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The Cross-Sectional Shape Effect on The Dynamic Behavior of Concrete Railway Bridge

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Abstract

The study of the structural behavior of bridges in high-speed railways, not short ago, is one of the main data references on which designers and maintenance teams rely in this field. Many studies have been conducted on this matter. Studies in recent years focused on showing the effect of some or one of the characteristics of the model to know its effect on the dynamic behavior of the structure. Most of the studies did make a comparison between different types of moving loads, or between the ballast paths and the paths free of it. This research focused on clarifying the effect of changing the cross-sectional shape of the bridge and making a comparison between the results of the dynamic analysis of two models, the first with a solid cross-section, and the second is a ribbed. The analysis was carried out using SAP2000 software. The results showed differences in the dynamic behavior parameters of the two bridge models. At MS1 the vertical acceleration and displacement values were highest in the solid cross-section with approximate values of 2.5 m/s^2 and 2.06 mm respectively, while at MS2 the higher values happened in the ribbed cross-section is 1.92 m/s^2 and 1.58 mm respectively. Conclusions were made about the effects of section change on dynamic behavior at different speeds.

Keywords:- railway bridge, track, ballast, stiffness, damping, vertical acceleration, displacement.

1- Introduction

In view of the rapid development witnessed by the field of transportation of passengers and goods through railways, and with the fact that transportation costs are high and its risks increase in other methods, it has become necessary to take the analysis of bridges into consideration with great importance. In general, it is necessary to conduct a dynamic analysis of all bridges over which trains pass at a speed of more than 200 km / h in the field of railways. Being one of the basic things on which the design of new bridges and the maintenance of existing ones depend**.** In a previous study [1] designed a train of wheel loads consisting of two subsystems with fixed periods, using an analytical approach, The researcher was able to determine the basic parameters that control the dynamic responses that they show to the beams, and through the premise of moving load. Numerical solutions were obtained using the Newmark-3 method based on the resonance condition and the exclusion condition of waves generated by the continuously moving loads on the bridge. The researcher presented

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a proposal for the ideal criteria that must be adopted to obtain a good design that is effective in preventing and suppressing resonance responses when designing a railway bridge over which trains pass at high speed. In order to obtain the optimal design of the beam, the design must include the imposition of the cancellation condition, and it has been proven that the inertial effect of moving vehicles tends to elongate the vibration period that occurs for the beam, and this causes resonance peaks to occur at smaller speeds, which are very large. decreases when damping is used. Range Relative to the length of the vehicle, no resonance response will occur on either beam, Where the first ring was cancelled.

A research paper [2] presented a study aiming at increasing the accuracy of the approved safety assessments for the panels of concrete surfaces to avoid increasing the cost required for the retrofitting of existing bridges. The study presented by the researcher was about five types of vehicle bridges, and three of the actual effects were taken into account. That study was conducted on bridges over which vehicles pass, not railway bridges. However, the researcher presented valuable results and facts regarding the dynamic behavior of bridges with concrete deck and their response that is worth paying attention to. The researcher used the finite element method to conduct the dynamic analysis of the models of bridges affected by the passage of vehicles on them. The parameters that affect and have importance in the interaction of the vehicle and the bridge were taken into account. The enthusiasm for the car appeared due to the presence of irregularities in the upper surface of the road, which resulted from the use of the power spectral density function. The type of cross-section of the bridge did not show a significant effect on the behavior of the deck of the bridge.

Lena Björklund [3] investigated a bridge on Swedish railways for the dynamic behavior of high-speed trains. The evaluation was done using a finite element modeling program (LUSAS). The speed at which the train crosses the bridge is constant and the forces of the moving axles are represented through it. The main concern was to make a comparison between different models of bridges. The effect shown by different parameters in the bridge was also studied, as the design of the bridge was optimal due to the passage of trains at high speed. The results showed that the speed of the trains is a very important parameter, as it affects the dynamic response shown by the bridge, which generally increases when the speed increases until it reaches its peak at speeds between 250 km/h and 300 km/h. The amount and shape of the dynamic response varies according to the model that represents the bridge. The highest damping coefficient gives lower values in the response of the overall structure of the bridge. The stiffness parameter in the bridge is also important, and the peak resonance values are at high speed when the stiffness is large. It has been shown that the mass of a bridge significantly affects its dynamic response. The value is lower for the peak of the vertical acceleration as the density increases. However, they do give peak values at the speed of lower velocities.

The researcher [4] presented in a study the results that obtained from analyzing the dynamic behavior of two steel bridges that the KTX train passes at high speed on them and located in Korea. Those results were compared with the requirements and specifications and with the dynamic responses of a bridge consisting of typical prestressed concrete box beams. The experiments were conducted on bridges with two spans of steel, each containing two girders. The length of the girder in the first was 40m, and the length of the girder in the second was 50m. The prestressed box girder bridge was 40m long. The researcher carried out several tests experimentally when operating the KTX, and a number of measures were used to measure the dynamic responses in acceleration, angle of rotation, and deviation. The

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results showed that the measured responses to the deviations in the vertical direction and the angles of rotation of the three bridge models that were all tested met the requirements of the specifications in a large way, but it was noted that the acceleration responses were very close to the value of the limit or exceeded it. Most of the responses to excessive acceleration occur when the train passes at a speed close to the critical speed, and this leads to an echo. No significant differences appeared in the dynamic responses of the bridges due to the difference in the structural material of the bridge (steel, concrete) in light of these experimental results.

In the study[**5**], the researcher made measurements of the dynamic aspects of two models of railway bridges at a speed of 350 km/h by using sap2000, the first represents part of the structure length of the Evon Bridge, which is a bridge composed of steel, and the second represents the values obtained from the Yonjaye Bridge, which is a bridge of pre-stressed beam. This bridge is located along the stretch of the Gyeongpo High-Speed Railway. The researcher compared the obtained results with standard values of dynamic performance specified in Eurocode and in Korean high-speed railways. In order to determine the dynamic performance of the bridge models that he tested, he measured and analyzed each of the elements of maximum acceleration in the vertical direction and maximum displacement in the same direction. Most of the measurements were within the permissible values. However, some results of vertical acceleration on Yonjai Bridge were somewhat greater than the regular value. Through the results of dynamic analysis, the steel composite bridge showed higher displacement values when compared with the values shown by the prestressed girder bridge, as well as the rotation angles. However, the results of the acceleration response showed lower values than the second type. The difference in the material constituting the bridge did not lead to differences in the characteristics of the bridges in terms of dynamics.

For the purpose of verifying the vibration that occurs in simple support beams passing the train at high speed. In this research, an analysis was made of the dynamic behavior of two continuous with two-span models of concrete bridges with the same characteristics, the difference between them is in the shape of the cross-section, the first will be a rectangular cross-section, while the other will be a ribbed. The aim is to find out the effect of changing the cross-section of the bridge on its dynamic behavior.

2- Methodology of the study

This research follows an approach that includes the design of two models that represent the bridge with two different sections, and its components will be simulated through these two models. SAP2000 program is used to analyze the dynamic behavior of the models. This program depends on the finite element method. Through the results that will appear, the dynamic response of the two models will be discussed and compared. with drawing conclusions.

