. The quality of results from visual inspection heavily depends on the competence and experience of the bridge inspectors [2].
The primary goals of BCA are the detection of defects and the establishment of their severity level [4]. Comprehensive bridge inspections are conducted frequently to assess severe defects and examine the extent of deterioration, while immediate risk inspections arising from distinctive defects are also conducted immediately after the occurrence of natural disasters, which include earthquakes, floods, fire, etc., [4].

Several methods have been used in the past to evaluate the current condition of bridges, and it has been found that the more thorough the method, the higher the cost it incurs [4]. In North America, for instance, the widespread technique used in BCA is by visual inspection and close observation of bridge elements, and this is due to the low financial implications and that it requires a minimal level of experience [4].
Visual evaluation of bridges aids in providing information on their physical condition through the observation of surface defects like spalling and cracking, whereas for subsurface defects, chain dragging and hammer sounding techniques are used to measure the areas of delamination within the concrete slab [4]. Destructive testing (DT) and Non-Destructive Testing (NDT) methods are employed for more detailed condition assessment if extreme damages are observed during bridge inspection and evaluation and also, DT methods are more expensive and time-consuming but give more accurate results, whereas the results from NDT methods are less expensive, indirect, and require interpretation from field experts to get useful outputs [4].

Victor et al. [5], while assessing the current state of bridges in major highways of four northern states in Nigeria, employed the use of visual inspection and an unmanned aerial vehicle. Documentation for bridge element condition rating was provided for the bridges inspected in accordance with [6]. This research, however, presented bridge inspection results using the member rating system of [6] and the structural review form of [7].

Petri [8] performed a five-day assessment on the bridge linking Nigeria and Cameroon in Cross Rivers state, using as-built drawings available from relevant sources. The study proved that bridge condition assessment is indeed very expensive and can be time-consuming. While recommendations were made for certain maintenance jobs to be carried out, the bridge was found to be able to withstand the existing vehicular live load, which was 45 tons as compared to 26 tons found in the original design. There was, however, no record of a structural review done before the inspection. A structural review could have reduced the amount of time spent on this assessment and rather focused on key bridge elements that needed attention. Structural review of CS 451 [7] was systematically prepared in such a way as to aid decision-making and facilitate quick assessment, thereby saving time and resources. It prioritises and identifies the necessity for an assessment of the key elements rather than entering vaguely into a full bridge assessment.

### 1.2 Bridge Condition Assessment by Structural Health Monitoring

There are presently several methods that have been proposed for the structural health monitoring (SHM) of bridges, which are primarily centered on the use of sensors and computer vision technology [9]. The challenge, however, is that developing countries like Nigeria have yet to fully embrace maintenance culture for their infrastructure; (especially for bridges), and thus the use of sensors or technology to monitor the structural health of bridges is still far from being implemented. Furthermore, the level of public utility vandalism and theft is another factor currently fighting against the use of such technology.

Rizzo and Enshaeian [10] stated that there are over 600,000 highway bridges in the United States, but the SHM program, aided by sensors and weigh-in-motion (WIM), is not active on all. Rizzo and Enshaeian [10] identified 60 bridges in addition to 9 others earlier discovered by [11], which had sensors installed on them for SHM. These statistics show that not all bridges in the United States have sensors installed on them for monitoring. Even in the most advanced nations, the cost of placing sensors or WIM facilities for bridges can be overwhelming. It therefore becomes imperative that alternate methods are adopted in bridge management and maintenance, and such technology should be employed to complement traditional periodic inspections, when bridges are nearing their design lifespan or showing abnormal signs tending to failure, just as it is done in the United States.

Makki et al. [12] studied the use of continuous and non-continuous SHM schemes to detect bridge damage. The Ground Penetrating Radar (GPR) was identified as a key tool in SHM. The cost of manufacturing the GPR was found to be as high as N17,150,000 ($14,000 in 2023), and that’s aside from the cost of importation. This high cost of availability makes it highly unlikely that the GPR technology would become available anytime soon for industry professionals to readily adopt in the maintenance of Nigerian highway bridges. Therefore, alternative measures which should be flexible and less costly have to be sought for in the condition assessment of bridges. The structural review method provides such an alternative.

Karimi and Mirza [13], while reviewing the existing methods in bridge damage identification and detection, emphasized that SHM through the use of sensors has limitations that make it unlikely to be perfectly reliable. Such limitations stem from the fact that sensors only give dynamic characteristics of the vehicles in motion and may not fully represent the condition of the structure. Furthermore, [13] reiterated that it is difficult to develop an SHM scheme that can serve all bridges since each bridge behaves in its peculiar way. This also brings to light that the method of periodic inspections is still useful and should be improved upon, which is the purpose of this research.

In recent times, the use of Artificial Intelligence (AI) and machine learning in predicting structural behaviour is gaining significance. However, the predictive nature of AI is only enhanced by the use of data collected from sensors, historical inspection reports, and environmental conditions [14]. The ability of the AI to accurately predict the condition of bridges also stems from the application of probabilistic and statistical methods given to it as instructions. These probabilistic methods are already duly applied in the structural review of a bridge as per the requirements of [7].

One other demerit of the SHM using data from sensors is that industry professionals are not very knowledgeable about it and how it operates. Millar et al. [15] reported from a survey on industry professionals in Canada that most professionals are at a loss as to how the data accumulated from sensors should be interpreted to give adequate information about the condition of bridges. As Millar et al. [15] further gathered, the proposed use of sensors is more familiar to academicians than engineering practitioners. However, the structural review format used in this research has made things easier by providing simplified approaches to SHM of bridges.

While the focus of structural integrity of bridges has been on SHM using sensors and WIM bridges to accumulate data concerning a particular bridge, there has not been any practical application of the structural review methods for bridge condition assessment known to the authors from the review of literature. While both [5] and [12] performed bridge assessment and presented results, neither performed a structural review nor presented details of any structural review. Therefore, there are no sufficient reasons to cast doubt on this method, which has not been fully harnessed. This research applies the structural review methods to aid in periodic assessment of bridges and to show how the results of bridge assessments should be properly documented for future inspections using record forms.

