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DYNAMIC BEHAVIOUR OF STEEL SIMPLE SPAN RAILWAY BRIDGES TRAVELED BY TRAINS

السلوك الديناميكي لكباري السكة الحديد المعدنية ذات البحور البسيطة عند تعرضها لعبور القطارات

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ملخص البحث : هذا البحث يقدم الاستجابة الديناميكية لكباري السكة الحديد المعدنية ذات البحور البسيطة عند تعرضها لعبور القطارات. وقد تم استخدام طريقة العناصر المحددة في عملية التحليل الديناميكي لهذه الكباري. واعتبر القطار في عملية التحليل سلسلة من الأحمال المتحركة تؤثر عند محاور العجلات، بينما تم اعتبار "عنصر الكمرة" كنموذج عند التحليل الديناميكي للكوبري. واستخدمت أحمال القطار طراز "D" الوارد في الكود المصري للأحمال علي كباري السكة الحديد في التحليل. تم إعداد برنامج علي الحاسب الآلي لإنجاز التحليل المطلوب. وقد تم تحليل ودراسة حالات حقيقية من كباري السكة الحديد المعدنية ذات البحور البسيطة والخط المفرد والأرضية المرتكزة علي طبقة من الصابورة بسمك أدنى ٢٠ سم اسفل الفلنكات. تم حساب أهم الخواص الديناميكية للكباري التي خضعت للدراسة ، ثم تحديد قيم دقيقة لمعاملات التأثير الديناميكي المبنية علي الترخيم وعلي عزوم الانحناء لهذه الكباري ثم مقارنتها بمعامل الصدم الوارد في المواصفات المصرية لكباري السكة الحديد. كما تم فحص ودراسة أهم العوامل التي تؤثر علي السلوك الديناميكي لكباري السكة الحديد المعدنية عند اجتيازها بواسطة القطارات، ومن هذه العوامل سرعة القطار، وعجلة القطار، وبحر الكوبري ومعامل الاضمحلال فيه.

ABSTRACT:

This paper presents the dynamic response of simply supported steel railway bridges due to a train moving across tbe bridge. The finite element technique is used in the analysis. The train is modeled as a series of concentrated moving loads, and a bridge witb a beam element. A train type "D" given in the Egyptian code of practice is used in this study. A computer program is developed to achieve the desired analysis. Actual cases of simple span, single-track steel girder bridges are analyzed. Natural frequencies and mode shapes of the investigated bridges are computed. The dynamic factor based on the deflection and the bending moment of these bridges, is also determined and plotted against the impact factor calculated from the empirical formula given in the Egyptian specifications of railway bridges. Different factors affecting the dynamic response of steel railway bridges, such as train speed, its acceleration, bridge span and damping coefficient of the bridge are studied.

KEY WORDS: Bridges, Railway, Simple Span, Steel, Dynamic.

1. INTRODUCTION

The determination of the dynamic response of railway bridges resulting from the passage of a moving train across the bridge span is a problem of great interest for bridge engineers. This is for two main reasons: (1) the resulting peak dynamic stresses are greater than those due to static-load application; and (2) the vibration of the bridge should not be excessive, to minimize fatigue effects and avoid impairing public confidence in the structure. Many factors influence the dynamic behaviour of steel railway bridges when traveled by moving trains. These factors include (1) material properties, dimensions and section properties of the bridge;

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(2) the damping characteristics; (3) the train factors which are the axle loads, speed, ... etc. Since railway bridges are dynamically loaded by moving trains, increase in deflections, normal stresses and shear stresses usually happen. The increase due to the dynamic component is normally treated in design through the use of impact factors, defined as the difference between the dynamic and static values divided by the static value. Bridge designer engineers are usually interested with the increase in stresses and displacements due to dynamic effect. The objective of this paper is to develop an analytical approach based on the finite element method, to study the influence of the different variables on the dynamic behaviour of bridges, according to the Egyptian code for loads on railway bridges.

2. DYNAMIC ANALYSIS OF RAILWAY BRIDGES

The equation of motion of vibratory systems takes the form:

$$[M]\{\ddot{Y}\} + [C]\{\dot{Y}\} + [K]\{Y\} = \{F\} \qquad (1)$$

Where:

[M], [C], [K] are the mass, damping and stiffness matrices respectively.

$\{\ddot{Y}\}$, $\{\dot{Y}\}$, $\{Y\}$ are the acceleration, velocity and displacement vectors respectively.

{F} is the external load vector.

Free vibration analysis of a railway bridge must be achieved first to provide the most important dynamic characteristics of the bridge, which are the natural frequencies and the corresponding modal shapes. The finite element approach is used for this analysis. Once these characteristics are determined the mode superposition method is used to determine the dynamic response of a railway bridge under the effect of moving trains. The internal actions occurred during vibrations at any station can be calculated from the equation:

$$\{P\}_E = [K]_E \{\delta\}_E + [M]_E \{\ddot{\delta}\}_E \qquad (2)$$

Where:

$\{P\}_E$ is the element end forces.

$[K]_E$ is the element stiffness matrix.

$[M]_E$ is the element mass matrix.

$\{\delta\}_E$ is the element end displacements.

$\{\ddot{\delta}\}_E$ is the element end accelerations.

