The 2016 World Congress on
The 2016 Structures Congress (Structures16)
Jeju Island, Korea, August 28-September 1, 2016

Dynamic Analysis of Bridge under Vehicle Load Using MATLAB and Evaluation of AASHTO Impact Formula

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ABSTRACT

Bridge structures are subjected to many kinds of dynamic loads including moving vehicle loads. Dynamic loads cause larger peak internal loads and deformation compared to static loads with the same magnitude. In this study, structural analysis is conducted considering the dynamic effect for proper structural design, repair and maintenance. AASHTO LRFD Bridge Design Specifications (2012) consider the dynamic effect of moving truck load by using a dynamic load allowance coefficient called "Impact Factor", and treat the dynamic truck load as static load amplified by (1 + Impact Factor). To evaluate this Impact Factor, a series of analyses are conducted and comparison is made between AASHTO code-based static analysis and dynamic analysis considering vibration. For the dynamic analysis, the writers' own program coded using MATLAB is used.

1. INTRODUCTION

In bridge design, it is important to consider loads that could affect bridge structures, including static and dynamic loads. In particular, bridge structures are correlated to moving vehicle loads which can cause dynamic effect of bridge structures. For proper structural design, repair and maintenance, structural analysis considering dynamic effect should be made. Because dynamic loads induce larger peak internal resultants and deformation compared to static loads with the same magnitude. In AASHTO LRFD Bridge Design Specifications, dynamic effect of bridge caused by moving design truck loads is considered as utilization of a dynamic load allowance coefficient called "Impact Factor". And the dynamic design truck load is treated as static load amplified by (1 + Impact Factor). Design truck load which is suggested by AASHTO is specified in Fig. 1 and Eq. (1) is Impact Formula which is suggested by AASHTO. (AASHTO 2012)

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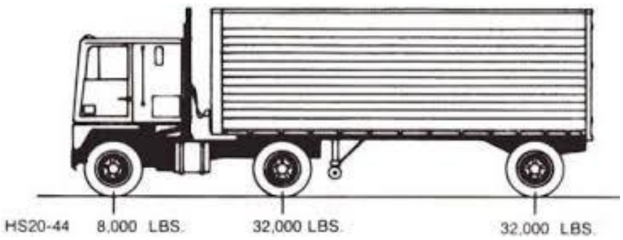

Fig. 1 HS20-44 truck load (AASHTO 2012)

$$I = \frac{15.24}{L + 38.1} \leq 0.3 \quad (1)$$

Where *I* is the Impact Factor and *L* is the length of the span in meters that is subjected to the live load. However, information on basis of Eq. (1) is not sufficiently available. Because, there are many variables that affect dynamic properties of bridge structure besides length of the span. And also effect of flexural stiffness reduction due to time-dependent structural deteriorations is not considered in Eq. (1). Therefore, it is needed to verify whether Eq. (1) properly reflects dynamic effect caused by design truck loading.

To verify adequacy of Eq. (1), a series of static and dynamic analyses are conducted and comparison is made between static analysis using Eq. (1) and dynamic analysis in consideration of dynamic parameters. The considered dynamic parameters in this paper are (1) the length of span, (2) effective flexural stiffness of bridge girder, and (3) vehicle speed. For the analyses, the writers' own MATLAB program is used.

2. DEVELOPMENT PROCESS OF MATLAB PROGRAM

To calculate dynamic response of bridge structures which are subjected to moving vehicle loads and evaluate that AASHTO Impact Factor is proper formula, writers made our own program using MATLAB. The program consists of 4 major parts which are shown in program's flowchart (Fig. 2).

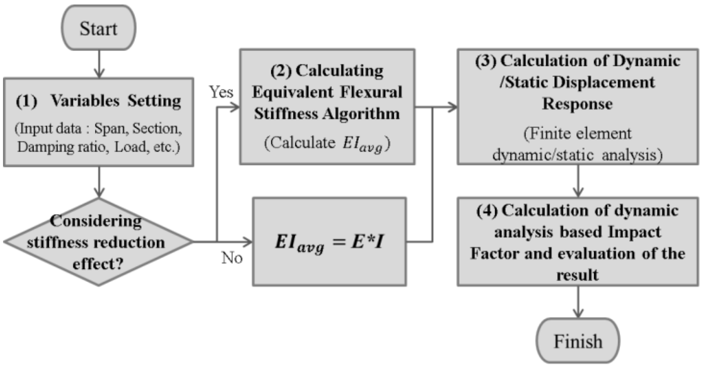

Fig. 2 The MATLAB program's flowchart

2.1 Variables setting

For the analysis, variables needed in dynamic analysis procedure should be specified. Information such as geometrical properties, material properties, loads and other properties to conduct analysis needs to be input in program. In particular, the load input should be carefully considered. The moving HS20-44 truck load should be input using a proper mathematical expression. Moving truck load could be expressed as in Eq. (2) with the application of Dirac-Delta function.