### 1.3 Structural Review of Bridges

Due to the huge amounts of money involved in delving into bridge assessment straightaway, it is expedient to perform a structural review before embarking on a full-scale assessment. Structural review of bridges focuses on examining and comparing any existing assessment results or original bridge design data, identifying deviations, and making predictions concerning the bridge. CS 451 [7] defines structural review as the "review of an individual structure or group of structures, to reaffirm or verify the authenticity of its latest assessment or original design, and identify any need and the priority for further assessment from the results of the review".

In bridges, structural review and assessment are prompted by changes in bridge condition (as observed during bridge inspections), proposed changes in bridge use (to accommodate heavier traffic), and observations of abnormal loading [16]. In this study, there were no observations of changes in bridge condition and abnormal loads; rather, the review was done purely to apply the research concept to a case study and make assertions. According to clause 2.1 of CS 451 [7], the structural review and assessment process of a bridge shall be carried out in two stages. The first stage is strictly on structural review, while the second stage focuses on the assessment proper. The results of this review will determine the necessity of an assessment and the extent of assessment to be performed.

The structural review is a risk evaluation that provides an assessment of the consequences of failure and uses the consequences of failure to establish shortcomings in the "carrying capacity of the structure" [7]. The criteria used for the risk appraisal include 'load carrying capacity of the bridge, current structural health of the bridge, accessibility of critical elements of the bridge, route carried and obstacles crossed, monitoring regime for the bridge, changes in bridge condition and increase in bridge loading' [7]. Basic things to note during a structural review include the year of construction of the bridge, if the bridge is within the scope for a structural review, and the load-carrying capacity of the bridge [7]. The results of the structural review 'are documented in a structural review form, which summarises the evidence with recommendations as to whether an assessment is required and the priority for any assessment' [7]. If the results of the structural review are not favourable, an assessment is recommended by the review team using the decision matrix of CS 451 [7]. Before going ahead with a full-scale assessment, a preliminary inspection to determine what type of assessment and extent of assessment is still carried out. This is called inspection for assessment [7].

CS 454 [16] emphasized that the evaluation of a highway structure (bridge in this case) for its current capacity to carry load should involve analysis, calculations, and inspection of the structure. It was further buttressed that "inspections are necessary to verify the form of construction, the dimensions of the structure, and the nature and condition of the structural components" [16]. In this research, visual inspection covers the condition of individual components as well as that of the structure as one system, while noting signs of distress and their likely cause. Before undertaking the inspection of a bridge structure, CS 454 [16] advised that "all existing information about the bridge should be collected, including as-built drawings, soil data, geotechnical parameters, past inspection reports, and monitoring records" as these may be of use in determining what further information should be obtained from the inspection and which items may require special attention. Bridge condition assessment can otherwise be done in the absence of the data mentioned above. CS 455 [17] made provisions for determining all required data necessary for assessment and multiplying by safety factors that account for human errors. CS 450 [22] noted that general inspections only are unlikely to be adequate for thorough assessment purposes.

This research applied the structural review method to assess the Overpass Bridge along the Benin-Sagamu road by visual inspection. No reference was made to past inspection results or as-built drawings, but rather, the bridge geometry was estimated purely by measurements, while the assessment load was adopted from previous research by the authors in [18]. The dimensions and geometry of the bridge have been represented graphically as shown in Figure 1. The sequence of work has been described in the methodology, while the results of the visual inspection were documented in the structural review form. Lastly, the state of the bridge was quantified using equations and tables from [7].

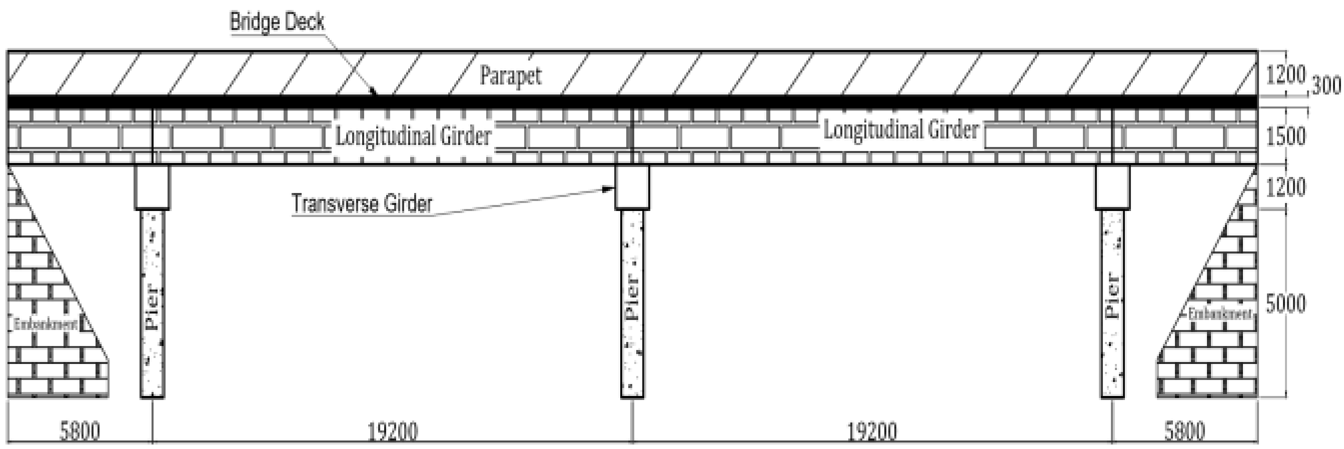


Figure 1. Bridge geometry and dimensions

## 2. METHODS

The methods applied to exemplify the research concept were coined from [19]. It includes subsections as [7], [16], and [17]. The general procedures have been described in section 2.3.

### 2.1 Inspection of Bridge

There was a performance of bridge inspection as provided by [7] to commence the structural review. Due to the non-availability of original design documents or access to previous assessment results, the dimensions of the bridge structural elements were measured for review. The inspection was a general inspection (GI), just for review. Figure 2 shows images of the bridge girders, approach alignment, utilities on the bridge walkway, and a section of slope protection of the bridge taken during inspection.

Figure 2. Bridge girders, approach alignment, utilities, slope protection

### 2.2 Structural Review and Assessment

A structural review of the structure was performed from the results of the inspection to establish the need for an assessment. The measures used to conduct the review were derived from equations A1 to A6 of [7]. This numerical way helped in establishing if there was any need for an assessment using the decision matrix, as shown in Table 12.