2.1 Numerical Example:

To verify the reliability of the method of analysis and the developed computer program, a simply supported beam of uniform cross-section shown in Fig. 1 is subjected to a load of magnitude P =20,000 lbf moving at a velocity of v = 748.14 in./sec. The following data are obtained from Wu and Dai (1987): length of beam L= 460 in., flexural rigidity EI= 6.0 x 10^{10} lbf.sq. in., and mass per unit length m = 0.45 lbm/in. The first lowest five natural frequencies obtained by the present approach have been compared with the previous results in Table 1. It can be seen that a very good agreement is achieved. The dynamic response calculated for the midpoint of the beam has been plotted in Fig. 2. Also shown in Fig. 2, are the results by Wu and Dai (1987) using the transfer matrix method. It is confirmed that the present solution agrees quite well with the previous one.

Table 1. First five natural frequencies for the simply supported beam:

Study	Natural Frequencies (rad/s)				
	ω_1	ω_2	ω_3	ω_4	ω_5
Wu and Dai (1987)	17.030	68.099	153.146	272.072	424.744
Warburton (1976)	17.031	68.126	153.286	272.504	425.788
Yang and Lin (1995)	17.032	68.133	153.365	272.956	427.469
Present study	17.031	68.126	153.283	272.504	425.787

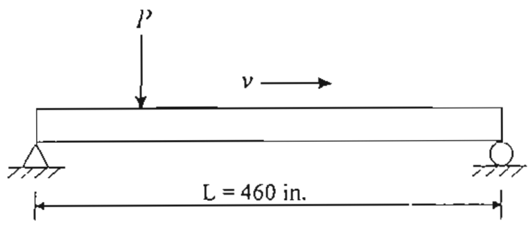


Fig. 1 Simply Supported Beam Subjected to Moving Load

3. EGYPTIAN CODE OF PRACTICE

3.1 Live Loads for Railway Bridges:

The Egyptian code of practice (1993) states that for the calculation of railway bridges and their substructures, the rolling live load, not including impact, shall be taken as one of the three Train-types "D", "H", or "L". The Train-type "D" shown in Fig. 3 is considered in the analysis for the present study.

3.2 Dynamic Effect on Railway Bridges:

The Egyptian code of practice (1993) considers the following empirical formula to determine the factor I by which the live load is to be multiplied to give the addition for the dynamic effects on railway bridges: $I = 24/(24+L)$, with a maximum of 75% and an absolute minimum of 25%, where L in meters, represents the loaded length of one track, or the sum of loaded lengtbs of double tracks in direction of motion producing worst stresses in member under consideration. For ballasted floor bridges with thickness of ballast 20 to 50 cms., I to be reduced by 20 %.

4. STUDY CASES

To study the dynamic behaviour of steel, simple span, railway bridges when traveled by trains, four practical and important cases of ballasted floor single-track deck bridges are examined. These bridges are bolted and welded plate girder bridges. Fig. 4 shows the cross-sections of the main girders of these bridges, while Fig. 5 shows the whole cross-section of

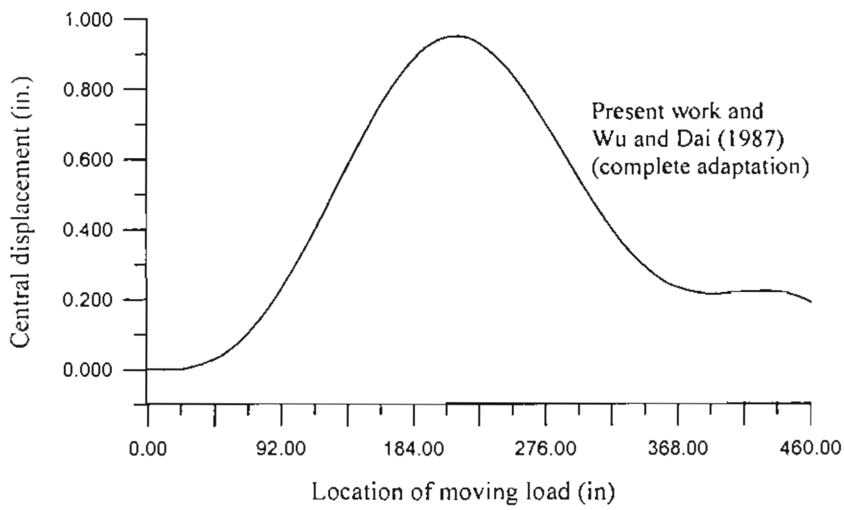


Fig. (2) Midpoint response of the simply supported beam (shown in Fig. 1)

