International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 10, October-2018

Study of SSI & Resonance effect on Bridge Structure under Moving Load

Kashmira Ajay Puranik[1] ,
Civil Engineering Department
SYCET
Aurangabad, India

***Abstract*— The analysis of dynamic behavior of bridge structures that are subjected to moving loads has been one of the research interests in recent years. Specifically in railway bridges, Resonance occurs when the load frequency is equal to a multiple of natural frequency of the structure. Resonance vibrations have been observed in railway bridges especially subjected to High Speed Lines. They are caused mainly because of two reasons one is the repeated application of axle loads and second is the speed of the train itself. When a bridge is subjected to the moving loads of a high speed train, the dynamic response of the structure is influenced by the soil lying beneath the foundations and surrounding the bridge.**

The main objective of this study is to analyze the dynamic response of railway bridges and the underlying soil under train traffic. This is achieved by modeling a 3D Vehicle-track-bridge-soil- interaction model and analyzing this model for moving loads using SAP2000 Software. The response of the soil medium lying beneath & around the source is observed by Boundary Element Analysis Method. Two types of soil conditions were examined infinitely stiff soil and stiff soil. The results are shown at the culmination of this work.

Two methods are considered for the analysis of dynamic response of railway bridges Moving load Problem and FE-BE method. In moving load problem, the bridge is considered as a simply supported single span beam. Row of forces having constant value travelling at a constant speed are applied in the beam. Only the structural components of the bridge are modelled in this method. Validation of three problems is given in chapter .

The other method is Finite element – Boundary element method, in which not only the bridge but the supports and the soil beneath and around the bridge is also examined. A 3-dimension soil structure interaction model is prepared. Vehicle is considered as a multi-body vehicle. The problem is studied for two types of soil namely, infinitely stiff and stiff soil. Analysis and results are then compared with the referred problems.

Keywords: Dynamic behaviour, High-speed railway bridges, moving loads, Resonance, Tuned mass dampers, Vibration control

I INTRODUCTION

Nowadays, in modern societies, the need to move people and goods is growing fast, both in number of transactions and in traveled distance. Therefore, transport infrastructures are being built all over the world, to cope with the market claim. The railways have been used for many decades to assure the conveyance of people and goods. With the launch of the high-speed trains (HST), this way of transportation became even more useful. [1]

In railway bridges, resonance occurs when the load frequency is equal to a multiple of the natural frequency of the structure. In short span bridges, the actual train operating speed can be close to resonance velocities. In that case, the high level vibrations reached in the resonance regime can lead to safety, passenger comfort and train stability problems. Therefore, the dynamic behavior of railway bridges is an important design issue. [2]

When a bridge is subjected to the loads of a high-speed train, the dynamic response of the structure is, obviously, influenced by the soil beneath the foundations and surrounding the supports. The magnitude of that influence is going to be studied, namely from the analysis of the variations obtained for the Eigen frequencies, displacements and accelerations. Greater attention will be given to the effect that changes in the vertical support stiffness have on the dynamic behavior of structures subjected to loads travelling at a speed that induces the resonant response. [3]

The effect of soil structure interaction is recognized to be important and cannot be in general be neglected. Even the seismic design provisions applicable to everyday building structures permit a significant reduction of equivalent static lateral load compared to that applicable for the fixed base structure. For the design of critical facilities, especially nuclear power plants, very complex analysis is required which are based on recent research result, some of which have not been fully evaluated. This has led to situation where the analysis of soil structure interaction has become a highly controversial matter.

In general however the structure will interact with the surrounding soil. It is not permissible to analyze only the structure. It must also be considered that in many important cases such as earthquake excitation the loading is applied to the soil region around the structure. This means that the former has to be modeled anyway. The soil is semi- infinite medium, an unbounded domain. For static loading, a fictitious boundary at a sufficient distance from the structure, where the response expected to have died out from practical point of view, can be introduced. This leads to finite domain for the soil which can be modeled similar to the structure. However for the dynamic lading this procedure cannot be used. This fictitious boundary would reflect wave originating from the vibrating structure back into the discredited soil region instated of letting them pass through and propagate toward infinity. This need to model the unbounded foundation medium properly distinguishes soil dynamics from structural dynamics. [4]

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1.2 Aim

To study Dynamic Soil-Structure Interaction for near field and far field soil medium considering the resonance effect on railway bridge structure. Analysis of the structure in time domain and performing the parametric study using SAP2000 software is to be performed.

The process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil is termed as soil-structure interaction (SSI). Soil-structure interaction has been described as the group of phenomena including the dynamic behavior of structures while interacting with the soil, induced by the application of loads in the system. In simple words it is a phenomenon involving the analysis of the relationship between the structure and the soil. Dynamics is concerned with the study of forces and motions which are time dependant. For dynamic loading the fictitious boundary would reflect waves originating from the vibrating structure back into discretized soil.

SSI will add two causes to the structure namely inertial interaction and kinematic interaction.Inertia developed in the structure due to its own vibrations. The mass of the super-structure transmits the inertial force to the soil causing further deformation in the soil, which is termed as inertial interaction. An Embedded Foundation into soil does not follow the free field motion this instability of the foundation to match the free field motion causes the kinematic interaction. SSI will induce some adverse effects in to the structure. SSI alters the natural frequency of the Structure; also add damping and some travelling wave effects. [9]

III RECENT DEVELOPMENTS

The railways have been used for many decades to assure the conveyance of people and goods. With the launch of the high-speed trains (HST), this way of transportation became even more useful. From the early 1980's, when the Paris-Lyon railway was built, with a total distance of 410 km, the high-speed railway (HSR) have grown and spread to all over the world.

With the appearance of the TransRapid05, in 1979, a new type of HST was born, the Magnetic Levitation Train or Maglev. The first commercial Maglev was opened in1984 in Birmingham, covering 600 meters between its airport and rail hub, but was eventually closed in 1995 due to technical problems. At the time of this dissertation, the only operating high-speed maglev line of note is the Initial Operating Segment(IOS) demonstration line of Shanghai, that transports people through 30 km to the airport in just 7 minutes 20 seconds, achieving a top velocity of 431 km/h and averaging 250 km/h.

