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FINITE ELEMENT ANALYSIS FOR BRIDGE DUE TO CORROSION

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Abstract: Bridge inspection is an essential element to maintain existing deteriorated bridges followed by using efficient and effective method to acknowledge the remaining internal strength in the structure. Simple and quick method is considered to be most applicable approach to observe the structure rapidly. Thus, by referring to AASHTO LRFD standard, live load distribution factor (LLDF) is taken into account as a facility to develop simple numerical equation to predict reaction force and internal moment values for damaged-structure. There are eighty one finite element models (FEM) were created using commercial package finite element analysis software. One is non-damage model, eighty corroded models with particular corrosion conditions. The eighty one models were then analysed using LLDF approach. It resulted that the larger amount of corrosion, the higher change of LLDF values occurred while the reaction force values generally became lower. By utilizing LLDF equation for non-damage structure and exponential equation obtained from the relationship between reaction force values and corrosion cases, reaction force equation for damaged structure can be developed. As for internal moment equation, instead of using exponential equation, polynomial equation was used. With the proposed numerical equations to predict residual strength for damaged-structure, commercial analytical software usage can be eliminated to reduce inspection budget and complexity

Keywords: AASHTO LRFD; bridge; corrosion; live load distribution factor (LLDF); internal forces

1. Introduction

Deficiencies in bridge infrastructures due to aging and corrosion have become a major concern. Most of them are subjected to corrosion due to exposure to aggressive environmental conditions and inadequate maintenance (Kaita et al., 2012 [1]). Structural strength of corroded structure may also be decreased. Therefore bridge inspection becomes an essential element of any BMS (bridge management system) particularly for deteriorated bridges due to corrosion (Golabi et al, 1993 [2]).

In bridge design, the maximum moment in the girders is necessary in the determination of bridge section. The AASHTO bridge specification provides approaches to analyse bridges, i.e., finite element analysis (FEA), live load distribution factor (LLDF) equation and grillage analysis. The LLDF equation is introduced to facilitate in determination of reaction force and maximum moment in the girders.

The objective of this study is to acknowledge the changing of LLDF values in corroded structures. Thereby, internal forces changing can also be observed and new equation of internal forces for damaged structure can be formulated. By this proposed approach, commercial software which is costly and complex may not be necessary to use anymore. Thus, it is expected that this proposed approach can be considered as a simple and more applicable for existing corroded bridge inspection which may need quick and simple judgement. In this study, the scope of the model is limited to concrete slab on steel I-girder bridge only.

2. AASHTO LRFD Specification (2004)

AASHTO LRFD [3] provides a more accurate and sophisticated formula to calculate the live load distribution factors. It is very important to remember that AASHTO LRFD uses axle load and lane load, instead of wheel load. In other words, the live load distribution factors in LRFD method is approximately half of lane load. The followings are equations of calculating live load distribution factors in AASHTO

LRFD. For concrete slab on stringer type bridges, the distribution factor for shear with two or more design lanes loaded is:

$$LLDF = 0.2 + \frac{S}{3658} - \left(\frac{S}{10668}\right)^2 \quad \text{(SI unit)} \tag{1}$$

The live load distribution factor for moment with two or more design lanes loaded is as illustrated in Equation 2.

(SI unit)

$$LLDF = 0.075 + \left(\frac{S}{2896}\right)^{0.6}\left(\frac{S}{L}\right)^{0.2}\left(\frac{K_g}{12Lt_s^3}\right)^{0.1} \tag{2}$$

To apply these equations, the bridge has to meet the following conditions:

$1067 \le S \le 4877$

$114 \le t_s \le 305$

$6096 \le L \le 73152$

$416231425 \le K_g \le 291361997900$

The minimum number of stringers is 4.

