TECHNICAL REPORT

Indigenous Photonic Technologies for Bridge Health Monitoring

Technology Demonstration on NH-16, NHAI Bridge at Tagarapuvalsa on Gosthani River, Visakhapatnam

by

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The responsibility of the author is only limited to the technical content of this report. The author is not responsible for any consequential effects, due to usage of the contents of this report.

EXECUTIVE SUMMARY

Indigenous photonic systems and technologies designed and developed by Prof. Rao Tatavarti at Visakhapatnam have a wide range of applications in the civilian as well as defence domains.

The systems have many advantages compared to the commercially available conventional systems and have superior sensitivities.

The systems and technologies are now in a mature stage, after undergoing rigorous testing and evaluations as per standard procedures in the laboratory and the field.

Two of the systems - VEDA and VIDUR, have applications in vibration and condition monitoring, in addition to structural health monitoring. These systems attracted the attention of the Ministry of Railways, and the Ministry of Road Transport and Highways, Government of India due to their potential applications pertaining to both the ministries.

Field evaluation trials for these were conducted on the KK Line, under the Waltair Division of East Coast Railway for the Ministry of Railways and at the NHAI Road Bridge on NH16, Visakhapatnam for the Ministry of Road Transport and Highways.

This report details the successful technology demonstration of VEDA and VIDUR, conducted on February 18, 2017 at Visakhapatnam, on a live road bridge in the presence of the Director General and Special Secretary of MORTH (Ministry of Road Transport and Highways), Govt. of India.

http://www.thehindu.com/news/cities/Visakhapatnam/now-get-updated-on-health-of-structures/article17328904.ece

Technology Demonstration of Indigenous Photonic Technologies – VEDA and VIDUR

Project Team for Technology Demonstration on February 18, 2017, Visakhapatnam.

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DG & Special Secretary of MORTH, Government of India has witnessed the Technology Demonstration. In addition to Director General and Special Secretary of MORTH, GOI other Senior Officers and Engineers from MORTH, NHAI and IBMS were present. Senior Correspondent and Photographer, from THE HINDU National Newspaper were also present. The report had later appeared in THE HINDU.

Prologue
The Ministry of Road Transport and Highways, Government of India desired the technology demonstration on a live NHAI maintained National Highway bridge identified under the aegis of IBMS Program of the Ministry. Accordingly, IBMS at Visakhapatnam identified an active bridge on the NH16 for demonstration of the novel photonic technologies developed by Prof. Rao Tatavarti, Visakhapatnam. The indigenous technologies have been successfully demonstrated **to Director General and Special Secretary, MORTH,** a team of personnel from NHAI Project Office and the representatives of IBMS on February 18, 2017 at Visakhapatnam. This report outlines all the pertinent technical details and the capabilities of the novel indigenous technologies, which can be beneficial to MORTH, GOI.

NHAI Old Bridge on River Gosthani, Tagarapuvalasa, Visakhapatnam
Old Bridge on Gosthani River at Tagarapuvalasa is a girder type reinforced concrete (RC) bridge located at 17^0 56'19''N and 83^0 25'17.1''E spanning over the Gosthani River in Tagarapuvalasa, Visakhapatnam, Andhra Pradesh, India. The bridge is aligned in the North-South direction at an angle of 345^0 to the North. The location of the bridge is about 40*km* from Visakhapatnam Airport. The bridge has a reinforced concrete construction having 12 spans with varying length (2 spans of 8*m* length, 2 spans of 30*m* length and 8 spans of 26.5*m* length) having an overall length of 288*m***.** The bridge is open to one way with two lanes having a total width of 7.5*m***.**

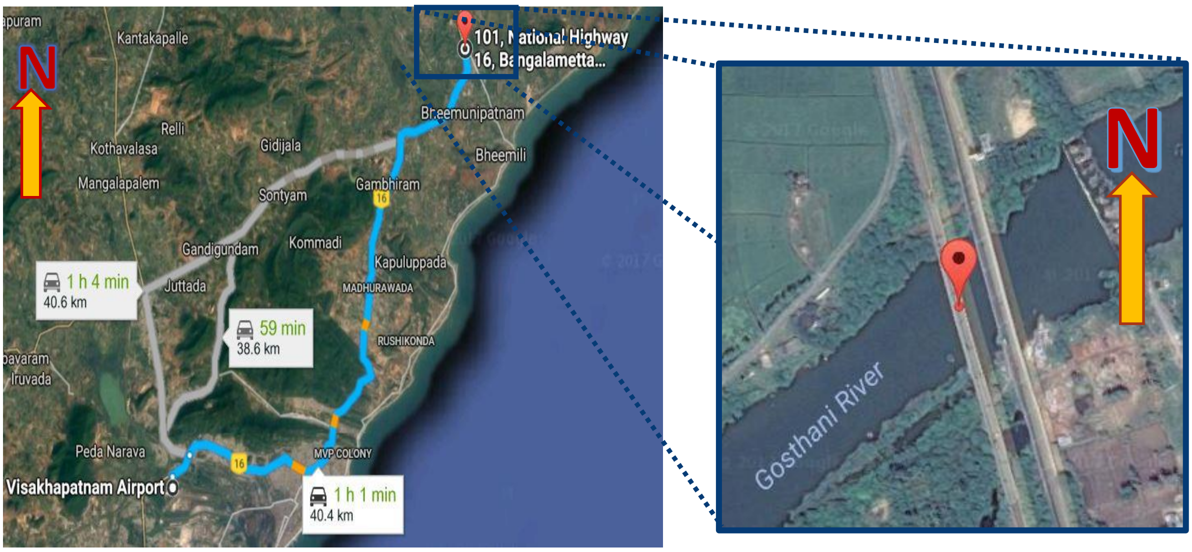
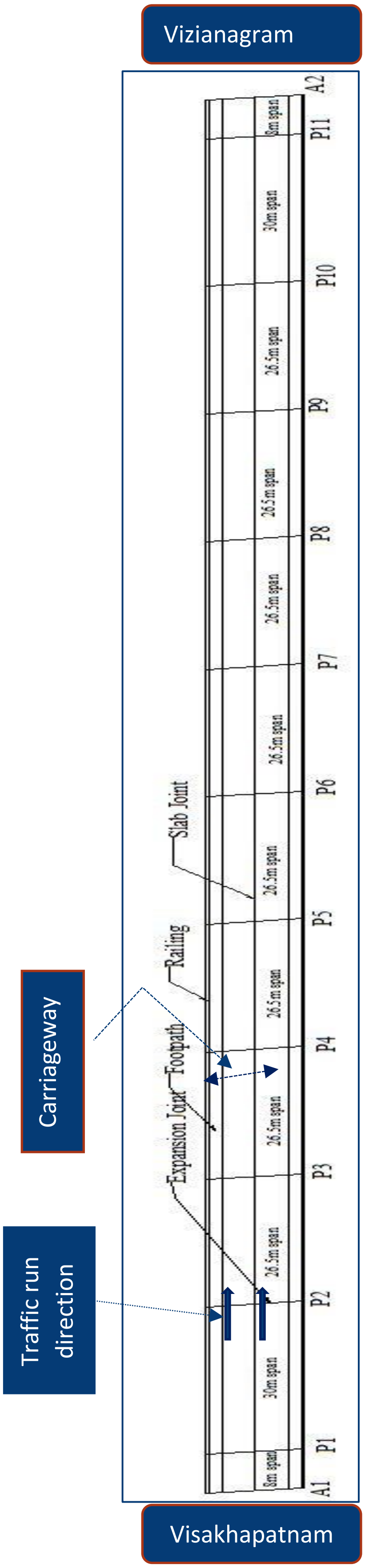