The oriental civilizations have always been in the front edge of the HSRs. In Japan, the Maglev experimental trains have achieved, in 2003, 581 km/h, but the high cost of its tracks makes it unprofitable for conventional passenger lines. While engineers are trying to lower the expenses involved with Maglev trains, the Shinkansen spreads its tracks around Japan. Since the initial Shinkansen opened in 1964 running at 210 km/h, the network (2,459 km) has expanded to link most major cities with running speeds of up to 300 km/h, in an earthquake and typhoon prone environment.

Fig 1.1 The Japanese HST: Shinkansen

Despite not being in the front edge, countries like Sweden and Portugal are now starting to implement HSR networks. The Bothnia Line, the new Swedish railway from Nyland, north of Sundsvall, to Umeå, will provide a direct rail link for the first time between Sundsvall, Örnsköldsvik and Umeå, serving about 350,000 people. It will also double the rail capacity between central and northern Sweden. This HSR consists of 190 km of railway with 150 bridges and 30 km of tunnels and it is designed for operation by 120 km/h freight trains and 250 km/h passenger trains, making this Sweden's first line capable of this speed. The line will be single track with 22 two or three-track, 1 km long, passing loops.

All these networks will need a large number of bridges and viaducts. In the case of trains running at high-speed, the risk of resonance in the structures is larger than classical trains, and assessment of vibration problems in the high-speed railway bridge is required during its design, to guarantee the safety of the crossing train, which is subordinated to strict crossing conditions. Therefore, performing dynamic analysis that investigates resonance of the bridge induced by the bridge train interaction constitutes an essential element of the design. [1]

IV ANALYSIS

4.1 Analysis of 2D simply supported Single Span Bridge

EXAMPLE 1

Single span bridge

The Banafjäl Bridge is a 42 m long, simply supported bridge, which carries one ballasted track. The bridge is a composite structure, with an ordinary reinforced concrete deck supported by two steel beams, and has the following physical properties:

- Mass of the composite section, m = 10700 kg/m;
- Density of ballast, $\rho_{ballast}$ = 2000 kg/m^3;
- Thickness of ballast, $h_{ballast}$ = 0.6 m;
- Width of ballast, $b_{ballast}$ = 6.2 m.

The composite cross-section was homogenized, after the homogenization the following characteristic values were used on the model:

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- Modulus of elasticity, $E = 210 * 10^9$ Pa;
- Moment of inertia, $I = 0.62\ m^4$;
- Area, $A = 0.57\ m^2$;
- Linear mass, $\mu = 1814$ kg/m;
- Density, $\rho = 31824.6\ kg/m^3$.

The FE model of the bridge was developed considering above physical properties in FE graphical interface of SAP2000 v14.2.4.

The supports were, initially, considered stiff to study its dynamic behavior and so that the results could be compared with the analytical solution. The first model is shown in figure *4.1, represented with stiff supports.*

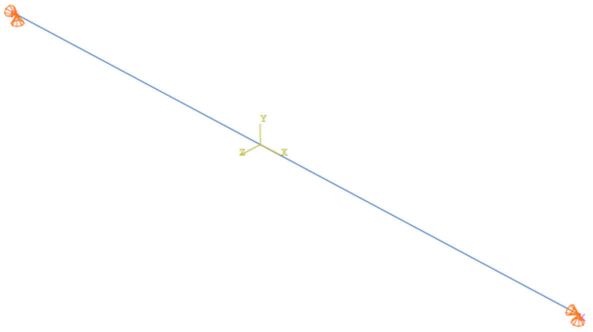

Figure 4.1: FE model of the single span bridge.

As can be seen in figure 4.1, only the permanent parts of the structure were modeled. International System units were used in the model definition and analysis. The damping was considered as direct damping and equal for the whole beam. The size assumed for beam is rectangular section with
Width b = 0.157m

Depth D = 3.613m

Material damping = 0.5%

Length of beam = 42m (Span to depth ratio = 11.627)

- Loading considered on Simply Supported Beam

Load of Vehicle as per table no 4.1 and fig no 4.2 shows the moving point load.
Axle Load Considered for Uncoupled Bogies = 170 KN
Distance Considered between two axles (d) = 3m
Speed of Train Considered = 250 Km/h (69.45 m/s)
Beam is analysed in linear direct integration History.

Table 4.1: Showing car, bogie and axle loads of Vehicle Traction and passenger cars

SN	Description (1)	Name (2)	Unit (2)	Traction cars (3)	Passenger cars (4)
1	Mass of car body	Mc	Kg	55790	24000
2	Mass of bogie	Mb	Kg	2380	3040
3	Mass of wheel axel	Mw	Kg	2048	2003

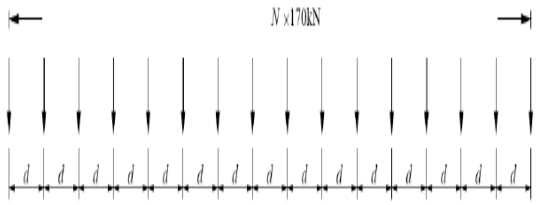

Figure 4.2: Moving Point load on simply supported single span bridge

Equation no (4.1) shows the exact circular bending frequencies, for j mode For Euler-Bernoulli beam.

$$w_j = \sqrt{\left(\frac{j\pi}{l}\right)^4 \frac{EI}{\mu}} \tag{4.1}$$

Following are the frequencies for first 10 modes with element length equal to 1/10th of the span
Frequencies obtained from analysis:-

$$F = \begin{bmatrix} 2.38536 \\ 9.54028 \\ 21.4 \\ 38.0712 \\ 59.2009 \\ 84.2789 \\ 116 \\ 152.7 \\ 193.5 \\ 238 \end{bmatrix}$$

Exact Frequencies calculated using eq no (4.1)

$$F = \begin{bmatrix} 2.39 \\ 9.54 \\ 21.17 \\ 38. \\ 59.64 \\ 85.88 \\ 116.90 \\ 152.68 \\ 193.24 \\ 238.57 \end{bmatrix}$$

Modeling of 42m single span bridge as a simply supported 2d beam in sap

Shown in Figure 4.3 is the 3D view and Front view for simply supported beam.