3- Study aim

This analytical study aims to compare between the results of the dynamic analysis of the bridge designed with its two models (solid and ribbed). For the purpose of knowing the effect caused by changing the shape of the cross-section of the bridge on its dynamic behavior, and because the difference in the cross-section results in a difference in the cost and complexity of constructing the bridges, the results and conclusions that will be presented will be very useful in the field of designing and constructing railway lines.

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4-Tested Bridges

4.1- General description

Two models are utilized in this study to simulate two different cross-sectional railroad bridges. Rectangular in the first cross-section and polygonal in the second. The two bridges are connected by two spans that total 28.8 meters in length and 15 meters in width Fig (1). As closely as feasible to an actual bridge, the two bridges depict a hypothetical state. The goal is to look into how modifying the bridge section affects its dynamic behavior.

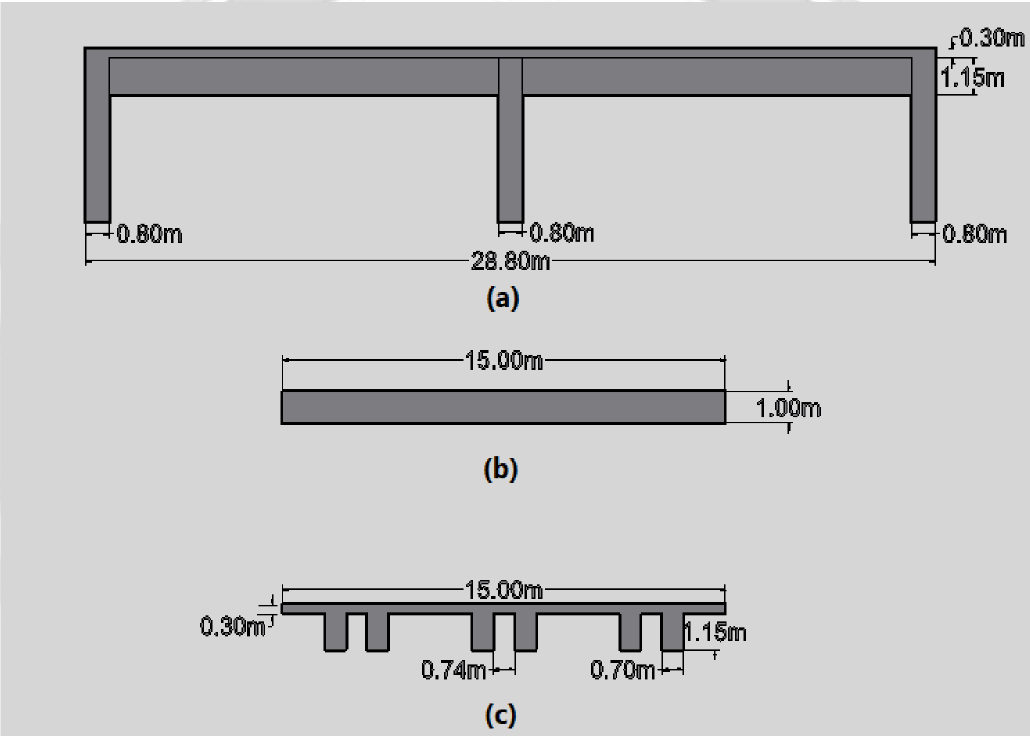

Fig (1) the bridges cross-sections: (a)side view of ribbed slab bridge, (b)rectangular section, (c)ribbed slab section

4.2- Stability conditions

To simulate the actual boundary conditions around the bridges, the two external supporting walls will be restrained with restraint joints that prevent the motion of the bridges in the x direction, also the base of the three supporting walls of the bridge will be restrained to prevent the displacement of the walls in the three directions.

4.3-Study of mesh

For the purpose of representing the bridge in the structural analysis program, which depends mainly on the finite element theory, it is necessary to find the appropriate dimensions that divide the structural parts of the bridge in the model that it represents. Several sizes of the divisions of the parts of the model were studied, starting the test from the ultra-coarse size, followed by the coarse size, then the fine, and finally the ultra-fine, the test was done on one space to make the test easy, the divisions were in the first try is 9 towards axis 1 and 9 towards axis 2, the second attempt It had 18 sections towards axis 1 and 18 sections towards axis 2, In the third try, 36 sections towards axis 1 and 36 of them towards axis 2, Fig (2) shows the vertical position of the bridge, divided into the divisions that have been tested . Finally, to get acceptable results from the bridge model's structural analysis, it is

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found that the model which will represent the bridge for the purpose of testing in both static and moving loads requires a specific division of the components of the bridge, the reason is that the elements that make up the bridge and the track are universally known dimensions and sizes, and at a fixed parameters and cannot be changed in their sizes to make them apply to the square-shaped subdivisions, and for this purpose And as required by the finite element method used to analyze the models, subdivisions with special dimensions that suit the analysis-program requirements and the characteristics of the components of the bridge and paths will be used, consisting of 72 divisions towards axis 1 and 24 divisions towards axis 2, as shown in Fig (2)-(d).