### 2.3 Structural Review Procedure

The procedure for structural reviews, as put forth in [7] and adopted in this research, is as follows:

i. Selection of the closest applicable scenario (B1, B2 or B3). The scenario to be chosen is determined by whether the structure has experienced any form of assessment previously or not.
ii. Selection from Table 1, Table 2 or Table 3 the value of variable $D$ (B1, B2, B3). Each scenario (B1, B2, B3) has its table, which depends on the period of construction.
iii. Selection from Table 4 to Table 11 values of variables $E$, $F$, $G$, $H$, $F$, $J$, $K$, $R_1$, $R_2$, $R_3$. These values are variables regarding, current condition of bridge, access to inspect critical elements, monitoring, change in condition, change in loading and class of road over the bridge.
iv. Determination from the inspection, values of the bridge's width ($W$), bridge length ($L$) and maximum bridge span ($S$) all in metres.
v. Application of the values from 1 to 4 into Equations 1 to 6.
vi. Using the risk and reliability indices derived from Equations 5 and 6, the decision matrix, Table 12, is used to determine if an assessment is required and, if any, to what extent.

### 2.4 Numerical Appraisal Equations

The numerical appraisal equations are consequences of failure formulations coined from [7]. They are used to quantify the risk score and reliability. They are as shown below.

**Consequence 1 ($C_1$)**

This combines the structure's width $W$, length $L$, as well as values of $R_1$ and $R_2$ from Tables 10 and 11, respectively.

$$C_1 = 18000[(S+70)\times R_1 + (W+70)\times R_2] \quad (1)$$

**Consequence 2 ($C_2$)**

This combines the structure's width $W$, length $L$ and maximum span $S$.

$$C_2 = [\{(9.6\times S)+242\}\times L + W] + (5124\times W) + (1742\times L) + 50000 \quad (2)$$

**Consequence 3 ($C_3$)**

This combines the values of $R_1$ and $R_2$ from Tables 10 and 11, respectively.

$$C_3 = 337500\times(R_1 + R_2) \quad (3)$$

**Consequence 4 ($C_4$)**

This combines the values of $R_1$ from Table 10 and the consequences $C_1$, $C_2$ and $C_3$ already derived above from Equations (1) to (3).

$$C_4 = 0.4(R_3 + C_1 + C_2 + C_3) \quad (4)$$

**Reliability**

This combines the value of variable $D$ from the best fit scenario of the bridge from Tables 1, 2 and 3 with values of variable $E$, $F$, $G$, $H$, $J$, and $K$ gotten from Tables 4, 5, 6, 7, 8 and 9, respectively.

$$Reliability = C_4\times(D\times E\times F\times G\times H\times J\times K) \quad (5)$$

**Risk**

This combines the values of variable $E$, $F$, $G$, $H$, $J$, $K$ gotten from Tables 4, 5, 6, 7, 8 and 9, to quantify the risk.

$$Risk = \frac{1}{1000(D\times E\times F\times G\times H\times J\times K)} \quad (6)$$

### 2.5 Structural Review and Risk Appraisal Tables

These tables represent different scenarios that aid in addressing the risks involved with an existing structure that has not had any load assessment, and even when an exact circumstance wasn't addressed with the tables, the closest available scenario can be adopted as long as the reason it was used is clearly stated [7]. These tables, which are found in [7], are described and shown in the following sections.

**i. Scenario B1 for variable D**

Table 1, which was adapted from CS 451 [7], presents values for the variable D for scenario B1, and describes situations where the assessment load is known. Where different parts of the bridge have different load capacity ratings, that of the lanes where the vehicle is passing is used.

Table 1: Values of variable D for scenario B1

| Capacity/Year | Pre-1950 or Unknown | 1950-1975 | 1976-1990 | Post-1990 |
|---|---|---|---|---|
| 38T+ | $1.0\times10^{-8}$ | $1.0\times10^{-8}$ | $1.0\times10^{-8}$ | $1.0\times10^{-8}$ |
| 26T | $4.0\times10^{-7}$ | $2.0\times10^{-7}$ | $1.0\times10^{-7}$ | $5.0\times10^{-8}$ |
| 18T | $5.0\times10^{-6}$ | $1.0\times10^{-6}$ | $8.0\times10^{-7}$ | $5.0\times10^{-7}$ |
| 7.5T | $1.0\times10^{-5}$ | $5.0\times10^{-5}$ | $1.0\times10^{-6}$ | $5.0\times10^{-7}$ |
| 3T | $1.0\times10^{-4}$ | $5.0\times10^{-5}$ | $1.0\times10^{-5}$ | $5.0\times10^{-6}$ |

*Note*. Adapted from CS 451 [7]

**ii. Scenario B2 for variable D**

Table 2, adapted from CS 451 [7], presents values for the variable D for scenario B2, and describes the level of confidence the inspectors have regarding the load capacity, knowledge of any previous assessment taken, and takes into consideration the year of construction. In this case, the bridge has not had an assessment, or there is insufficient documentation to confirm the assessment.

**iii. Scenario B3 for variable D**

Table 3, was adapted from CS 451 [7], and presents values for the variable D for scenario B3, describing the scenario when the bridge does not have any assessment requirement, and also takes into consideration the year of construction. This could be due to preventive maintenance works that have kept the bridge in shape or due to any other factor that suggests there are insufficient reasons to perform an assessment.

Table 2: Values of variable D for scenario B2

| Confidence Level/Year | Pre-1950 or Unknown | 1950-1975 | 1976-1990 | Post-1990 |
|---|---|---|---|---|
| Some records show load capacity is satisfactory | $5.0 \times 10^{-8}$ | $2.0 \times 10^{-8}$ | $1.0 \times 10^{-8}$ | $1.0 \times 10^{-8}$ |
| High confidence that the assessment was completed for current applied loading | $6.0 \times 10^{-8}$ | $3.0 \times 10^{-8}$ | $2.0 \times 10^{-8}$ | $1.0 \times 10^{-8}$ |
| Medium confidence that assessment has been undertaken where it was a requirement | $1.0 \times 10^{-7}$ | $6.0 \times 10^{-8}$ | $3.0 \times 10^{-8}$ | $1.0 \times 10^{-8}$ |
| Low confidence that assessment has been undertaken where it was a requirement | $1.0 \times 10^{-5}$ | $1.0 \times 10^{-6}$ | $1.0 \times 10^{-7}$ | $1.0 \times 10^{-8}$ |

*Note*. Adapted from CS 451 [7]

Table 3: Values of variable D for scenario B3

| Year | Pre-1950 or Unknown | 1950-1975 | 1976-1990 | Post-1990 |
|---|---|---|---|---|
| No assessment requirement for the structure | $6.0 \times 10^{-8}$ | $3.0 \times 10^{-8}$ | $2.0 \times 10^{-8}$ | $1.0 \times 10^{-8}$ |

*Note*. Adapted from CS 451 [7]

### iv. Variable E

Table 4, which was adapted from CS 451 [7], presents values for the variable E for different load limits placed on the bridge, if there is a load limit signage. This is important because it affects the lifespan of the bridge in various ways. The tonnage of load allowed on the bridge determines the type of actions it has resisted over the years.