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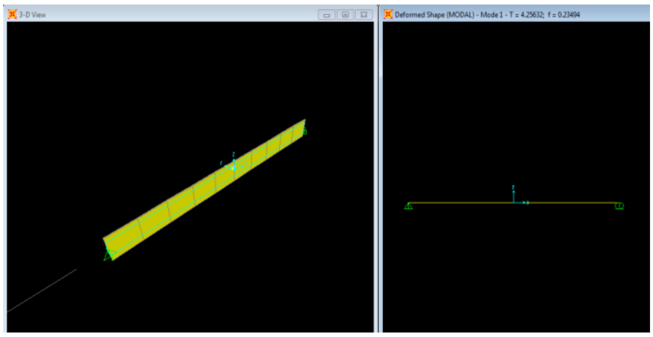

Figure 4.3: SAP model for 42m single span Bridge

In figure 4.4 shown below we can observe the deformed shape of the beam.

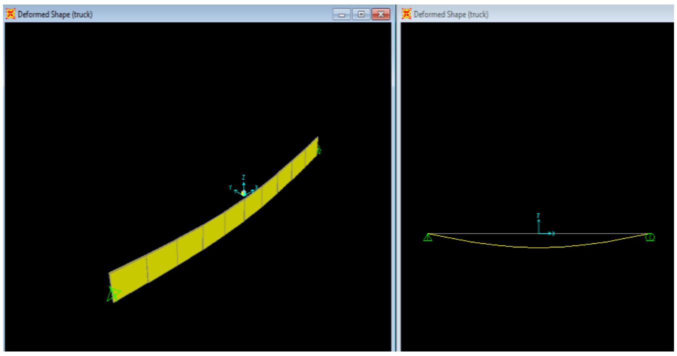

Figure 4.4: SAP model showing deformed shape of bridge

Post Analysis Results of 42m Single span bridge model

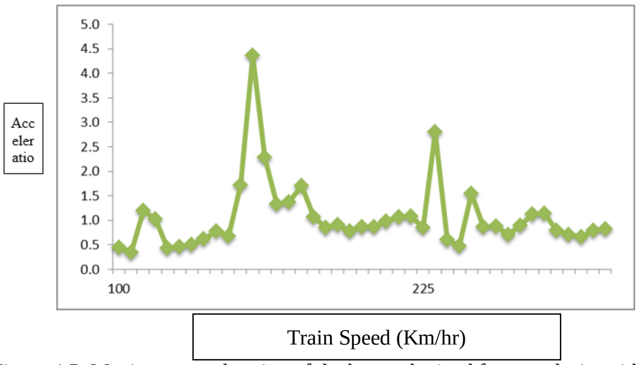

Figure 4.5: Maximum acceleration of the beam obtained from analysis, with time step equal to 0.002

Referred problem with time step as parameter

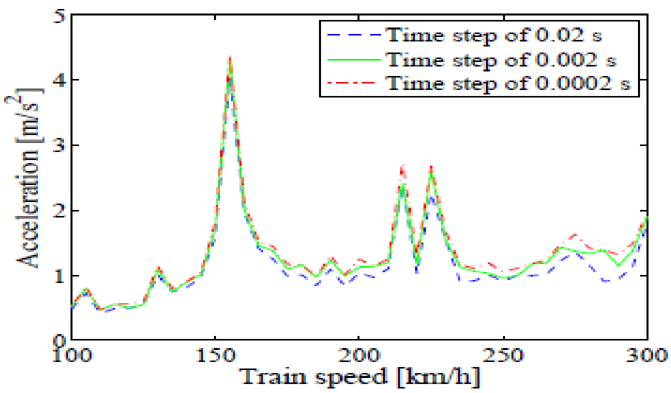

Figure 4.6: Maximum acceleration of referred problem

RESULTS

Graphs obtained from the analysis

1. Displacement Vs Time

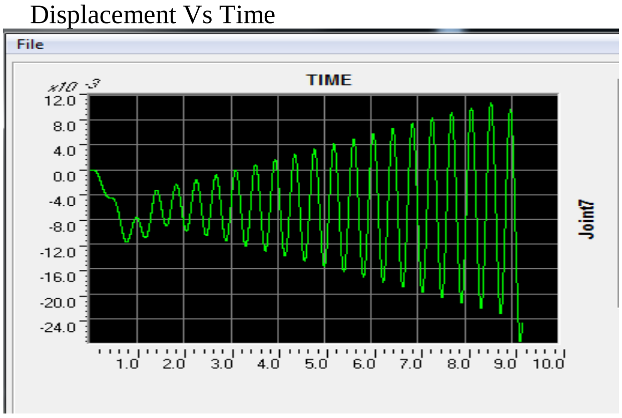

Figure 4.7: Mid Span displacement time history graph for single span bridge

2. Acceleration Vs Time

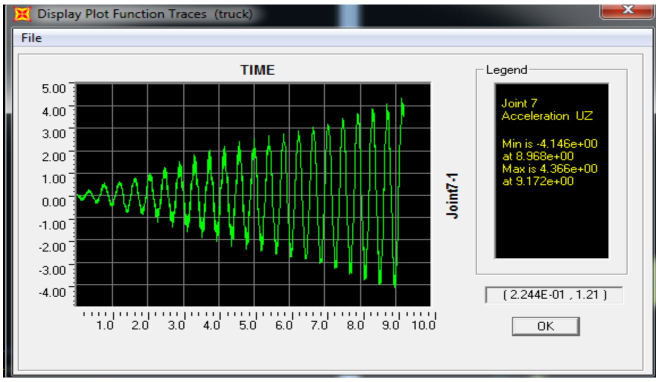

Figure 4.8: Mid Span acceleration time history graph for single span bridge

3. Moment Vs Time

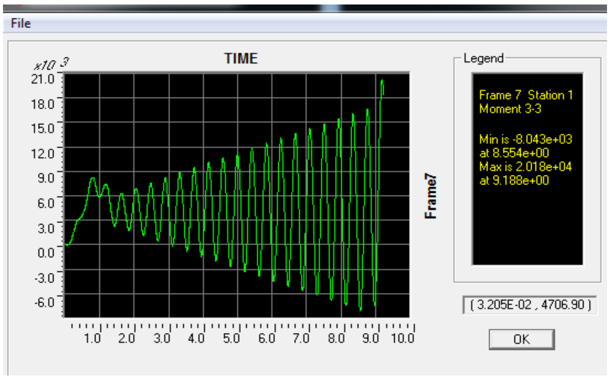

Figure 4.9: Mid Span Moment time history graph for single span bridge

Comparisons of results for time step 0.002 shown in table no 4.2

Table 4.2: Showing results for referred problem and Analyzed problem

SN	Description (1)	Referred Problem results (2)	Analysis Results (3)
1	Displacement (cm)	2.28	2.278
2	Acceleration (m/s^2)	4.32	4.366
3	Moment (MNm)	20.5	20.18