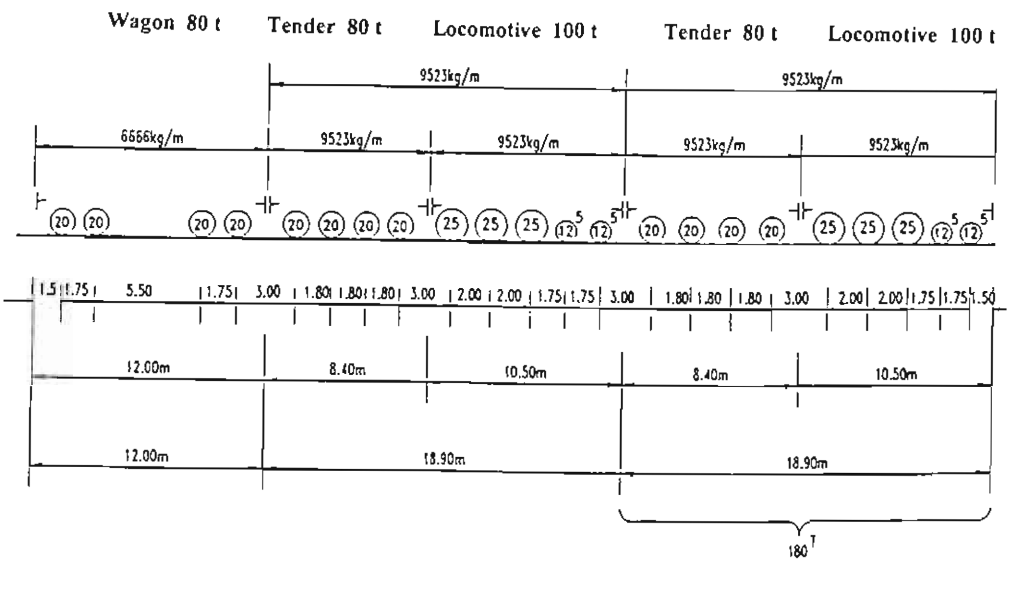
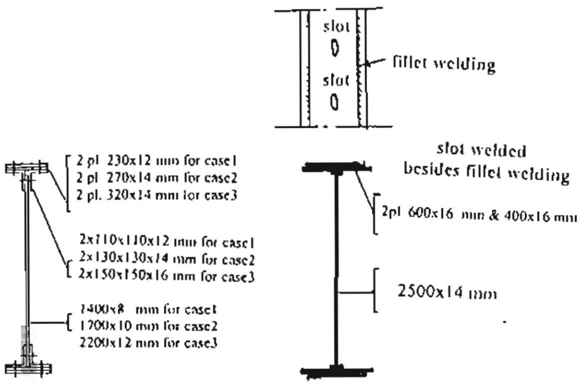


Fig. (3) Train Type "D" According to Egyptian Code

the bridge. The material of construction is steel 52. It is to be noted that the flange plates of the welded main girders are slot welded. The data of the considered cases are as follows:

<u>Case 1:</u> A simple span bolted plate girder bridge is shown in Fig. 4. The span = 15.00 m. is divided into 20 elements 0.75 m each. EI = 250425 t.m^2, Mass M = 4.065 t/m.
<u>Case 2:</u> A simple span bolted plate girder bridge is shown in Fig. 4. The span = 21.00 m. is divided into 28 elements 0.75 m each. EI = 516040 t.m^2, Mass M = 4.24 t/m.
<u>Case 3:</u> A simple span bolted plate girder bridge is shown in Fig. 4. The span = 25.50 m, is divided into 34 elements 0.75 m each. EI = 1120350 t.m^2, Mass M = 4.43 t/m.
<u>Case 4:</u> A simple span welded plate girder bridge is shown in Fig. 5. The span = 30.00 m. is divided into 40 elements 0.75 m each. EI = 1457190 t.m^2, Mass M = 4.59 t/m.

Where EI is for one main girder only.



Bolted sections Welded sections

Fig. (4) Cross-Sections of Main Girders

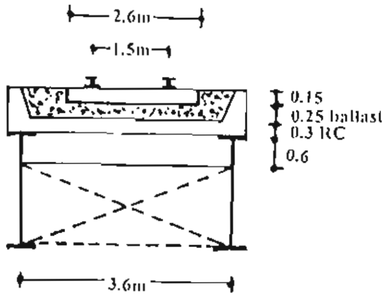


Fig. (5) Cross-section of the bridge

5. RESULTS AND DISCUSSIONS

The dynamic response of steel railway bridges traversed by trains is affected by several parameters concerning the bridge and the moving train. Among these parameters are (1) the train speed; (2) the span of the bridge; (3) the train acceleration; (4) the damping of the bridge. All cases of the investigated bridges are studied for these different parameters. The undamped case is considered for the analysis of the first three items. The results of this study are presented in this section. The dynamic effect factor (I) is calculated from the following formula:

$$I = \left[\frac{Maximum\ dynamic\ response}{Maximum\ static\ response} - 1 \right] x\ 100 \qquad (3)$$

The natural frequencies for the analyzed cases are given in the following table (Table 2). It is to be noted that the calculated moments and displacements are due to the train loads only.

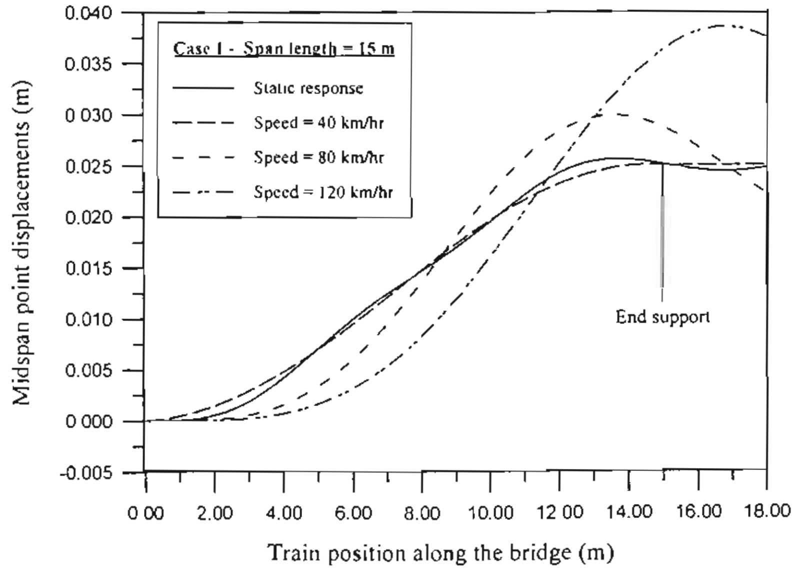


Fig. (6) Effect of Train Speed on Displacement of Midspan Point for Case (1)