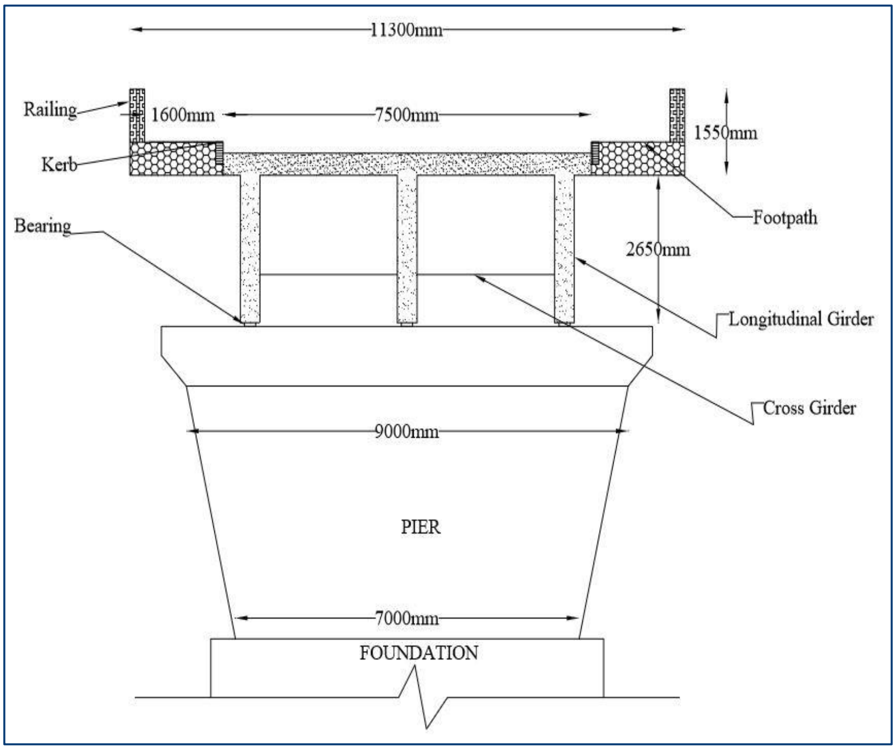
Figure 1: Location of the bridge with reference to Visakhapatnam airport and the alignment of bridge with true North.


Figure 2: Old Bridge on Gosthani River at Tagarapuvalasa, NH-16, Visakhapatnam.

Plan and Cross-Sectional Views of the Bridge



Plan View of Bridge



Cross-Section view of Bridge

A – Abutment P – Pier

Figure 3: Plan and Cross section views of Bridge.

Components of Bridge

Superstructure						
Components	**Material**	**Shape**	**Number**	**Visual Damage**	**Accessibility**	**Remarks**
Pavements	Cement Concrete.		2 lanes, one-way traffic.	Yes	Yes	Some cracks are visible across the width of the road
Slabs	Reinforced Concrete slab blocks	Rectangular	2 numbers for each span.	Partially damage	Yes	
Footpaths	Reinforced Concrete slab blocks	Rectangular	1 number on each side of the carriageway	Yes	Yes	Portions of footpath were missing completely
Railings	Bricks and reinforced concrete	Rectangular	1 on each side of the pavement	No	Yes	
Longitudinal Girders	Reinforced Concrete	I-Section	3 numbers in each span	No	No	
Cross Girders	Reinforced Concrete	Rectangular	7 numbers in each span	No	No	
Bearings	Neoprene	Rectangular	4 numbers.at abutment, and 8 numbers.at pier	Yes	Partially Accessible	Uneven and Non uniform contacts between bearings and girders
Substructure						
Piers	Reinforced Concrete	Trapezoidal	11 numbers for overall span of bridge	No	Partially Accessible	
Abutments	Rock filled	Triangular	2 numbers, one on each end	No	Partially Accessible	
Foundation						
Pile Foundations	Reinforced concrete	Circular	1 at each pier location	No	No	Submerged in the river water and are at inaccessible locations. Masked with a layer of soil at the accessible locations

Table 1: Components of the Old NHAI Bridge at Tagarapuvalasa, NH 16, Visakhapatnam.

Visual Inspection of Bridge

SUPERSTRUCTURE

Pavement: Reinforcement Cement Concrete type Slab. Some of the expansion joints were damaged and filled by large amount of bituminous material. Whenever heavy vehicles passed over the bridge, large amplitude vibrations were observed, which were also a function of the speed of the vehicle. Larger Vibrations were observed at the center of each span than at the location above the support. Some cracks were visible on the pavement along the width of the road

Footpath: A footpath of width 1.5*m* was provided on each side of the pavement, along with the railings and posts. The footpath on one side of the bridge was damaged with several concrete slabs either damaged or missing completely exposing the soil beneath. In addition to the pedestrians on footpaths, two-wheeler vehicular traffic was common. Large amplitude vibrations were felt on footpaths when heavy vehicles passed on the bridge.

Figure 4: Traffic runs from Visakhapatnam to Vizianagram on Tagarapuvalasa Bridge.

Longitudinal Girders: Girders supporting the pavement along the length or span of bridge were concrete I-section members. They were 3 longitudinal girders spaced 2.5*m* apart. No visible damages were observed.

Figure 5: Longitudinal Girders of the bridge.

Cross Girders: Girders placed perpendicular to length of the bridge were rectangular members with lesser depth than that of longitudinal girders. There were 7 cross girders in each span. Cross girder at support were in 'A' shape geometry. No damage was observe on the cross girders.

Figure 6: Cross Girders of the bridge.

Bearings: Bearings - the structures for load transferring mechanism between longitudinal girders and piers – were observed to be Neoprene sheets providing a hinge support. At abutments, three bearings, and at piers six bearings were observed to provide the support. Bearings at abutments were inaccessible. However, wear and tear of bearings was evident from a distance.

Figure 7: Bearing on Pier showing non-uniform contact.