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EXAMPLE 2

Problem statement

Simply supported bridge of span= 40 m,

Damping ratio= 1%,

Bending stiffness= 280.1329×106 kNm2 and

Line mass = 30 Ton/m

Modeling of 40m single span bridge as a simply supported 2d beam in sap

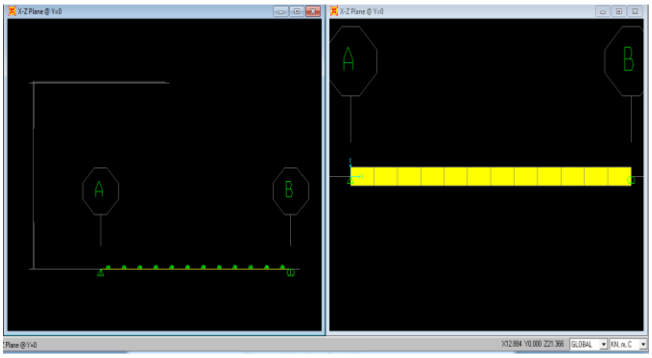

Figure 4.10: SAP2000 Model for 40m simply supported beam

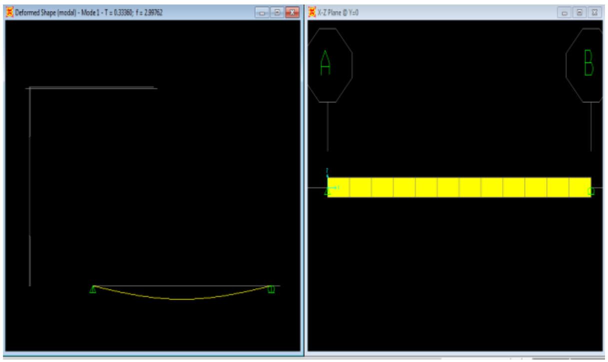

Figure 4.11: Deformed shape for 40m simply supported beam

Modal frequencies obtained from the analysis:-

$$F=\begin{bmatrix}2.9976\\11.99\\26.97\\47.911\\74.716\\107.13\\144.53\\185.86\end{bmatrix}$$

Results

Maximum Acceleration v/s Time graph shown in figure 4.12

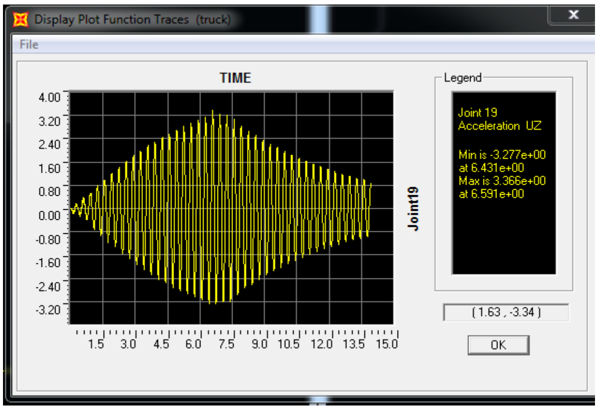

Figure 4.12: Acceleration time history plot for 40m simply supported beam

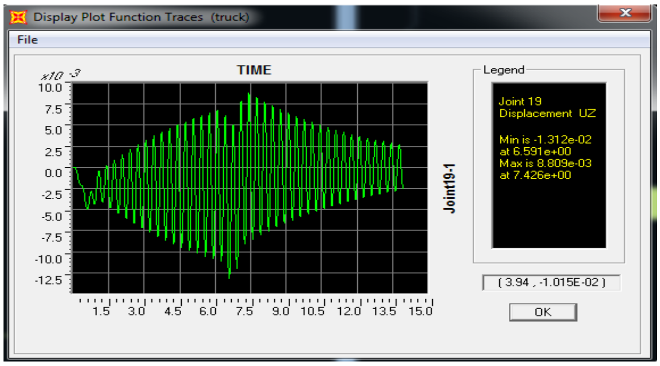

Figure 4.13: Displacement time history plot for 40m simply supported beam

RESULTS

Graph obtained from the analysis shown in fig 4.14 & Fig 4.15

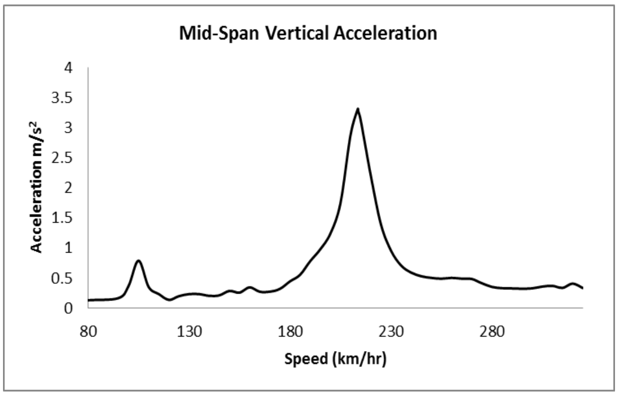

Figure no 4.14: Maximum mid span vertical acceleration

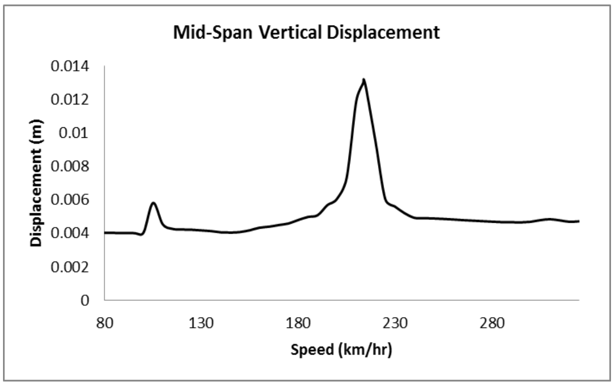

Figure no 4.15: Maximum mid span vertical displacement

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4.2 Analysis of Euler- Bernoulli Beam

EXAMPLE 3

Analyses of Simply Supported Beam with Finite Length

In this study, the dynamic response analysis of a rail as an Euler Bernoulli with finite length on a Pasternek-type viscoelastic bed and fully defined supports and subjected to moving loads is investigated.

