Influence of road surface roughness on dynamic impact factor of bridge by full-scale dynamic testing

Young Suk Park, Dong Ku Shin, and Tae Ju Chung

Abstract: Effects of road surface roughness on the dynamic impact factor of bridge are investigated through full-scale field loading tests under controlled traffic conditions. The dynamic time histories of displacements are obtained for twenty-five bridges on Korean highways. The impact factors of the bridges are evaluated by using the measured displacements. The road surface profiles of the twenty-five bridges are also measured at every 10 to 30 cm interval in the span direction. By using the measured road surface profiles, the international roughness index (IRI) and the roughness coefficients of the bridges are evaluated. The linear regression and correlation analyses are performed to obtain the coherences between the IRI and the roughness coefficient and between the IRI and the impact factor. The sample correlation coefficients between the impact factor and the IRI and between the impact factor and the roughness coefficient are calculated to be 0.61 and 0.62, respectively, showing a strong coherence between the road surface roughness and the impact factor.

Key words: bridge, impact factor, road surface roughness, international roughness index, roughness coefficient.

Résumé : Les effets de la rugosité de la couche de roulement sur le coefficient de majoration dynamique d'un pont ont été examinés par des essais de charge à pleine échelle sous des conditions de circulation contrôlées. Les antécédents dynamiques des déplacements dans le temps sont obtenus pour 25 ponts des autoroutes de la Corée. Les coefficients de majoration dynamique des ponts ont été évalués en utilisant les déplacements mesurés. Les profils de la couche de roulement des 25 ponts sont également mesurés à des intervalles de 10 à 30 cm dans le sens de la portée du pont. Ces profils de la couche de roulement servent à évaluer l'indice de rugosité international (IRI) et les coefficients de rugosité des ponts. Des analyses de régression linéaire et de corrélation sont effectuées pour obtenir les cohérences entre l'IRI et le coefficient de rugosité et entre l'IRI et le coefficient de majoration dynamique. Les coefficients de corrélation des échantillons entre le coefficient de majoration dynamique et l'IRI et entre le coefficient de majoration dynamique et le coefficient de rugosité sont calculés comme étant 0,61 et 0,62 respectivement, montrant une forte cohérence entre la rugosité de la couche de roulement et le coefficient de majoration dynamique.

Mots clés : pont, coefficient de majoration dynamique, rugosité de la couche de roulement, indice de rugosité international, coefficient de rugosité.

[Traduit par la Rédaction]

Introduction

The dynamic effect of a moving vehicle on a bridge is generally incorporated in the bridge design codes as a dynamic load allowance (DLA). Most codes specify DLA as a function of either span length or natural frequency of a bridge. Although it is convenient and somewhat reliable to specify the dynamic effect in such a way, it is widely accepted that there exist some other factors, such as the speed, weight, dynamic characteristics of the traffic, geometrical and structural properties of the bridge, and irregularities of roadway surface and expansion joints, that influence the dynamic response of a bridge. These parameters, however, are difficult to account for in code format. A comprehensive discussion on the previous analytical and experimental studies on the bridge dynamics and dynamic amplification factors is given in a survey paper by Paultre et al. (1992).

There have been several research efforts to investigate the effect of roadway irregularities on the dynamic responses of a bridge. The majority of the experimental studies (Csagoly et al. 1972; Whitmore 1970) reported that roadway imperfections and irregularities are major factors influencing dynamic responses of bridge. Similar observations have been made in previous analytical works (Honda et al. 1982; Palamas et al. 1985; Coussy et al. 1989).

One of the primary objectives of the present study is to investigate the effect of road surface profile on the dynamic

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Y.-S. Park and D.-K. Shin.[1] Department of Civil and Environmental Engineering, Myongji University, 38–2 Nam-dong, Yong-In, Korea, 449-728.
T.-J. Chung. Department of Civil Engineering, Halla University, Won-Ju, Korea, 220-712.

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[1]Corresponding author (e-mail: dkshin@mju.ac.kr).

