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Evaluation of DAF For Steel Truss Railway Bridge Using Experimental and Numerical Approach

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Abstract

This research studies the differences between the real measured Dynamic Amplification Factor (DAF) and the calculated one according to the new Egyptian Standard. One of the arched steel railway bridges in Egypt was subjected to loading capacity evaluation process, during this process a study to evaluate the (DAF) was carried out.

The actual DAF was determined experimentally by using dynamic loading tests that were carried out under the bridge normal operation conditions. The results of the dynamic loading tests were also validated by using numerical models for the bridge and the train loads. The numerical model was calibrated also with the results of the measured bridge dynamic characteristics.

The results obtained from the experiments and from the numerical model were compared to the DAF obtained from the Egyptian standards. The research results indicated that, there is a considerable difference between the two actual values and the Egyptian standard calculated one.

Keywords:

Dynamic Testing, Arched Steel Bridge, Impact Factor, Dynamic Response

1. Introduction

The Dynamic Amplification Factor (DAF) is an important factor in the bridge design procedures. The dynamic amplification factor in the new Egyptian standards, Egyptian Code for Loads - 2012 [1], is calculated using a numerical formula with one variable which is the bridge span. It is known that the dynamic amplification factor for bridges is a function of many variables, some of them related to passing trains like speed, suspension system and weights, while others variables are related to bridge dynamic characteristics and bridge roughness of the rails and the bridge boundary conditions.

Many researchers studied factors affecting the DAF such as roughness of surface [2]. The effects of high speed trains on structures were studied in [3]. A study was done [4] using the most critical static load position and a dynamic test to determine the maximum DAF trying to calculate the most economic design load. Also, the effect of different velocities on a roadway bridge was studied in [5].

The main purpose of this research is to investigate the degree of accuracy in calculating the DAF according to Egyptian standard formula for simply supported arched truss steel railway bridges. For this purpose, an experimental test were done to determine the DAF that taking into consideration all factors affecting the DAF for one of the railway arched truss steel bridges in Egypt. The experimental results were validated numerically, and the measured DAF was compared to the one that calculated according to the Egyptian standard [1].

2. Bridge Description

The bridge is known as El-Kanater Railway Bridge and it was constructed in

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1907. The bridge is a steel bridge which has 490m total length and consists of seven spans of 70m in length for each. Six edge spans are fixed while the middle one is swing. The Bridge is supported by seven concrete piers within the river water channel (Dimmitta branch of the River Nile) and two abutments at the channel sides. Each span is composed of two main steel arched trusses as main girders with rivets connection. The depth of the main girder is variable where it changes from 3.50m at the edges to 7.80m at the middle. The distance between the two main girders is 5.30m and connected transversally at the bottom by cross beams at spacing of 5.292m and cross bracing. The bridge dick is open timber flooring type. Top cross bracing is used only at the middle 37 meters of the span to allow for the required clear height of the train. The Main girder is supported by concrete piers via steel Hinged and Roller Bearing at its ends. Figure 1 shows a general view for the bridge.

Figure 1: General view for the tested bridge

3. Experimental Work

Dynamic tests were done using two locomotives with total weight of 132 ton. The bridge dynamic response (acceleration, strain and deflection) was measured under the effect of four different speeds that represents the most common working speeds on that line. The locomotive speeds were 10.0, 20.0, 40.0 and 80.0 km/hr. The studies were executed on one of the bridge typical spans. Six accelerometers were mounted to the bottom flange of the two external main girders from point No. 1 to Point No. 6. One LVDT and strain gauge sensors were fixed at midpoint of one of the main girders at Point No. 2. Figure 2 shows the positions of all the measured points.

