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. Vibration of Railway Bridges in Audible Frequency Range"A Review"

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ABSTRACT: The aim is to control the vibration in railway bridges, study of different sources vibration and noise, different means to control it. The vibrational energy propagates through the bridge causing the whole bridge to radiate noise. The lowest noise levels are found in the concrete bridge with ballasted track and highest in the steel bridge with directly fastened track mainly 15dB higher than previous one. Noise is undesired, but unavoidable phenomenon. We cannot stop its generation at the source level, but control it at the listener level up to some extent. This generated noise in the case of railway bridges may be controlled by different means such as vibration isolation, vibration damping, acoustic absorption and mass addition etc. Train induced vibration may cause several damaged not only to the bridge but also to the track structure such as ballast instability.

KEYWORDS: Railway Bridge, track, noise, vibration control

I. INTRODUCTION

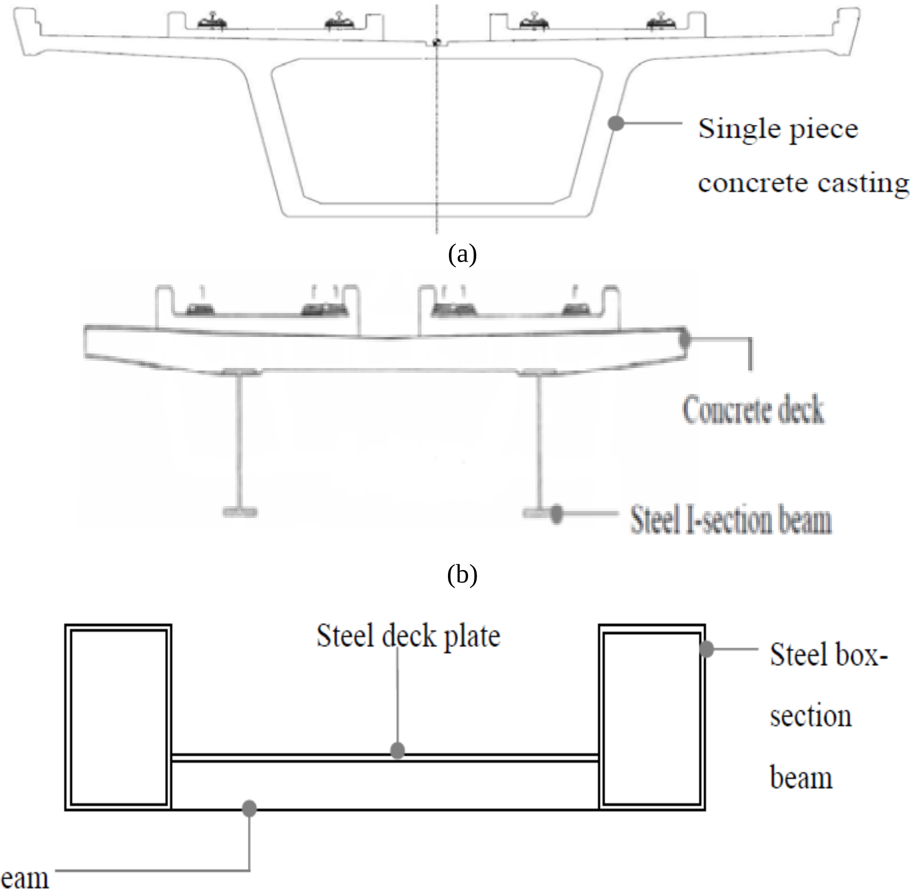
Transportation noise is the main component of environmental noise. It is estimated that road traffic is the major source of noise with a long-term averagesound level greater than 65dB (A) of the locations with noise levels higher than this. It is estimated that around 1.7% are due to noise from railways. Relative to road and aircraft noise, it is also found that rail noise is lessannoying for a given noise level[1].

When a train is travelling on a bridgevibration generated by the combinedwheel-rail roughness is transmitted from the rail to the bridge via the track supportstructure. Because track has non-elastic behaviour and during vibration displacement of particles is irreversible.So it may induce deterioration and reduce safety.Large amplitude of vibration of railway bridges can cause damages such as ballast instability can change the geometry .So geometry and quality of components must be regularly maintained.

The vibrational energy propagates through the bridge causing the wholebridge to radiate noise[2]. The noise radiated by this large structure normally constitutes a significant addition to the wheel-rail rollingnoise and other noise sources. In some cases, the different type of track structureused on bridges than on plain track at-grade also causes a significant increase in therolling noise[3]. Measurements show that the overallnoise level associated with a train travelling on a bridge may be up to 20dB greaterthan that for a train on plain track at grade[4].