$$F_{truck}(x,t) = (\tfrac{1}{9}P)\delta(x - v_{truck}t) + (\tfrac{4}{9}P)\delta(x - (v_{truck}t - D_w)) + (\tfrac{4}{9}P)\delta(x - (v_{truck}t - 2D_w)) \quad (2)$$

Where $F_{truck}(x,t)$ is the load function of moving HS Truck, P is the total weight of an HS Truck in Newtons which is set as 320 kN, x is the location in meters, t is the time in seconds, v_{truck} is the truck speed in meters per second, D_w is the wheel to wheel distance in meters which is set as 4.2 m, and δ is the Dirac-Delta function.

2.2 Equivalent flexural stiffness algorithm

To consider structural properties of real-world bridge girder, flexural stiffness reduction caused by time-dependent structural deterioration should be taken into account in analysis procedure. Equivalent flexural stiffness algorithm can determine the average stiffness of a bridge girder which has varying stiffness values with the span. A basic assumption in modeling deteriorated girder is to make a girder have five piecewise constant EI values throughout the span. (Martin 2009) five different stiffness values could be substituted in each segment considering level of deterioration. Each stiffness value could be determined by experimental data, literatures or engineer's judgement. For example, in cracked bridge which is deteriorated, stiffness values of each segment is obtained, equivalent flexural stiffness of the whole length is calculated as 0.79 EI_g using the algorithm. By obtaining the average flexural stiffness of a bridge girder, the effect of stiffness reduction is taken into account when calculating dynamic and static properties.

2.3 Finite element analysis procedure for dynamic/static displacement responses

Dynamic and static displacement responses could be calculated using finite element method. In dynamic analysis, the modal superposition method is also used. In the finite element procedure, beam element is used. The modal equations which are 2nd linear ordinary differential equation are solved using the Wilson-θ method which is one of the powerful numeric methods. The finite element analysis procedure could be summarized as solving matrix equations. For static analysis, Eq. (3) should be solved. And, for dynamic analysis, Eq. (4) should be solved.

$$\underset{\sim}{K}\underset{\sim}{u} = \underset{\sim}{F} \quad (3)$$

$$\underset{\sim}{M}\underset{\sim}{\ddot{u}} + \underset{\sim}{C}\underset{\sim}{\dot{u}} + \underset{\sim}{K}\underset{\sim}{u} = \underset{\sim}{F} \quad (4)$$

Where $\underset{\sim}{K}$ is stiffness matrix, $\underset{\sim}{C}$ is damping matrix, $\underset{\sim}{M}$ is mass matrix, $\underset{\sim}{F}$ is force vector/matrix, and $\underset{\sim}{u}$ is displacement vector/matrix.

2.4 Evaluation of dynamic analysis results in consideration of Impact Factor

The MATLAB Program has an algorithm that calculates Impact Factor (I) based on dynamic/static analysis result. And evaluation of AASHTO Impact Factor could be made by the following procedure. First, the AASHTO Impact Factor should be calculated using Eq. (1). Then, the maximum static center-span displacement ($\delta_{max\_stat\_HS}$) and maximum dynamic center-span displacement ($\delta_{max\_dyna\_HS}$) which is only due to the HS20-44 truck load excluding other static loads are obtained from the program. Finally, using Eq. (5), the Impact Factor based on the MATLAB program ($I_{analysis}$) could be obtained. If this value is smaller than Impact Factor obtained from Eq. (1), It could be considered that Eq. (1) gives a reasonable value of Impact Factor and Eq. (1) is a proper formula.

$$I_{analysis} = \frac{\delta_{\text{max\_dyna\_HS}}}{\delta_{\text{max\_stat\_HS}}} - 1 \tag{5}$$

3. EVALUATION OF AASHTO IMPACT FACTOR BASED ON DYNAMIC ANALYSIS RESULTS

The dynamic effect of a bridge structure under moving HS20-44 truck load is evaluated by calculation of Impact Factor using the MATLAB program. From this, it could be known that how much dynamic maximum displacement is amplified, compared to the static maximum displacement with the same magnitude. To investigate the relationship between Impact Factor and each variables related to dynamic response, a series of analyses were conducted by changing a target variable with other variables fixed as offset values which are indicated in Table. 1. Where the damping ratio of 3% could be used for concrete structures at their working stress level. (Chopra 2006)

Table. 1 Variables and offset values

Variable	Offset Value
Section Type	AASHTO Type 2 Girder
Span Length	20 m
Stiffness Distribution	[1EI$_g$ 0.85EI$_g$ 0.7EI$_g$ 0.85EI$_g$ 1EI$_g$] (No Stiffness Reduction)
Vehicle (HS truck) Speed	10 m/s
Damping Ratio	3 %

In this study, dynamic/static analyses were performed for 11 cases of span length, 2 cases of flexural stiffness distribution, and 26 cases of HS20-44 truck's speed. Therefore, a total 572 cases were analyzed and Impact Factor values of each case were calculated. The selected analysis results are shown in Fig. 3.