SUBSTRUCTURE

__Piers__: Piers - the supports provided above the foundation where the load from above is transferred to the foundation below through the bearing, were oval type in cross- section, trapezoidal shape in longitudinal section with a width of 7*m* at base and of 9*m* at top of pier having a depth of 4.5*m*. There were no visible damages on piers.

__Abutments__: Abutments - the supports placed to support the soil, and for transferring loads to the ground, were rock filled triangular type. These are at both ends of the bridge. These are partially visible, partially accessible and with no visible cracks.

Figure 8: Piers of the bridge submerged in River

FOUNDATION

Foundation - the structure to transfer the load to the ground, were observed to be underwater and undersoil. Pile foundations were observed having a diameter of approximately 8*m.*

Figure 9: Pile Foundations of the Bridge

Dynamic Response of Bridge to Moving Vehicles

The behaviour of highway bridges under the passage of heavy vehicles has been the subject of numerous investigations since the early 1950s. Numerous attempts to correlate the dynamic response of a bridge to a single bridge characteristic - *either the span length or the fundamental frequency* - were unsuccessful in the real world scenario. Vibrations of a bridge resulting from the passage of live loads across the span is an important consideration in design, because a vehicle moving across a bridge at a normal speed produces greater stresses than a vehicle that remains in a static position on the structure. The increase in stresses is often referred to as the amplification of the dynamic effect. However, dynamic effect may also refer to the amplification of deflections, shears: or reactions. The term commonly used to specify dynamic effect, is impact. Paultre and Proulx (1992) stressed that although the dynamic amplification factor is an important parameter in the design of highway bridges, there is no consensus so far as its value is concerned. Moreover, disagreement exists between provisions of various national bridge codes. This is because the dynamic amplification factor depends, in addition to the maximum span or the natural frequency, on many other parameters that are difficult to take into account with reasonable accuracy. Vehicle speed, weight, and dynamic characteristics, the state of the structure, roadway roughness, expansion joints, the type of bridge supports, soil-structure interaction, and influence of secondary elements are some aspects influencing the dynamic amplification factor.

The dynamic response of a bridge to moving vehicles is known to be a function of the following (Deng, 1998):

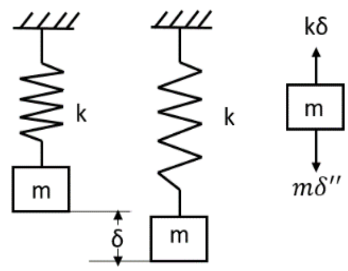
1. Dynamic characteristics of the vehicle, such as suspension stiffness and damping
2. The speed, weight, and type of the vehicle
3. Bridge characteristics such as damping and natural frequencies of vibration;
4. Surface roughness of the approach roadway and bridge deck
5. Traffic intensity
6. Braking and acceleration of the vehicle.

Structural engineers now understand that the interaction between the vehicles and the bridge significantly affects the dynamic characteristics of the bridge in different ways. First, the dynamic nature of the response amplifies the deflections and stresses induced in the bridge structure. Second, the vibrations induced by dynamic interaction may have adverse psychological effect on the pedestrians using the bridge. Based on the analytical investigations of the responses of a simplified beam model traversed by a moving mass, various researchers identified many different governing parameters. However, additional studies are still required to understand the dynamic characteristics of skew bridges and multispan bridges to moving vehicles (loads). *Thus, in spite of a number of analytical and experimental investigations on the dynamic response of bridges to moving vehicle loads, the controlling parameters that govern the response, have not been clearly identified. This has in turn, inhibited the development of rational design procedures and appropriate codes of standards for practicing engineers.*

However, in the absence of sophisticated analytical modelling, we attempt to gain the basic dynamic response characteristics from simplified fundamental bridge characteristics (*following*, Krishna Raju, 2010; IRC 6-2014; British Standards BS117, BS5400).

Determination of Natural Frequencies – Fundamental Principles

When we consider a spring-mass system suspended from a fixed support with mass "m" suspended using spring of stiffness "k". The natural frequency of this system is given by,



$$N_f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

From the equation of motion, we get,

$$k\delta = mg$$

i.e. $\frac{k}{m} = \frac{g}{\delta}$

Therefore, $N_f = \frac{1}{2\pi}\sqrt{\frac{g}{\delta}}$

From Young, W.C. and Budnyas, R.G. (Seventh Edition- 2001). Roark's formulas for stress and strain, McGraw-Hill Companies, Inc. p-765.

For simply supported beam with stiffness "k" and with uniform loading of "w", N/m including the self-weight of the structure,

$$N_f = \frac{k_n}{2\pi}\sqrt{\frac{EIg}{wl^4}}$$

Where, N_f is the natural frequency of the structure.

k_n is the constant where n represents the mode of vibration given as,

Mode	k_n
1	9.87
2	39.5
3	88.8
4	158
5	247

E is the modulus of elasticity of the material of the structure (in *N/m²*)

I is the moment of inertia of the structure (in m^4)

g is the acceleration due to gravity (in m/s^2)

w is the weight per *m* of the structure (in *N/m*)

l is the span (in *m*)

Dimensional Analysis of formula of frequency,

$$N_f = \sqrt{\frac{[MLT^{-2}L^{-2}][L^4][LT^{-2}]}{[MLT^{-2}L^{-1}][L^4]}} = [T^{-1}]$$