II. RAILWAY BRIDGE STRUCTURES

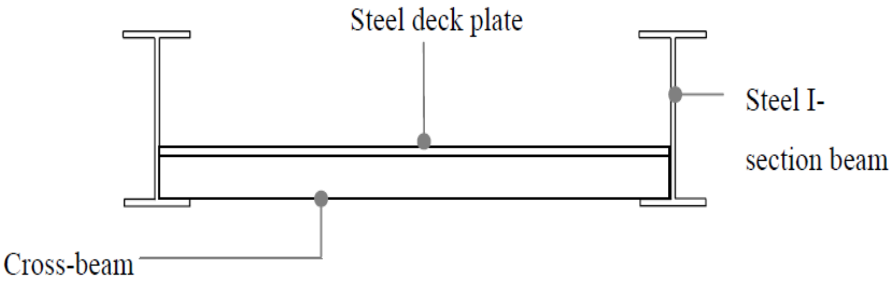
In modern time bridges and viaducts are required in the railway in order to cross valleys, water (rivers, river estuaries and flood plains), roads and other railway lines. The term viaduct is used here to refer to a longer elevated structure, composedof many consecutive spans. The majority of modern bridges and viaducts can bedivided into three group'srespectively Concrete box-section, Concrete-steel composite and all steel shown in Fig.1



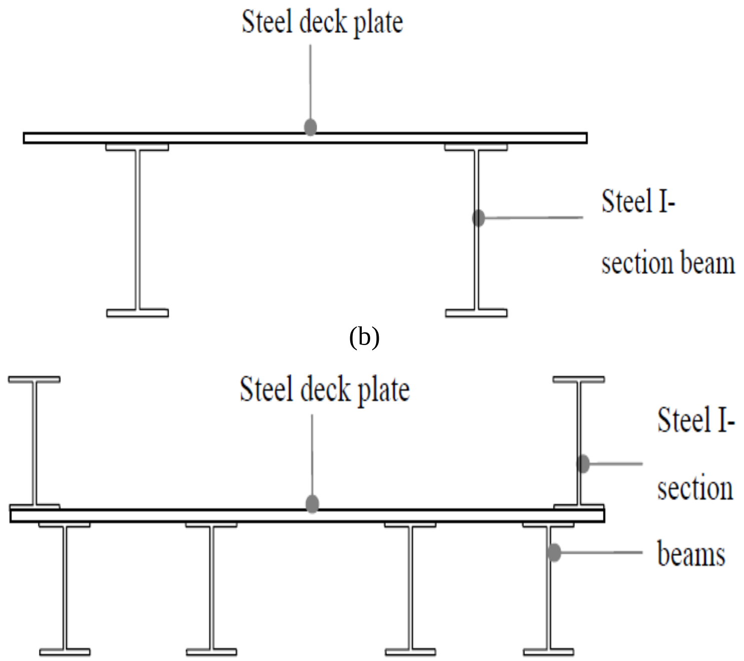
(c)

Fig. 1.Modern bridge structures.(a) Concrete box section,(b) Concrete steel composite, (c) All steel[5]

In the past, masonry, iron and steel bridges were built for the railway. Masonrybridges are normally regarded as very low-noise elevated structures[7].Such that they have required little attention with regard to noise. However such structures have not been built in recent years because of their high cost. Iron and steel bridges have been built in various different configurations. They are constructed only from beams and these will be referred to here as open bridge. Some of the most common configurations for historical iron and steel bridges are shown in Fig.2



(a)



(b)

(c)

Fig.2. Historical design for iron and steel railway bridges,(a) Side-deck I-beam,(b) Under-deck I-beam,(c) Side and under-deck I-beam.[6]

A. TRACK STRUCTURES WITH A BALLAST LAYER

Most of the railway track is ballasted, which means that the rails are fastened to sleepers,which are supported by a layer of ballast. A cross-sectional view of a typical ballasted track arrangement on a bridge is shown in Fig.3

