강거더 연속교에 대한 충격계수에 관한 실험적 연구

Traffic Induced Dynamic Load Factors on Continuous Steel Girder Bridges Based on Field Testing

엄 준 식^{1)*}
 Jun-Sik Eom

최 종 대²⁾
 Jong-Dae Choi

Abstract

The objective of the paper is to present the results of analytical and experimental studies dealing with dynamic load for continuous steel girder bridges due to normal truck traffic. Various bridge design codes specify dynamic load factor (defined as a fraction of static portion of live load) for short span structures at the level of about 0.3. However, there are not definite values specified for continuous bridges. Therefore, it is an usual practice to use the code specified dynamic load factors for simple span bridges to continuous bridges without clear background. The field measurement results indicate that the actual dynamic load factors are less than 0.2 for a single truck, and less than 0.05 for two trucks side-by-side, regardless of positive and negative moment region.

Keywords : Dynamic load factor, Impact factor, Diagnostic load testing

1. INTRODUCTION

The time-variation of strain and stress due to a truck crossing the bridge depends on several factors. If a truck moves very slowly (at a crawling speed), then the strain and stress can be gradually increased to reach the maximum value, and then gradually decrease to zero when the truck is off the bridge. An example of the strain/stress as a function of time, recorded at a selected point, with peaks corresponding to axles, is shown in Fig. 1. However, at the regular highway speed, the actual values of stress can be affected by several factors. Dynamic load factors (DLF's) are defined in several ways, as discussed in previous study (Bakht and Pinjarkar, 1989). In this study, the dynamic load factor was taken as the ratio of the maximum dynamic strain and the maximum static strain. Collected data were

filtered by applying numerical procedures to increase the signal-to-noise ratio, and to reduce the effect of random,

Fig. 1 Dynamic and Static Strain under a Truck at Highway Speed

1) 정희원, 상지대학교 건설시스템공학과 교수, 교신저자
 2) 정희원, 상지대학교 건설시스템공학과 박사과정

* Corresponding author : eomj@sangji.ac.kr

• 본 논문에 대한 토의를 2013년 12월 31일까지 학회로 보내주시면 2014년 1월호에 토론결과를 게재하겠습니다.

and non-periodic noise.

Magnitude of strain/stress oscillates around the values corresponding to the crawling speed. This behavior is due to changing load and dynamic response of the bridge structure. In a typical girder bridge, the outside forces (wheel loads) are applied to the concrete slab, which distributes them to girders, and then they are transferred to foundations (via piers and abutments). The wheel forces can vary due to roughness of the riding surface and dynamic characteristics of the suspension system of the vehicle. In addition, this is combined with bridge dynamics, as the natural frequency of vibration of the bridge (often 4-8 Hz) can be close to the frequency of applied forces (1-2 Hz), as it can take less than a second for a truck to cross the bridge.

In the result, the bridge live load can be considered as a sum of static and dynamic components. The dynamic component is usually considered in form of the dynamic load factor, DLF, which is defined as a fraction of the static load, so that:

$$DLF = \frac{DL}{LL} \quad (1)$$

where: LL - static component of live load;

DL - dynamic component of live load.

LL and DL can be given in terms of moment, strain, or deflection.

The objective of the paper is to compare design code specified values of DLF with the results of previous analytical simulations and field measurements. The actual value of the dynamic load factor is based on the results of field tests.

2. DESIGN VALUE OF DYNAMIC LOAD

The code specified values of DLF vary depending on the documents. In general, for short span bridges, DLF is about 0.3, or even higher for some codes. It can be specified as a function of span length, natural frequency of vibration, type of component (beam, slab, joint, foundation), material, and so on.

Values of DLF specified in various bridge design codes are considerably different. In the Korean Standard Specification for Highway Bridges (2005):

$$DLF = \frac{15}{(40 + L)} < 0.30 \quad (2)$$

and in the AASHTO Standard (2005):

$$DLF = \frac{15}{(38 + L)} < 0.30 \quad (3)$$

where: L - span length (m).

For short span bridges (up to 12m) and reinforced concrete slabs, DLF = 0.30. DLF is less than 0.10 for the span exceeding 112 m.

In the new AASHTO LRFD Code (2013), live load is a superposition of HS20 truck (325 kN), and lane loading of 9.3 kN/m. DLF is specified as 0.33 of the truck effect, with no DLF applied to the lane load. In practice, this results in DLF = 0.3 for shorter spans.

In the first two editions of the Ontario Highway Bridge Design Code (OHBD, 1991), dynamic load factor was specified as a function of natural frequency of vibration. For bridges with span length up to 15m, this results in DLF = 0.30. In the third edition of OHBD (1991), DLF = 0.25, except of very short spans, with two and one axles governing, then DLF is 0.3 and 0.4, respectively.

In the Japanese bridge design code, the dynamic load factor corresponding to the design truck is given as a function of span:

$$DLF = \frac{20}{(50 + L)} \quad (4)$$

For 10m span, DLF = 0.33.