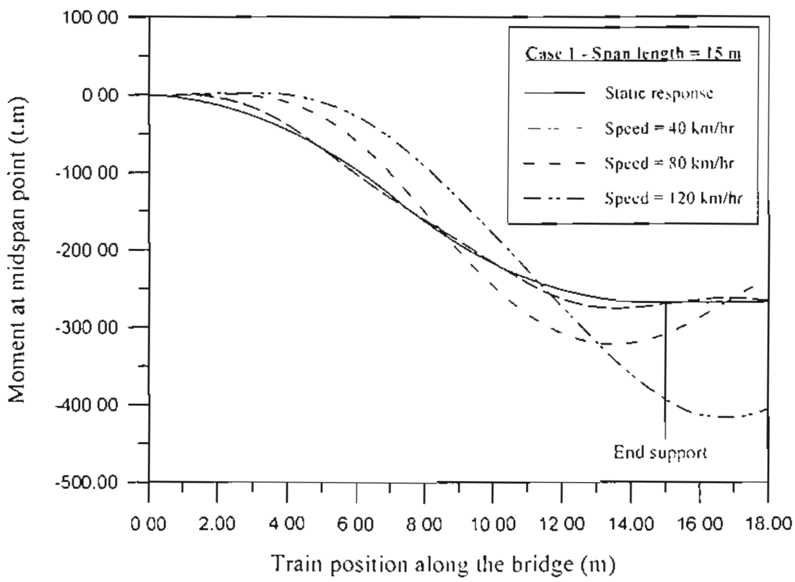


Fig. (7) Effect of Train Speed on Moment at Midspan Point for Case (1)

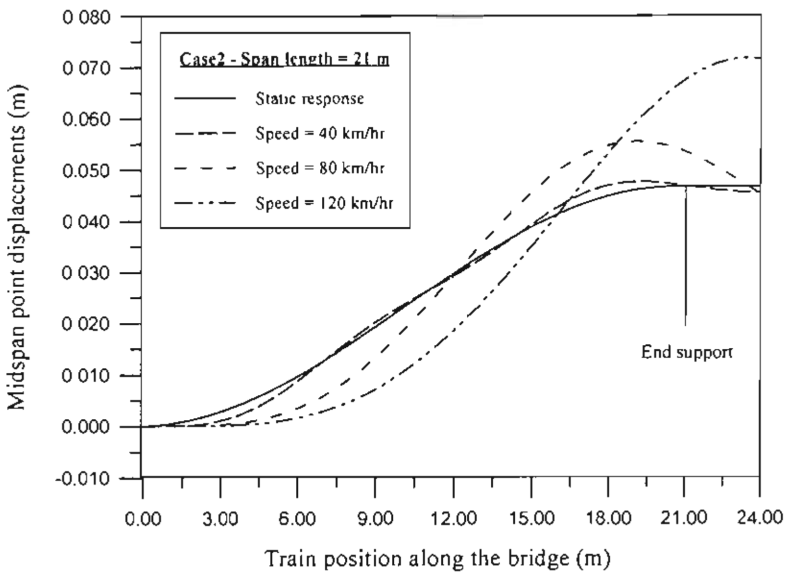


Fig. (8) Effect of Train Speed on Displacement of Midspan Point for Case (2)

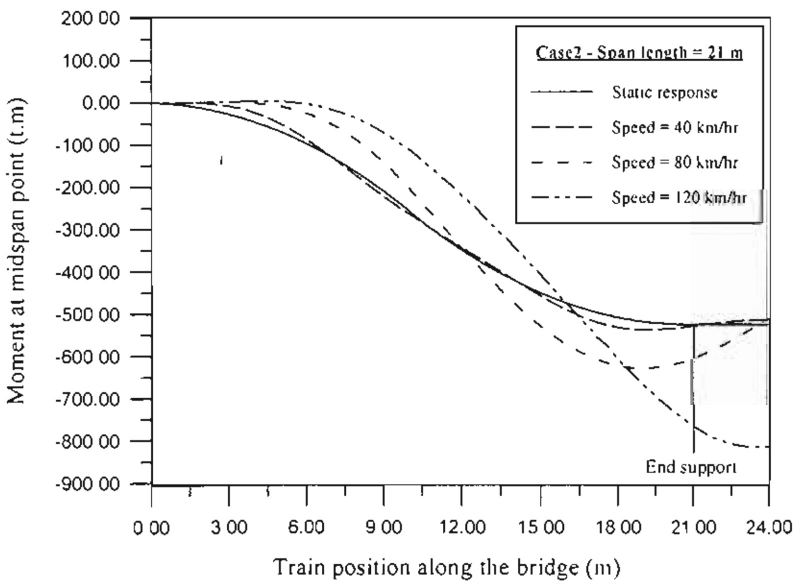


Fig. (9) Effect of Train Speed on Moment at Midspan Point for Case (2)

