IMPACT OF TRAFFIC VIBRATION ON HERITAGE STRUCTURES

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ABSTRACT

Vibration is one of the main factors for fatigue in structure. Produced by different sources vibrations propagate from one medium to another. Long term contact to vibrations can cause damages in buildings, minor effect such as cracks, which in critical cases could result in collapse, especially in historic buildings. Heritage structures are very valuable from cultural point of view of India. Ground-borne vibrations are generated due to road traffic, railway, blasting, construction induced, machine, pile driving etc.Vibration testing is accomplished by introducing a forcing function into a structure, usually with some type of shaker. Alternately, a DUT (device under test) is attached to the "table" of a shaker. Vibration testing is performed to examine the response of a device under test (DUT) to a defined vibration environment. The measured response may be fatigue life, resonant frequencies or squeak and rattle sound output (NVH). Squeak and rattle testing is performed with a special type of quiet shaker that produces very low sound levels while under operation. Hence in this research work of ours we tried to investigate the effects of vibration on heritage structures and the way these harmful effects if any can be controlled.

Keywords: ***Heritage Structures, NVGATE Software, Traffic Vibration, Vibration Analyser And Vibration Impact Assessment*.**

I. INTRODUCTION

Vibration is one of the main factors for fatigue in structure. Vibrations produced by different sources propagate from one medium to another. Long term exposure to vibrations can cause damages in buildings leading to minor effect such as cracks. These minor damages in critical cases could result in collapse, especially in historic buildings.

1.1 Types of Vibration

Vibrations can be categorized in several ways as follows:

a) Continuous vibrations in which the cyclic variation in amplitude is repeated many times.

b) Transient vibrations in which the cyclic variation in amplitude reaches a peak and then declines towards zero relatively quickly.

c) Intermittent vibrations in which a sequence (sometimes regular, sometimes irregular) of transient vibrations occurs, but with sufficient intervals between successive events to permit the amplitude to diminish to an insignificant level in the interim periods.

The response of soil and structures to continuous vibrations is to vibrate in sympathy with the vibrating source, i.e. at the same frequency or harmonics thereof. The resulting vibrations are, therefore, known as forced vibrations. Impulsive shocks give rise to transient vibrations. On the other hand they excite the natural frequencies of the soil-structure combination and result into the vibrations which are known as free vibrations.

Operation of construction equipment and construction techniques such as blasting generates ground vibration. Maintenance operations and traffic travelling on roadways can also be a source of such vibration. If its amplitudes are high enough, ground vibration has the potential to damage structures. It can cause cosmetic damage (e.g., crack plaster), or disrupt the operation of vibration sensitive equipment such as electron microscopes and advanced technology production and research equipment. Ground vibration and ground borne noise can also be a source of annoyance to individuals who live or work close to vibration-generating activities. Pile driving, demolition activity, blasting, and crack-and-seat operations are the primary sources of vibration addressed by Caltrans. Traffic, including heavy trucks travelling on a highway, sometimes generates vibration amplitudes high enough to cause structural or cosmetic damage. However, there have been cases in which heavy trucks travelling over potholes or other discontinuities in the pavement have caused vibration high enough to result in complaints from nearby residents. These types of issues typically can be resolved by smoothing the roadway surface.

Heritage structures are very valuable from cultural point of view of India. Ground-borne vibrations are generated due to transit system (Rail, bus, cars) in nearby structure when it passes near to it. Such a vibration cause structural or/and non-structural damage. Therefore, it is necessary to predict and access the vibration effect on historical buildings. It is also necessary to mitigate the effects of traffic vibrations along with remedial measures. Especially in Ahmedabad many heritage structure exist. In Ahmedabad day by day traffic intensity is increased due to increasing use of vehicles and it may be affect the nearby heritage structure, thus our project is to analyse the ground-borne vibrations in heritage structure and compare it with permissible vibration limit of that heritage structure.

II. LITERATURE REVIEW

FTA Manual "Transit noise and vibration impact assessment", MAY-2006

This report is the second edition of a guidance manual originally issued in 1995. It presents procedures for predicting and assessing noise and vibration impacts of proposed mass transit projects. All types of bus and rail projects are covered. Procedures for assessing noise and vibration impacts are provided for different stages of project development, from early planning before mode and alignment have been selected through preliminary engineering and final design. Both for noise and vibration, there are three levels of analysis described. The framework acts as a screening process, reserving detailed analysis for projects with the greatest potential for impacts while allowing a simpler process for projects with little or no effects. This updated guidance contains noise and vibration impact criteria that are used to assess the magnitude of predicted impacts. A range of mitigation measures are described for dealing with adverse noise and vibration impacts. There is a discussion of noise and vibration during the construction stage and also discussion of how the technical information should be presented in the Federal Transit Administration's environmental documents. This guidance will be of interest not only to technical specialists who conduct the analyses but also to transit agency staff, federal agency reviewers, and members of the general public who may be affected by the projects.