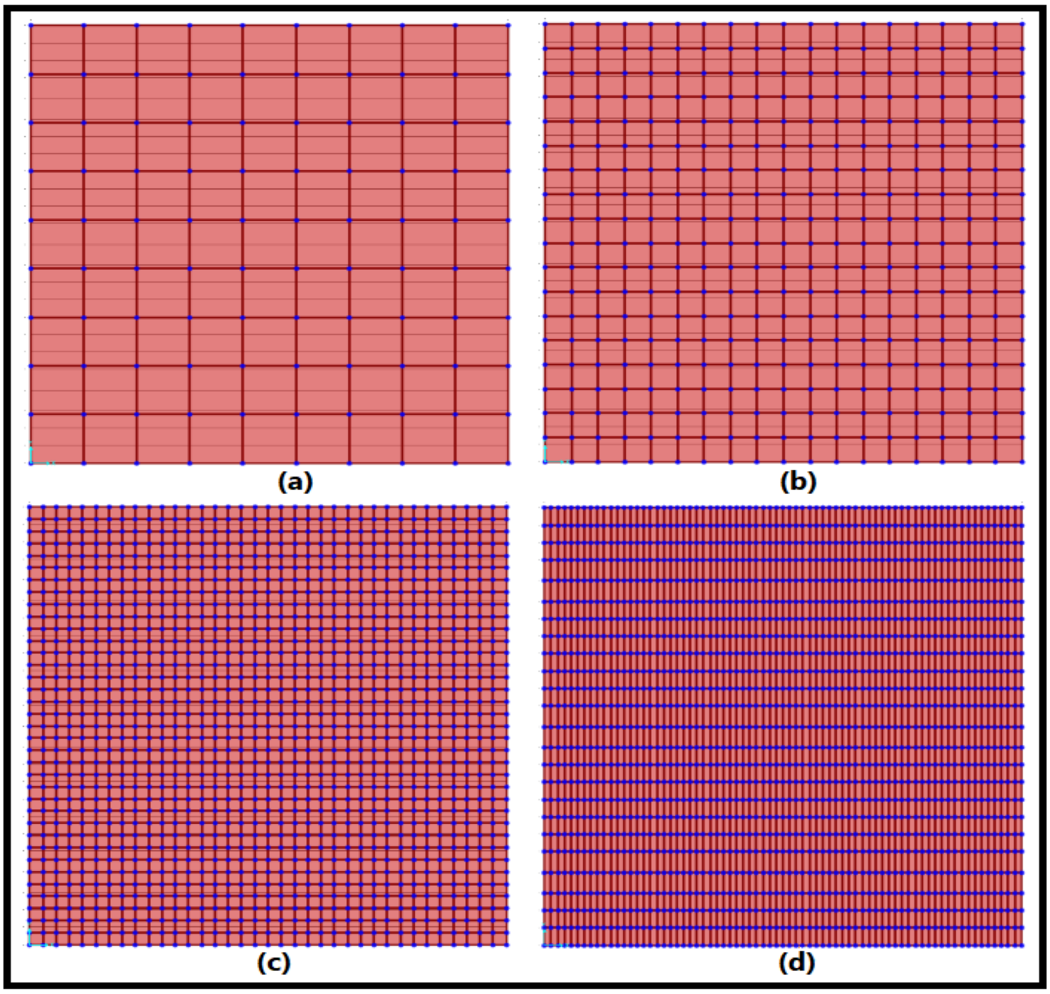

Fig (2) Tested four divisions of meshes, (a) first mesh, (b) second mesh, (c) third mesh, (d) fourth mesh

The values of the most important parameter were measured in the static state of the bridge, which is the maximum vertical displacement, through the results a chart was drawn that representing the relationship between the number of subdivisions and the maximum vertical displacement values, as shown in Fig (3).

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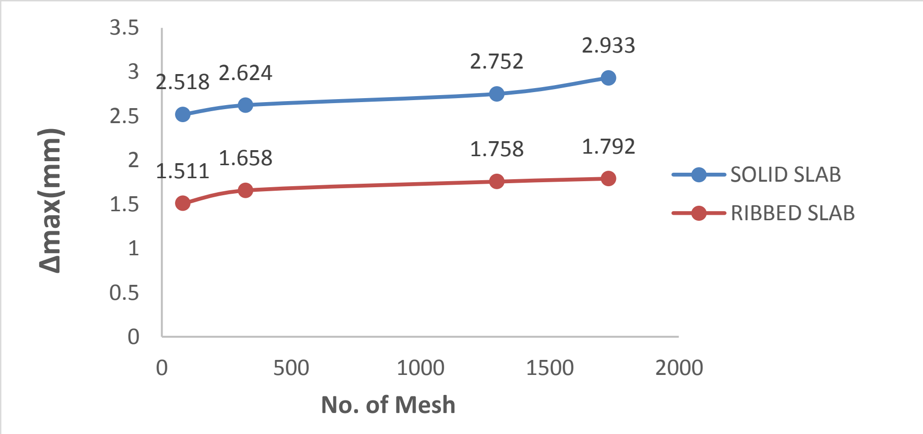

Fig (3) Results of testing different meshes

It is clear that the chart shows that increasing the fineness in the divisions gives higher and more accurate values. For this reason, the divisions shown in Fig (2)-(d) will be used.

5- Typical train loads

In this study the locomotive model is used defined within the American specifications for railways (AREMA) and shown in [6, Fig .4] The loads represent the full load of each axle (two wheels), and the loads are distributed on the two tracks rails, the spacing between two parallel rails is 1.44 m.

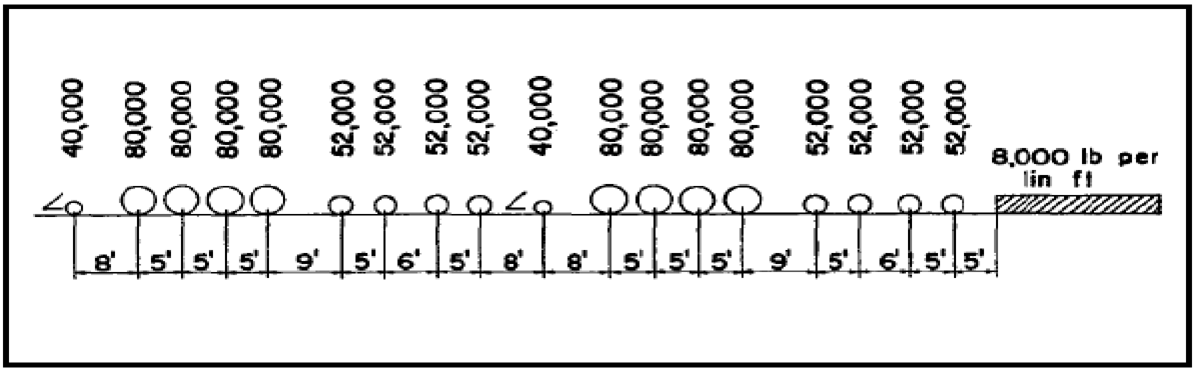

Fig (4) Cooper's E80 standard train loads [6].

6- Modeling for analysis

In this study a model is required to simulate the dynamic behavior of a bridge In two different shapes of the cross-section, the first model is with solid cross-section and the second model with ribbed cross-section.in previous studies. The two models design are differently, with analytical models with different characteristics [7], the mechanical properties were taken and represented in the program using program tools that simulate the characteristics of the track very closely in order to obtain acceptable results. The rails according to the characteristics of type UIC60 are represented by a Tymoshenko-beam element [8], with properties known worldwide and widely used in previous research. In previous studies, the dynamic response of the sleepers under the rails has been analyzed in several ways [9]. In this study, the theory was applied, which in studies provided logical results in previous studies [10], which is (Euler-Bernoulli beam) for the purpose of representing sleepers, and it was used for it ɣ = 25 kN / m3, E = 36000 MPa [11], The poison's ratios were used according to the values used in previous research, without taking their maximum values because it does not represent the typical state of the railway track, as shown in Table (1). The characteristics

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of the ballast layer were represented using a system of spring-damper with widely used properties obtained from previous practical and laboratory experiments shown in Table (2).

Table (1) the rail, sleeper, and ballast boisson's ratio [12]

Property	Rail	Sleeper	Ballast
Poisson's ratio	0.3	0.2	0.25

Table (2) certain track parameters [13]

Parameters		Value
Rail pad and fastener	Stiffness coefficient/(MN/m)	78
	Damping coefficient/(KN s/m)	50
Sleeper	Sleeper interval/(m)	0.60
	Mass/(Kg)	250
	Length/(m)	2.6
	Width/(m)	0.25
	Height/(m)	0.20
Ballast	Stiffness coefficient/(MN/m)	180
	Damping coefficient/(KN s/m)	60

A group of researchers such as Wanming ZHAI and Xiang SUN [14] used the model shown in Fig (5) with coefficients of stiffness and damping between the elements that represent the ballast with each other with the same values which were used for them in the location of their contact with the sleepers and with the deck of the bridge, in this study the same model was used without, but with using different values for the damping coefficient and the shear coefficient Table (3) at points of contact of the ballast particles with each other, because the shear forces between the ballast particles were taken into account and for the ease of analysis [15].