In Eurocode (2003), the dynamic load is included in the specified live load, so no DLF is given.

The German code (DIN 1072) specifies DLF as a linear function of span:

$$DLF = 0.4 - 0.008L \quad (5)$$

And for spans less than 12m, DLF = 0.3.

For all considered codes, there is no definite specification of dynamic load factors regarding the continuous bridges.

3. ANALYTICAL MODELS

The analytical model was developed by Hwang and Nowak (1991) for simple span bridges. In their study, The bridge superstructure was treated as a prismatic beam. Traffic was represented by two vehicles; a two axle truck and a three axle truck, with the suspension system modeled using actual measurement data. Roughness of the surface was also modeled using the actual measurements, with three categories: smooth, medium and rough.

In the study of Hwang and Nowak (1991), a computer program was developed for simulation of the dynamic load factor (DLF) for steel and prestressed concrete girder bridges. The simulations clearly indicated that DLF decreases with the increasing truck weight. The results (Hwang and Nowak, 1991) are summarized in Fig. 2 for a five axle truck and

Fig. 2 Simulated Values of DLF vs. Truck Weight for 5 Axle Trucks

Fig. 3 for a three axle truck. This study aims to verify if the similar results can be seen for various types of continuous bridges, including varying side shapes.

4. BRIDGE SELECTION AND INSTRUMENTATION

This study is focused on steel continuous girder bridges. All bridges carry two lanes. Detailed dimensions of selected bridges are illustrated in Table 1. The strain transducers were attached to the lower surface of the bottom flange of steel girders at midspan and at the support. A typical transducer instrumentation is shown in Fig. 4. Strain transducers were connected to the SCXI data acquisition system from the National Instruments. The data acquisition system consists of a four slot SCXI-1000 chassis, one SCXI-1200 data acquisition module, two SCXI-1100 multiplexer modules, and one notebook computer with Labview software. For the normal speed tests, a sampling rate of 300 per second was used for calculation of dynamic effects. This is equivalent to 11.4 samples per meter at a truck speed of 95 km/h. Fig. 5 shows the detailed cross-section and side elevation

Fig. 3 Simulated Values of DLF vs. Truck Weight for 3 Axle Trucks

Table 1 Selected Bridges

Bridge Number	No. Of Spans	No. of Lanes	Total Bridge Length [m]	No. of Girders	Girder Spacing [m]	Year Constructed	Skew Angle	ADT
A	3	2	102	6	2.15	1982	1	164
B	3	2	111	6	2.50	1980	19	1460
C	4	2	138	6	2.50	1979	7	550

Fig. 4 Removable Strain Transducer instrumentation

of bridges tested.

5. LOADING

In Michigan, the United States, the maximum mid-span moment in medium span bridges is caused by 11-axle trucks, with gross vehicle weight (GVW) up to 730 kN

depending the axle configuration. The vehicles used in the analysis were fully loaded, three-unit, 11-axle trucks. A typical side-view of a truck used in the tests is shown in Fig. 6, and in Fig. 7, the axle configuration. Field test was performed under single truck loading, and two trucks side-by-side truck loading condition. In order to simulate static loading condition, trucks were at first driven at crawling speed. From the crawling speed test, LL's in Eq.1 were collected, and this test was repeated multiple times to achieve accurate reading. The passage of truck tires were marked each time to prepare normal speed test. In normal speed test, Trucks were carefully driven to follow the marks made during crawling speed test, The normal speed tests were also performed multiple times to eliminate the variation of truck paths. Bridges may behave differently, as speed changes. However, in this study, trucks were carefully driven to achieve the legal maximum speed limits to simulate real traffic condition.

Fig. 5 Details of Selected Bridges

Fig. 6 Typical Side-View of Trucks used in the test

Fig. 7 Axle Configuration of Trucks used in the test

6. FIELD MEASUREMENT RESULTS

The objective of this study is to measure the actual

values of DLF, and compare them with design values. Static and dynamic strains were measured, and DLF was calculated using Eq. 1. For the tested bridges, the measured dynamic load factors for one truck passage are shown in Fig. 8 and Fig. 9 for each tested bridge. In the same figure, DLF's measured from two truck side-by-side loadings are also shown. Values of DLF are plotted for each girder. In the Figs 8 and 9, DLF's are plotted for all load cases involving normal speed. The Fig. 8 shows DLF's measured at the maximum positive moment region, and Fig. 9 for negative moment (over piers). As shown in the figures, dynamic load factors for exterior girders are high because the static strains in these girders are very low. In other words, large values of DLF in exterior girders correspond to load cases with a single truck in the opposite lane (resulting in very low static strain). This indicates that even if the value of DLF's are extremely high for exterior girder,

Fig. 8 DLF's measured at the maximum positive moment region

Fig. 9 DLF's measured at the maximum negative moment region (over piers)

Fig. 10 Static and Dynamic Strain Vs. DLF's measured at the maximum positive moment region

Fig. 11 Static and Dynamic Strain Vs. DLF's measured at the maximum negative moment region (over piers)

this does not mean those girders are under greater stress because the absolute level of static load itself is very low.