Properties for Euler Bernoulli Beam: table no 4.3 shows the beam load parameters. Width b = 0.009 m Depth D = 0.112 m

Table 4.3: Showing Beam Load and Parameters

Sr. No.	Beam load and parameters (1)	Values (2)
1	L(m)	10
2	E(GPa)	207
3	$I(m^4)$	$1.04*10^{-6}$
4	$A(m^2)$	0.001
5	$P(kg\ m^{-2})$	7040
6	$V(Km\ h^{-1})$	12
7	$F_o(N)$	700

SAP2000 model for simply supported beam: -Deformed shape for simply supported beam

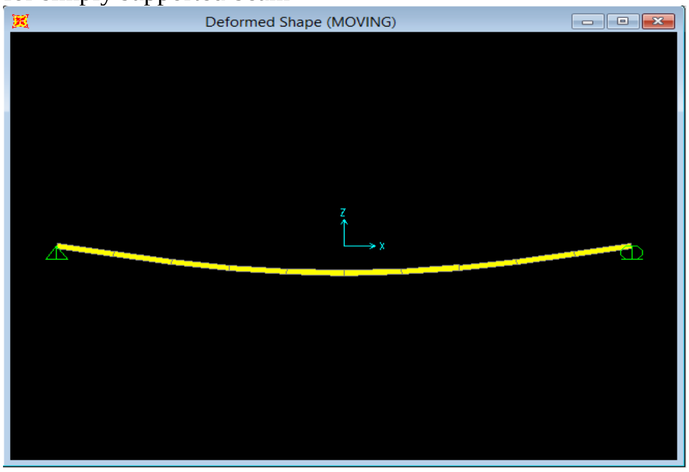

Figure 4.16: Deformed shape for simply supported Euler Bernoulli Beam

Results

1. Maximum mid span deflection obtained from SAP analysis = 6.4cm shown in fig 4.17

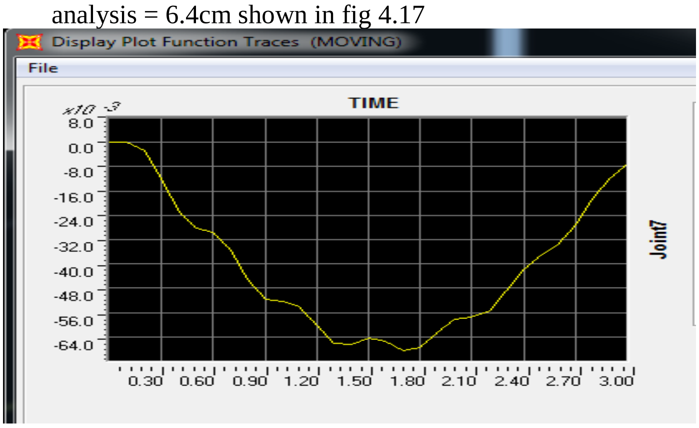

Figure 4.17: Maximum mid span displacement for Euler Bernoulli beam

2. Deflection at mid span of referred problem of Euler Bernoulli Beam = 6.8cm shown in fig 4.18

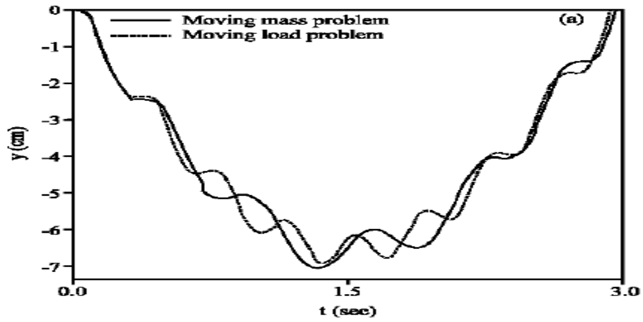

Figure 4.18: Maximum mid span displacement for Euler Bernoulli beam for referred problem

4.3 Analysis of Timoshenko Beam

EXAMPLE 4

Beam parameters shown in table no 4.4.Properties for Timoshenko Beam with Finite span width b = 0.0366 m and depth D = 0.235 m

Table 4.4: Showing Beam Load and Parameters

Sr. No.	Beam and load parameters (1)	Value (2)
1	L(m)	10
2	E(GPa)	207
3	$I(m^4)$	$39.5*10^{-6}$
4	$A(m^2)$	$86.13*10^{-4}$
5	$\rho(kg\ m^{-3})$	7820
6	$V(km\ h^{-1})$	60
7	K*	0.85
8	K_f (MPa)	20
9	μ(KN sec)	69
10	η(KPa sec)	138
11	ν	0.3
12	F_0	144