### v. Variable F

Table 5, adapted from CS 451 [7], presents values for the variable F concerning the current condition of the bridge as rated by the bridge inspector. At this stage, the level of qualification, experience, and engineering judgment of the bridge assessor is paramount in selecting the right value for the variable.

Table 4: Values of variable E

| Measure | Variable E |
|---|---|
| 3T limit signage | 0.05 |
| 7.5T limit signage | 0.1 |
| 18T limit signage | 0.5 |
| 26T limit signage | 0.75 |
| Physical restraints for vehicles | 0.001 |
| Not applicable | 1 |

*Note*. Adapted from CS 451 [7]

Table 5: Values of variable F

| Condition | Variable F |
|---|---|
| Good | 30 |
| Fair | 20 |
| Poor | 1000 |

*Note*. Adapted from CS 451 [7]

### vi. Variable G

Table 6, was adapted from CS 451 [7], and presents values for the variable G, declaring the accessibility of bridge critical elements to the assessor. Usually, the values will depend on the obstacle the bridge crosses and the height of the bridge above ground level. Bridges crossing water bodies would have high values, while those crossing land obstacles would have low values.

Table 6: Values of variable G

| Accessibility of Bridge's Elements | Variable G |
|---|---|
| Critical element(s) not hidden and can be adequately inspected during a PI | 1 |
| Critical element(s) are hidden and/or cannot be adequately inspected during a PI | 10 |

*Note*. Adapted from CS 451 [7]

### vii. Variable H

Table 7, adapted from CS 451 [7], presents values for the variable H for bridges which has an SHM in place. If the finances are available, it is expedient for every bridge to have such a system put in place, but when that is not the case, a structural review can still be performed. This shows the flexibility of the structural review approach, which takes bridges without SHM into consideration.

**viii. Variable J**

Table 8, which was adapted from CS 451 [7], presents values for the variable J, which represents the level of deterioration since the bridge came into service or since the last assessment. Again, professionalism and engineering judgment of the assessor play a major role.

Table 7: Values of variable H

| Availability of any Monitoring System | Variable H |
|---|---|
| Appropriate monitoring in place | 0.1 |
| No monitoring in place or not required | 1.0 |

*Note*. Adapted from CS 451 [7]

Table 8: Values of variable J

| Level of Deterioration | Variable J |
|---|---|
| Significant deterioration in condition since design/assessment | 500 |
| Slight deterioration in condition since design/assessment | 2 |
| No significant deterioration in condition since design/assessment | 1 |

*Note*. Adapted from CS 451 [7]

**ix. Variable K**

Table 9, adapted from CS 451 [7], presents values for the variable K, which identifies the increase in bridge loading since design or when the bridge came into service, or since the last assessment.

**x. Variable R1 and R3**

Table 10, which was adapted from CS 451 [7], indicates values for variables R1 and R3 that represent the route the bridge is supporting, depending on the type of motorway. It also includes railways and pedestal bridges.

Table 9: Values of variable K

| Increase in Loading | Variable K |
|---|---|
| Significant increase in operational load-carrying requirements since design/assessment | 50 |
| Moderate (10-30%) increase in operational load carrying requirements since design/assessment | 5 |
| Slight increase in loading since design/assessment | 1.1 |
| No increase in loading since design/assessment | 1 |
| Need to assess for STGO/SO loads | 500 |

*Note*. Adapted from CS 451 [7]

Table 10: Values of variables R1 and R3

| Supporting Route | Variable R1 | Variable R3 |
|---|---|---|
| Motorway/railway | 7 | $1.0 \times 10^7$ |
| A road | 3.5 | $1.0 \times 10^6$ |
| B road | 0.8 | $1.0 \times 10^5$ |
| Other road/footpath/canal | 0.2 | $1.0 \times 10^4$ |

*Note*. Adapted from CS 451 [7]

**xi. Variable R2**

Table 11 was adapted from CS 451 [7], and indicates values for the variable R2, which represents the obstacle the bridge is crossing, whether land routes, canals, or other water bodies.

Table 11: Values of variable R2

| Obstacle Crossed | Variable R2 |
|---|---|
| Motorway/railway | 7 |
| A road | 3.5 |
| B road | 0.8 |
| Other road | 0.15 |
| Other – bridleway, canal, disused land, etc. | 0.1 |

*Note*. Adapted from CS 451 [7]

### xii. Reliability and risk score

Table 12, which was also adapted from CS 451 [7], indicates values for the reliability, risk score, and appropriate recommendations, based on the results from applying Equations (1) to (6). These give the measures on which the right decision on the bridge is made.

Table 12: Estimated values of reliability, risk score, and recommendation

| Risk score | Reliability | | | |
|---|---|---|---|---|
| | 0 to 13.2 | 13.3 to 25.0 | 25.1 to 83.0 | 83+ |
| 0 to 1.00 | Assessment recommended (low priority) | Assessment recommended (medium priority) | Assessment recommended (high priority) | Assessment recommended (very high priority) |
| 1.01 to 10.00 | Review need for assessment at next structural review | Assessment recommended (low priority) | Assessment recommended (medium priority) | Assessment recommended (high priority) |
| 10+ | Review need for assessment at next structural review | Review need for assessment at next structural review | Review need for assessment at next structural review | Assessment recommended (low priority) |

*Note*. Adapted from CS 451 [7]

## 3. RESULTS AND DISCUSSIONS

### 3.1 Results from Bridge Inspection

Table 13, adapted from Zulfiqar et al. [20], shows the results from visual inspection using the structural element rating formats in [6, 20]. The rating uses 11 conditions from 0 to 9 and N. The case study being reviewed does not cross a waterway but rather crosses a road. Therefore, any water element that pertains to bridges crossing a waterway is marked with 'N'. The rest conditions are chosen from 0 to 9, and the best condition that describes the element was ticked during the inspection.