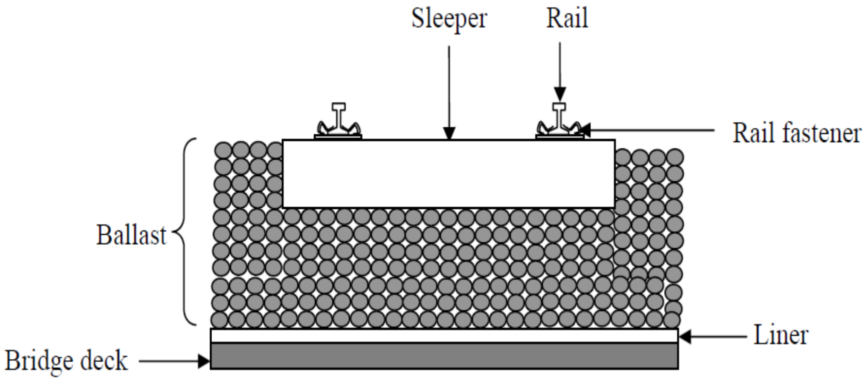


Fig.3.Typical Ballast Track Arrangement on a Bridge[7]

Ballast is usually crushed natural rock, such as granite. Specifications for railwayBallast require a carefully controlled range of ballast grain sizes and an angular grain shape in order to promote interlocking between the grains and high internal friction. The ballast layer is typically 250mm to 500mm deep, measured from the underside of the sleeper.The ballast is packed under the sleeper only in the areas beneath the rails duringTrack construction and maintenance operations in order to promote track stability. The sleeper should be fully embedded in the ballast, as shown in above Fig .3 to prevent lateral and longitudinal motion of the sleeper under the moving load of the train. Wooden sleepers were widely used in the first half of the 20th century, but concrete sleepers are now the most usually used. The sleepers are normally set at a distance of between 0.6 and 0.75m apart, measured parallel to the axis of the bridge[7]. Some form of liner is normally placed between the ballast and the bridge deck. In the past wood has been used for this purpose to protect the deck from impact damage. Specialist liners are used on modern bridges, which may also prevent rainwater reaching the bridge deck in order to guard against corrosion of the structure.

Rail fasteners are used to connect the rails to the sleepers. The fastener normallyconsists of a clip to provide the required clamping load to the rail-foot and anelastomeric rail-pad fitted between the rail and sleeper. This resilient connectionprotects the sleeper from high-frequency excitation[7]. which preventscrack formation in concrete sleepers and generally extends the service life of sleepers.

B. TRACK STRUCTURES WITHOUT A BALLAST LAYER

Some railway track structures both at grade and on bridges do not include a ballastLayer or sleepers. These will be referred to as directly-fastened track. The mainreason for using this type of track is that it requires less maintenance than ballastedtrack. The cost associated with maintenance of ballasted track may be a significantpart of the running costs of a railway[9]. However construction costs for directly-fastened track are greater than those for ballasted track. For bridges, the use of directly-fastened track in preference to ballasted track also brings a significant reduction in the weight that the bridge must support and therefore the bearing strength requirements. Further use of directly-fastened track can lead to the reduction in the overall depth of the bridge below rail height.Modern rail fasteners on directly-fastened track are referred to as baseplate-type rail,fasteners or base plateshere. A range of different base plates are used.

The base-plate consists of a rail pad fitted between the rail and a cast-ironplate that is fixed to the bridge structure using bolts. The stiffness of the railpad used in base-plate rail fasteners may be much lower than that in ballasted track because the rail pad is normally the only source of resilience in directly-fastened track. More complex base-plate designs are used where relatively low levels of vertical stiffnessare required.

III. SOURCE OF VIBRATION IN RAILWAY BRIDGES

The vibration set up by the train as it cross a bridge are mainly caused by the hammer blow due to the balance-weight which are attached to the driving wheels of a locomotive for the purpose of minimizing the inertia effect of its reciprocating parts[9].Due to the fact that moving load is more or less suddenly applied. But oscillations of this character are very short lived and relatively insignificant in magnitude .vibrations also may be caused by rail-joints.The necessary bridge and locomotive characteristics can be computed with a precision which is quite sufficient for all the practical purposes.