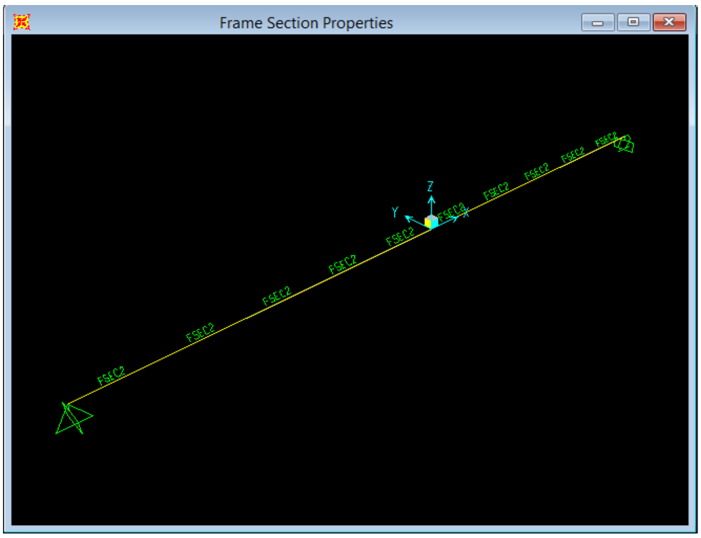

Figure 4.19: SAP model for simply supported Timoshenko beam

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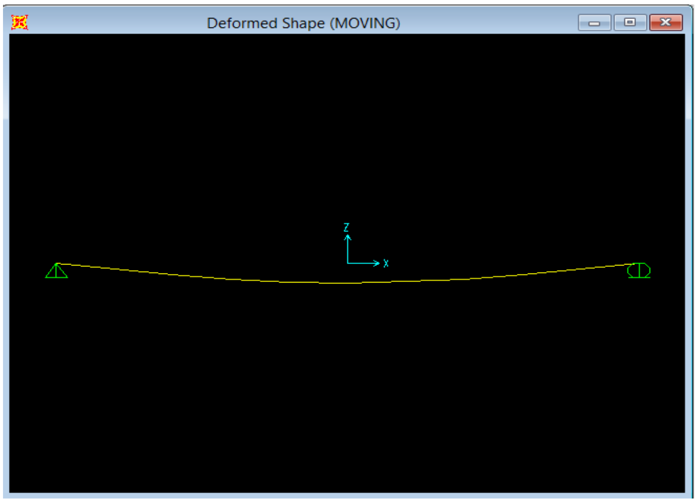


Figure 4.20: Deformed shape for simply supported Timoshenko Beam

RESULTS

1. Maximum mid span deflection in meters modelled in sap shown in fig 4.21

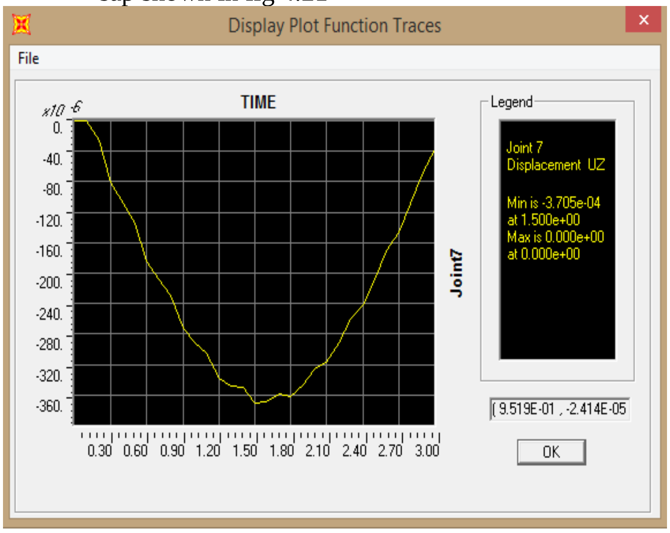


Figure 4.21: Maximum mid span deflection for simply supported Timoshenko Beam

2. Deflection at midspan for Timoshenko Beam referred problem shown in fig 4.22

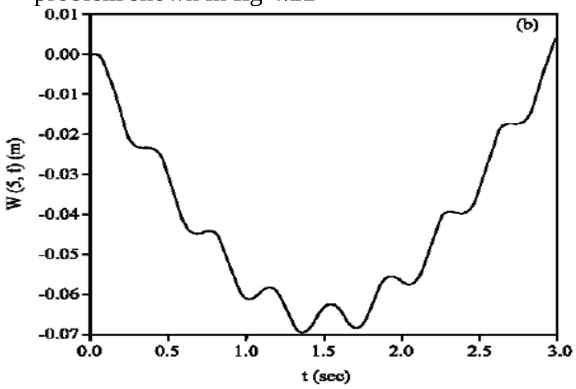


Figure 4.22: Maximum mid span deflection for referred problem

From the above results it can be seen that the results obtained from sap 2000 V14.2.4 are in fair agreement with the results mentioned in the referred literature. Extending the concept of above section, an attempt is made to conduct the moving load analysis for 3D system, using sap 2000V14.2.4, in the next section.

V ANALYSIS AND RESULTS:

The 3D model is analyzed for two boundary conditions.

Case no 1 Fixed base: - Fig 5.10 shows the model in SAP and fig 5.11 shows the modal deformed shape obtained after analysis.

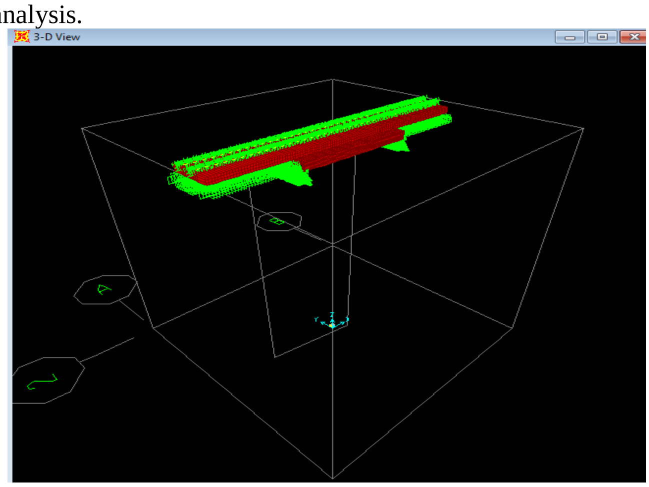


Figure 5.10: 3D SAP model for fixed Bridge Deck

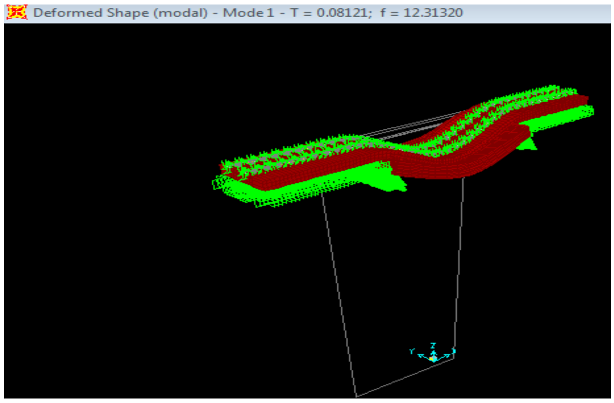
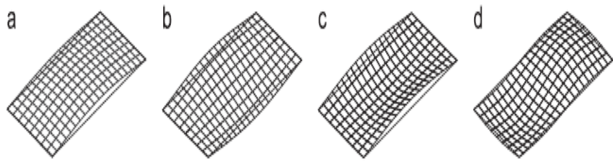