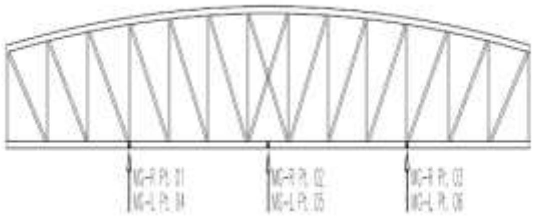
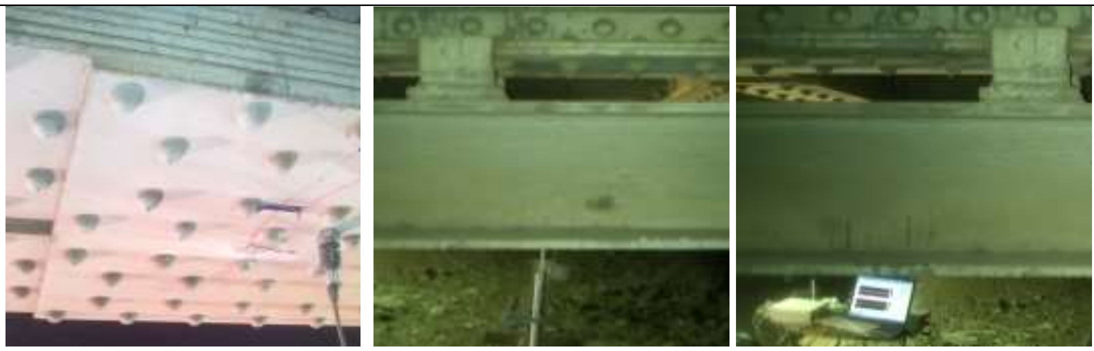


Figure 2: Accelerometers, LVDT and Strain Gauge positions

The accelerometers were distributed all over the span of the bridge, three accelerometers at each main girder. The accelerometers send the measured signals to data acquisition card through connecting cables. The results of the dynamic tests were also used to determine the bridge dynamic characteristics. The records are filtered, averaged and transformed to Power spectra curves and the basic frequencies are determined. Figure 3 shows a photo of one of the installed accelerometers the positions of these accelerometers.



a) Accelerometer & Strain gauge b) LVDT c) Data acquisition system

Figure 3: Photo of one of the installed Devices

At each location the peak acceleration response was determined for each locomotive speed. Also, the deflection and strain were measured at the middle point of the bridge span only where the maximum deflection and strain are expected. Figure 4 displays samples of the acceleration time records

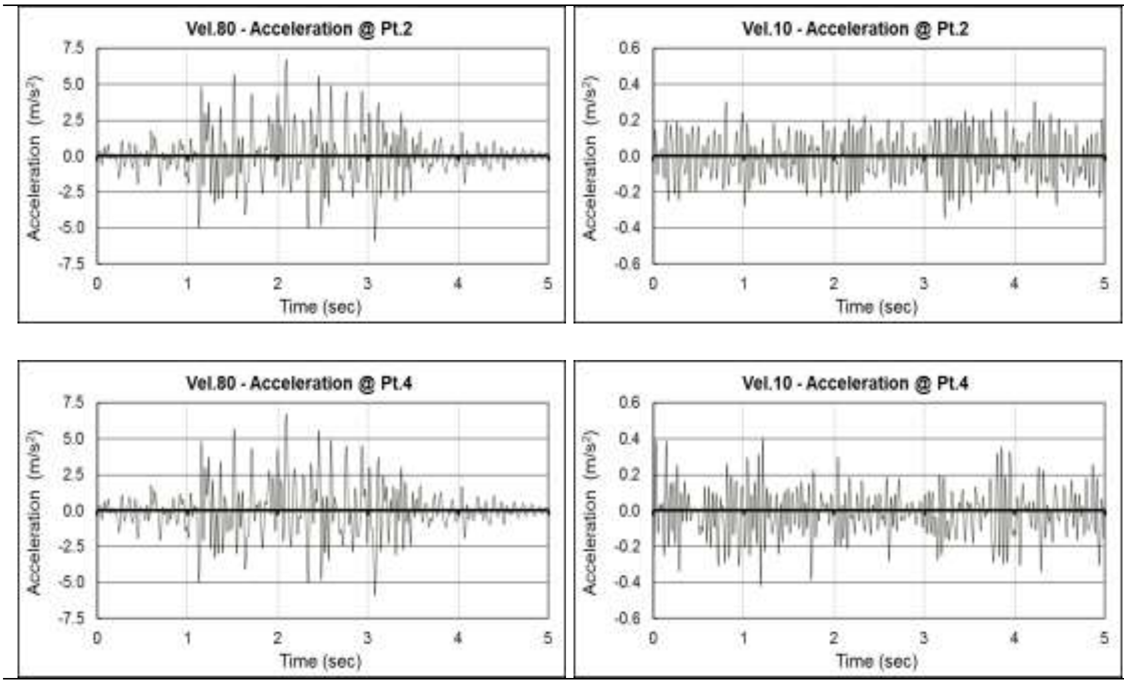
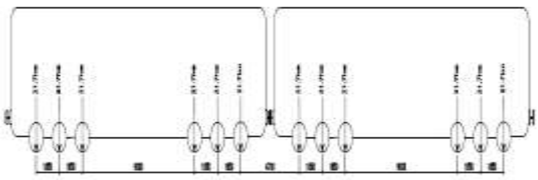
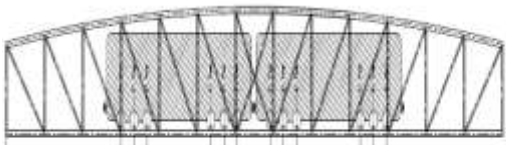