Jaswal Haridayal "Analysis of micro-vibrations in buildings" 2007

In this paper general guideline was given for analysis effect of vibration in buildings, and find efficient way to reduce intensity of vibration propagating in structures. A building at riverside at 158th street, New York City, USA was chosen as the site for investigation. Accelerometer was used to collect the data for theoretical analysis;

accelerating of vibrating floor was measured. Computer programmes MATLABTM and Working ModelTM , were used to calculate and analysis theoretical results. Analysis was used to reduce the intensity of vibration.

BS 5228-2:2009 "Code of practice for noise and vibration control on construction and open sites, Part 2: Vibration"

This British Standard refers to the need for the protection against noise and vibration of persons living and working in the vicinity of, and those working on, construction and open sites. It recommends procedures for noise and vibration control in respect of construction operations and aims to assist architects, contractors and site operatives, designers, developers, engineers, local authority environmental health officers and planners.

Jones & Stokes, "Transportation- and Construction-Induced Vibration Guidance Manual", JUNE-2004

This manual provides practical guidance to Caltrans engineers, planners, and consultants who must address vibration issues associated with the construction, operation, and maintenance of California Department of Transportation (Caltrans) projects. The guidance and procedures provided in this manual should be treated as screening tools for assessing the potential for adverse effects related to human perception and structural damage. General information on the potential effects of vibration on vibration-sensitive research and advanced technology facilities is also provided, but a discussion of detailed assessment methods in this area is beyond the scope of this manual. Most situations involving research and advanced technology facilities will require consultation with experts with specialized expertise in this area.

Hunaidi Osama, "Traffic Vibrations in Buildings" June-2000

This paper gives information about vibration. In this paper the effects of traffic vibration on the structure has been explained. In this paper general guideline for measurement of traffic vibration on structure, Factors affecting the vibration and Frequency has been explained.

Suggestive measure to mitigate vibration has also given in this paper. The Vibration analysis had been taken out on few houses of CANADA, the effect of vibration was measured on those houses and suggestive guidelines for mitigate traffic vibration.

Walter Konon and John R. Schuring, Members, ASCE, "Vibration criteria for HISTORIC buildings":

The 2.0 in./sec (50 mm/s) peak particle velocity criterion that traditionally used to protect structures from construction-induced vibration damage is non-conservative for historic and sensitive older building. The relevant parameters which must be considered in establishing vibration criteria for historic and sensitive older buildings are to be examined. Existing criteria by past investigators are reviewed and a new criterion for this class of structure is recommended.

J.H. Rainer, "Effects of Vibrations on HISTORIC Buildings" DBR Paper No-1091:

Vibrations reduce lifetime of buildings because vibrations are readily perceived, they frequently take the major blame for deterioration. Thermal problems water and frost action, chemical changes in mortar or other building materials caused by atmospheric pollutants. Organic action of bacteria on soil and rock materials, effect of trees on removal of soil moisture, and consequent settlement and de-watering as a result of changes in the water table.

Y.X. Jia1, W.N. Liu, W.F. Liu, and H.G. Zhang, "Study of vibration effects on historical buildings due to moving trains in Beijing":

The Diameter line under constructed is an important underground line linking the two main railway stations in Beijing. There are three historic buildings are in close proximity to the Diameter Line and existing metro lines. It is an urgent requisite on the preservation of the ancient architectures, since environmental and time impacts have been abating their structural resistance capability. The vibration prediction and assessment of the three historic buildings induced by trains are presented in this paper. Dynamic finite element models are made to simulate the dynamic response in the structures. The excitation of trains onto the tunnel structure is obtained using the vehicle-track interaction model. The results shown: the velocity values in historic structures vary regularly along with the horizontal and vertical distance; the vertical dynamic response is a major factor in underground structures while the horizontal in structure on the ground; train-induced vibration in historic buildings is within but close to the criteria, so vibration mitigation fastener should be taken to reduce the impacts and special measures are not necessary.