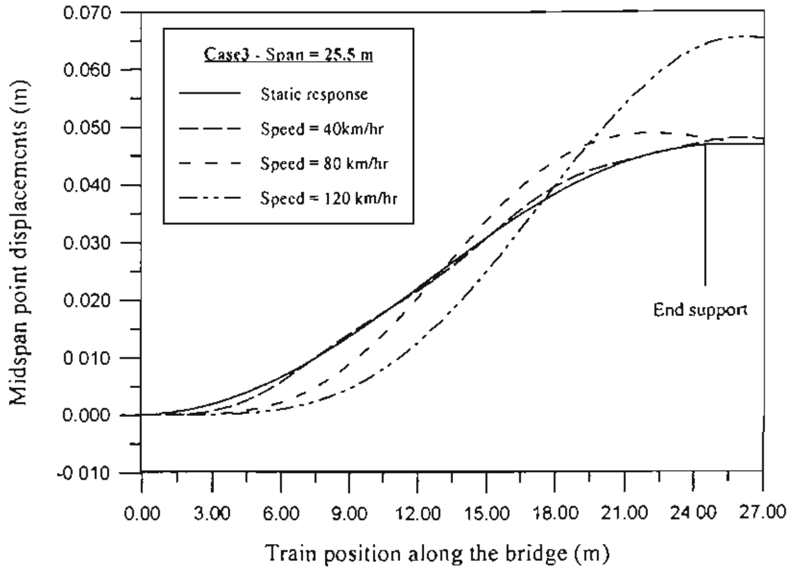


Fig. (10) Effect of Train Speed on Displacement of Midspan Point for Case (3)

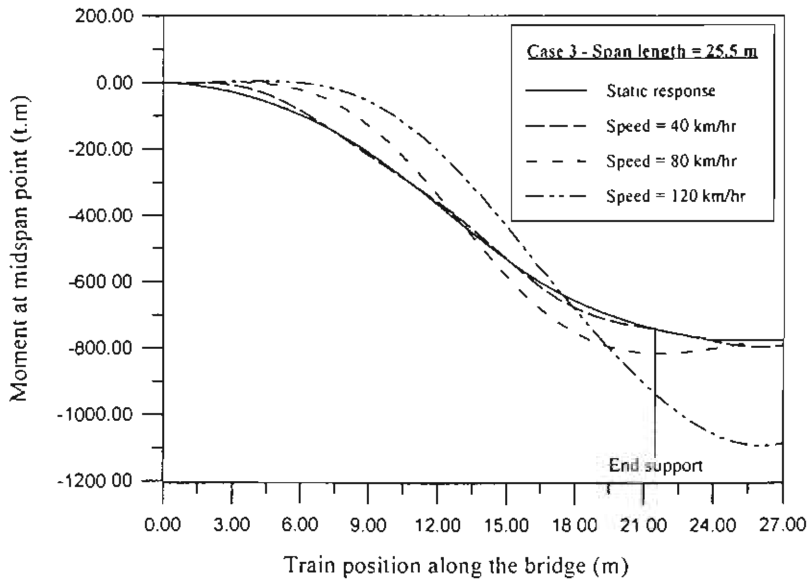


Fig. (11) Effect of Train Speed on Moment at Midspan Point for Case (3)

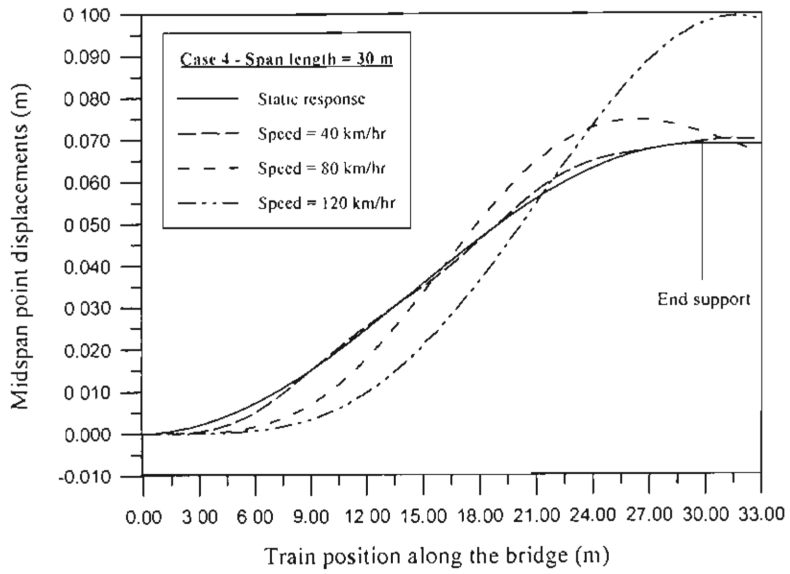


Fig. (12) Effect of Train Speed on Displacement of Midspan Point for Case (4)