Figure 4: Samples of Bridge Acceleration Response at different locations Speeds

The configuration of the used locomotives and their photos and position during static loading test are displayed in figure.



a) Used Locmotive



b) Locmotives Position at Static Loading

c) Locomotives during test.

Figure 5: Loading Configrations

4. Experimental results

The bridge free vibration responses were used to determine the bridge dynamic characteristics. Figure 6 displays the acceleration wave forms for the measured six points, while figure 7 displays the response spectra for each point record.

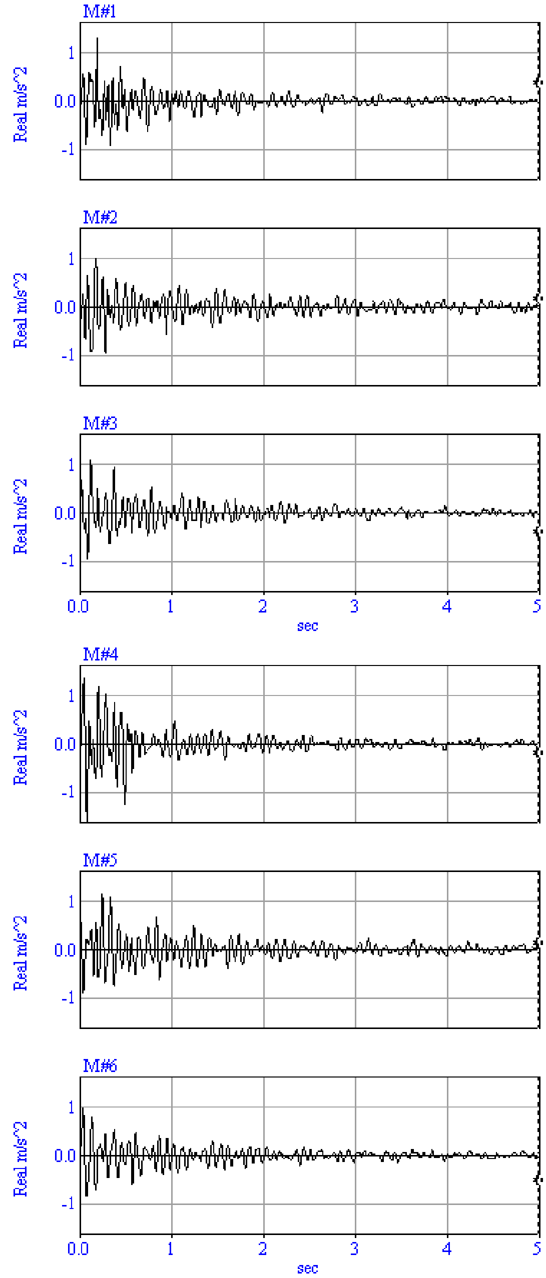


Figure 6: Time records for bridge response due to free vibrations

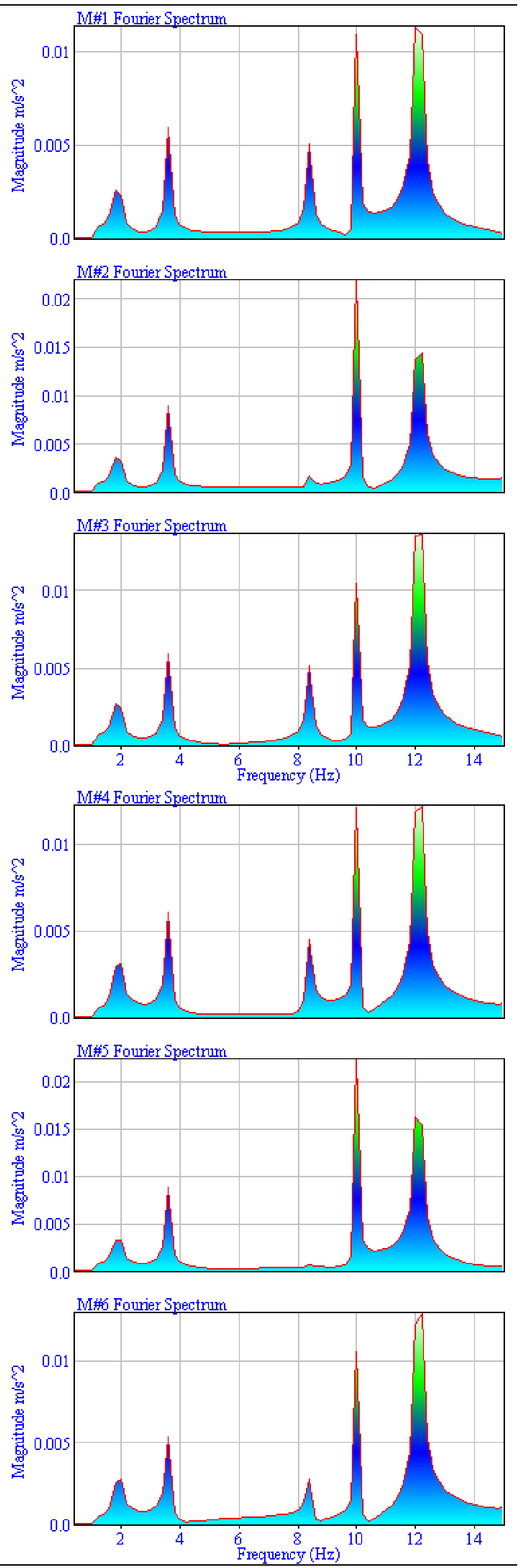
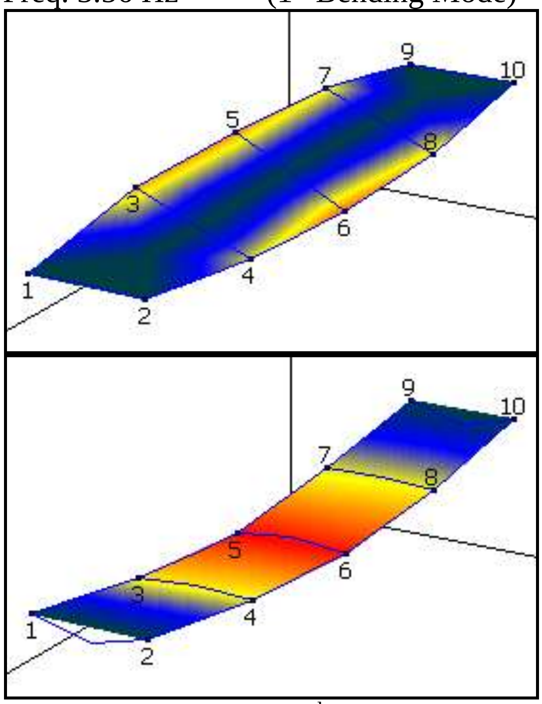


Figure 7: The acceleration Response Spectra

Four modes could be detected from the analysis of bridge acceleration responses these modes were two bending modes first second and two torsional modes first & third. The bridge detected fundamentals frequencies and mode shapes are displayed in figure 8.