IAN HUME “Road traffic vibration on historic building”:

The effects of vibration on buildings and their occupants is a very technical and complex subject. Vibrations can be caused by passing road traffic, by railways, both surface and underground, by users of the building and by other sources like blasting, building works, and piling. Peak vibration levels greater on the upper floors and walls at the front of the building rather than at foundation level. Vibrations from road traffic did not cause any problems to the structure of a fairly robust historic building, but that they might possibly cause problem to fragile buildings. The traffic vibration on a building would become intolerable to the occupants long before structural damage was caused.

Antony Williams, John Sleeman, Michael Allan, James Hong, David Geiger, Mikel Lacis, “Noise and Vibration Assessment Construction, Operations and Maintenance”, CBD Metro Environmental Assessment, Technical Paper-3, August 2009.

The proposed CBD Metro will run from Central to Rozelle and consist of approximately 7 km of underground railway with six stations. The majority of the proposed alignment would be located within twin-bored tunnels, with the tunnels running beneath or close to numerous buildings. Some of these buildings within the CBD are already exposed to railway noise and/or vibration as a result of train operations on the existing City Rail underground rail network. Residential buildings in Pyrmont and Rozelle are also close to the proposed route of the Metro. The objective of this study is to evaluate and assess the potential noise and vibration impacts associated with the construction, operation and maintenance of the CBD Metro, including the operating railway lines, stations, train depot and other associated facilities. It identifies appropriate design goals based on local and international guidelines. Where noise and vibration levels are predicted to exceed the design goals, options and recommendations for mitigating or managing the potential impacts are presented.

III. THEORY

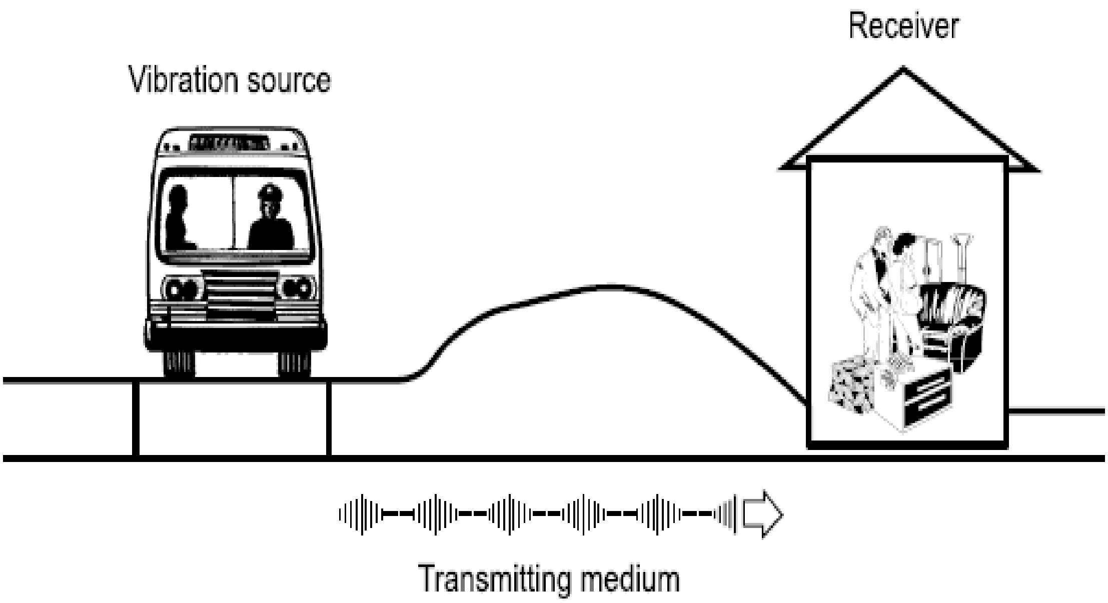
3.1 Vibration

Vibration is the time dependent displacement of a particle or a system of particles with respect to an equilibrium position. Vibrations surround us, for nature provides its own vibration sources such as earthquakes, wind and ocean waves. With the advent of the technological era, vibration sources have multiplied and have become a concern to residents of modern buildings and to those whose motive is to preserve historic structures. A common vibration source (including road traffic) and how they affect historic buildings will be discussed in this paper. In addition, case studies and possible remedial action where vibration levels are deemed excessive will be reviewed.The literature concerning vibration effects on historic buildings is not abundant, especially that relating to permissible and safe vibration levels, and conclusive studies of damage from vibrations are rare. It is not surprising when one considers the complex nature of the problem and the interrelation among the many environmental factors that cause deterioration of historic buildings. It is often impossible to separate vibration effects from the detrimental effects of atmospheric pollution on mortar and stone, wetting and drying, freezing and thawing, and other seasonal and daily dimensional changes caused by heating and cooling. Changes in the water table due to removal of moisture by trees or drainage works, cause subsequent damage to foundations, etc., can also be a cause of distress for buildings.