Table 13: Bridge element rating from visual inspection

| | | Condition Rating | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **S/N** | **Element** | **N** | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| | **Roadway Elements** | | | | | | | | | | | |
| 1 | Approach Roadways | | | | | | | | ✓ | | | |
| 2 | Traffic Safety Features | ✓ | | | | | | | | | | |
| 3 | General Alignment | | | | | | | | | | ✓ | |
| 4 | Approach Alignment | | | | | | | | | ✓ | | |
| 5 | Deflections | ✓ | | | | | | | | | | |
| 6 | Settlement | ✓ | | | | | | | | | | |
| | **Deck Elements** | | | | | | | | | | | |
| 1 | Bridge Deck Top | | | | | | | | | | ✓ | |
| 2 | Bridge Deck Bottom | | | | | | | | | | | ✓ |
| 3 | Expansion Joints | | | | | | | ✓ | | | | |
| 4 | Sidewalks and Railings | | | | | | | | | | ✓ | |
| 5 | Signing | ✓ | | | | | | | | | | |
| 6 | Electrical-lighting | ✓ | | | | | | | | | | |
| 7 | Barriers, gates, and other traffic control devices | ✓ | | | | | | | | | | |
| | **Superstructure Elements** | | | | | | | | | | | |
| 1 | Primary load-carrying Members | | | | | | | | | | | ✓ |
| 2 | Secondary Members | | | | | | | | | | | ✓ |
| 3 | Bracings | | | | | | | | | | ✓ | |
| 4 | Utilities and their attachments | | | | | | | | | ✓ | | |
| 5 | Anchorages | | | | | | | ✓ | | | | |
| 6 | Bearings | | | | | | | | | ✓ | | |
| | **Substructure Elements** | | | | | | | | | | | |
| 1 | Abutments | | | | | | | | | ✓ | | |
| 2 | Piers | | | | | | | | ✓ | | | |
| 3 | Footings | | | | | | | | | ✓ | | |
| 4 | Piles | ✓ | | | | | | | | | | |

| | | Condition Rating | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **S/N** | **Element** | **N** | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| 5 | Curtain Walls | ✓ | | | | | | | | | | |
| 6 | Skewbacks | | | | | | | | | ✓ | | |
| 7 | Slope Protection | | | | | | | | ✓ | | | |
| | **Channel and Waterway Elements (Carriageway in this case)** | | | | | | | | | | | |
| 1 | Channel Profile and Alignment | | | | | | ✓ | | | | | |
| 2 | Channel Streambed | ✓ | | | | | | | | | | |
| 3 | Channel Embankment | | | | | | | | | ✓ | | |
| 4 | Channel Embankment Protection | ✓ | | | | | | | | | | |
| 5 | Hydraulic Opening Fenders | ✓ | | | | | | | | | | |
| 6 | Water Depth Scales | ✓ | | | | | | | | | | |
| 7 | Navigational Lights and aids | ✓ | | | | | | | | | | |
| 8 | Dolphins | ✓ | | | | | | | | | | |
| 9 | Hydraulic Control Devices | ✓ | | | | | | | | | | |

*Note*. Adapted from Zulfiqar et al. [20]

As observed from the inspection results above, there is no immediate threat to the safety of the bridge or bridge users. However, key infrastructural elements of the bridge did show early signs of deterioration, and these elements, if not maintained, could deteriorate even worse and be detrimental to the bridge's safety in the long term. Bridge elements such as expansion joints, approach roadway, anchorages, piers, slope protection, approach alignment, utilities and their attachments, bearings, abutment, and footings show some minor problems. Some of the problems are insignificant, physically speaking. General preventive maintenance can solve these minor issues.

### 3.2 Bridge Inspector's Rating Criteria

The bridge inspection results were quantified by values in the previous section. This quantification is an estimate of the current condition of bridge elements. Table 14 was adapted from Zulfiqar et al. [20], and it interprets each quantification given in Table 13 and its implications, and was adopted from [6, 20].

Table 14: Bridge inspector ratings

| S/N | Code | Condition | Description |
|---|---|---|---|
| 1. | N | NOT APPLICABLE | |
| 2. | 9 | EXCELLENT | |
| 3. | 8 | VERY GOOD | No problems noted. |
| 4. | 7 | GOOD | Some minor problems. |
| 5. | 6 | SATISFACTORY | Structural elements show some minor deterioration. |
| 6. | 5 | FAIR | All primary structural elements are sound but may have minor section loss, cracking, spalling, or scour. |
| 7. | 4 | POOR | Advanced section loss, deterioration, spalling or scour. |
| 8. | 3 | SERIOUS | Loss of section, deterioration, spalling or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present. |
| 9. | 2 | CRITICAL | Advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored, it may be necessary to close the bridge until corrective action is taken. |
| 10. | 1 | IMMINENT FAILURE | Major deterioration or section loss is present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put back in light service. |
| 11. | 0 | FAILED | Out of service – beyond corrective action. |

*Note*. Adapted from Zulfiqar et al. [20]

### 3.3 Results from Structural Review

Using the format prescribed in [7], reproduced here in Section 2.4 (Tables 1 to 12), the following results were obtained from numerical structural review of the structure.

i. The scenario chosen was B2 since there was no access to any document to prove whether there had been an assessment or not.

ii. Variable D was taken from Table 2 as $1.0 \times 10^{-8}$.
iii. Since there was no physical restraint for vehicles, variable E was taken as 1 from Table 4.
iv. The bridge's overall current condition can be said to be good, and thus, variable F from Table 5 was taken as 30.
v. Variable G for the ability to inspect critical elements was 1 from Table 6.
vi. From Table 7, variable H for monitoring is taken as 1.
vii. Regarding the change in condition variable, J, 2 was chosen from Table 8.
viii. From Table 9, variable K, which represents the change in loading, was taken as 5.
ix. From Table 10, variables R1 and R3 for the route supported by the bridge are taken as 3.5 and $1.0 \times 10^{6}$, respectively.
x. Variable R2, which represents the trunk of the road, is taken as 3.5 for Road Trunk A, from Table 11.
xi. From the structure, L is 50m; W is 9.6m, and the maximum span S is 19.2m.