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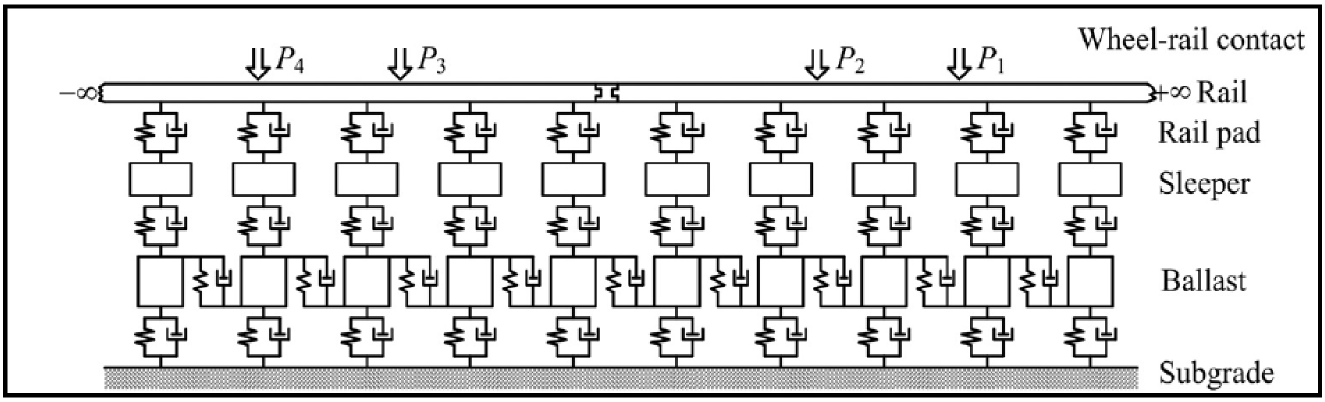

Fig (5) shows the stiffness and damping of the contact between the subgrade, the ballast particles, and the sleepers.

Table (3) the ballast particles' shear coefficients

Parameter	**Value**
Shear stiffness of ballast ($N.m^{-1}$)	7.84×10^7
Shear damping of ballast ($N.s.m^{-1}$)	8.0×10^4

7- Dynamic analysis of the modeled bridges

The dynamic behavior of the designed models was tested. Three speeds were used: 150km/h, 200km/h, and 250 km/h, and two points were chosen to follow up the response of the bridge models.The first at the mid of the first span MS1, the other at the mid of the second span MS2, a critical case of loading for a bridge with three tracks from AREMA will be used.The values of two main parameters were extracted in the dynamic behavior of the two specified points. The two parameters were the vertical displacement, the other was the vertical acceleration. The time history test was conducted for five seconds and $\Delta t = 0.5$, the results of the vertical displacement are shown in Figs (6-8).

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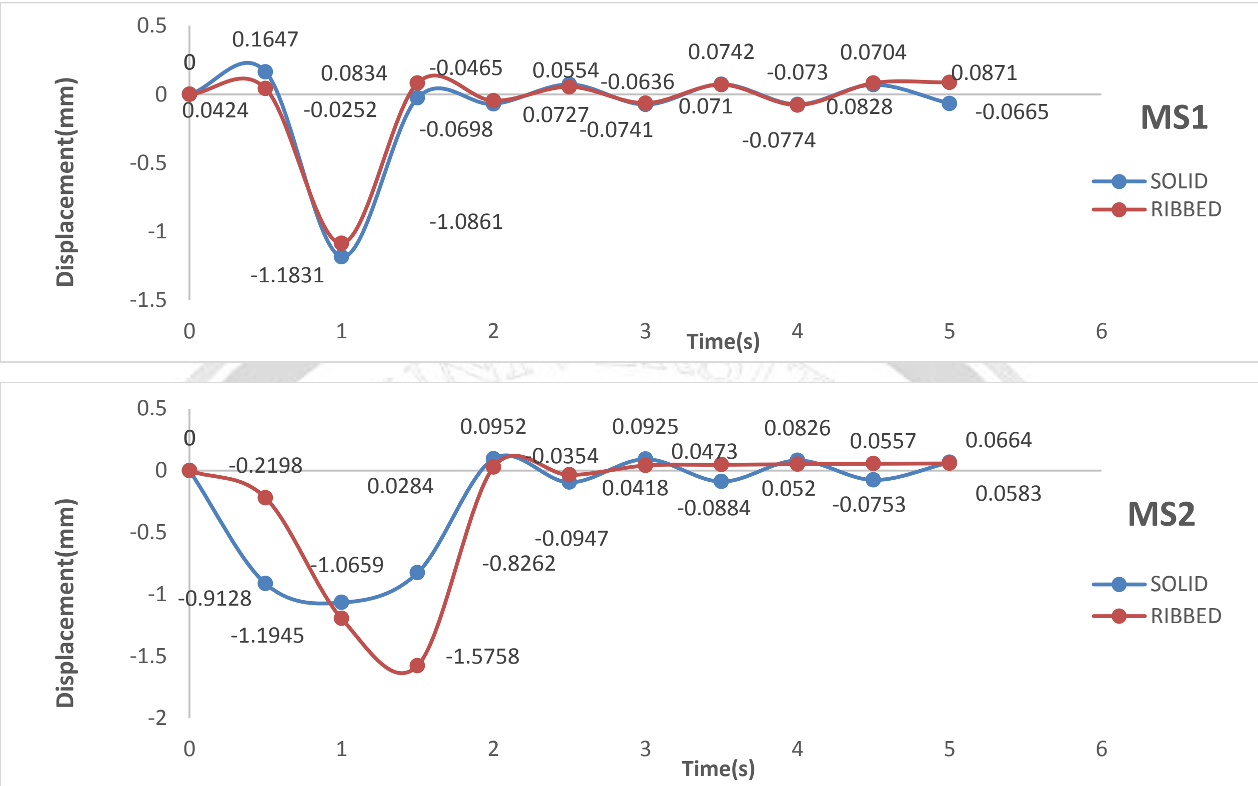

Fig (6) Displacement time history at speed=150 km/h for solid and ribbed slab at MS1 and MS2