3.2 How Does Traffic Generate Vibration?

Like most vibration problems, traffic vibrations can be characterized by a source-path receiver scenario (Figure 1.0). Vehicle contact with irregularities in the road surface (e.g. potholes, cracks and uneven manhole covers) induces dynamic loads on the pavement. These loads generate stress waves, which propagate in the soil, eventually reaching the foundations of adjacent buildings and causing them to vibrate. Traffic vibrations are mainly caused by heavy vehicles such as buses and trucks. Passenger cars and light trucks rarely induce vibrations that are perceptible in buildings.

Fig1: Traffic Vibrations Can Be Characterized By A Source Path-Receiver Scenario.



When a bus or a truck strikes an irregularity in the road surface, it generates an impact load and an oscillating load due to the subsequent "axle hop" of the vehicle. The impact load generates ground vibrations that are predominant at the natural vibration frequencies of the soil whereas the axle hop generates vibrations at the hop frequency (a characteristic of the vehicle's suspension system). If the natural frequencies of the soil coincide with any of the natural frequencies of the building structure or its components, resonance occurs and vibrations will be amplified.In contrast to irregularities such as manhole covers or potholes, normal road surface roughness induces continuous dynamic loads on the road. If the road surface roughness includes a harmonic component that, at the posted speed, leads to a forcing frequency. That forcing frequency coincides with any of the natural frequencies of the vehicle and/or those of the soil, substantial vibration may be induced. This effect is familiar to car drivers travelling over dirt or gravel roads with ripples (termed "the washboard effect"). At a certain speed, the vehicle shudders excessively but the vibration subsides at higher or lower speeds.

IV. EXPERIMENT

The whole procedure of vibration analysis has been explained in two steps

4.1 Instrument Detail

Fig2: 16-Channel Vibration Analyzer

For noise and vibration impact studies we will use OROS-3 series analyzer.OROS-3 series features powerful modular hardware resources to offer the most efficient instrument for data acquisition, real-time analysis and post analysis.OROS-3 analyzer is a 16 channel analyzer and each channel can work simultaneously.The capacity of each channel is 640 to 2000 samples in 1 second.

4.2 Experiment Work

Experiment of vibration analysis has to be carried out in three stages,

4.2.1 Screening procedure

Screening procedure is based on the flow chart which includes; No Impact (Box A): The decisions in step 1 lead to either box A, "No vibration impact likely," or box B. Reaching box A indicates that further analysis is not required. The majority of smaller FTA-assisted projects, such as bus terminals and park-and-ride lots, will be eliminated from further consideration of ground-borne vibration impact in the first step. Screening Distances (Box B): If the result of the first step is that there is potential for vibration impact, determine if any vibration-sensitive land uses are within the screening zones. Vibration-sensitive land uses are identified in this report. Impact: If there are any vibration-sensitive land uses within the screening distances, there is the potential for vibration impact. The result of the screening procedure is that a General Vibration Assessment should be done as part of the environmental analysis.

4.2.2 Site Selection

In Ahmedabad, there exists so many Historic Buildings and Monuments. Among all of those monuments such as “SidiSaiyad Ni Jali”, “Julta-Minara”, “Hathi Singh Na Dera” and gates such as “Lal-Darvaja”, “Delhi-

Darvaja", etc exists in the heavy traffic area. These all historic buildings are the pride of Ahmedabad and INDIA.

Due to heavy traffic which is day by day increasing, it cause structural and cosmetic damage to the historic structure that is nearer to the heavy traffic area, so our work has to done analysis on those structure. We select few heritage structures where the traffic intensity is high.

4.2.3 Data Acquisition & Detail Analysis

Analysis of the heritage buildings has been done by special instrument "16 Channel Vibration Analyser". This instrument is attached with the sensors one is Uniaxial and another is Triaxial. These sensors are then put on the ground surface of building. The Uniaxial sensor collects data in only one direction and the triaxial sensor collects vibration data in three directions.The position of the uniaxial sensors are placed parallel to traffic and another normal to it.With the help of these sensors the Horizontal and Vertical Vibrations are collected.