Freq. 1.90 Hz (1st Torsion Mode)
Freq. 3.56 Hz (1st Bending Mode)



Freq. 8.38 Hz (2nd Bending Mode)
Freq. 17.30 Hz (3rd Torsion Mode)

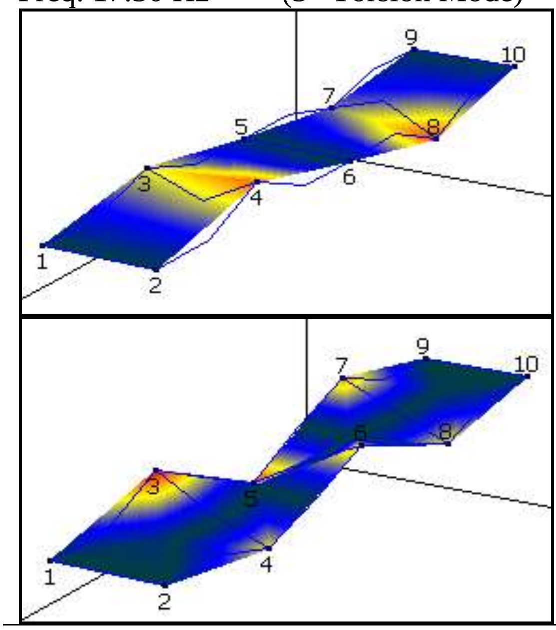


Figure 8: The Bridge detected fundamental modes

The peak acceleration responses were calculated at each measured point and plotted against its excitation train speed to study the effect of train speed one the bridge acceleration response. Figure 9 displays the relation between acceleration response and train speed at different locations of the main girder

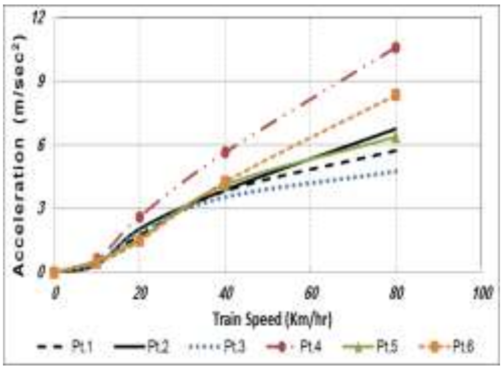


Figure 9: The relation between acceleration response and train speed

It is clear from figure 9 that all the measured points has the same trend and the acceleration response increases as the train speed increases wherever the locations of the measured point.

The deflection amplification ratio due to the dynamic effect of train speed is calculated from the relation between the deflection due to static loading case and the deflection due to dynamic loading case as following

(Dynamic Deflection – Static Deflection) / (Static Deflection)

Also, the strain amplification ratio due to the dynamic effect of train speed is calculated from the relation between the strain due to static loading case and the strain due to dynamic loading case as following

(Dynamic Strain – Static Strain) / (Static Strain)

Figure 10 displays the relation between the strain amplification ratio, the deflection amplification ratio and the train speed.

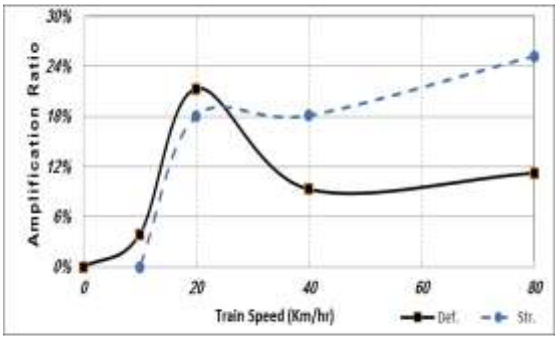


Figure 10 The relation between Amplification Ratio and train speed

It can noticed from figure 10 that the deflection amplification factor and the strain amplification factor have matching trend. Also from the above figure the DAF is ranges from (18% – 25 %) with average value equal to 22% related to strain results, while it is ranges from (9.30 % – 21.30 %) with average value equal to 15 % related to deflection results.