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Table 1. International roughness index (IRI), roughness coefficient, and impact factor of 25 measured bridges.

Bridge No.	IRI (mm/m)	Roughness coefficient (10^{-6} m^2·cycle^{-1}/m)	Impact factor (%)	Natural frequency (Hz)	ISO classification
1	4.54	150	22.96	9.55	Poor
2	1.47	19	10.37	10.89	Good
3	3.82	110	11.82	9.4	Average
4	3.68	60	23.31	7.59	Average
5	2.63	48	14.87	11.94	Average
6	3.14	29	11.44	3.8	Good
7	6.14	35	21.56	4.15	Average
8	1.88	35	12.15	6.57	Average
9	4.27	52	15.93	3.63	Average
10	2.27	49	23.09	4.71	Average
11	5.21	125	20.71	3.7	Average
12	2.28	29	13.49	5.35	Good
13	1.29	14	12.89	4.47	Good
14	4.53	75	14.53	3.4	Average
15	2.07	40	14.87	4.18	Average
16	4.67	62	17.2	4.28	Average
17	2.41	15	8.66	3.95	Good
18	2.16	23	2.03	2.75	Good
19	1.84	19	11.59	3.5	Good
20	2.05	24	7.63	2	Good
21	8.57	100	20.6	3.3	Average
22	3.26	43	15.47	6.14	Average
23	2.13	38	10.54	5.55	Average
24	1.82	53	17.06	7.4	Average
25	7.29	120	22.77	6.59	Average

behavior of bridges. Twenty-five bridges in Korean highways are tested using controlled test vehicles. The bridges have various superstructure types, materials, span lengths, and ages. The time histories of displacements are measured, and the impact factors of the bridges are evaluated using the recorded displacement measurements. Another objective of this study is to find statistical relationships between the IRI and the roughness coefficients from the PSD function and between the international roughness index (IRI) and the impact factor. The roadway roughness of the 25 bridges are measured by a surveyor's level at an interval of 10–30 cm in the direction parallel to bridge span. After obtaining the roughness coefficients from the power spectral densities by the fast Fourier transform (FFT) method and evaluating IRI, the statistical relationships between the roughness coefficient and the IRI and between the IRI and the impact factor are evaluated by the linear regression and correlation analyses.

Loading test

In the field tests, dynamic responses are measured for the 25 bridges with various superstructure types (5 WF steel girder, 7 plate girder, 8 steel box girder, and 5 PC girder), materials, span lengths, and ages. The tests are performed for both static and dynamic load cases. In dynamic tests, the responses are measured for a wide range of vehicle speeds typically from 5 to 70 km/h. A 3-axle dump truck or a 3-axle tractor with semi-trailer is used as a test vehicle with gross weight ranging from 151 to 288 kN. Two lines parallel to traffic direction are marked on the pavement surface be-

Fig. 1. Field measurement and testing (bridge no. 15). (All dimensions are in metres).