Where S = spacing of stringers (mm)

L = span length (mm)

K_g = longitudinal stiffness parameter of the stringer (mm^4)

t_s = depth of concrete slab (mm)

$$K_g = n\left(I + Ae_g^2\right) \tag{3}$$

Where n = ration of modulus of elasticity between stringer material and concrete slab

I = moment of inertia of the stringer (mm^4)

A = section area of the stringer (mm^2)

e_g = distance between the centres of gravity of the stringer and the slab (mm)

3. Bridge Modelling using Finite-Element Method

3.1 Finite Element Model (FEM)

The modelling of bridge model was carried out using FEM, with ABAQUS software shown in Figure 1. In this FEM, the structure was divided into three different parts, those are, bridge deck part, stringer part, and rubber support part. Those three parts were then assembled at the nodes to form an approximate system of equations for the whole structure. The joint condition at each connection between parts was "tie" connection. The material of bridge deck, the four stringers underneath, and support are concrete, steel and rubber respectively. Material properties used in the model can be seen in Table 1 and for geometric data shown in Table 2.

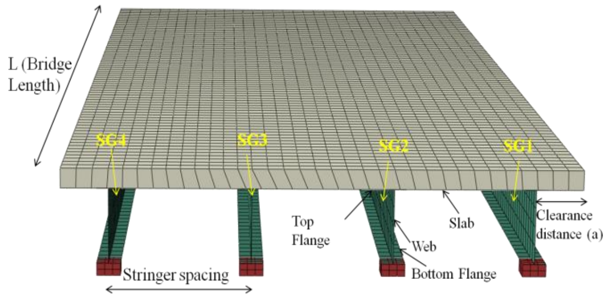

Fig 01: Finite Element Model using ABAQUS

The non-damaged bridge model was created named as SG0 and four different corroded bridge models were also created named as SG1, SG2, SG3 andSG4. The first and second letters represent "Steel Girder" in which the corrosion is located. The numbering refers to each steel girder 1, steel girder 2, steel girder 3 and steel girder 4 respectively. Each corrosion case SG1 to SG4 are broken down into ten corrosion cases (C1 to C10). C1 represent for 8% corrosion amount of the overall steel bottom flange, which means 1200 mm corrosion occurred out of 15000 mm the total length of steel bottom flange, 16% for C2, 24% for C3, 32% for C4, 40% for C5, 48% for C6, 60% for C7, 72% for C8, 84% for C9 and 100% for C10 in which each corrosion models will be subjected to two types of thickness reduction those are 50% and 67% thickness reduction due to corrosion in steel girder bottom flange.

Table 1: Material Properties of Bridge Model

Part	Density (T/mm^3)	Young Modulus (MPa)	Poisson Ratio
Concrete Slab[4]	2.4×10^{-9}	2.0×10^4	0.2
Steel Girder[5]	8.1×10^{-9}	2.0×10^5	0.26
Rubber[6]	-	2.0×10^3	0.48

In the models, it was considered that fixed support at one edge and simply support at another edge were applied in this study. This FEM is conducted to see the tendency of structural behaviour due to corrosion only. As for FEM validation, it has not yet been done and may be seen in next publication.

3.2 Loading Condition of FEM

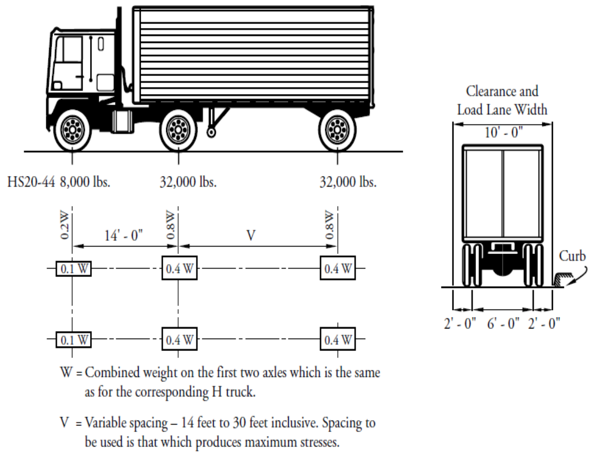

Fig 02: HS20-44 Truck (AASHTO, 2004)

4. Results and Discussions

4.1 Live Load Distribution Factor (LLDF) Value Evaluation

In total, 81 FEM models including non-damaged model were generated and analysed by using commercial package of ABAQUS software. The analytical results and numerical result from Equation 1 were then used to obtain load distribution for non-damaged model. Thereby, the loads will then be used to evaluate LLDF value changes for damaged models.