Also, the DAF for stringer and cross girder was calculated using strain measurements and the relation between the DAF and train speed were plotted in figure 11. The max value of DAF for stringer was 80% and almost has a constant average value equal to 73% for all train speeds. The DAF for the cross girder has a small negative values except at the higher speed (80 Km/hr) the DAF reaches to only 5%.

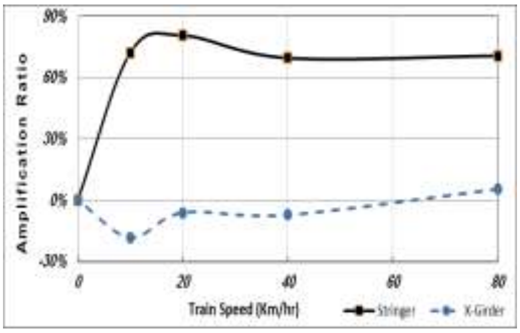


Figure 11 The Relation between Amplification Ratio and train speed

5. Numerical model

Finite Element Model for the bridge was performed using SAP2000 Nonlinear V.14 [6] using time history dynamic analysis to model the train with different velocities. The finite element model is described in the following section.

3-D finite element model, shown in Figure 12, with the real cross sections of all elements in the bridge was used to ensure the time period and the mode shapes determined from experiments. The masses of the dead load of the bridge are added to the model as a distributed mass. This model was calibrated with the dynamic properties (mode shapes and time period) obtained from the dynamic tests.

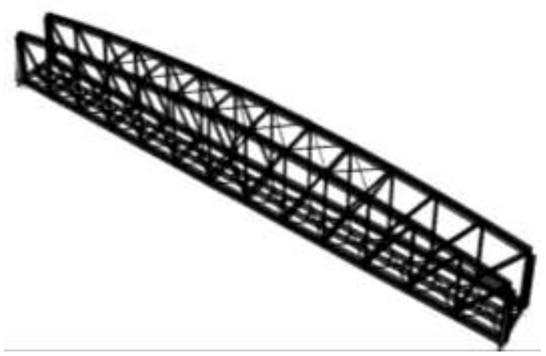


Fig. 12 The Finite Element Models of the Bridge

The dynamic properties obtained from the numerical model and the experimental test is shown in Table 1. This table shows that the results of the experimental test are matching with results of the numerical model.

Table 1: Comparison between dynamic properties

Mode	Frequency [Hz]	
	from test	from Model
1st Bending	3.56	3.10
2nd Bending	8.38	9.40

The procedure used to define the train with different velocities is applying load history in each node of the bridge [3]. For time step t_i and axle load F, a nodal load F_J (function in time) is assigned to the node J if the axle is above a frame element that contains node J.

The magnitude of F_J depends linearly on the distance from the axle to the node. F_J equals zero, when the axle is above the start node of the stringer frame element (node J-1) or above the end node (node J+1), and FJ equals the full axle load if the axle is above the mid-point of the frame element (node J). This procedure is outlined in Figure 13 for the axle load of the train. This scheme has been implemented in the finite element program.

The time step Δt is the time taken by the truck to move from node J-1 to node J. This time step was adjusted for the different velocities of the locomotive taken into consideration in the study.

The value of the axle load was taken = 130.2 t at each stringer to model the weight of the locomotives.

The results described in this paper have been obtained for the bridge for the different velocities.

Direct time integration of the significant Eigen modes was used to perform the time history dynamic analysis.

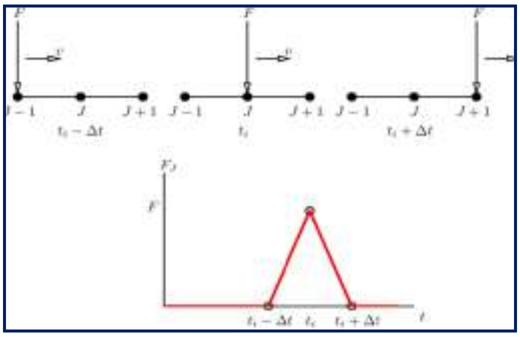


Figure 13: Nodal Force Time History Definition for an Axle Load "F" Moving at Velocity "v"