Considering the *first mode* of vibration where k_n=9.87

$$N_f = \frac{9.87}{2\pi}\sqrt{\frac{EIg}{wl^4}}$$

$$N_f = \frac{1.57}{l^2}\sqrt{\frac{EIg}{w}}$$

Considering the *second mode* of vibration where k_n=39.5

$$N_f = \frac{39.5}{2\pi}\sqrt{\frac{EIg}{wl^4}}$$

$$N_f = \frac{6.28}{l^2}\sqrt{\frac{EIg}{w}}$$

Considering the *third mode* of vibration where k_n=88.8

$$N_f = \frac{88.8}{2\pi}\sqrt{\frac{EIg}{wl^4}}$$

$$N_f = \frac{14.13}{l^2}\sqrt{\frac{EIg}{w}}$$

Considering the *fourth mode* of vibration where k_n=158

$$N_f = \frac{158}{2\pi}\sqrt{\frac{EIg}{wl^4}}$$

$$N_f = \frac{25.15}{l^2}\sqrt{\frac{EIg}{w}}$$

Considering the fifth mode of vibration where k_n=247

$$N_f = \frac{247}{2\pi}\sqrt{\frac{EIg}{wl^4}}$$

$$N_f = \frac{39.31}{l^2}\sqrt{\frac{EIg}{w}}$$

COMPUTATIONAL FLOW CHART

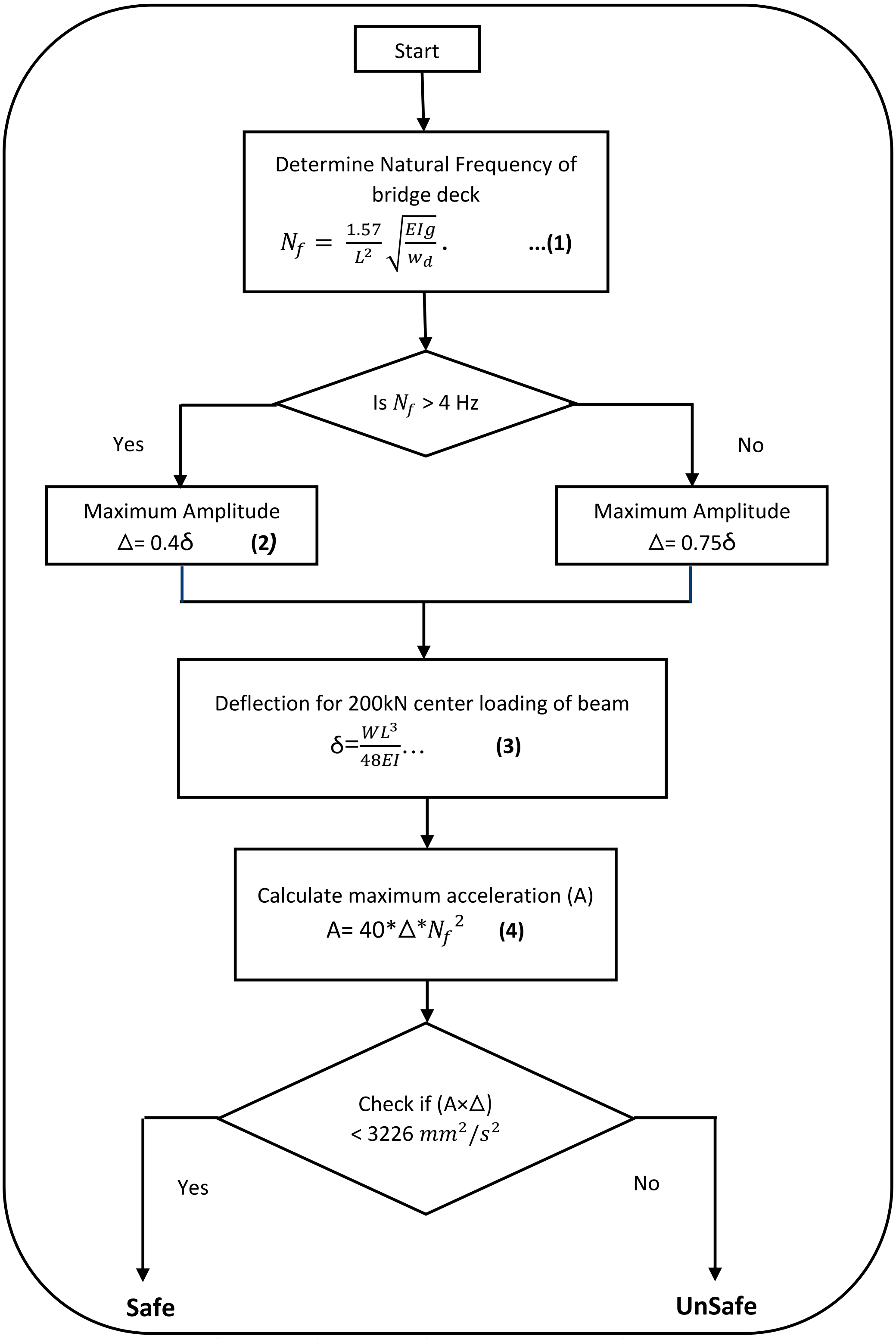


Table 2: Computational flow chart for design of dynamic response of bridges to moving loads.

Dynamic response of bridge

Step **(1)**: Determine the natural frequency, $N_f = \frac{1.57}{L^2}\sqrt{\frac{EIg}{w_d}}$

where,

L is the span of bridge
EI is flexural rigidity (in kNm^2)
E is the modulus of elasticity of concrete
I is the moment of inertia
g is the acceleration due to gravity (i.e. 9.81m/s^2)
w_d dead weight of deck with floor finish

Step **(2)**: Determine the maximum amplitude, (Δ)

where,

Δ = 0.4; for N_f> 4 cycles per second
Δ = 0.75; for $N_f < 4$ cycles per second

Step **(3)**: Determine the maximum deflection, δ;
Assuming 200kN acting at center of span calculated as δ= $\frac{WL^3}{48EI}$,

where,

L is the span of bridge
EI is flexural rigidity (in kNm^2)
E is the modulus of elasticity of concrete
I is the moment of inertia
W is 200kN load acting on centre of span

Step **(4)**: Determine the maximum acceleration (A) = 40 Δ N_f^2

where,

Δ is maximum amplitude
N_f is natural frequency of bridge slab

Calculations for Old Bridge on Gosthani River

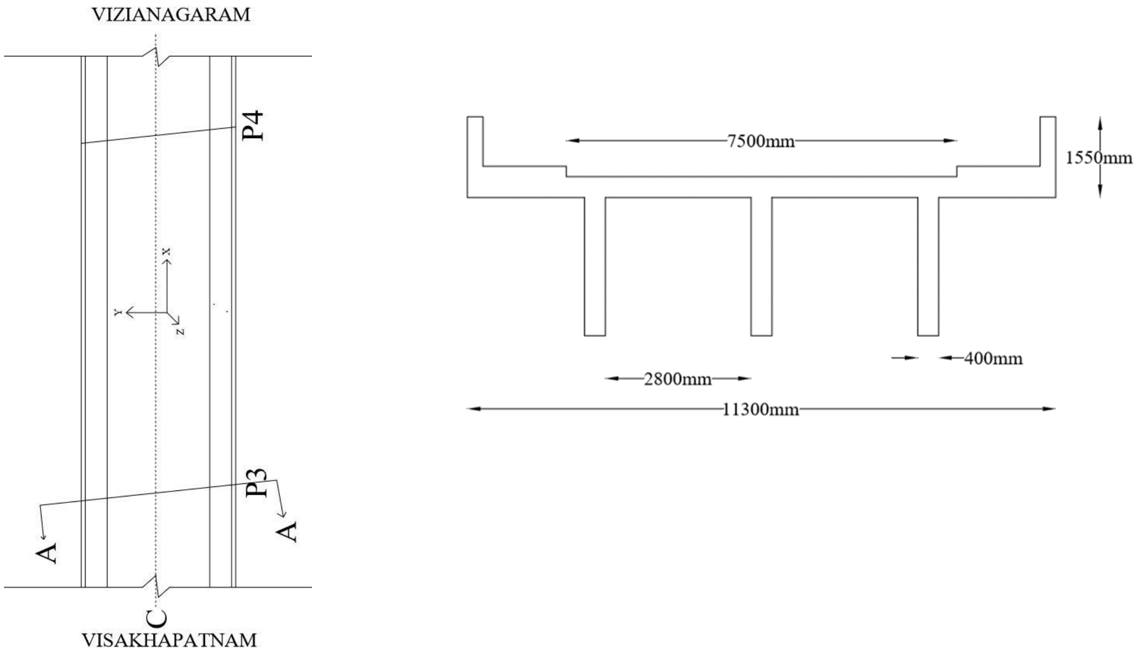


Figure 10: Plan of the bridge with axes of notation and the bridge Section

Section Properties

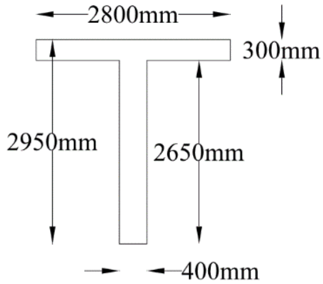


Figure 11: T-section of longitudinal girder of bridge

Assumptions made for the calculations
:

- *The slab thickness of bridge deck was assumed 300mm and wearing coat of 80mm over it.*
- *The grade of concrete was assumed M25.*
- *The longitudinal girders were assumed to be of T-girders with slab resting on the rectangular sections, which is not the case. Actually, the longitudinal girders are I- section in nature.*
- *Flexural stiffness of bridge was assumed to be provided only by the slab deck and the longitudinal girders.*
- *The 3 longitudinal girders with slab were considered to be of same properties.*
- *The dead load on bridge deck was based on assumptive calculations.*
- *For calculation of maximum amplitude, the point load of 200kN was assumed to act at center of span of bridge.*
- *The self-weight for dead weight calculation was taken as weight of reinforced concrete, etc.*
- *Weight of parapet, railing posts, etc. was taken as lump sum weight.*
- *Calculations about horizontal and vertical axes were based on same assumptions.*
- *Other dimensions of bridge were taken from above figure*
- *Modulus of elasticity of concrete (E) = 5000*$\sqrt{fck}$ *= 5000*$\sqrt{25}$ *=25000*N/mm^2

Numerical Calculations for Gosthani Bridge

- Bridge slab of 300mm depth
- Effective span 30m and 26.5m
- M25 Grade of concrete used
- Other dimensions of bridge are taken from figure

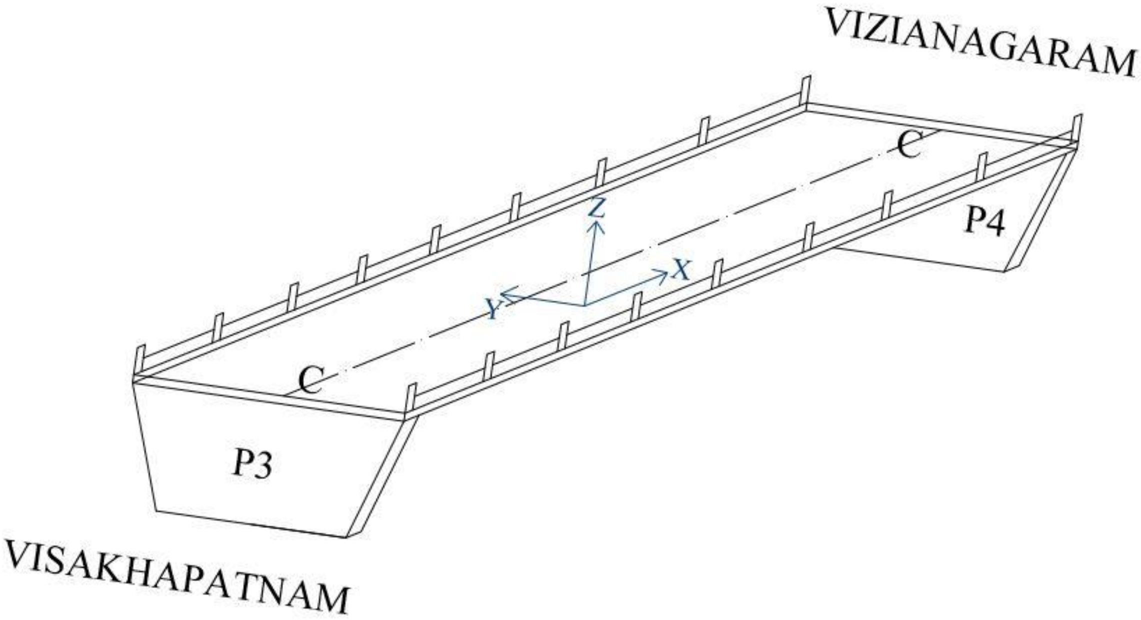


Figure 12: Isometric view of the bridge with axis of notation

Three T- Girder beams supporting the bridge deck weight,

Centroid of T-beams= $\frac{\sum a_i z_i}{\sum a_i}$

Where, a_i = area of i^{th} section

z_i = centroid of the i^{th} section from top of the bridge deck

$=\frac{2800*300*150+2650*400*1625}{2800*300+2650*400}$

=973mm from top

Horizontal Moment of inertia (I_{yy}) = $\sum \frac{b_i d_i^3}{12} + a_i h_i^2$

Where, b_i= width of the ith section

d_i= depth of the ith section

h_i= distance between the centroid of structure and centroid of ith section

$I_{yy} = \frac{2.8*0.3^3}{12} + 2.8*0.3*0.823^2 + \frac{0.4*2.65^3}{12} + 0.4*2.65*0.652^2$

= $1.65m^4$

Effective Moment of Inertia= $3*I_{yy}$= 3*1.65 = $4.95m^4$

Flexural Rigidity= EI_{yy} = $25 * 10^6 * 4.95$

= $123.25 * 10^6 kNm^2$

From IRC: 6-2014,

For the design of 2 lane bridges with carriageway width between 5.3m and 9.6m, either one lane of class 70R or two lanes of class-A vehicles,

Considering two class-A vehicles at the center of the span,

Load of each vehicle is taken as 40 and 60 tones i.e. the total weight acting at center of span is 80 and 120 tones and also another line of these vehicles moving in tandem.