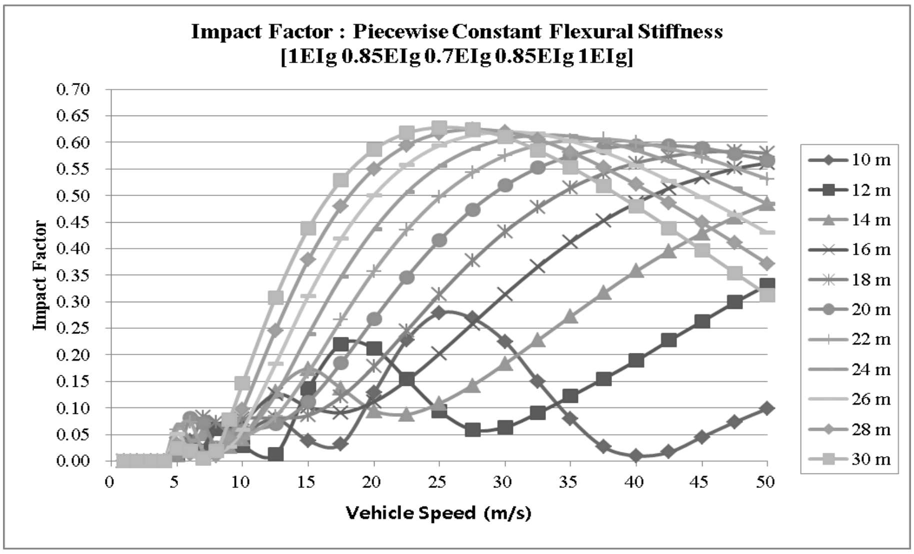

Fig. 3 Impact Factor : Piecewise constant flexural stiffness
(cracked bridge) [1EI_g 0.85EI_g 0.7EI_g 0.85EI_g 1EI_g]

As Fig. 3 shows, there is no significant difference between two cases of stiffness distribution. It is turns out that the average flexural stiffness of bridge girder is not influential parameter on the Impact Factor. However, Impact Factor curves are significantly fluctuating for the vehicle speed. It indicates vehicle speed as well as span length is important parameter on the Impact Factor. But, Impact Factor for structural design should not be a function of vehicle speed, although Impact Factor is actually depends on vehicle speed. Because a vehicle speed is a random variable that could not be expected. Therefore, in designing a bridge structure, it is desirable to apply the upper bound value of Impact Factor. Figure 3 indicates that upper bound values of the Impact Factor are about 0.6 in every case of span length. Considering that the upper bound of AASHTO Impact Factor is set equal to 0.3 for any case, such results notice that the Impact formula which is specified in AASHTO code may give an unconservative value of the Impact Factor. Based on these dynamic analyses results, it is recommended to revisit the AASHTO Impact formula.

4. CONCLUSIONS

In this study, dynamic finite element analysis algorithm for bridge girder using MATLAB was developed. The algorithm has following features, (1) the algorithm that calculates equivalent flexural stiffness of bridge girder, (2) finite element analysis procedure that calculates both dynamic and static displacement responses, and (3) the algorithm that calculates Impact Factor based on both analysis results and AASHTO code. And using the developed MATLAB algorithm, the relationship between the length of span, stiffness distribution, or vehicle speed and Impact Factor value is investigated. From the analyses results, the following results could be obtained.

(1) The average stiffness values of bridge girders is not a significantly affecting parameter for the Impact Factor value;

(2) Both span length and vehicle speed are governing parameters on the Impact Factor. The upper bound value of the Impact Factor is about 0.6 for every span length case, although the specified upper limit is 0.3. As such, there are some differences between the result values and those from the AASHTO Impact formula

(3) The AASHTO Impact formula may give unconservative design criteria, and it is necessary to re-examine appropriateness of the formula in the further study.

REFERENCES

Chopra, A. K. (2006), *Dynamics of Structures*, 3rd ed., Prentice Hall, New Jersey.

Martin, R. D., Pei, J.-S., Lakshmivarahan, S., Sandburg, C. J., and Kang, T. H-.K. (2009), “Identification of Piecewise-Constant Flexural Stiffness of a Real-World AASHTO Type Ⅱ Girder from Static Test Data”, *Proceedings of 5th International Workshop on Advanced Smart Materials and Smart Structures Technology*, Boston, MA.

The American Association of State Highway and Transportation Officials (2012), *AASHTO LRFD Bridge Design Specifications*, 6th ed., Washington DC.