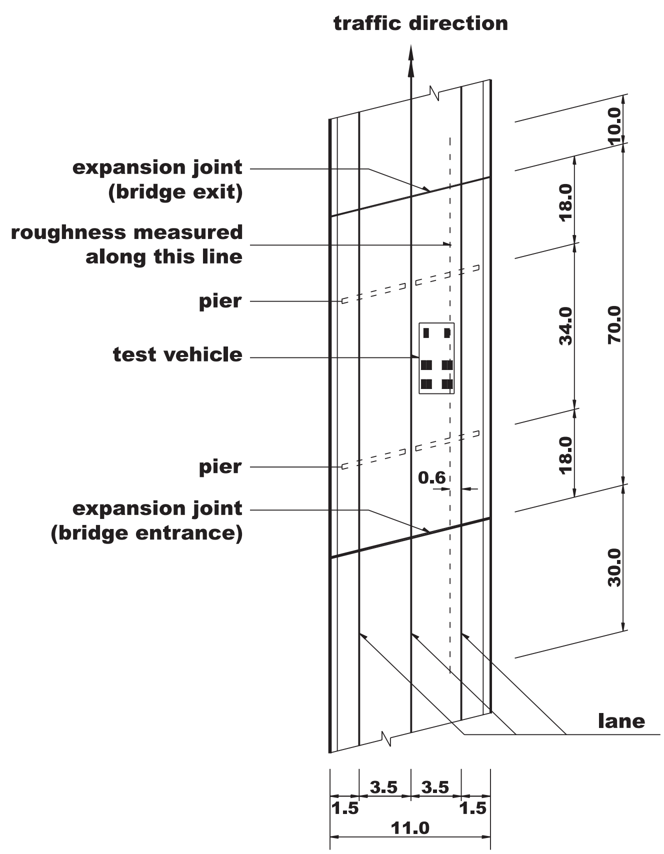
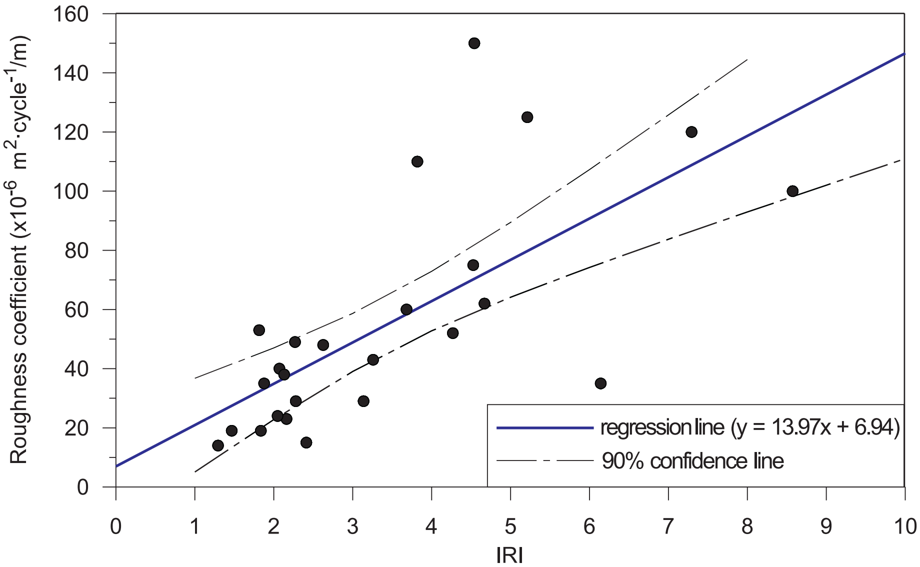


Fig. 2. Distribution, regression line, and 90% confidence curves of IRI and roughness coefficient.



fore the test so that the test vehicle can pass along the marked lines. The roadway profile is measured along one or both of the marked lines. The transducers are placed at the centre and quarter spans of bridge in the longitudinal direction.

Evaluation of impact factor

The following form of dynamic impact factor I is used (Paultre et al. 1992):

$$[1] \qquad I = \frac{D_{\mathrm{dyn}} - D_{\mathrm{sta}}}{D_{\mathrm{sta}}} \times 100$$

In the above equation, D_{dyn} denotes the maximum dynamic deflection and D_{sta} the maximum static deflection. The impact factor presented in Table 1 corresponds to the maximum value among the impact factors for different speed of test vehicle.

Field measurement of roadway profile

Using the intelligent total station used in surveying, the road profiles are measured along the longitudinal direction from the point 20 to 30 m ahead of bridge entrance to the point 10 m behind of bridge exit. They are measured at every 30 cm for the normal pavement surface and at every 10 cm for approximately 2 m near expansion joints where significant surface irregularities are frequently observed.

To explain the procedure of measuring the roadway roughness, the plan view of the bridge no. 15 is shown in Fig. 1. The total span length of the three-span continuous steel-girder bridge is 70 m (2 × 18 + 34 = 70) and the width is 11 m. The roughness is measured along the dashed line located on the right hand side (RHS) of the lane as shown in Fig. 1. This is attributed to the understanding that most heavy trucks travel on the RHS lane. The roadway surface of the RHS lane contains more irregularities.