The LLDF calculation resulted that it was found significant change in LLDF values as seen in Figure 4 and Figure 5 for 50% and 67% thickness reduction respectively. From those figures, LLDF values percentage gets higher whilst the corrosion amount also gets higher. In addition to that, LLDF value change percentage reached above 5% in which the change percentages are considered as a high transformation.

Table 2: Geometric data for Slab-on-Stringer Bridge Model (see Figure 1)

Span length (mm)	Stringer Spacing (mm)	Clearance distance (a) (mm)	Slab thickness (mm)	Flange Thickness (mm)	Flange width (mm)	Web thickness (mm)	Slab width (mm)
15000	1830	610	240	24	304	24	6710

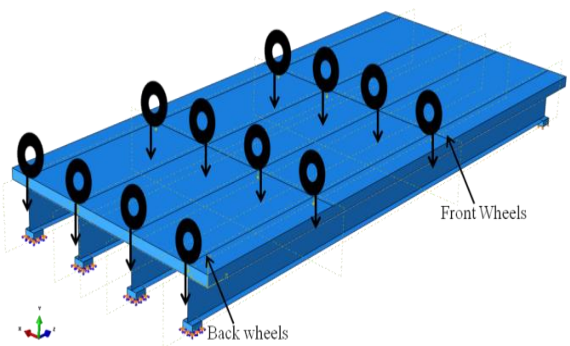

Fig 03: Location of HS20-44 truck on the 3D Model

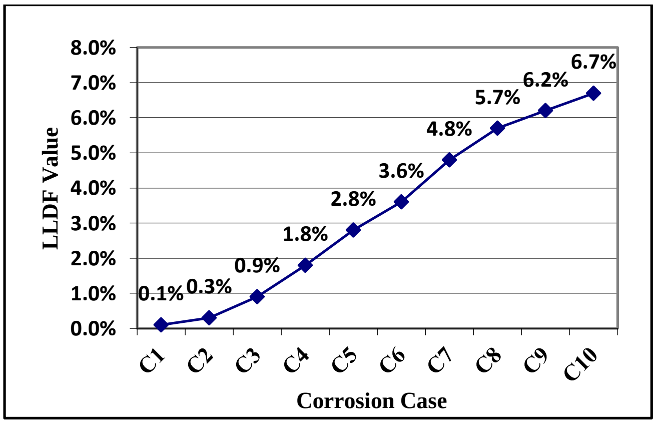

Fig 04: LLDF value changes for corroded model SG3 with 50% thickness reduction

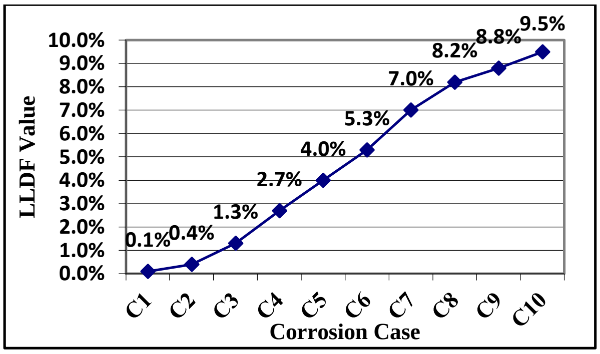

Fig 05: LLDF value changes for corroded model SG3 with 67% thickness reduction

As for LLDF calculation results for moment using Equation 2, it can be seen in the Figure 6 and 7 for 50% and 67% thickness reduction respectively.