Actual Loads on the bridge girders,

Self-weight of deck slab= 0.3*11.3*25 = 84.75kN/m

Weight of wearing coat= 0.08*7.5*22 = 13.2kN/m

Self-weight of four girders= 3*0.4*2.65*25 = 79.5kN/m

Self-weight of cross girders= 12kN/m

Assumed weight of parapet/railings, etc. = 10.55kN/m

Now,

Natural Frequency of vibration (N_f) = $\frac{1.57}{L^2}\sqrt{\frac{EI_{yy}g}{w_d}}$

Where,

L= Span of bridge = 26.5m

EI_{yy}= Flexural Rigidity = $123.25 * 10^6 kNm^2$

g = acceleration due to gravity = $9.81 m/s^2$

w_d = Total weight on the girders = 200kN/m

Again, for span of 26.5m, along y-axis of bridge,

$\boldsymbol{N_f} = \frac{1.57}{26.5^2}\sqrt{\frac{123.25*10^6*9.81}{200}}$ = **5.49 cycles/second**

Deflection for 200kN load at center of beam,

$\delta_z = \frac{WL^3}{48EI_{yy}}$

Here,

W= Point Load = 200kN

L=Span of bridge =26.5m

EI_{yy}= Flexural Rigidity = $123.25 * 10^6 kNm^2$

Therefore,

$\delta_z = -\frac{200*26.5^3}{48*123.25*10^6} = -6.29 * 10^{-4} m = -0.629mm$

Maximum Amplitude of vibration (Δ),
Since N_f >4 cycles per second

Δ =0.40δ_z

Here, Deflection is taken for 200kN point load at center of beam as 0.629mm

Therefore, Δ= 0.4*0.629 = 0.25mm

Now, For Dynamic Response,

Maximum acceleration (A)is given by,

A= 40 Δ N_f^2

where, Δ= Maximum Amplitude of vibration = 0.25mm

N_f= Natural Frequency of vibration = 7 cycles per second

Therefore A= 40*0.25*5.49^2 = 301.4mm/s^2

Also, (A*Δ)= 301.4*0.58 = 174.81mm^2/s^2 which is less than 3226mm^2/s^2. Hence safe.

Deflection for 800kN load at center of beam,

$\delta_z = -\frac{800*26.5^3}{48*123.25*10^6} = -2.51 * 10^{-3} m = -2.51mm$

Maximum Amplitude of vibration (Δ),
Since N_f >4 cycles per second

Δ =0.40δ_z

Here, Deflection for 200kN point load at center of beam is taken as 2.51mm

Therefore, Δ= 0.4*2.51 = 1.004mm

Now, For Dynamic Response,

Maximum acceleration (A) is given by,

A= 40 Δ N_f^2

Where, Δ= Maximum Amplitude of vibration = 1.004mm

N_f= Natural Frequency of vibration = 5.49 cycles per second

Therefore A= 40*1.004*5.49^2 = 1210.43mm/s^2

Also, (A*Δ)= 1210.43*1.004 = 1215.27mm^2/s^2 which is less than 3226mm^2/s^2.

Deflection for 1200kN load at center of beam,

$$\delta_z = -\frac{1200*26.5^3}{48*123.25*10^6} = -3.77*10^{-3}m = -3.77mm$$

Maximum Amplitude of vibration (Δ),
Since N_f >4 cycles per second

Δ =0.40δ_z

Here, Deflection for 1200kN point load at center of beam is taken as 3.77mm

Therefore, Δ= 0.4*3.77 = 1.508mm

Now, For Dynamic Response,

Maximum acceleration (A)is given by,

A= 40 Δ N_f^2

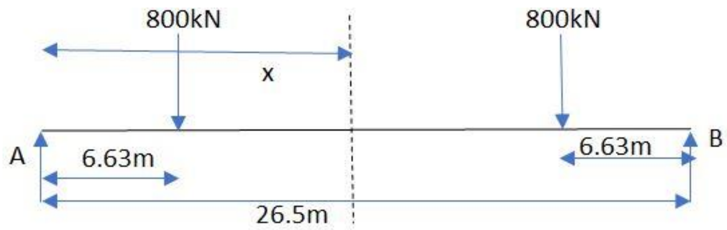
where, Δ= Maximum Amplitude of vibration = 1.508mm

N_f= Natural Frequency of vibration = 5.49 cycles per second

Therefore A= 40*1.508*7^2 = 1818.05mm/s^2

Also, (A*Δ)= 1818.05*1.508 = 2741.62mm^2/s^2 which is less than 3226mm^2/s^2.

Deflection for two 800kN load in tandem on beam,



Bending moment equation $M = 800x - 800(x - 6.63)$

From bending theory $\frac{\mathrm{M}}{\mathrm{I}} = \frac{\sigma}{\delta_z} = \frac{\mathrm{E}}{\mathrm{R}}$

$\mathrm{M} = \text{Bending moment}$

$\mathrm{I} = \text{Moment of inertia}$

$\sigma = \text{Bending stress}$

$\delta_z = \text{distance of extreme fiber from N.A}$

$\mathrm{E} = \text{Youngs modulus}$

$\mathrm{R} = \text{Radius of curvature}$

$\frac{\mathrm{EI}}{\mathrm{R}} = \mathrm{M};\ \ \text{Curvature}\left\{\frac{1}{\mathrm{R}}\right\} = \frac{\mathrm{d}^2\delta_z}{\mathrm{dx}^2}$

From above equations

$$EI\frac{d^2\delta_z}{dx^2} = M$$

$$EI\frac{d^2\delta_z}{dx^2} = 800x - 800(x - 6.63)$$

Applying integration on both sides,

$$\int EI\frac{d^2\delta_z}{dx^2} = \int (800x - 800(x - 6.63))dx$$

$$EI\frac{d\delta_z}{dx} = 5304x + C_1$$

Again, applying integration on both sides,

$$\int EI\frac{d\delta_z}{dx} = \int (5304x + C_1)$$

$$EI\delta_z = \frac{5304 * x^2}{2} + C_1x + C_2$$

Applying boundary conditions @ $x = 0\ ;\ \delta_z = 0$

$$C_2 = 0$$

Applying boundary conditions @ $x = l/2\ ;\ \frac{d\delta_z}{dx} = 0$

$$5304x + C_1 = 0$$

$$C_1 = -5304x$$

To get Maximum deflection i.e. at center substitute $x = \frac{l}{2} = \frac{26.5}{2} = 13.25$m in deflection equation

$$EI\delta_z = 5304 * \frac{13.25^2}{2} + (-5304 * 13.25)$$

$$EI\delta_z = 395313.75$$

$$\delta_z = -\frac{395313.75}{25 * 10^6 * 4.95}$$

$\text{Deflection}(\delta_z) = -3.19\text{mm}$ ($-$ve indicates downward deflection)

Maximum Amplitude of vibration (Δ),

Since N_f >4 cycles per second

Δ =0.40δ_z

Here, Deflection for 800kN load in tandem is taken as 3.19 mm

Therefore, Δ= 0.4*3.19 = 1.276 mm

Now, For Dynamic Response,

Maximum acceleration (A)is given by,

A= 40 Δ N_f^2

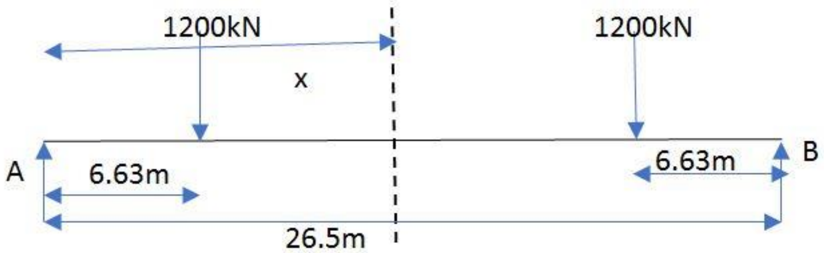
Where, Δ= Maximum Amplitude of vibration = 1.276mm

N_f= Natural Frequency of vibration = 5.49 cycles per second

Therefore A= 40*1.276*5.49^2 = 1538.35mm/s^2

Also, (A*Δ)= 1538.35*1.276 = 1962.93mm^2/s^2 which is less than 3226mm^2/s^2.