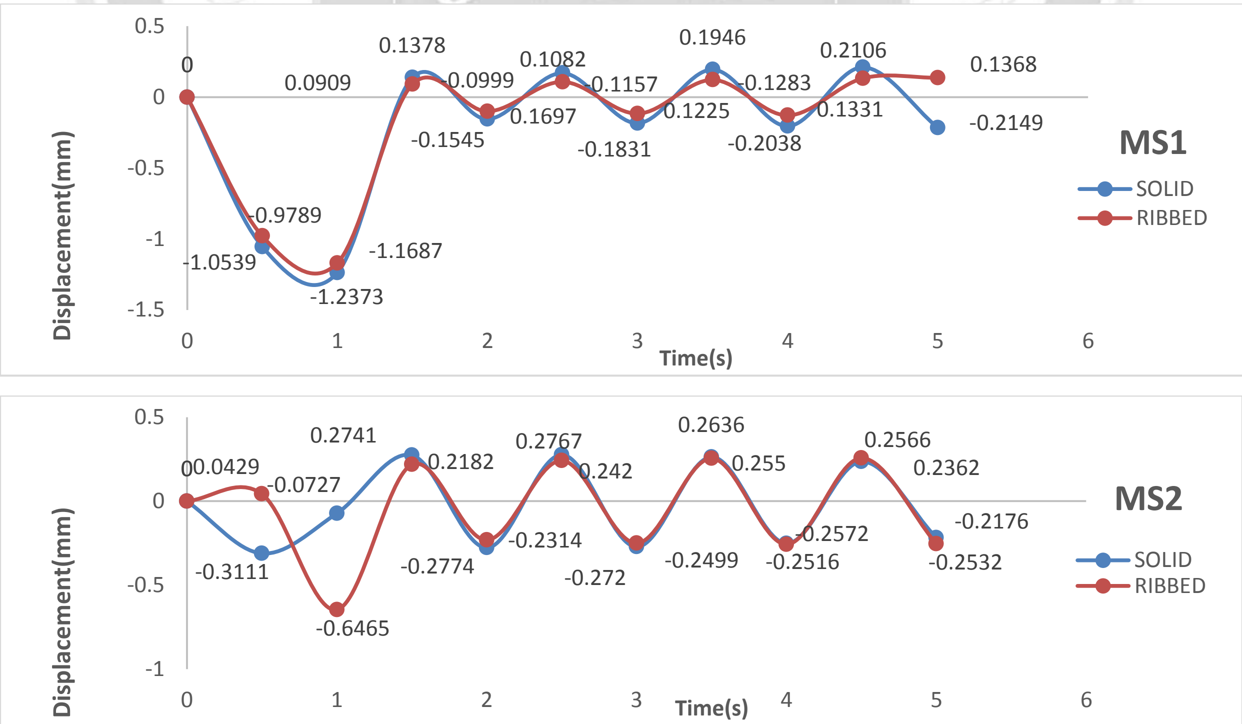

Fig (7) Displacement time history at speed=200 km/h for solid and ribbed slab at MS1 and MS2

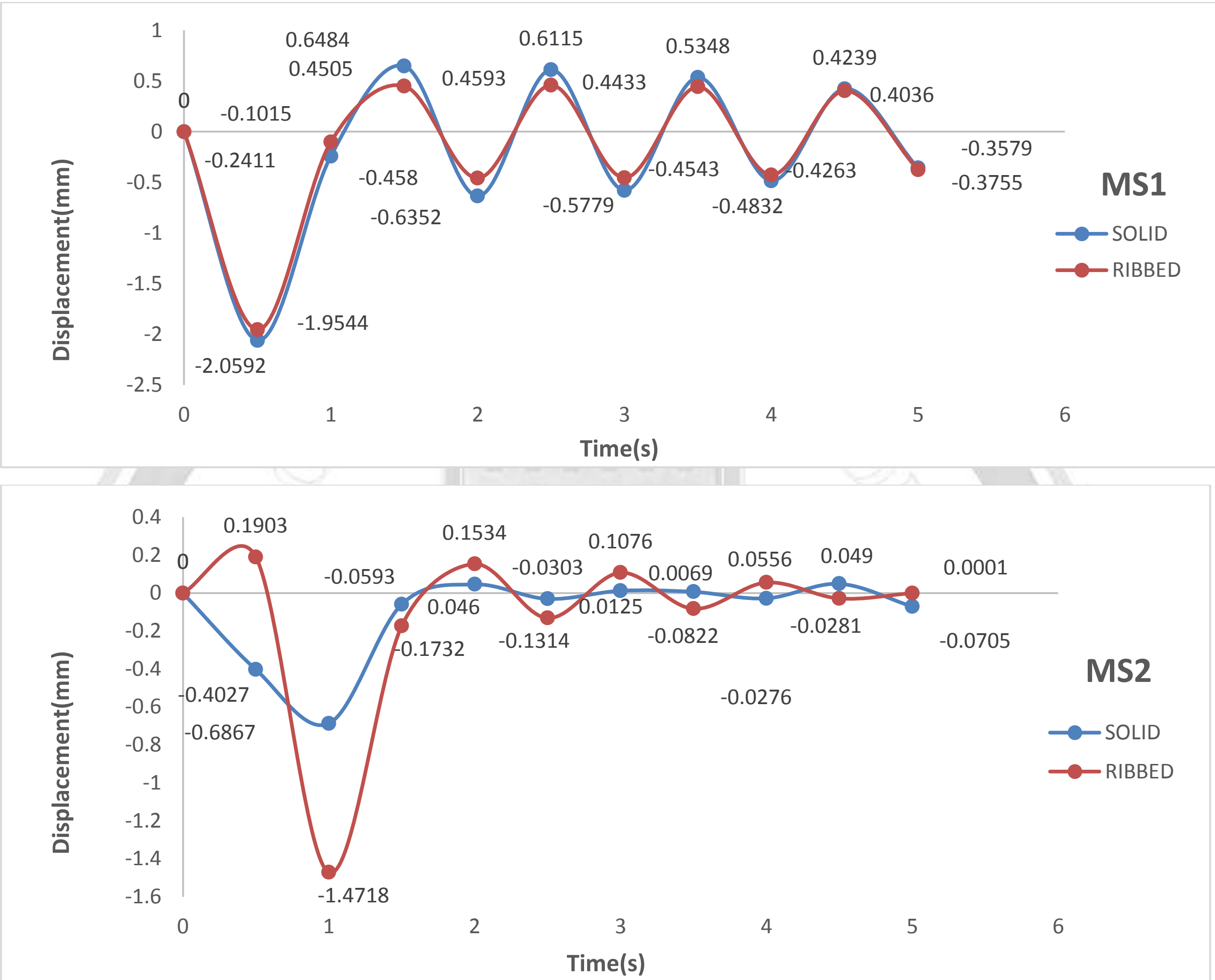

Fig (8) Displacement time history at speed=250 km/h for solid and ribbed slab at MS1 and MS2

From the figures above (6-8) it is clear that the solid section gives displacement values higher than of the ribbed section at MS1, this is because the point receives the load of two trains at an earlier time than MS2, and the effect of the impact load affects the section whose mass is greater in a greater way, resulting in a greater displacement of the heavier section. The greater displacement between the two segments alternately is not fixed, affected by exclamation in the case of free vibration, which is inversely proportional to the mass.