### 3.4 Numerical Appraisal Values

When the numerical formulations from Equations (1) to (6) are applied, the following results are deduced.

From Equation (1), $C_1 = 18000[(19.2 + 70) \times 3.5 + (9.6 + 70) \times 3.5]$
$C_1 = 5{,}619{,}878.6$

From Equation (2), $C_2 = [\{(9.6 \times 19.2) + 242\} \times 50 + 9.6] + (5124 \times 9.6) + (1742 \times 50) + 50000$
$C_2 = 207{,}606.4$

From Equation (3), $C_3 = 337500 \times (3.5 + 3.5)$
$C_3 = 2{,}362{,}500$

From Equation (4), $C_4 = 0.4((1.0 \times 10^{6}) + 5619878.6 + 207606.4 + 2362500)$
$C_4 = 3{,}675{,}994$

From Equation (5), $Reliability = 3675994 \times ((1.0 \times 10^{-8}) \times 1 \times 30 \times 1 \times 1 \times 2 \times 5)$
$Reliability = 11.028$

From Equation (6), Risk is given as;

$$Risk = \frac{1}{1000((1.0 \times 10^{-8}) \times 1 \times 30 \times 1 \times 1 \times 2 \times 5)}$$

$Risk = 333.33$

The results have proven that the bridge is in good condition and that another structural review should be scheduled after a certain number of years, as deemed fit by the bridge authority. This review has also shown the reliability of the structure as 11.028, which is fairly high for a structure of 23 years.

### 3.5 Structural Review Form

The computed results above and the results from the inspection are the deciding factors when filling out the structural review form. The form serves as a starting point for any future assessment and gives any future assessor relevant information to work with. The sample review form for this research is demonstrated in Table 15 (CS 451) [7] and it contains all relevant information deduced from the review.

Coupled with the form above, the inspecting officer or team is expected to sign, indicating their names and qualifications, as well as the organizations, with the date. If there are conditions to be attached to the acceptance of the results, these are stated and countersigned by inspecting officers [7]. The results presented in this form can be accepted or rejected by the bridge authority, depending on the depth of assessment desired.

### 3.6 Cost Comparison between Structural Review and Assessment Proper

Using the case study adopted for this study, the costs for performing an inspection for structural review, inspection for assessment, and an assessment proper were estimated to show the price variations. The activities that would take place during the inspection for structural review, inspection for assessment, and an assessment proper were mentioned to give a background.

#### 3.6.1 Activities during inspection for structural review [7]

i. Verification of load capacity from the original design loading.
ii. Verify if there is an interim measure by load limit signage on the bridge.
iii. Verify the current condition of the structure from a recent Principal Inspection (Details about Principal Inspection can be found in [22]).
iv. Verify if the critical bridge elements are accessible for the inspection.

v. Identify the presence of any SHM regime for the bridge structure (By use of sensors or other monitoring devices).
vi. Verify if there are changes in the condition of the bridge structure that can affect its load capacity, since the last assessment (if any), or since the design.
vii. Verify for an increase in loading on the bridge since the last assessment (if any) or since when the bridge came into service.
viii. Verify if there is any proposed increase in loading for the bridge by the government or the bridge authority.
ix. Verify the route carried and obstacles crossed.

Table 15: Record of structural review form

| S/N | Record of structural review form | | | |
|---|---|---|---|---|
| **1.** | **Structure Details** | | | |
| | **Structure Name** | Benin-Sagamu Bypass Bridge | | |
| | **Structure Number** | **--** | | |
| | **Structure Key (if used)** | -- | | |
| | **Date Commissioned** | 2002 | | |
| | **Obstacles Crossed** | Benin City Road | | |
| | **Bridge Carriers** | Benin-Sagamu Road | | |
| | **Brief Description of Bridge** | | | |
| | The Benin-Sagamu Bypass overhead twin bridge is a two-carriageway reinforced concrete bridge whose structural elements were built separately at a distance of 0.6m. One carriageway has four spans that are simply supported, covering an effective length of 50m. The critical spans are the two middle spans, which cover a length of 19.2m each, whereas the remaining portion has spans of 5.8m each. The width of the bridge, including walkway and abutment, is 9.6m. It is characterized by an open cross-section composed of six (6) precast reinforced concrete longitudinal girders of flange thickness 0.3m, web thickness of 0.4m, and depth of 1.5m set at a constant spacing of 1.2m. The bridge came into service in the year 2002 and has not undergone any major rehabilitation. | | | |
| | **Elements to be Reviewed (where not the whole structure)** | | | |
| | The entire bridge, except the substructure | | | |
| | **Reason for structural review** | For research purposes | | |
| **2.** | **Existing Assessment Details or Design Records** | | | |
| | **Inspection for Assessment Date** | -- | -- | -- |
| | **AIP for Assessment** | -- | -- | -- |
| | **Assessment Date** | -- | -- | -- |
| | **Current Assessed/Design Capacity (include Reserve Factors)** | | | |
| | HA/ALL | 46 Ton Assessment Live Load [17] | SV/STGO/SO | Nil |
| | **Critical Elements** | Bridge pier, transverse girders, longitudinal girders, Parapet, slope protection | | |
| | **Parapet** | Concrete parapet; Satisfactory condition | | |
| | **Pier Impact** | Satisfactory Condition; Very low risk of impact | | |
| | **Certification** | Not found | | |
| | **Calculations** | Not found | | |
| | **As-built drawings** | Not found | | |
| | **Comments on Assessment or Design** | | | |
| | Not Available | | | |
| **3.** | **Evaluation** | | | |
| | **Inspection Date** | Not Found | | |
| | **Change in Condition** | There have been no major changes in condition since construction. The only obvious changes are expansion joints and the presence of grasses along the walkway and slope protection. Also, due to the speed of vehicles plying the road, there seems to be impingement on the piers that leaves tiny holes on their bodies. | | |
| | **Change in Standards** | Standards have remained the same since the design. | | |
| | **Change in Loading** | Changes in loading can only be confirmed by a change in traffic intensity. | | |
| | **Required Capacity** | 46 Ton Assessment Live Load [18] | | |
| | **Vulnerable Details** | -- | | |
| | **Hidden Critical Elements** | -- | | |
| | **Interim Measures** | -- | | |
| | **Condition** | -- | | |

| S/N | Record of structural review form | |
|---|---|---|
| | **Conclusion** | Having considered the results of the numeric appraisal and records available, the bridge can be said to be functioning in its capacity.<br>The assessment method used was simply visual inspection. From the assessment, impingements could be found on the body of the pier. This could be due to the impact of sand and dust on their bodies caused by moving vehicles at high speed under the bridge. Shrubs have taken over most of the abutment. Mobile phone cable lines and other services were noticed on the walkway of the bridge. The expansion joints on the bridge need to be repaired. There is no immediate threat to life and property arising from the incapacitated bridge. However, the bridge authority should still move in for a proper and more detailed assessment. |
| **4.** | **Recommendation (delete and complete as applicable)**<br>Since no existing assessment was found, it is recommended that an assessment be done to which future assessments can be referenced. The assessment to be done should be by a Principal Inspection. | |