IV. GOVERNING PARAMETERS AND INFLUENCE ON THE RESPONSE

The partial differential equation governing the flexural behaviour of a simply supported beam subjected to atrain of concentrated loads can be used[10]. Neglecting the effects of shear deformation and rotary inertiaand considering that the loads are aligned with the axis of symmetry of the cross-section (Y-axis) thegoverning equation is written as

$$\mathrm{m}\frac{\partial^2 y}{\partial^2 t} + \frac{\partial^2}{\partial^2 x}\left(EI\,\frac{\partial^2 y}{\partial^2 x}\right) = q(x,t) \qquad (1)$$

The deformed shape is expressed as a linear combination of a family of sine$\emptyset_j\,(x)$shown in equation below

$$\mathrm{y(x,t)}=\sum_{j=1}^{N_{mod}} \varepsilon_j\,(t)\emptyset_j\,(x)=\sum_{j=1}^{N_{mod}} \varepsilon_j\,(t)\sin\left(\frac{j\pi x}{L}\right) \qquad (2)$$

A. WIND-INDUCED VIBRATION

Among the various types of dynamic excitation wind-induced vibration is the most critical for long-span bridges, such as suspension bridges and cable-stayed bridges. It should be noted that wind flow around the bridge (deck) is easily modified when the bridge moves and the bridge receives additional motion dependent forces from the wind. These motion dependent forces may lead to a self-excitationvibration with very large amplitudes. Wind induced vibration shown in Fig.4

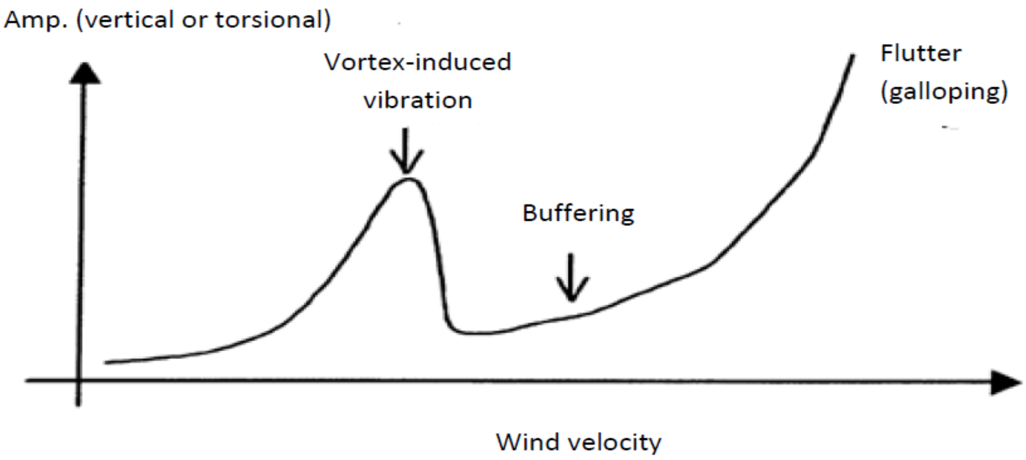


Fig.4.Wind-induced vibration

Girders with box sections often exhibit large amplitude vortex-induced vibrations. Whereas truss girders rarely show large vortex-induced vibrations. Flutter/galloping is a divergent-type of vibration, due to motion-dependent aerodynamic forces leading to the collapse of the bridge. Fluctuating wind forces produce a gust response that is basically random and increases in proportion to the wind velocity.

Wind-induced vibration may occur in the complete bridge. Wind-induced vibration of bridges and their components such as cables is generally strongly non-linear and turbulence contained in the natural wind sometimes significantly changes the characteristics of wind-induced vibration. Due to the strong non-linearity associated with the fluid.

B. HUMAN-INDUCED VIBRATION

Wind-induced vibration, such as vortex-induced vibration is characterized by motion-dependent, self-excited forces. Similarly human walking possesses adaptive and feedback nature inducing motion dependent human walking forces on bridges.

The vertical periodic forces due to human walking excite the vertical motion of the girders. The frequency of human walking is about 2 Hz (two steps per second) and the natural frequency of the vertical modes should be outside from 1.7 to 2.5 Hz to avoid the resonance vibration of the girder. There is a small fraction of horizontal periodic force generated by human walking, because human beings use two legs in walking [11] and its frequency is around 1 Hz. This force can potentially excite lateral motion of the girder if the natural frequency of the lateral modes is close to1 Hz.

C. VIBRATION OF CABLES

Stay cables are essential members in cable-stayed bridges and they can be almost as long as 500m in span, resulting in low natural frequencies such as 0.2 or 0.3 Hz in the lowest mode. Further their inherent damping is as low as 0.1% critical damping ratio. It can be said that stay cables are the most vibrating structural members in bridges.

The cables exhibit various types of wind-induced vibration. Rain and wind induced vibration and Vibration can occur only when certain conditions are satisfied[12]a limited range of the wind direction and velocity, moderate rainfall and smooth approaching wind. The amplitude is an order of the diameter of the cable; it takes place not only in the first mode, but also in higher modes. This rain-and wind-induced vibration found to occur in many cable-stayed bridges in the world and control of this vibration became one of the concerns in long-span cable-stayed bridges.