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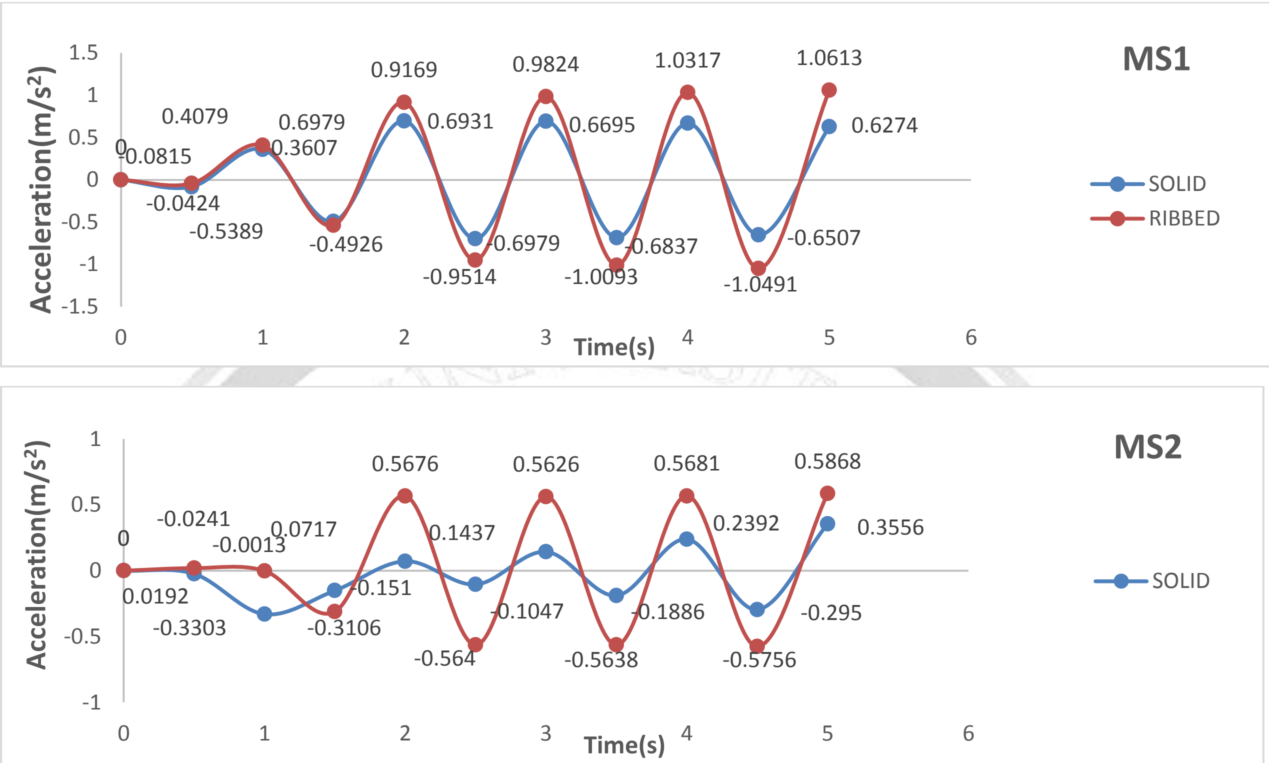

Fig (9) Acceleration time history at speed=150 km/h for solid and ribbed slab at MS1 and MS2

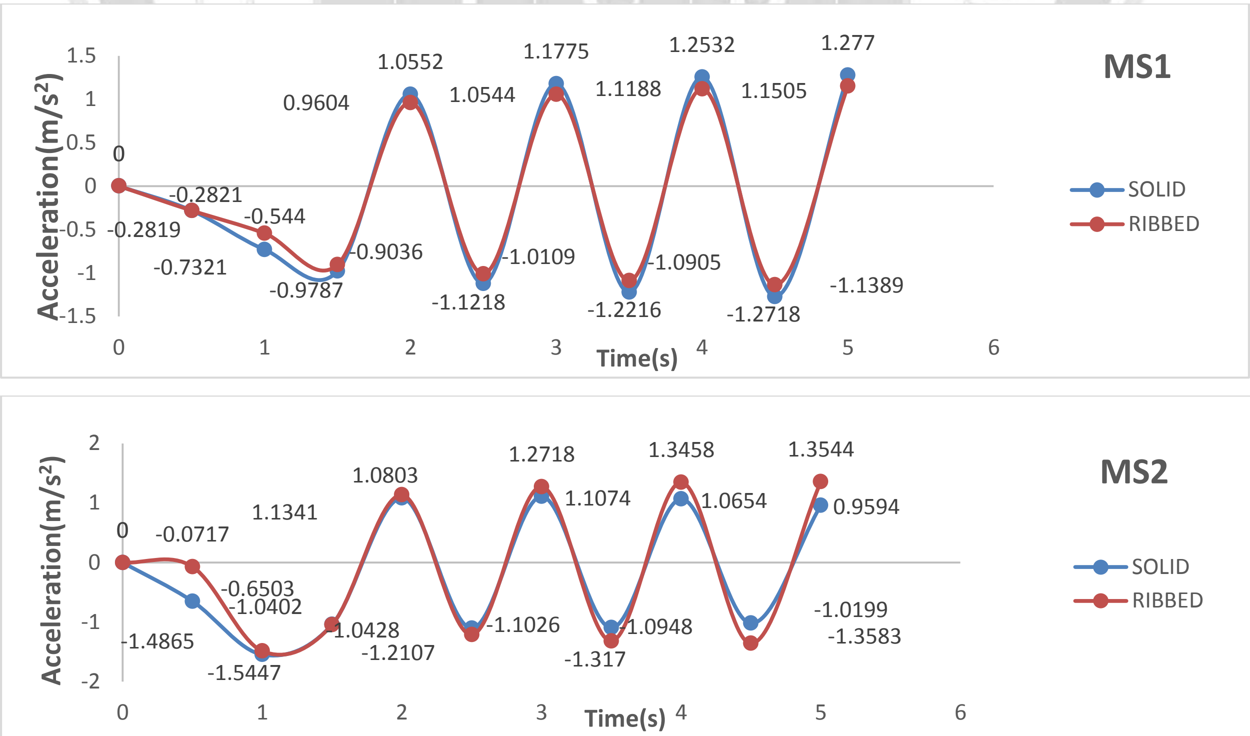

Fig (10) Acceleration time history at speed=200 km/h for solid and ribbed slab at MS1 and MS2