*Note*. Adapted from CS 451 [7]

**1. Key activities, equipment, and instruments needed to achieve the inspection for structural review**

i. Visiting the bridge authority or owner for assessment documents and original design documents (Requires transportation fee).
ii. Cameras, tapes, etc.
iii. Taking bridge dimensions in the absence of bridge documents.
iv. Performing physical hands-on inspection (General Inspection).

**2. Projected Expenses**

i. Transportation cost (N150,000).
ii. Professional fee for at least one qualified personnel and one assistant (N350,000).
iii. Renting of inspection equipment and instruments such as cameras, ladders, measuring tapes, safety PPE, etc. (N200,000).
iv. Total cost N700,000.

### 3.6.2 Activities during 'inspection for assessment' [7]

i. Review of every existing information about the bridge structure (historical design documents, as-built drawings, data regarding the ground properties and geotechnical parameters, past inspection and assessment reports, and monitoring records) and determination of information required from the inspection for assessment, and identifying items requiring special attention.
ii. Identification of the form of construction.
iii. Confirmation of the geometry of the bridge from the original design or by taking measurements.
iv. Identify the geometry of the carriageway, lane markings, and horizontal alignment.
v. Identification of the nature and condition of the bridge's key structural members.
vi. Identify parameters needed to determine the structural resistance, such as the strength of steel, the strength of concrete, the weight of the carriageway, etc.
vii. Confirm the overall condition of the bridge system as a whole and identify signs of distress, damage, and deterioration.
viii. Identify any evidence of previous strengthening.
ix. Identify changes to the load capacity and resistance due to the installation of services such as street lights, telecommunication cables, etc.
x. Identify road service category (Advice on road surface category can be found in [16]).
xi. Identification of hidden defects in the bridge as per [23] guidance.

**1. Key activities, equipment, and instruments needed for 'inspection for assessment'**

i. Visiting the bridge authority or owner for assessment documents and original design documents (Requires transportation fee).
ii. Collation of original design data (if not available, then geotechnical tests should be done).
iii. Ladder/Scaffold.
iv. Camera, tapes, etc.

**2. Projected expenses**

i. Transportation cost (N250,000).
ii. Professional fee for at least one qualified personnel and two assistants (N750,000).

iii. Renting of inspection equipment and instruments such as camera, ladders, Scaffold, measuring tapes, safety PPE, etc. (N500,000).
iv. Total cost N1,500,000.

### 3.6.3 Activities during assessment [16]

i. Description of the extent of structure to be assessed.
ii. Identification of actions (Live or traffic actions, dead and superimposed dead load, dynamic, braking actions, etc.) to be included in the assessment.
iii. Decisions on the limit states to be included in the assessment (Ultimate, serviceability, limit states, fatigue limit states, etc.)
iv. Determination of the maximum load in terms of vehicular traffic, the structure can withstand with an acceptable likelihood that it does not suffer severe damage that can endanger human traffic on the structure or near the structure, or cause loss of function. If a simple conservative assessment is insufficient to demonstrate this, higher levels of assessment based on refinement of the structural analysis methods should be carried out. Load testing covered in [24] can also be used to determine the capacity efficiently.

**1. Activities, equipment, and instruments needed to achieve the structural review**

i. Visiting the bridge authority or owner for assessment documents and original design documents (Requires transportation fee).
ii. Ladder/Scaffold.
iii. Camera.
iv. Rigging.
v. Manlift or Bucket Truck.
vi. Design trucks for load testing.

**2. Projected Expenses**

i. Transportation cost for manpower and equipment (N1,500,000).
ii. Professional fee for at least one qualified personnel and two assistants (N4,000,000).
iii. Renting of inspection equipment and instruments such as camera, ladders/scaffolds, manlift, bucket truck, measuring tapes, safety PPE, etc. (N3,000,000).
iv. Projected cost for renting instruments for concrete strength test, reinforced steel test, chemical attack testing instrument, etc. (N600,000).
v. Geotechnical test (N1,500,000).
vi. Assuming load testing is done on the bridge (N7,500,000).
vii. Total cost N16,600,000.

**3. Clear difference**

Total Cost for the inspection for assessment, and the assessment proper is;
N1,500,000 + N16,600,000 = **N18,100,000.**
The cost for inspection for structural review only is **N700,000.**

### 3.6.4 Iterations from the cost analysis

We can find that a full-scale bridge inspection for the case study adopted for this research can cost as much as N18,100,000, depending on the extent of the inspection. If bridge load testing is done, the figure can even soar higher. Whereas, a structural review will only cost as much as N700,000 to execute, and it is only a meagre 3.87% of the cost of an inspection proper.

### 3.7 Discussions

This research has successfully exemplified the structural review of a bridge in accordance with [7]. The result of the review corresponds with what is obtainable on site. From the inspection, it was observed that the bridge has no imminent structural issues at hand. There are no signs of deterioration or cracks, or possible failure. The bridge deck does have concerns regarding the expansion joints. The faulty expansion joints increase the level of vibration of vehicles crossing the bridge, thereby increasing the dynamic impact on bridge members. The only way the magnitude of dynamic forces can be estimated is through the use of vibration-sensitive sensors, and with the data they show, inspectors can investigate if they are above threshold limits. It could take years, but if the expansion joints on the wearing course are not repaired, the vibrations can lead to further openings at the expansion joints and cause damage elsewhere. These concerns were, however, reflected during the review process, and yet, the results showed they were favourable.