4.3 Measurement and analysis of traffic vibration

For proper evaluation of the effect of building vibrations induced by road traffic, measured vibrations must be undistorted and data processing and analysis must follow established procedures. Instrumentation for the measurement of vibration signals, which usually includes vibration sensors, signal conditioners and recording equipment, should have sufficient resolution and sensitivity. Measurements should be made at locations where the vibration levels reflect the purpose of the evaluation.

To evaluate the effect of vibrations on a building, measurements should normally be made on the foundation or on the ground close to the building on the side facing the road. Vibration sensors should be mounted using methods that can faithfully transmit to the transducer the actual motion of the ground or building components over the frequency range of interest. If the mounting method is suspected of distorting the motion, alternative methods should be tested. The degree of detail required in the analysis of the vibration signals depends on the nature and purpose of the investigation. For a preliminary evaluation, it might be sufficient to find the peak of the vibration signal and to determine the predominant frequency of vibration by counting the number of negative and positive peaks in a given time interval.

These vibrations are in forms of Acceleration vs. Time Graph .These data will displayed through the Software "NVGATE" in computer screen which is attached to the Analyser.

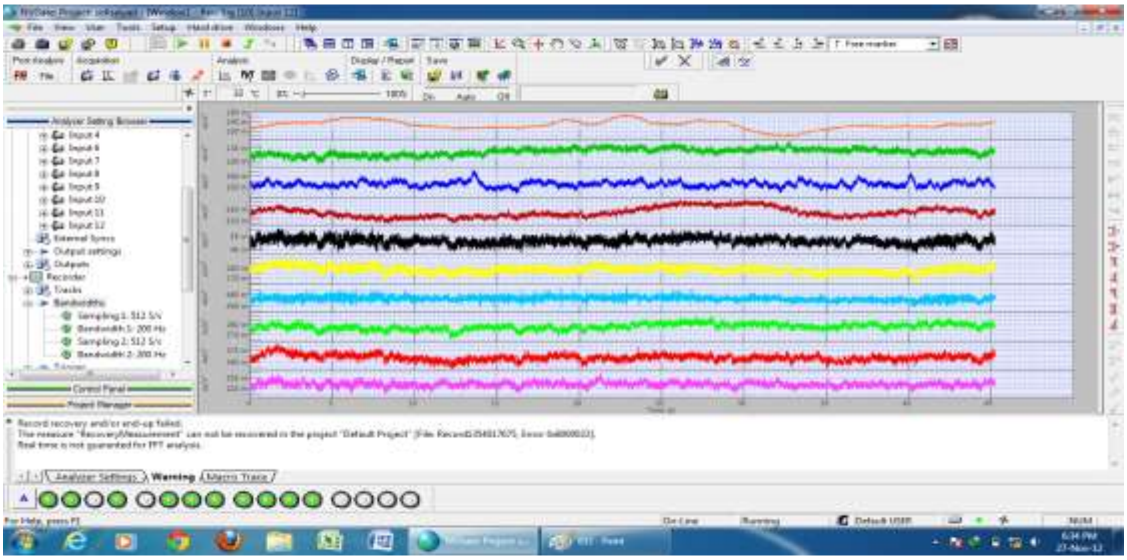


Fig 4: Acceleration Vs. Time Graph (Nvgate Software)

V. EQUATIONS

For Velocity (V)

eqn1

$$V = \frac{A1 + A2}{2} * dt$$

Where

V=Velocity

A1=Initial acceleration

A2=Final acceleration

dt = Time interval

VI. TABLE

6.1 Chae Building Vibration Criteria

Class	PPV (Single Blast) (in/sec)	PPV (Repeated Blast) (in/sec)
Structures of substantial construction	4	2
Relatively new residential structures in sound condition	2	1
Relatively old residential structures in poor condition	1	0.5
Relatively old residential structures in very poor condition	0.5	—

6.2 Swiss Association of Standardization Vibration Damage Criteria

Building Class	Continuous Source PPV (in/sec)	Single-Event Source PPV (in/sec)
Class I: buildings in steel or reinforced concrete, such as factories, retaining walls, bridges, steel towers, open channels, underground chambers and tunnels with and without concrete alignment	0.5	1.2
Class II: buildings with foundation walls and floors in concrete, walls in concrete or masonry, stone masonry retaining walls, underground chambers and tunnels with masonry alignments, conduits in loose material	0.3	0.7
Class III: buildings as mentioned above but with wooden ceilings and walls in masonry	0.2	0.5
Class IV: construction very sensitive to vibration; objects of historic interest	0.12	0.3