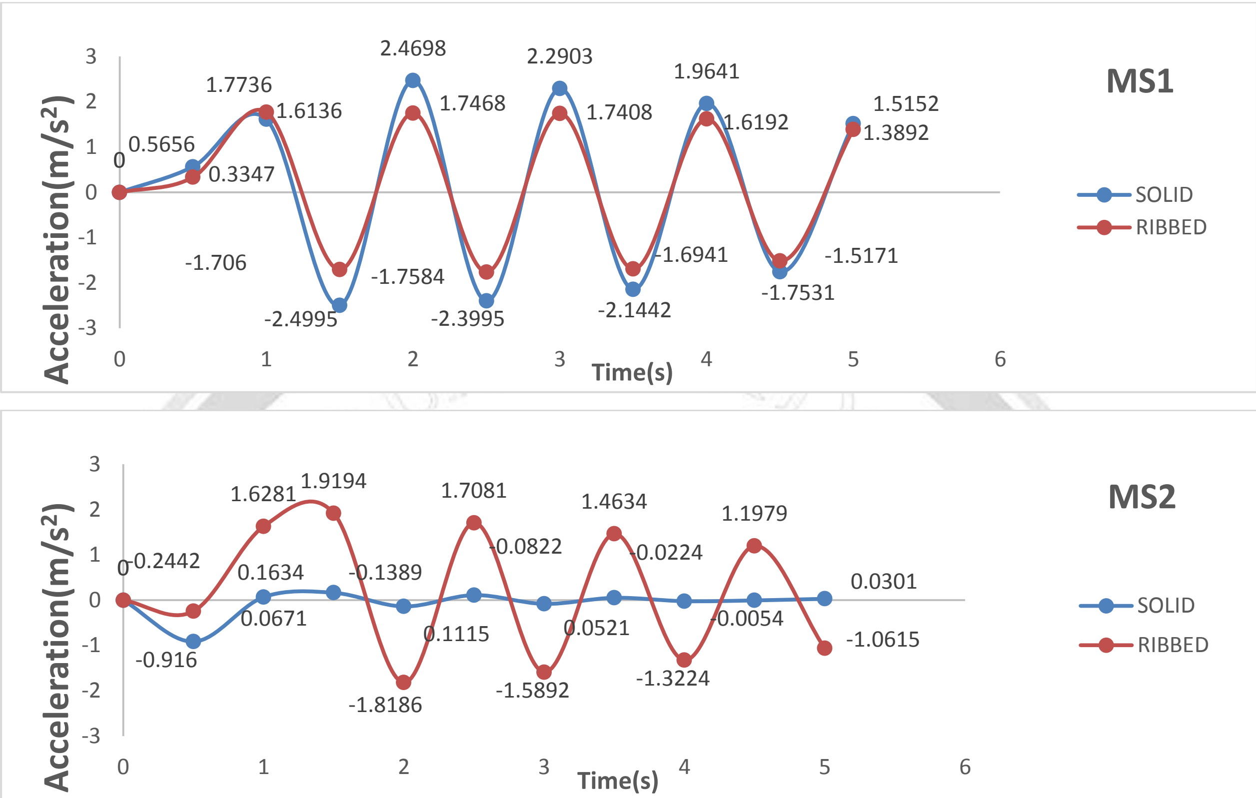

Fig (11) Acceleration time history at speed=250 km/h for solid and ribbed slab at MS1 and MS2

Charts (9-11) above show the results of the dynamic analysis of the two specified points at different speeds. From the speed charts of 150 km/h and 250 km/h, it was found that point MS1 gave close values for the two cross-sections during the passage of the moving load due to its impact that causes the reduced in vibration and reduces the effect of mass, and gradually we notice an increase in the acceleration values of the ribbed section because it is less mass due to the realization of the free vibration state that governs the vibrational movement. The state of free vibration in which the model with a lower mass gives a greater acceleration.

As for the speed of 200 km / h, it showed a great convergence in the values of vertical acceleration in both cross-sections, and this depends on the natural frequency of the bridge with its two different cross-sections and the extent to which the value of this frequency matches the values of the frequency resulting from the speed of the moving load, which makes the vibration regular.

For the purpose of comparing the vertical displacement and vertical acceleration values shown by the dynamic behavior analysis of the two cross-sections, the diagrams were drawn Fig (12-13).

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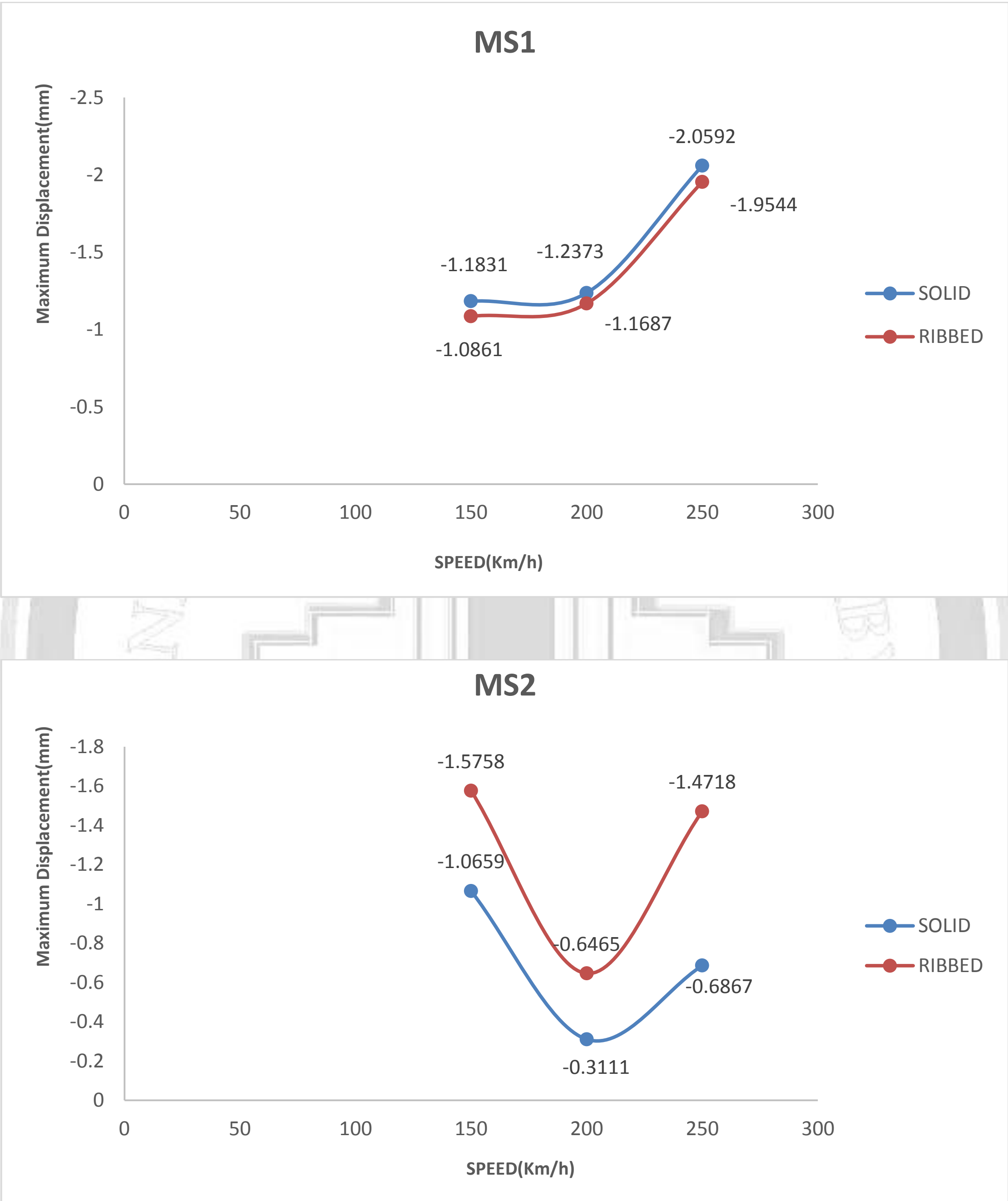