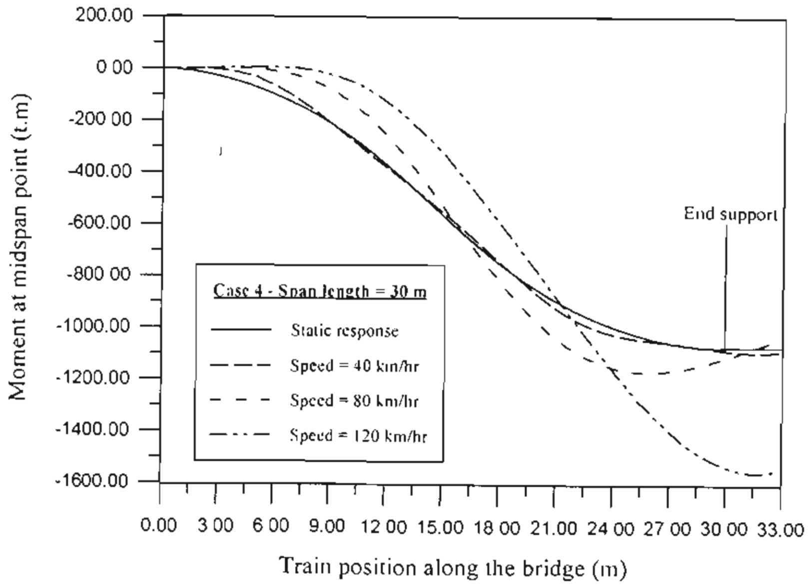


Fig. (13) Effect of Train Speed on Moment at Midspan Point for Case (4)

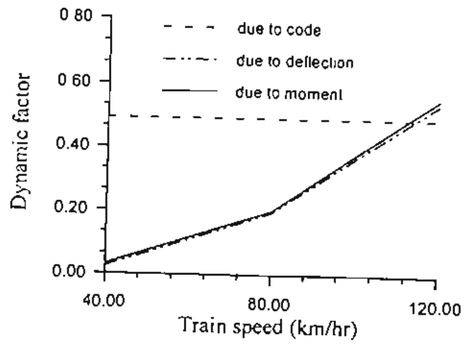


Fig. (14) Speed - Dynamic Factor Diagram for Case 1 (span = 15.0 m)

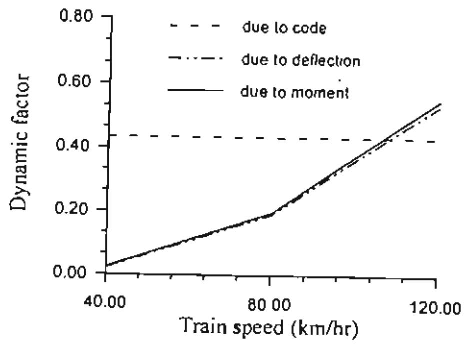


Fig. (15) Speed - Dynamic Factor Diagram for Case 2 (span = 21 m)

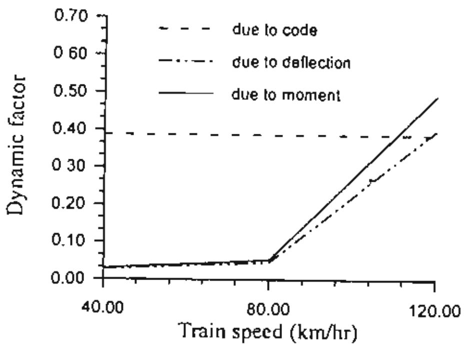


Fig. (16) Speed - Dynamic Factor Diagram for Case 3 (span = 25.5 m)

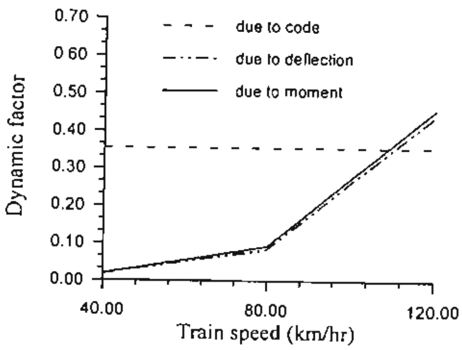


Fig. (17) Speed - Dynamic Factor Diagram for Case 4 (span = 30 m)

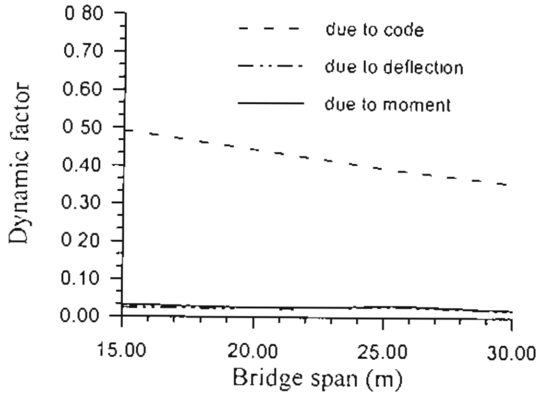


Fig. (18) Span - Dynamic Factor Diagram (for Speed = 40 km/hr)

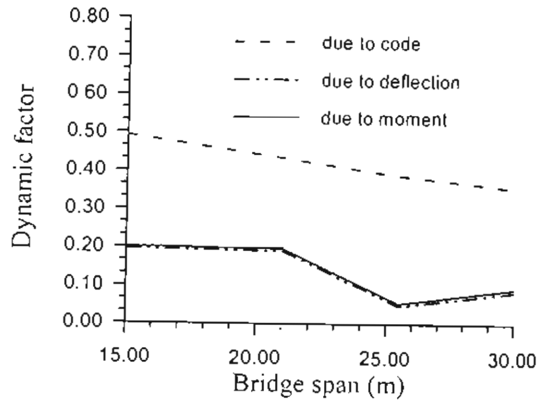


Fig. (19) Span - Dynamic Factor Diagram (for Speed = 80 km/hr)