6.3 Konan Vibration Criteria for Historic and Sensitive Buildings

Frequency Range (Hz)	Transient Vibration PPV (in/sec)	Steady-State Vibration PPV (in/sec)
1–10	0.25	0.12
10–40	0.25–0.5	0.12–0.25
40–100	0.5	0.25

6.4Whiffen Vibration Criteria for ContinuousVibration

PPV (in/sec)	Effect on Buildings
0.4–0.6	Architectural damage and possible minor structural damage
0.2	Threshold at which there is a risk of architectural damage to normal dwelling houses (houses with plastered walls and ceilings)
0.1	Virtually no risk of architectural damage to normal buildings
0.08	Recommended upper limit of vibration to which ruins and ancient monuments should be subjected
0.006–0.019	Vibration unlikely to cause damage of any type

6.5Siskind Vibration Damage Thresholds

	PPV (in/sec)			
Damage Type	5% Probability	10% Probability	50% Probability	90% Probability
Threshold damage: loosening of paint, small plaster cracks at joints between construction elements	0.5	0.7	2.5	9.0
Minor damage: loosening and falling of plaster, cracks in masonry around openings near partitions, hairline to 3-mm (0–1/8-in.) cracks, fall of loose mortar	1.8	2.2	5.0	16.0
Major damage: cracks of several mm in walls, rupture of opening vaults, structural weakening, fall of masonry, load support ability affected	2.5	3.0	6.0	17.0

6.6 AASHTO Maximum Vibration Levels for Preventing Damage

(The American Association of State Highway and Transportation Officials)

Type of Situation	Limiting Velocity (in/sec)
Historic sites or other critical locations	0.1
Residential buildings, plastered walls	0.2–0.3
Residential buildings in good repair with gypsum board walls	0.4–0.5
Engineered structures, without plaster	1.0–1.5

VII. CONCLUSION

Studies were carried out at different historical heritages likeSIDI SAIYAD NI JALIASTODIYA GATE, RAIPUR GATE, DELHI DARWAJA, USMANPURA TOMB .From study of different vibration criteria we used 3mm/s (0.12in/sec) max. ppv value as a safe limit criteria for historical and fragile buildings for continuous traffic vibration. There is general agreement that peak particle velocity* should be less than 2.0 in./sec (50 mm/s). . From results we can say that historical structures where testing has been done are safe from structural & architectural damage due to traffic vibration. But, due to traffic vibration, cosmetic damage to these historical structures is possible.

REFERENCES

[1] BS 5228-2:2009, "*Code of practice for noise and vibration control on construction and open sites, Part 2: Vibration*".

[2] FTA Manual, "*Transit noise and vibration impact assessment"*, May-2006.

[3] HaridayalJaiswal, *"Analysis of micro-vibrations in buildings",* 2007.

[4] Jones & Stokes, *"Transportation- and Construction-Induced Vibration Guidance Manual"*, June-2004.

[5] Konon Walter and Schuring John R., Members, ASCE, "*Vibration criteria for HISTORIC buildings".*

[6] Osama Hunaidi, *"Traffic Vibrations in Buildings",* June-2000.

[7] Rainer J.H. *"Effects of Vibrations on HISTORIC Buildings"*, DBR Paper No-1091.

[8] BS 7385-1 1990, *"Evaluation and measurement for vibration in buildings" (Part 1: Guide for measurement of vibrations and evaluation of their effects on buildings)".*

[9] BS 7385-2 1993 Part 2: *"Guide to damage levels from ground born vibration".*

[10] Garg Naveen and Sharma Omkar, *"Investigations on transportation induced ground vibrations"* Proceedings of 20th International Congress on Acoustics, ICA 2010 23-27 August 2010, Sydney, Australia.

[11] Hume Ian, *"Road traffic vibration on historic buildings".*

[12] 12 Jia Y.X, Liu W.N, LIU W.F, ZHANG H.G, *"Study of vibration effects on historic buildings due to moving trains in beijing".*

[13] 13 ERKAL Aykut, LAEFER Debra, FANNING Paul,DURUKALEser, HANCILAR Ufuk5,e and KAYA Yavuz*"Investigation of the Rail-induced Vibrations on a Masonry Historical Building".*