Deflection for two 1200kN load in tandem on beam,



Bending moment equation at distance x from support A,

$M_x = 1200x - 1200(x - 6.63)$

$$From\ bending\ theory \frac{M}{I} = \frac{\sigma}{\delta_z} = \frac{E}{R}$$

$M = Bending\ moment$

$I = Moment\ of\ inertia$

$\sigma = Bending\ stress$

$\delta_z = distance\ of\ extreme\ fiber\ from\ N.A$

$E = Youngs\ modulus$

$R = Radius\ of\ curvature$

$$\frac{EI}{R} = M;\ \ Curvature \left\{\frac{1}{R}\right\} = \frac{d^2\delta_z}{dx^2}$$

From above equations

$$EI\frac{d^2\delta_z}{dx^2} = M$$

$$EI\frac{d^2\delta_z}{dx^2} = 1200x - 1200(x - 6.63)$$

Applying integration on both sides,

$$\int EI\frac{d^2\delta_z}{dx^2} = \int (1200x - 1200(x - 6.63))dx$$

$$EI\frac{d\delta_z}{dx} = 7956x + C_1$$

Again, applying integration on both sides,

$$\int EI\frac{d\delta_z}{dx} = \int (7956x + C_1)$$

$$EI\delta_z = \frac{7956 * x^2}{2} + C_1x + C_2$$

Applying boundary conditions @ $x = 0\,;\,\delta = 0$

$$C_2 = 0$$

Applying boundary conditions @ $x = l/2\,;\,\frac{d\delta}{dx} = 0$

$$7956x + C_1 = 0$$

$$C_1 = -7956x$$

To get Maximum deflection i.e. at center substitute $x = \frac{l}{2} = \frac{26.5}{2}$ = 13.25m in deflection equation

$$EI\delta_z = 7956 * \frac{13.25^2}{2} + (-7956 * 13.25)$$

$$EI\delta_z = 592970.63$$

$$\delta_z = -\frac{592970.63}{25 * 10^6 * 4.95}$$

$\text{Deflection}(\delta_z) = -4.79\text{mm}$ (−ve indicates downward deflection)

Maximum Amplitude of vibration (Δ),

Since N_f >4 cycles per second

$\Delta = 0.40\delta_z$

Here, Deflection for 1200kN point load in tandem on beam at center is taken as 4.79 mm

Therefore, Δ= 0.4*4.79 = 1.916 mm

Now, For Dynamic Response,

Maximum acceleration (A)is given by,

A= 40 Δ N_f^2

Where, Δ= Maximum Amplitude of vibration = 1.916mm

N_f= Natural Frequency of vibration = 5.49 cycles per second

Therefore A= 40*1.916*5.49^2 = 2309.94mm/s^2

Also, (A*Δ)= 2309.94*1.916 = **4425.85**mm^2/s^2 which is more than 3226mm^2/s^2.

Considering z-axis of bridge for 26.5m span,

$I_{zz} = \frac{8.4*0.3^3}{12} + \frac{0.4*2.65^3}{12} + 0.4 * 2.65 * 3.2^2 + \frac{0.4*2.65^3}{12} + \frac{0.4*2.65^3}{12} + 0.4 * 2.65 * 3.2^2$

= 23.59m^4

Therefore, $N_f = \frac{1.57}{26.5^2}\sqrt{\frac{589.75*10^6*9.81}{200}}$ = 12.02 cycles/second

Deflection for 200kN load at center of beam,

$\delta_y = -\frac{200*26.5^3}{48*589.75*10^6} = -1.31 * 10^{-4}m = -0.131mm$

Maximum Amplitude of vibration (Δ),
Since N_f >4 cycles per second

Δ =0.4δ_y

Here, Deflection for 200kN point load at center of beam is taken as 0.131mm

Therefore, Δ= 0.4*0.131 = 0.052 mm

Now, For Dynamic Response,

Maximum acceleration (A)is given by,

A= 40 Δ N_f^2

Where, Δ= Maximum Amplitude of vibration = 0.052mm

$\boldsymbol{N_f}$= Natural Frequency of vibration = **12.02 cycles per second**

Therefore A= 40*0.052*12.02^2 = 300.52 mm/s^2

Also, (A*Δ)= 300.52*0.052 = 15.63 mm^2/s^2

Deflection for 800kN load at center of beam,

$$\delta_y = -\frac{800*26.5^3}{48*589.75*10^6} = -5.26*10^{-4}m = -0.526mm$$

Maximum Amplitude of vibration (Δ),

Since N_f >4 cycles per second

$\Delta = 0.40\delta_y$

Here, Deflection for 800kN point load at center of beam is taken as 0.526mm

Therefore, Δ= 0.4*0.526 = 0.21mm

Now, For Dynamic Response,

Maximum acceleration (A) is given by,

$A = 40\,\Delta\, N_f^2$

where, Δ= Maximum Amplitude of vibration = 0.21mm

N_f = Natural Frequency of vibration = 12.02 cycles per second

Therefore A= 40*0.21*12.02^2 = 1213.64mm/s^2

Also, (A*Δ)= 1213.64*0.21 = 254.86mm^2/s^2 which is less than 3226mm^2/s^2.

Deflection for two 800kN load in tandem on beam,

$$\delta_y = -\frac{395313.75}{25*10^6*23.59}$$

$$Deflection(\delta_y) = -6.7*10^{-4}m \text{ (−ve indicates downward deflection)}$$

Maximum Amplitude of vibration (Δ),

Since N_f >4 cycles per second

$\Delta = 0.40\delta_y$

Here, Deflection for 800kN point load in tandem in bridge at center is taken as 0.67 mm

Therefore, Δ= 0.4*0.67 = 0.268 mm

Now, For Dynamic Response,

Maximum acceleration (A) is given by,

$A = 40\,\Delta\, N_f^2$

Where, Δ= Maximum Amplitude of vibration = 0.268mm

N_f= Natural Frequency of vibration = 12.02 cycles per second

Therefore A= 40*0.268*12.02^2 = 1548.83mm/s^2

Also, (A*Δ)= 1548.83*0.268 = 415.09mm^2/s^2 which is less than 3226mm^2/s^2.