Fig (12) Maximum vertical displacement at different train speed

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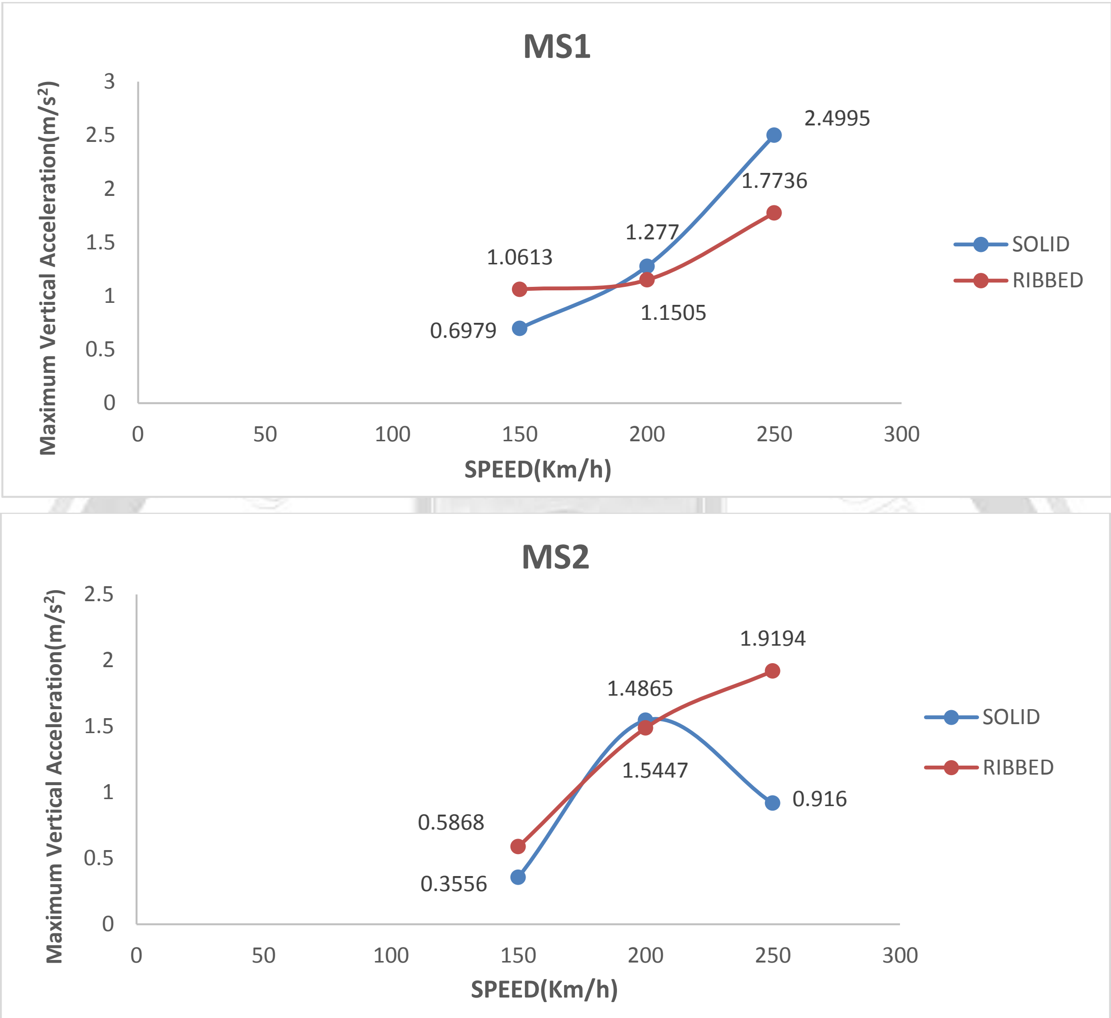

Fig (13) Maximum vertical acceleration at different train speed

In point, MS1, the above diagrams showed that both cross-sections had the largest vertical displacement and the largest vertical acceleration at a speed of 250 km/h, and that the dynamic response of the bridge increases with increasing speed in both cross-sections. The values of the two parameters were higher in the solid cross-section by a small difference.

Point MS2 showed lower values of vertical displacement at a speed of 200 km/h, and that the values of vertical acceleration and displacement were higher in the ribbed cross-section with a large difference in the vertical displacement and less difference in vertical acceleration between the two cross-sections.

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8- Conclusions

The aim of this study was to show the effect of changing the cross-section of the bridge structure. Through the results of the analysis of the dynamic behavior of the bridge with its two cross-sections, which were shown in the drawings that were drawn, some conclusions can be identified as follows:

- In both models, the vertical acceleration values were acceptable and within the internationally permitted limits for tracks with ballast, not more than 3.5 g. Likewise for vertical displacement.
- Within the speeds that were used to test the models, the values of vertical displacement and vertical acceleration were increasing with increasing train speed.
- The difference in begin loading times between MS1 and MS2 sites leads to a difference in their dynamic behavior, so that we see the maximum values of the vertical acceleration and displacement occurs in MS1for the solid cross-section(heaviest), while in the natural conditions of loading when the loading stability occur the highest values occur in the(lightest) cross-section.
- The solid cross-section gives greater vertical displacement values than the ribbed cross-section, in the case of vibration in the presence of force and in the case of free vibration.
- The vertical acceleration values are lower in the solid cross-section at all speeds that were used in the MS2 site, as well as at a speed of 150 km/h in the MS1 site.
- At high speeds, it is preferable to use a solid cross-section for the bridge, in order to avoid fatigue failure due to repeated vibrational stresses, and also for more comfortable to the passengers.

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تأثير شكل المقطع العرضي على السلوك الديناميكي لجسر سكك حديد خرساني

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الخلاصة

تعتبر دراسة السلوك الإنشائي لجسور السكك الحديدية عالية السرعة، منذ وقت ليس ببعيد، أحد مراجع البيانات الرئيسية التي يعتمد عليها المصممون وفرق الصيانة في هذا المجال. وقد أجريت العديد من الدراسات حول هذا الموضوع. ركزت الدراسات في السنوات الأخيرة على إظهار تأثير بعض خصائص النموذج لمعرفة تأثيرها على السلوك الديناميكي للمنشأ. لقد قامت معظم الدراسات بإجراء مقارنة بين أنواع الأحمال المتحركة المختلفة، أو بين مسارات الصابورة والمسارات الخالية منها. ركز هذا البحث على توضيح تأثير تغيير شكل المقطع العرضي للجسر وإجراء مقارنة بين نتائج التحليل الديناميكي لنموذجين الأول ذو مقطع عرضي مصمت والثاني مضلع. تم إجراء التحليل باستخدام برنامج SAP2000. أظهرت النتائج وجود اختلافات في معايير السلوك الديناميكي لنموذجي الجسر. في MS1 كانت قيم التسارع والإزاحة العمودية أعلى في المقطع العرضي المصمت بقيم تقريبية تبلغ ٢.٥ م/ث٢ و٢.٠٦ مم على التوالي، بينما في MS2 كانت القيم الأعلى في المقطع العرضي المضلع هي ١.٩٢ م/ث٢ و١.٥٨ مم على التوالى. تم التوصل إلى استنتاجات حول تأثيرات تغيير القسم على السلوك الديناميكي بسرعات مختلفة.

الكلمات الدالة: جسر السكك الحديدية، المسار، الصابورة، الجساءة، الاخماد، التسارع الرأسي، الازاحة.