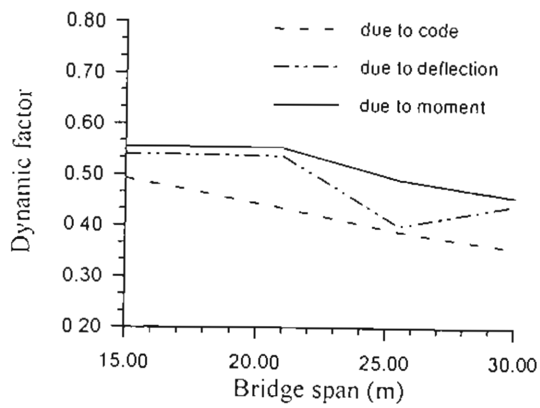


Fig. (20) Span - Dynamic Factor Diagram (for Speed = 120 km/hr)

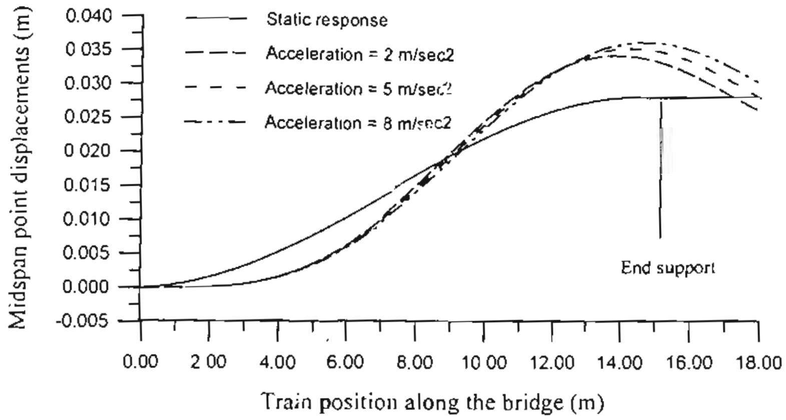


Fig. (21) Effect of Train Acceleration on Displacement of Midspan Point (Span = 15.0 m and Initial Speed = 80 km/hr)

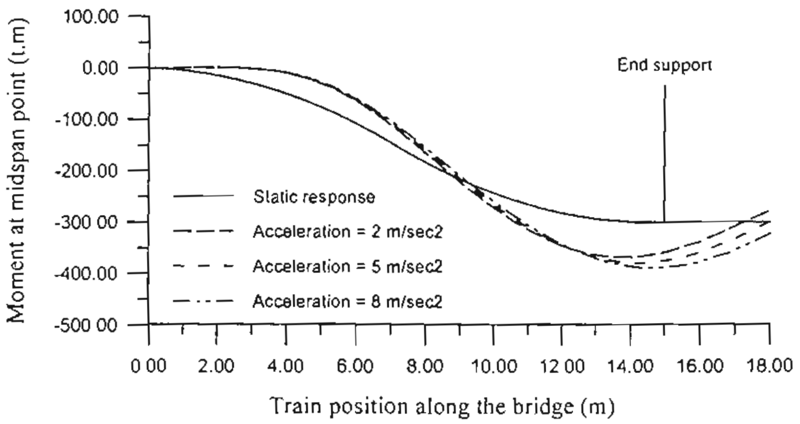


Fig. (22) Effect of Train Acceleration on Moment at Midspan Point (Span = 15.0 m and Initial Speed = 80 km/hr)

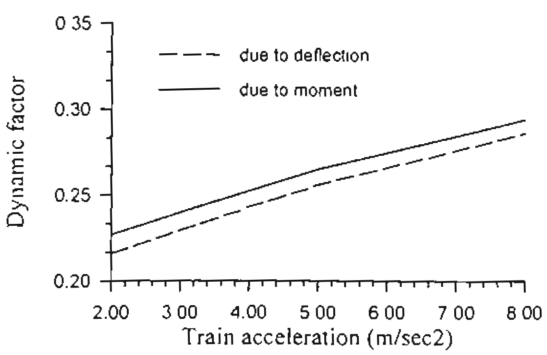


Fig. (23) Acceleration - Dynamic Factor Diagram (Span = 15.0 m and Initial Speed = 80 km/hr)

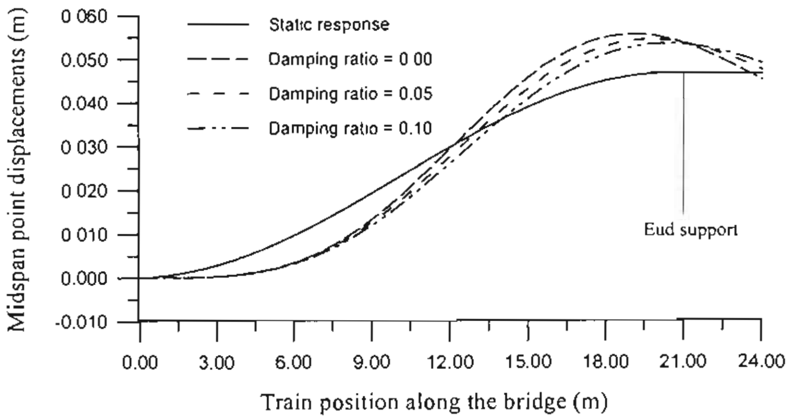


Fig. (24) Effect of Damping on Displacement of Midspan Point (Span = 21.0 m and Speed = 80 km/hr)