Power spectral density of road surface roughness

The power spectral density is obtained by applying the FFT technique. The procedure proposed by Dodds and Robson (1973) is applied to obtain the roughness coefficients. The calculated roughness coefficients are in the range of 14×10^{-6} to 150×10^{-6} $m^2 \cdot cycle^{-1}/m$ as presented in Table 1. The mean and coefficient of variation are calculated to be 54.68×10^{-6} $m^2 \cdot cycle^{-1}/m$ and 69.28%. According to the roughness classification method proposed by Dodds and Robson (1973), the road surface of 25 bridges falls into the category of "good" to "poor" conditions.

International roughness index

The IRI (Dodds 1972) is proposed as a common roughness measure in the world. The IRI is defined as characteristics of the longitudinal profile of a traveled wheel track. In the present study, an attempt is made to observe a quantitative relationship between the roughness coefficient obtained by FFT and the IRI. The IRIs of 25 bridges are summarized in the second column of Table 1. The procedure to calculate the IRI is given in Hwang (1990). It can be seen from Table 1 that the IRIs range from 1.29 to 8.57 mm/m, showing a relatively wide scatter. The mean value and coefficient of variation of the IRIs for the 25 bridges are calculated to be 3.42 mm/m and 54.82%, respectively.

Discussion

The statistical analyses are carried out to derive a relationship between the roughness coefficient and the IRI. Figure 2 shows the distribution of measured data, the regression line, and the ranges with 90% confidence level. In Fig. 2, the variables x and y denote the IRI and the roughness coefficient, respectively. The linear regression analysis demonstrates a linear relation between the roughness coefficient and the IRI with the slope of 13.97. The sample correlation coefficient between the roughness coefficient and the IRI is

Fig. 3. Distribution, regression line, and 90% confidence curves of IRI and impact factor.