6. Numerical Model Results

The maximum axial force induced in the main girder at the middle of the bridge was obtained due to different velocities (40 Km/hr, 60 Km/hr, 90 Km/hr, and 120 K**m**/hr). The relation between the DAF calculated according to this axial force obtained from the dynamic loading case compared to that obtained from the static loading case were plotted in figure 14. The amplification ratio was calculated as following

(Dynamic force – Static force) / (Static force)

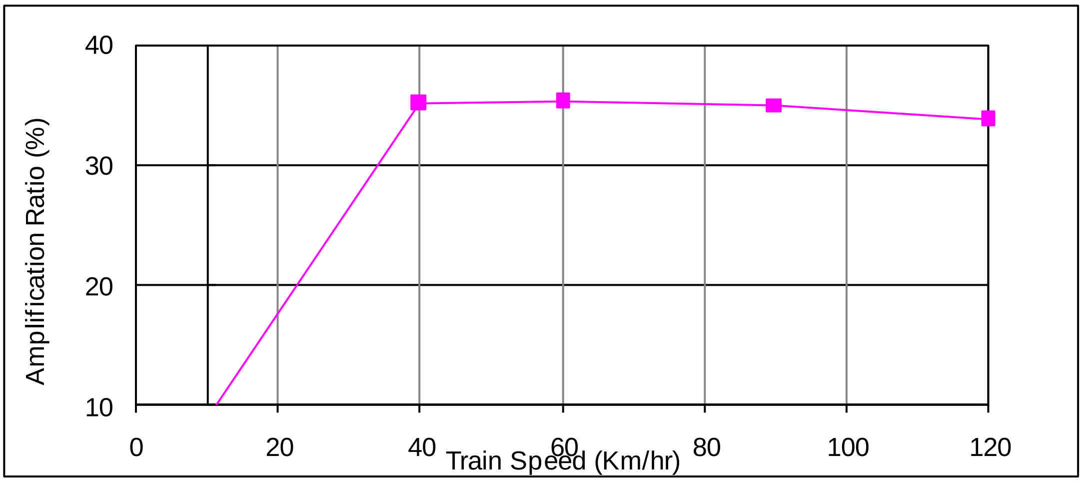


Figure 14 The relation between Amplification Ratio and train speed

It can be noticed from figure 14 that for the axial force amplification factor (which is equal to the strain amplification factor) obtained from the numerical model and the strain amplification factor obtained from the dynamic tests have matching trend. Also from the above figure the DAF is ranges from (33% – 35 %) with average value equal to 34% related to strain results.

7. Analysis of the Results

Figure 10, Figure 11 and Figure 14 show the DAF determined from the experimental work and the DAF calculated from the numerical model. The DAF was calculated according to the new Egyptian Code for Loads for the main girder, cross girder and stringer these DAF were compared with the measured one based on the dynamic strain measurements as displayed in Table 2 .

Table 2 : Comparison between the measured DAF and the Standard Calculated

Element	DAF	
	Egy. Stand.	Exper.
M.Girder	10%	22%
X.Girder	44%	5%
Stringer	30%	73%

For the main girder The DAF obtained from the experimental work and numerical model are higher than the DAF calculated from the code. For the case of cross girder the calculated value is much higher than the measured one while in case of stringer the measured value is 243% greater than the calculated one.

All the factors affect the DAF as Bridge dynamic characteristics (such as; bridge surface condition, vehicle suspension system, mass, velocity, and damping ratio) were taken into consideration when determining the DAF based on the experimental work. The results show that these factors have the major contribution in the DAF.

8. Conclusions

The results obtained from the experiments and from the numerical model were compared to DAF obtained from the Egyptian code. This comparison leads to the following conclusions:

- The DAF obtained from dynamic test has average value equal to 22% related to strain results, while it was equal to 15 % related to deflection results.
- The DAF obtained from the experimental work and numerical

model are higher than the DAF calculated from the code.

- The DAF must be studied taking into consideration all factors such as bridge dynamic characteristics, railway condition, train suspension system, mass, velocity.
- DAF formula used in the Egyptian standard which takes into consideration the bridge span only should be modified to take into consideration the other factors affecting the DAF.

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