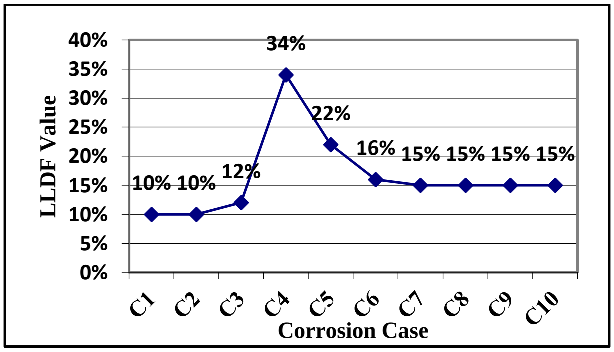

Figure 6: LLDF value changes for corroded model SG1 with 50% thickness reduction

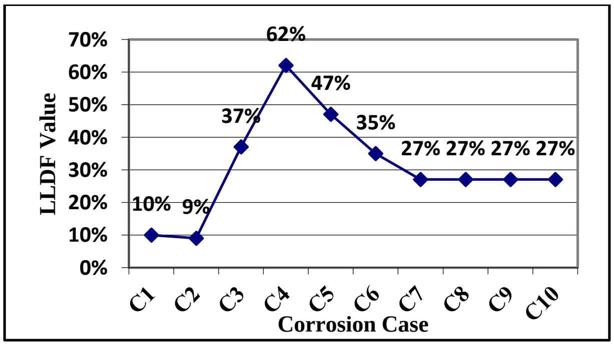

Fig 07: LLDF value changes for corroded model SG1 with 67% thickness reduction

Dramatically LLDF values were changed from moment evaluation. It was then also ascertained that internal forces such as reaction force and internal moment are in crucial deterioration. Lacking information of remaining internal forces in damaged-structure may cause an immediate collapse. Thus, quick action and more applicable approach are highly required to overcome this situation. In this study, LLDF equation for non-damaged model is used to develop new equation for calculating reaction force and moment of damaged-structure. More detail will be explained in the next sub-section.

4.2 Proposed Equations for Reaction Force and Moment of Damaged-structure due to corrosion

It is indeed very quick to analyse the overall structural behaviour using ABAQUS. But, in this study, it is expected to have simple numerical calculation by only using Microsoft excel and eliminating costly analytical software usage. This approach is being proposed to achieve most applicable approach to predict the structural condition quickly without depending on commercial analytical software. The following equation 4 and equation 5 illustrate how to calculate reaction force and moment respectively by utilizing LLDF approach for non-damaged structure.

$$R_{nd} = LLDF_{nd} \times P_{nd} \qquad (4)$$

$$M_{ndy} = R_{nd} \times y \qquad (5)$$

where R_{nd} = reaction force for non-damaged structure (kN)

$LLDF_{nd}$ = live Load Distribution Factor for non-damaged structure

P_{nd} = load distribution (kN)

M_{ndy} = moment of non-damaged structure at a distance y from rolled-support

y = distance from rolled-support

Figure 8 and Figure 9 show the relationship between reaction force values and amount of corrosion in corroded model SG3 with 50% and 67% thickness reduction respectively. It can be seen that generally reaction force get lower when the corrosion amount get higher. From these graphs, exponential equation can be obtained as seen in Figure 9, thereby damaged structural behaviour can be observed. The equation is then used to develop reaction force equation for damaged-structure as in Equation 5

$$R_d = R_{nd} \times 30.61e^{-0.012x} \qquad (6)$$

where R_d = reaction force for damaged structure (kN)

R_{nd} = reaction force for non-damaged structure (kN)

$LLDF_{nd}$ = live Load Distribution Factor for non-damaged structure

P_{nd} = load distribution (kN)

x = size of damage or amount of corrosion (%) of total observed element

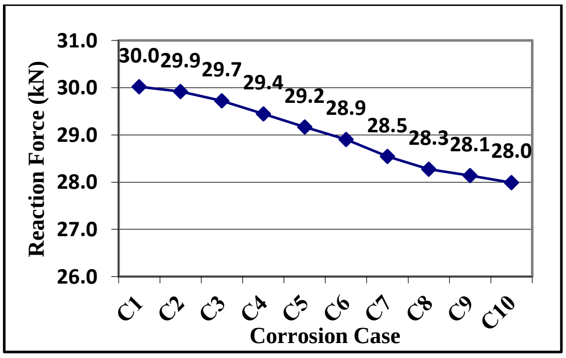

Fig 08: Relationship between reaction force and corrosion case for model SG3 with 50% thickness reduction