Figure 5.11: Modal Deformed shape For Bridge deck model



Modal frequencies obtained from the analysis:-

$$F=\begin{bmatrix} 12.313 \\ 14.576 \\ 26.168 \\ 41.46 \\ 98.01 \end{bmatrix}$$

Fig 5.12 shows the maximum acceleration for infinitely stiff soil

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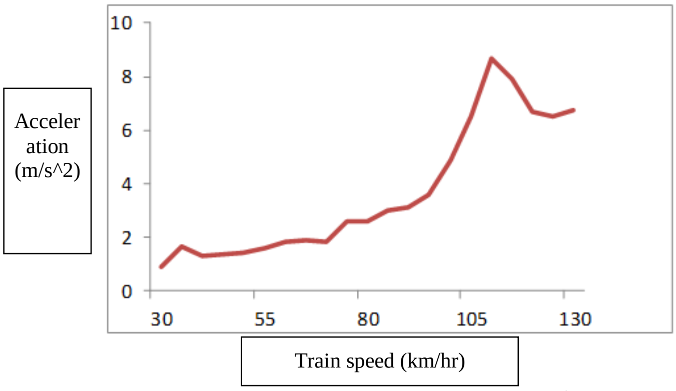

Figure 5.12: Maximum vertical acceleration at the centre of the mid-span for Cs= ∞ m/s

Case 2 Hard soil (Fig 5.13)

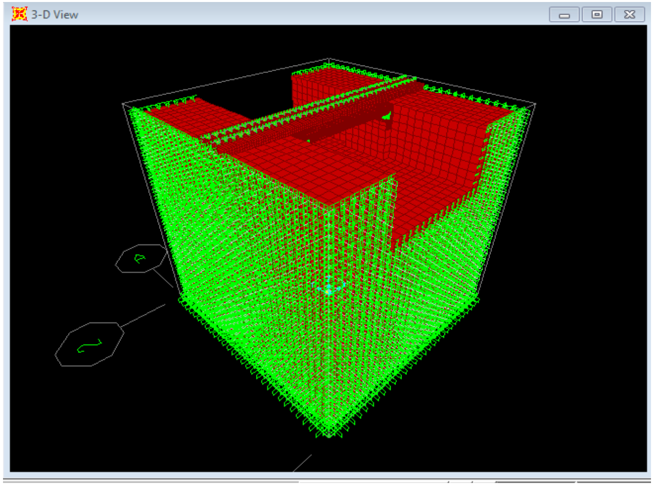

Figure 5.13: 3D soil-structure model with shear wave velocity Cs = 400m/s assuming overall damping ratio as 0.034

Modal Deformed shape

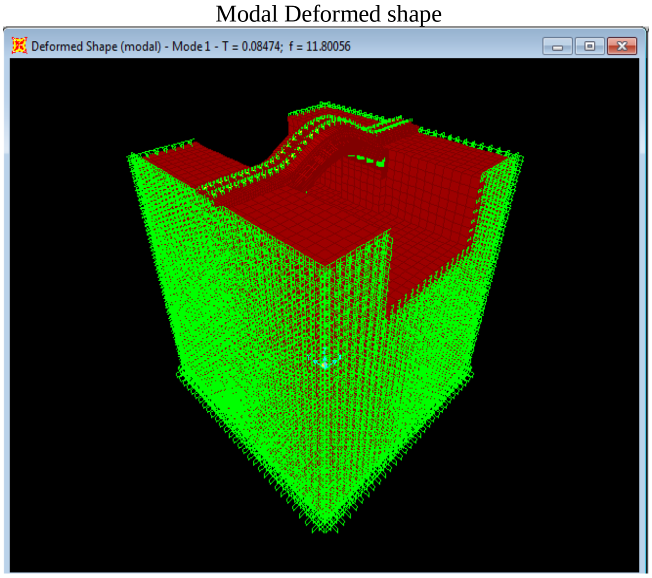

Figure 5.14: Modal Deformed shape obtained after analysis

Modal frequencies obtained from the analysis

$$F=\begin{bmatrix}11.01\\16.296\\34.467\\63.345\end{bmatrix}$$

Maximum acceleration at mid span v/s train speed is shown in Fig. 5.15.

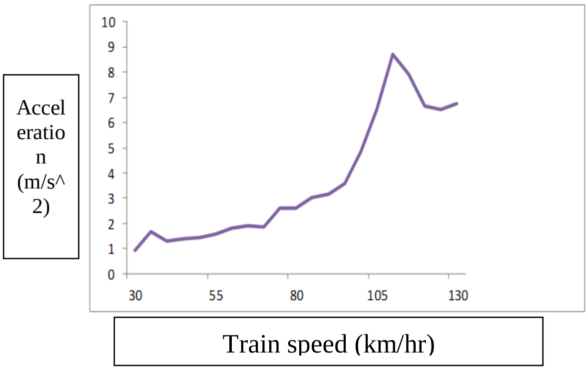

Figure 5.15: Maximum vertical acceleration at the centre of the mid-span for Cs=400 m/s

Comparison of results obtained from analysis and referred problem

Referred problem result

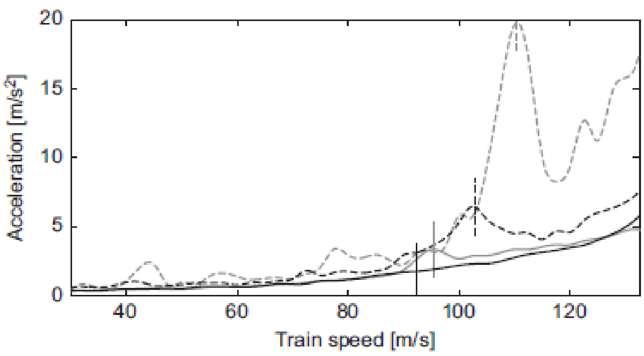

Figure 5.16: Maximum vertical acceleration at the centre of the mid-span deck for Cs=∞m/s (grey dashed line), Cs=400 m/s(black dashed line) referred problem