From the decision matrix of Table 12, the structural review results show that the best decision regarding the bridge is to allow for another review after a certain number of years, which means there only needs to be a ‘review need for assessment at the next structural review for the bridge’ [7]. The review should be repeated until an assessment is required before the commencement of a proper assessment. A 12-year interval is adequate for repeating the review process in view of an assessment [7]. This indicates the bridge is functional and in good condition, and thus, there would not be any need for an in-depth assessment except for the issue bothering the expansion joint, as explained earlier. The need to perform DT and

NDT to carry out condition assessment has been bypassed. This has saved bridge owners time and resources if a full-scale assessment were to be conducted.

This outcome further solidifies results from the durability assessment of the bridge's longitudinal and transverse girders by the authors in [25], which gave the same favourable outputs. The reliability deduced from this work is way higher than that in [25], and this could probably be from the fact that while the results here take the entire bridge structure (system reliability) into cognisance, those of [25] were specifically for the girders. This observation was reiterated by [26], who deduced that the load-carrying capacity of a bridge structure as a system is much larger than what is determined if individual components were to be assessed.

The structural review program is a decision-making tool that gives requirements and advice on the risks associated with a highway structure that has not had a load assessment [7]. It could not be categorically established if the value of reliability derived from the numerical appraisal in this structural review is a direct measure of the system reliability of the bridge as a whole. That is to say, in the event a probabilistic and reliability analysis is done on the bridge, it would yield the same results as deduced from this exercise. However, it was clear that the value aids in making informed decisions using the decision matrix of Table 12. The risk score, though, is a direct measure of all the risks associated with this particular structure. It is therefore a reliable decision-making tool.

The rating of structural elements, which has been presented, serves as a guide to quickly identify deteriorating members in the next structural review, even if the review is conducted by entirely new assessors. This rating goes a long way in identifying specific elements that should be prioritised in the next assessment. Zulfiqar et al. [20] did question whether an objective system of rating won't produce better and quality results compared to this subjective system that rates bridge elements from 0 to 9. However, Victor et al. [5] did rate structural elements using the critical deficiency or safety hazard criteria of [6], which had only four conditions from 1 to 4. The authors do think this system of rating (from 0 to 9) is more befitting of a structural review as it presents a more detailed description of the structural elements, which aids in making informed decisions, and the criteria adopted by [5] should be used when it is very obvious the bridge is in deteriorating condition.

The methods adopted from [7], though drafted to maintain, operate, and improve England's major highway structures, are still sufficiently adequate to apply to Nigeria's roads and bridges. The main standard of reference in the construction of Nigerian bridges is the BS Code, and [7] drafted its guidelines and methods from the same BS Code. Therefore, applying this review method to the Nigerian bridge system is adequate.

This research has revealed, to an extent, the likely costs of condition assessment of a bridge in Nigeria, though it was intended as just a guide. The costs shown here would usually be lower than the actual figures when it is applied, and it will depend on a variety of factors such as the span of the bridge, the obstacle the bridge crosses (water body, a road, etc.), experience of personnel, extent of assessment, among other factors. Furthermore, the assumptions on cost were based on the fact that the bridge authority isn't too far from the bridge location.

The results of the structural review are documented in a structural review form and signed by bridge assessors. The structural review record form serves as an official document that can be used as a reference point when the next assessment is conducted on the bridge, thus serving as a database for future bridge assessors. The authenticity of the form, by signing, indicates the level of importance attached to the form.

Since as-built drawings and design data, as well as geotechnical data, were not applied to the review, there must have been variances to the final results. However, the review numerical appraisal equations take into cognisant such variations, and so, the impact would be minimal.

The inspection rating format was not specific to the bridge that was reviewed. The form in Table 13 was for a general case and more specific to a bridge crossing a water body. The generation of a more site-specific sheet would generally present more reliable inspection rating data.

## 4. CONCLUSION

What this research has brought to light is the applicability of the bridge structural review method and how it should be adopted in Nigeria as a bridge management tool, while the use of sensors and WIM data has not taken precedence. It doesn't cost much to apply, and review can be done with just one or two professionals supervising (depending on the other factors as well). If this is applied, it will abate the fear of spending so much for bridge maintenance, which discourages bridge owners from engaging in SHM programs.

The major findings from this research are as follows:

i. The structural review method for bridge condition assessment has demonstrated the ability to reflect, to a large extent, the present condition of the bridge. For the case study used, it was recommended that the bridge needs no major assessment until another review is done.

ii. The numerical appraisal equations not only show the risks associated with the bridge but also give a measure of the reliability of the bridge, which is a very important measure as far as bridge condition assessment is concerned.

iii. Also, the criteria for structural element condition rating during inspection should depend on the level of physical deterioration observed on the bridge.

iv. The suitability and applicability of the reference standard used for the structural review to local Nigerian bridges shouldn't be a cause for concern because bridges are constructed in Nigeria using the British Standard codes and Eurocodes, which were the basis on which the reference standard was formulated.
v. The cost of performing a structural review may be just about 4% of the total cost that a full assessment could cost in Nigeria.

This intuitive tool of structural review by numerical appraisal, which combines probabilistic and statistical methods to arrive at a decision, should be embraced more in order to save cost during bridge condition assessment and avoid going into an assessment vaguely. In developing countries where the maintenance of public infrastructure isn't prioritised, it becomes difficult to present the cost of assessments of bridges to the government. The government would rather spend its money on constructing new infrastructure than maintaining existing infrastructure due to the costs involved. If this method of bridge inspection by structural review is adopted, it will not just save the cost of repair from bridge damage but also preserve the integrity of bridges. It will further encourage the government to invest in bridge management and maintenance. Researchers and bridge inspectors are therefore enjoined to apply the structural review technique and publish the outcome even when they are engaging in specific NDT methods or using sensors and SHM programs to determine the structural health of bridges. By combining the different methods, its credibility can be verified. Also, as more results of structural review from different bridges are obtained and published following standard practices, it will go a long way in solidifying the degree of accuracy and efficiency of this method and show any shortcomings associated with it, thereby improving its applicability and credibility. With the results of the structural review, a database can be established for all bridges across the country, and actions taken to prioritise those bridges that need urgent attention in maintenance and repairs. This can be used as the starting point for data collation for Nigeria's bridge management system.

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