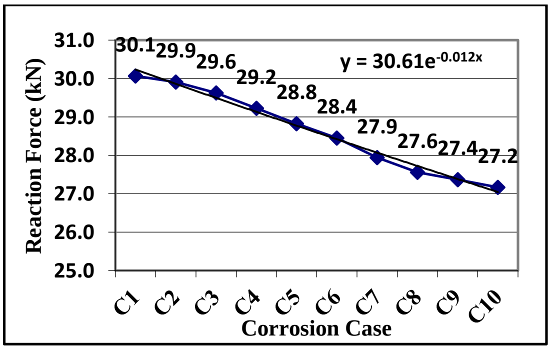

Fig 09: Relationship between reaction force and corrosion case for model SG3 with 67% thickness reduction

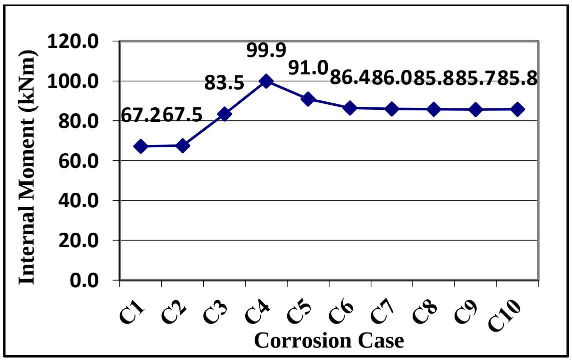

Fig 10: Relationship between internal moment and corrosion case for model SG1 with 50% thickness reduction

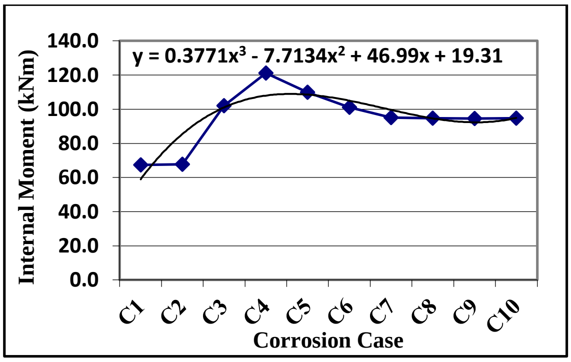

Fig 11: Relationship between internal moment and corrosion case for model SG1 with 67% thickness reduction

Figure 10 and Figure 11 show moment relationship with corrosion case, it can be seen in the Figure 10 and Figure 11 for model SG1 with 50% and 67% thickness reduction respectively. As seen in Figure 11, polynomial equation was applied in this case as considered to get more accurate results. Here is the following internal moment equation for damaged-structure by multiplying the polynomial equation to the non-damage equation as follow

$$M_{dy} = M_{ndy} \times \left(0.38x^3 - 7.7x^2 + 47x + 19.3\right) \quad (7)$$

Where M_{dy} = internal moment for damaged structure at a distance y from rolled-support

M_{ndy} = moment of non-damaged structure at a distance y from rolled-support

y = distance from rolled-support

x = size of damage or amount of corrosion (%) of total observed element

By these equations, it now enables us to predict the reaction force and moment for damaged structure by using Microsoft excel only. Commercial analytical software is now not necessary to use anymore. Simple Quick judgement for bridge inspection is now present.

5. Conclusions

In total, 81 FEM models have been generated by using ABAQUS software. 1 non-damage model and 80 damaged models with various corrosion cases have been applied to the models as explained in the section 3. LLDF approach has been chosen to develop reaction force and internal moment equations for damaged-structure. In the LLDF calculation, it resulted that the higher amount of corrosion occurred, the higher LLDF values change happened in which significant change to the internal strength of the structure may be occurred. It was confirmed that reaction force and internal moment values are changing as explained in previous section. Since the condition in the field may be quite challenging, deteriorated bridges are highly required quick judgement in its inspection procedures. Uncomplicated and simple numerical is the solution. The proposed equations in this study only require Microsoft excel for the calculation process. Costly commercial and complicated analytical software is not necessary anymore. The easiest and the quickest bridge inspection method can now be done by these proposed numerical equations. Experimental research is planned to conduct as a validation test for FEM, therefore the accuracy of the result from this study can be confirmed faithfully.

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