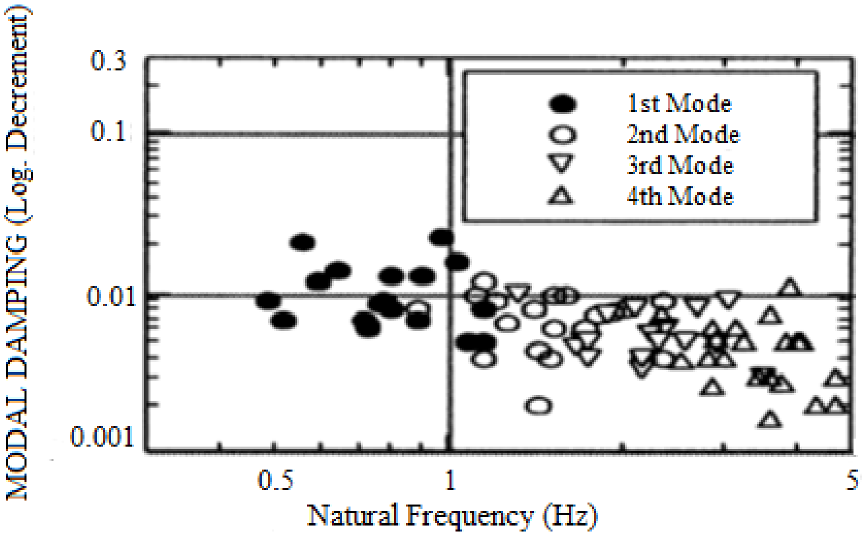


Fig.5. Relation between modal damping and natural frequency in stay cables[11]

V. MONITORING OF LONG SPAN SUSPENSION BRIDGE

Long span bridges are usually a critical link in the transportation system and are monitoring continuously for the purpose of traffic as well as structural performance. The monitoring of structures using vibration measurements has been attracting wide interest. Vibration response itself can be used to examine the performance of structures and could possibly be used to evaluate the structural state by inversely solving the structural parameters based on the measurement. Dynamic properties are extremely important for long span bridges that are very flexible and can become unstable due to dynamic wind effects.

Ambient vibration measurement is one of the most practical and convenient vibration measurement methods for large structures because no specific excitation device is required and can be measured even under service conditions [13]. Ambient sources such as wind and ground motion tend to have broadband frequency components that are suitable to identify multiple vibration modes. However monitoring through vibration measurement has several difficulties. For instance, reliable measurement and identification of higher vibration modes are usually difficult due to measurement noise and limitation of density of measurement points, although information of higher modes is essential to identify local defects with satisfactory resolution.

TABLE.1. COMPARISON OF SOME OF THE NATURAL FREQUENCIES FROM AMBIENT MOTION, FORCED VIBRATION AND FEM

Vibration Mode			Natural Frequency (Hz)		
			Forced	Ambient	Analysis
Girder Vertical Mode	Symmetric	1	0.129	0.131	0.123
		2	0.218	0.223	0.217
		3	0.435	0.440	0.436
		4	0.719	0.724	0.720
	Anti-Symmetric	1	0.149	0.152	0.149
		2	0.317	0.318	0.320
		3	0.568	0.571	0.567
		4	0.906	0.902	0.893
	Symmetric	1	0.487	0.494	0.472
		2	1.164	1.160	1.128

Girder Torsional Mode		**3**	**1.866**	**1.860**	**1.852**
	Anti-Symmetric	**1**	**0.722**	**0.778**	**0.761**
		2	**1.502**	**1.530**	**1.490**
Girder Lateral Mode	**Symmetric**	**1**	**0.099**	**0.093**	**0.101**
		2	**0.560**	**0.566**	**0.541**
Tower in-plane Mode		**1**	**0.599**	**0.598**	**0.624**

VI. SURVEY OF BRIDGE NOISE AND NOISE CONTROL MEASURES FOR RAILWAY BRIDGES

All bridges within each classification have similar construction and noise characteristics. Mean A-weighted noise levels are given for each of these bridge classifications at a distance of 25m from the track. The lowest noise levels are for concrete bridges with ballasted track and can be compared with the at-grade track for given train speed[14].The highest noise levels are those for steel bridges with directly-fastened track mainly 15dB higher than those for previous track. The lower noise levels found for bridges with ballasted track than those with directly-fastened track to the added mass on the bridge deck, vibration damping in the ballast and the sound absorption properties of the ballast.