Analysis results

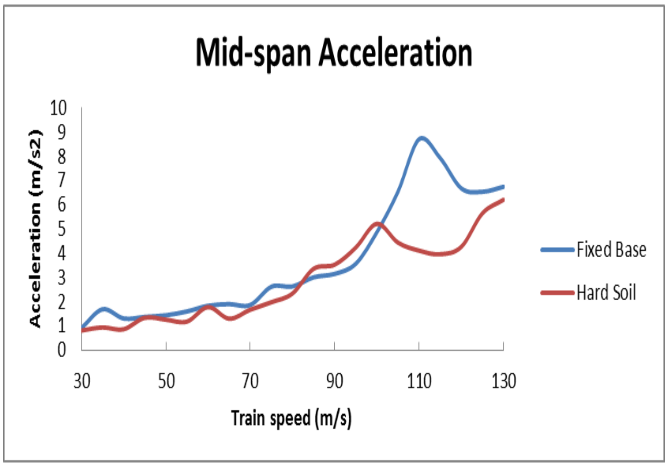

Figure 5.16: Maximum vertical acceleration at the centre of the mid-span deck for Cs=∞ m/s (Blue), Cs=400 m/s (Red)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 10, October-2018

CALCULATIONS

The resonant condition of a bridge excited by a row of moving forces can be expressed as follows

$$v_{n,i} = \frac{f_n d}{i} (n=1, 2\dots\ i=1, 2\dots)$$

$v_{n,i}$= resonant train speed

f_n = n^{th} resonant frequency of the bridge.

d = characteristic distance between moving loads.

For fixed base condition

$v_{n,i}$= 110m/s

f_n= 12.313

$$i = 2$$

$$d = \frac{110 * 2}{12.313}$$

$$= 17.867\text{m}$$

For hard soil condition

$v_{n,i}$ = 100m/s

f_n = 11.01

i = 2

$$d = \frac{105 * 2}{11.8}$$

$$= 18.16\text{m}$$

The deck acceleration was found to increase with train speed**.** Local maxima were reached at resonant speeds corresponding to the first bending mode shape, considering the distance between bogies d= 17.8 m. Fig. 5.16 shows maximum vibration levels at speed $v_{1,2}$=110 m/s when soil–bridge interaction was not considered. The response of the structure changed substantially when soil– structure interaction was considered. The second resonant speed of the first mode shape decreased to $v_{1,2}$=105 m/s. for stiff soil, due to the change in the dynamic behavior of the system.

VI CONCLUSION

The following conclusions can be drawn from the results obtained:

The three cases (first without considering soil/fixed boundary conditions second considering soil with $C_{s=}$400m/s and without considering soil with fixed base) are discussed in the above section. Figure 5.16 has a close agreement. The results of figure from analysis plot have close agreement with the fig from the refereed problem plot. Also the variation in the results in figure A must be due to exclusion of bogie inertia moment primary/secondary suspension stiffness and damping in the train model. Since the moving load is considered purely as point load. Even then the resonance is achieved as per the calculations

Soil–structure interaction leads to changes in dynamic behavior. The fundamental periods and damping ratios of the response were higher when soil–structure interaction was considered than when it was not.

The resonance condition in railway bridges depends on resonance frequencies. Resonant train speeds were lower when soil–bridge interaction was considered. Amplification in the resonant regime was also lower.

Moreover, resonance effects may occur at lower operation speeds than those predicted when soil–bridge interaction is not considered. Therefore, dynamic effects on railway bridges considering soil–structure interaction are an important issue in structure design.

VII REFERENCES

(1) Rui Tavares, (2007) "Influence of The Vertical Support Stiffness on The Dynamic Behavior Of High-Speed Railway Bridges". *TRITA-BKN; Master Thesis* Vol 255.

(2) A. Romero, M. Solis, J. Dominguez and P. Galvin, (2012) "Soil-Structure Interaction in Resonant Railway Bridges" *Soil Dynamics and Earthquake Engineering*, Vol. 47, pp 108–116.

(3) Mahir Ulker, Kaustell, Raid Coroumi and Costin Pascoste, (2010) "Simplified Analysis of The Dynamic Soil Structure Interaction of A Portal Frame Railway Bridge", *The Royal Institute of Tech. Stockholm, Sweden,* Vol.32 pp 3692-3698.

(4) M. Zehsaz, M. H. Sadeghi and A. Ziaei Asl, (2009) "Dynamic Response of Railway Under A Moving Load" *Journal of Applied Sciences* Vol.9(8) pp 1474-1481.

(5) J. G. Sieffert, "Dynamic Soil-Structure Interaction: Recent Developments and Simplified Design" *Laboratoire d'Etudes Et De Recherche En Genie Civil De Strasbourg, France*, Vol 24.

(6) Andreas H. Nielsen, (2006) "Absorbing Boundary Conditions For Seismic Analysis in ABAQUS" *Conference Jacobs Babtie, Bothwell St. Glasgow, UK*, Vol.95 pp 359-370.

(7) Ladislav Fryba, (2001) "A Rough Assessment of Railway Bridges For High-Speed Trains". *Engineering Structures*; Vol.23, pp 548-556.

(8) Christopher Adam and Patrick Salcher, (2011) "Assessment of High-Speed Train-Induced Bridge Vibrations" *Proceedings of The 8th International Conference on Structural Dynamics, EURODYN 2011 Leuven, Belgium*, pp 1302-1309

(9) John P. Wolf "Dynamic Soil-Structure Interaction" Prentice-Hall, INC., Englewood Cliffs, N.J. 07632, 1985, pp 10-45.

(10) Ashish Gupta, Amandeep Singh (2014) " Dynamic Analysis of Railway Bridges under High Speed Trains" *Universal Journal Of Mechanical Engineering* 2(6): 199-204

(11) P Museros and M D Martinez-Rodrigo (2007) "Vibration Control of simply supported beams under moving loads using fluid viscous dampers" *Journal Of Sound And Vibration* 292-315

(12) Alain Pecker (2005) "Rion-Antirion Bridge, Greece- Concept, design and construction" *Structural Engineering International Journal* 22-27

(13) Shane Crawford, Martin Murray and John Powell, (2001) "Development of A Mechanistic Model for the Determination of Track Modulus", *7th International Heavy Haul Conference, Brisbane, Australia*, PP 1-7.

(14) Dheeraj Raj and Bharathi M, (2013) "Effect of Soil – Structure Interaction on Regular and Braced RCC Building" *Proceedings of Indian Geotechnical Conference Roorkee,* pp 1-10.

(15) Suriyon Premapote, Mohammad H Bazyar, Chongmin Song (2007) "A Direct procedure for the transient analysis of dynamic Soil Structure interaction"