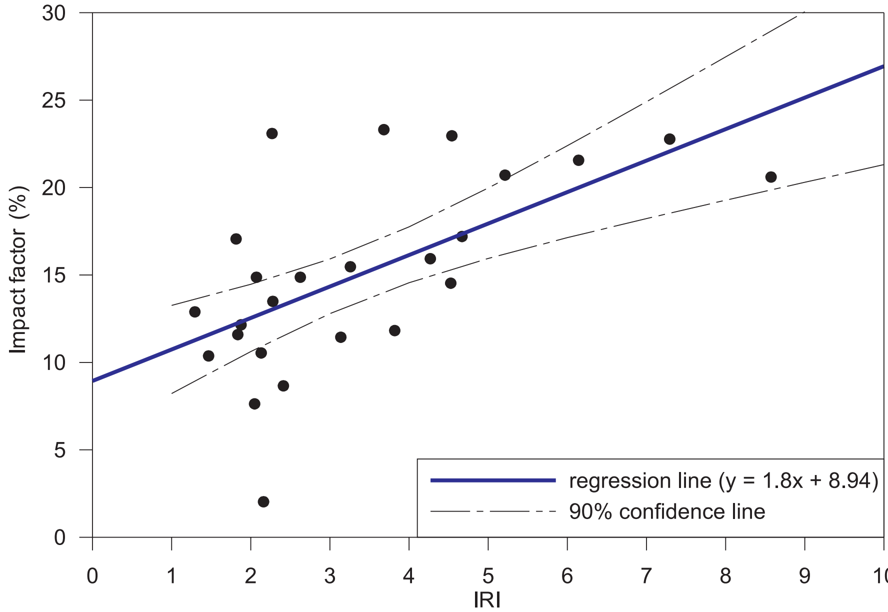
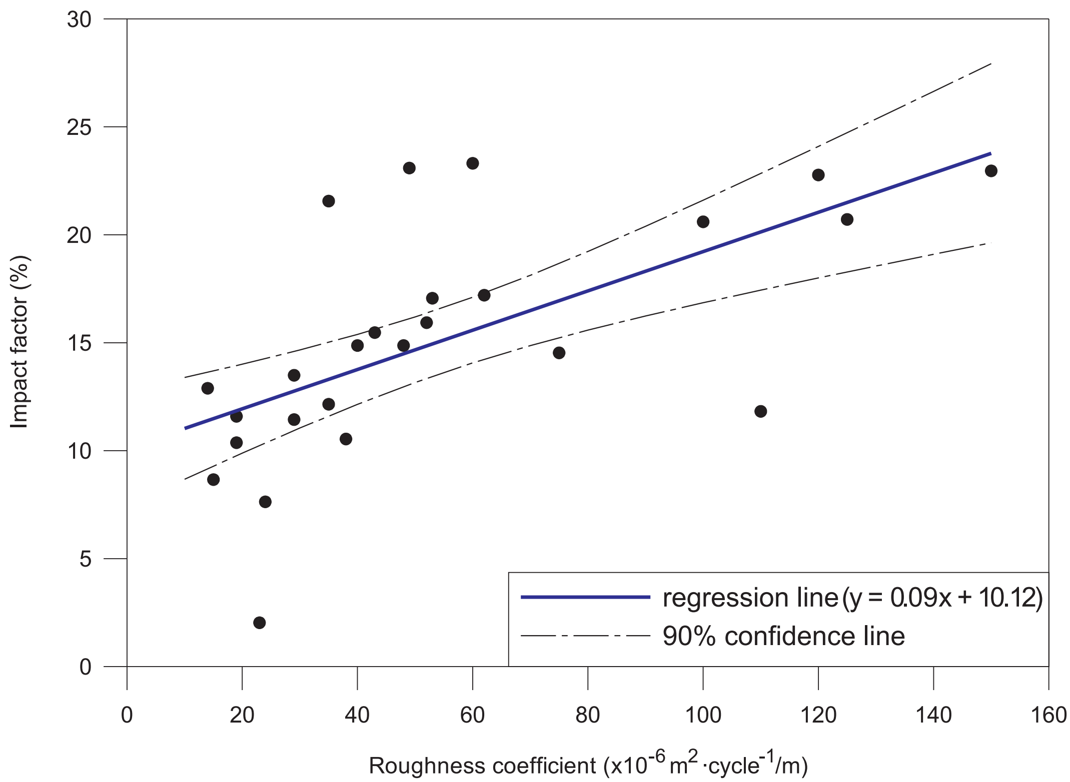


Fig. 4. Distribution, regression line, and 90% confidence curves of roughness coefficient and impact factor.



computed to be 0.69, thereby showing a strong coherence between them.

The regression and correlation analyses are performed to observe the effect of road surface roughness on the impact factor. Figures 3 and 4 show the relations between the impact factor and the IRI and between the impact factor and the roughness coefficient, respectively. From Figs. 3 and 4, it can be observed that the impact factor increases almost linearly as the IRI or the roughness coefficient increases. The acceptability of the linear regression model is established by observing some statistical properties of residual errors. The sample correlation coefficients between the impact factor and the IRI and between the impact factor and the roughness coefficient are calculated to be 0.61 and 0.62, respectively. The judgement made on the basis of only the sample correlation coefficient and the linear regression curve showed that the roadway roughness influences the impact factor to some degree. It should be noted, however, that the calculated correlation coefficient reflects combined effects of many factors since the 25 bridges have various span lengths, types of superstructures, natural frequencies, and roadway profiles.

Concluding remarks

The effects of road surface roughness on the dynamic behavior of highway bridges are investigated. There is a strong coherence between the IRI and the roughness coefficient. The sample correlation coefficient between them is computed to be 0.69. A linear relationship, in a statistical sense, exists between the roughness coefficient and the IRI. The sample correlation coefficients between the impact factor and the IRI and between the impact factor and the roughness coefficient are calculated to be 0.61 and 0.62, respectively. The judgement made on the basis of only the sample correlation coefficient and the linear regression curve showed that the roadway roughness influences the impact factor to some degree.

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