In one of the report of noise survey[15]it was found that concrete bridges produce noise mainly in the frequency range up to about 500Hz, while steel bridges produce significant noise over a much larger range up to about 2kHz.

As described earlier bridges with a concrete deck and steel support beams have been built in recent years, mainly on the basis of relatively low construction costs. These bridges are referred to here as composite bridges. These have been linked to high noise levels particularly compared with all-concrete structures[12]. Noise from composite bridges has been the cause of complaints from local residents. These complaints were linked to very high noise levels at low frequencies, particularly for the 63Hz one-third octave band, often described as bridge ‘rumbling’ noise. This case demonstrates that overall A-weighted noise levels, which emphasise the higher-frequency noise components, may not correlate well with the disturbance caused by railway bridge noise to local residents.

It is identified that seven different approaches to noise control for railway bridges[7]. (i) source reduction, (ii) vibration isolation, (iii) vibration damping,(iv) mass addition, (v) acoustic isolation, (vi) acoustic absorption, (vii) reduction of radiating area. Source reduction for railway bridge noise refers to improving the quality of the wheel and rail running surfaces. But there is normally very limited scope for such improvements[13].

VII. CONCLUSIONS

Finite Element model (FEM) used for bridge noise and vibration normally restricted to only some lower part of the frequency range. The main difficulty in using this model to predict bridge vibration and noise is the enormous number of modes expected in the frequency range of interest for bridge noise. The Statistical Energy Analysis (SEA) method used to predict bridge noise and vibration is more attractive for complex systems at high frequencies where the number of effective modes is large and involves comparatively very low computational cost. Hence SEA has been widely used. Greatest state of oscillation set up when resonance is established. The resonant vibrations that may appear in simply supported beams when subjected to moving loads can be drastically reduced with the damping system proposed here. The damping system may apply to other situations where simply supported beams vibrate at resonance due to different causes. Regular vibration monitoring of long-span bridges, especially of cable-supported steel bridges is essential for better structural performance.Active vibration isolation may be possible by using springs.

REFERENCES

[1] Miedema, H.M.E. and Vos, H. Exposure-Response Relationships for Transportation Noise, Journal of the Acoustical Society of Americavol.104, pp.3432-3445,.1998

[2] M.H.A. and Thompson, D.J. A Calculation Model for the Noise from Steel Railway Bridges.Journal of Sound and Vibration,vol-193, pp.295-305,1996.

[3] Poisson, F. and Margiocchi. F. Journal of Sound and Vibration, vol.51, pp.944-952,2006.

[4] Hardy, A.E.J. Proc. Inst. Mech. Eng., Part F, Noise from Railway Bridges. vol.213, pp.161-172,1999.

[5] Bewes, O. TheCalculation of Noise from Railway Bridges and Viaducts. Engineering Doctorate Thesis, University of Southampton. 2006

[6] Shield, B., Roberts, J. and Vuillermoz, M, Noise on the Docklands Light Railway.Applied Acoustics, vol.26, pp.305-315.1989.

[7] Zhai , W.M., Wang, K.Y. and Lin, J.H. Modelling and Experiment of Railway Ballast Vibrations.Journal of Sound and Vibration,vol.270,pp.673-683, 2004.

[8] Ban, Y. and Miyamoto, T. Noise Control of High-Speed Railways. ,Journal of Sound and Vibration, vol.43, pp. 273-280, 1975.

[9] A Mathematical Treatise on Vibration in Railway Bridges by C.E.Inglis in University of Cambridge 1934.
[10] M. Olsson, On the fundamental moving load problem, Journal of Sound and Vibration, vol.145pp.299–307,1991.
[11] Bachmann, H., Ammann, W. Vibrations in structures structural engineering documents, No.36, IABSE.
[12] Hikami Y. Rain- and wind-induced vibration. Journal of Wind Engineering ,pp.27-40,1990.
[13] Abdel-GhaffarAM, Scanlan RH. Ambient vibration studies of Golden Gate Bridge I. Suspended structure. Journal of Engineering Mechanics, ASCE, pp.463–482,1985.
[14] Kurzweil, L.G. Prediction and Control of Noise from Railway Bridges and Tracked Transit Elevated structures. Journal of Sound and Vibration, vol,51,pp. 419 – 439,1977
[15] Thompson, D.J. Modelling and Means of Control,. Railway Noise and Vibration – Mechanisms, Elsevier Ltd,2009