The static and dynamic loads are plotted vs. DLF in Figs 10 and 11 for all tested bridges respectively. Fig. 10 indicates the static and dynamic strains compared to the DLF's at the positive moment region, and Fig. 11 for negative moment region. It is clear that DLF decreases for larger static strain. Furthermore, it was observed that absolute values of the dynamic strain do not depend on static strain. The open circles correspond to static strain, ϵ_{stat} , and black solid squares correspond to dynamic strain, ϵ_{dyn} . For each static strain value (open circle), the corresponding dynamic strain is denoted by solid square (the numbers of circles and squares are same). Dynamic strains remain nearly constant, while static strains increase as truck loading increases. This results in large dynamic load factors for low static strains.

The maximum value of DLF obtained from the measurements was 0.17 for a single truck, and less than 0.05 for two

trucks side-by-side. Therefore, the field tests confirmed the validity of prior analytical simulations. The measured DLF turned out to be even lower than analytically predicted by Hwang and Nowak (1991).

7. CONCLUSIONS

The dynamic load factors (DLF) obtained from the tests are summarized in Figs 7 and 8 for positive strains measured at the midspan and negative strains measured near support over pier. As shown in the figures, dynamic load factors for exterior girders are high because the static strains in these girders are very low. In other words, large values of DLF in exterior girders correspond to load cases with a single truck in the opposite lane (resulting in very low static strain).

The relationship between DLF, static and dynamic strains is presented for positive and negative moments, respectively.

Dynamic strains remain nearly constant, while static strains increase as truck loading increases. This results in large dynamic load factors for low static strains.

For all tested bridges, the DLF corresponding to the maximum static strain, is less than 0.20 for a one lane loading. For two trucks side-by-side, DLF is less than 0.05 for all the tested bridges.

In general, DLF's for continuous spans are lower than DLF's for simple spans. DLF's are lower for a negative moment (over the support) than for a positive moment (mid-span). The test results showed that DLF for a single heavy truck is less than 0.15. For two trucks side-by-side, DLF is less than 0.05 for the tested bridges. There are not much differences for DLF's between positive strain region and negative strain region. Therefore, for evaluation of existing steel girder bridges it is highly feasible, conservatively, to expect maximum value of $DLF = 0.10$ for two lane loading, and $DLF = 0.20$ for a single truck load case. However, for the new construction, this results should be used with care, to achieve a conservative design.

Acknowledgements

이 논문은 2011년도 상지대학교 연구년제 지원에 의한 것임

References

1. AASHTO LRFD, Bridge Design Specifications. American Association of State and Transportation Officials, Washington, D.C., 2013.
2. AASHTO, Standard Specifications for Highway Bridges, American Association of State Highway and Transportation Officials, Washington, D.C., 2002.
3. Bakht, B. and Pinjarkar, S. G., Dynamic Testing of Highway Bridges-A Review. Transportation Research Record 1223, Transportation Research Board, National Research Council, Washington, D.C., 1989, pp.93-100.
4. EN1991-2 Eurocode 1, Actions on structures? Part 2: Traffic loads on bridges, European Standard, Brussels: CEN, 2003.
5. Hwang, E. S. and Nowak, A. S., Simulation of Dynamic Load for Bridges, ASCE Journal of Structural Engineering, Vol. 117, No. 5, May, 1991, pp.1413-1434.
6. Korean Standard Specifications for Highway Bridges, Ministry of Land and Infrastructure and Transportation, 2005 (in Korean).
7. Nowak, A. S. and Collins, K. R., Reliability of Structures, McGraw-Hill, New York, 2000.
8. OHBDC, Ontario Highway Bridge Design Code, Ministry of Transportation, Ontario, Canada, 1st Edition 1979, 2nd Edition 1983 and 3rd Edition 1991.

Received : 09/12/2013

Revised : 10/14/2013

Accepted : 10/18/2013

요 지

본 연구에서는 강거더 연속교에 대해 국내외 설계기준에 규정되어 있는 활하중으로 인한 충격계수를 실험을 통해 검증하였다. 대부분의 도로교의 설계기준에서는 도로교의 경우 충격계수를 약 0.3 정도의 값으로 규정하고 있으나, 연속교의 경우에는 명확한 규정 및 명시가 없는 상황이다. 그러므로 단순교에 적용되는 충격계수를 연속교에 동일하게 적용하는 것이 일반적이다. 이 연구에서는 현장실험을 통해 연속교의 충격계수가 단순교에 적용되는 경우와 같이 사용될 수 있는지를 검증하였다. 현장실험 결과 얻어진 충격계수는 2차선 교량에서 1대의 만재트럭이 통과했을 경우 가장 하중이 많이 작용한 거더에서 0.2 이내의 충격계수가 계측되었으며, 2개의 차선을 동시에 만재트럭이 통과한 경우 그 충격계수는 0.05 이내의 값을 얻었다.

핵심 용어 : 동하중계수, 충격계수, 교량 현장 재하 실험