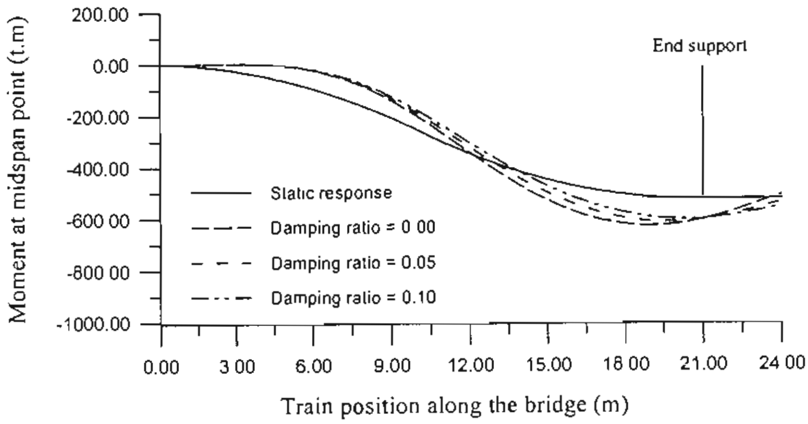


Fig. (25) Effect of Damping on Moment at Midspan Point (Span = 21.0 m and Speed = 80 km/hr)

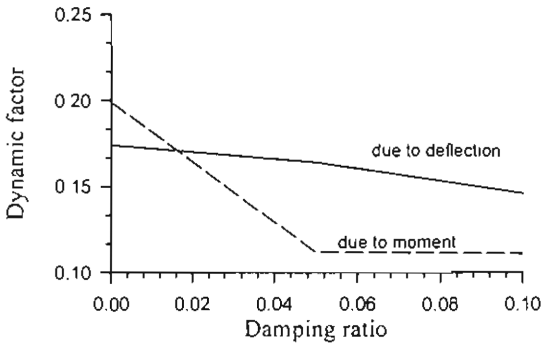


Fig. (26) Damping ratio - Dynamic Factor Diagram (Span = 21 m and Speed = 80 km/hr)

Table 2. First five natural frequencies for the investigated bridges:

Study Case	Natural Frequencies (rad/s)				
	ω_1	ω_2	ω_3	ω_4	ω_5
Case 1	10.887	43.549	97.983	174.178	272.103
Case 2	07.807	31.231	70.268	124.919	195.177
Case 3	07.633	30.532	68.697	122.126	190.818
Case 4	06.179	24.716	55.610	98.816	154.469

5.1 Speed Effect

The effect of train speed on the dynamic behaviour of the bridge is studied for all the investigated cases. The speeds considered in the analysis are 40 km/hr, 80 km/hr and 120 km/hr. Figs. 6 through 13 show the effect of train speed on the displacements and moments at mid-span points for the different study cases. Figs. 14 to 17 show the speed – dynamic factor diagrams for these cases. The impact factor calculated from the empirical formula given in the Egyptian code of practice is plotted also in these diagrams.

5.2 Span Effect

The effect of the span on the dynamic response of the bridge is illustrated in Figs. 18, 19, and 20. The spans considered herein, are 15.00, 21.00, 25.50, and 30.00 meters respectively.

5.3 Acceleration Effect

The acceleration of the moving train is considered in this study to be 2, 5 and 8 m/sec^2 respectively. The initial velocity of the moving train is taken as 80 km/hr. Figs. 21 and 22 indicate the effect of train acceleration on displacements and moments at mid-span point for study case 1, while Fig. 23 shows the acceleration – dynamic factor diagram for this case. The impact factor calculated from the empirical formula given in the Egyptian code of practice is plotted also in this diagram.

5.4 Damping Effect

The study case 2 is investigated for different damping ratios to illustrate the effect of damping on the dynamic response. Damping ratios considered in the analysis are 0.0, 0.05 and 0.10 while the train speed is considered to be 80 km/hr. Figs. 24 and 25 illustrate the effect of damping on displacements and moments of mid-span point of the investigated bridge. The damping ratio – dynamic factor diagram is shown in Fig. 26.

6. CONCLUSIONS

1- The actual dynamic effect on railway bridges is approximately equal to the impact factor given by the Egyptian code for a speed of 110 km/hr, while it can be neglected for speeds less than or equal to 40 km/hr. For intermediate speeds a linear relation can be adopted. Speeds more than 110 km/hr give a bigger dynamic effect than that given by the code.
2- The maximum dynamic responses are increased with the increase of the train acceleration.

3- The dynamic effect decreases with the increase of the span length and has approximately the same values given in the code for speed of 120 km/hr. For lower speeds, the dynamic factor takes smaller values compared with that given in the code.
4- The dynamic effect factors calculated for moments are slightly larger than those for deflections for all the studied cases.
5- The effect of damping on the dynamic response of railway bridges is small and can be neglected.

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