Deflection for 1200kN load at center of beam,

$$\delta_y = -\frac{1200*26.5^3}{48*589.75*10^6} = -7.89*10^{-4}m = -0.789mm$$

Maximum Amplitude of vibration (Δ),

Since N_f >4 cycles per second

Δ =0.40δ_y

Here, Deflection for 1200kN point load at center of beam is taken as 0.789mm

Therefore, Δ= 0.4*0.789 = 0.316mm

Now, For Dynamic Response,

Maximum acceleration (A)is given by,

A= 40 Δ N_f^2

where, Δ= Maximum Amplitude of vibration = 0.316mm

N_f= Natural Frequency of vibration = 12.02 cycles per second

Therefore A= 40*0.316*12.02^2 = 1826.23mm/s^2

Also, (A*Δ)= 1826.23*0.316 = 577.09mm^2/s^2 which is less than 3226mm^2/s^2.

Deflection for two 1200kN load in tandem on beam,

$$\delta_y = -\frac{592970.63}{25*10^6*23.59}$$

$$Deflection(\delta_y) = -1.01*10^{-3}m \text{ (−ve indicates downward deflection)}$$

Deflection is written as δ_y= 1.01mm

Maximum Amplitude of vibration (Δ),

Since N_f > 4 cycles per second

Δ =0.40δ_y

Here, Deflection for 1200kN point load in tandem in bridge at center is taken as 1.01 mm

Therefore, Δ= 0.4*1.01 = 0.404 mm

Now, For Dynamic Response,

Maximum acceleration (A) is given by,

A= 40 Δ N_f^2

Where, Δ= Maximum Amplitude of vibration = 0.404mm

N_f= Natural Frequency of vibration = 12.02 cycles per second

Therefore A= 40*0.404*12.02^2 = 2334.8mm/s^2

Also, (A*Δ) = 2334.8*0.404 = 942.94mm^2/s^2 which is less than 3226mm^2/s^2.

Structural Health Monitoring

The complex process of the design, development and execution of a damage identification strategy for Aerospace, Marine, Civil and Mechanical Engineering infrastructure is broadly referred to as Structural Health Monitoring (SHM). The process involves the systematic synoptic observations of a structure or mechanical system over time using spatio-temporal measurements using sensors that generally need to be positioned on the structure, the extraction of damage-sensitive features from these measurements and the statistical analysis of these features to determine the current state of system health. For long-term SHM, the output of this process is periodically updated information regarding the ability of the structure to continue to perform its intended function in light of the inevitable aging and damage accumulation resulting from the operational environments. Under an extreme event, such as a natural calamity or an unanticipated blast loading, SHM is used for rapid condition screening. This screening is intended to provide, in near real-time, reliable information about system performance during such extreme events and the subsequent integrity of the system.

The fundamental caveat in SHM feature selection is the presumption that the damage would significantly alter the stiffness, mass or energy dissipation properties of a system, which, in turn, alters the measured dynamic response of that system. Although the basis for feature selection appears intuitive, its actual application poses many significant technical challenges. The most fundamental challenge is the fact that damage is typically a local phenomenon and may not significantly influence the lower-frequency global response of structures that is normally measured with the available sensors during system operation. This fundamental challenge is common in many engineering fields, where the ability to capture the system response on widely varying length- and time-scales has proven very difficult, if not impossible with the known sensors and technologies.

Another fundamental challenge is that in many situations feature selection and damage identification must be performed in an unsupervised learning mode, as damage can accumulate over widely varying time-scales, which poses significant challenges for the SHM sensing system. Many practical issues associated with making accurate and repeatable measurements over long periods at spatially separated locations on complex structures in adverse environments supplement this challenge.

Various Non-Destructive Tests (NDT) can be carried out initially for easy inspection at various locations.

VISUAL INSPECTION

Visual inspection can be used as initial part of SHM. This visual inspection is initial inspection method which provides information for cracks detection in surface, problems in expansion joints, spalling of concrete, visible settlement of bridge, etc. It is very limited in its application as it can be applied in easily accessible locations only and provides the damages when they are visible only, also the visual inspection provides no information for size of damages. Additional equipment like borescopes, magnifying glasses can be used for ease of operation.

REBOUND HAMMER TEST

Rebound Hammer test can be performed at various locations of bridge deck as well as the pier to determine the compressive strength of concrete around the surface which shows if there is any degradation in compressive strength of concrete since its initial construction. But this provides information of certain location only in terms of surface compressive strength. Number of repetitions in calculation has to be done at various locations for better result. This test is highly subjected to the user performing the test.

ULTRASONIC PULSE VELOCITY (UPV) TEST

Ultrasonic Pulse Velocity (UPV) test is the other NDT method that can be applied to determine the homogeneity of concrete mixture used during the construction or the presence of voids or honeycomb effect in the concrete structure with passing of time. This method has limitations as the presence of reinforcement reduces the accuracy of results. This method provides the concrete properties for a small area concentration only. Number of repetitions have to be carried out for measurement in small area which is also time consuming. This provides results for local area only and does not properly specify extent of damage in structure. This UPV method is highly subjective in regards to the handler of the equipment.

DYNAMIC BASED DAMAGE DETECTION METHODS

Based on an extensive literature, Worden et al. (2007) identified a set of fundamental axioms for damage identification:

a) All materials have inherent flaws or defects.
b) The assessment of damage requires a comparison between two system states.
c) Identifying the existence and location of damage can be done in an unsupervised learning mode, but identifying the type of damage present and the damage severity can generally only be done in a supervised learning mode.
d) Sensors cannot measure damage. Feature extraction through signal processing and statistical classification is necessary to convert sensor data into damage information. Without intelligent feature extraction, the more sensitive a measurement is to damage, the more sensitive it is to changing operational and environmental conditions.
e) The length- and time-scales associated with damage initiation and evolution dictates the required properties of the SHM sensing system.
f) There is a trade-off between the sensitivity to damage of an algorithm and its noise rejection capability.
g) The size of damage that can be detected from changes in system dynamics is inversely proportional to the frequency range of excitation.

The dynamic based damage detection of SHM is based on comparison of the modal parameters to the non-damage or initial modal parameters. These initial modal parameters can be obtained by numerical modeling in suitable finite element package or by measurement in initial stage itself. Extraction of this initial modal parameters provides the difficulty in damage detection.

STRAIN GAUGES

Strain gauges can be used to determine the displacement of bearings in bridges and in the measurement of deflection of various parts of bridges for different loading conditions. But these strain gauges are difficult to place in all areas and also the data recording should be done continuously for readings at various conditions. Also, these strain gauges give readings at a particular location and number of sensor should be used at many location for global monitoring of structures.

ACCELEROMETERS

Using Sensor like accelerometers for catching the response of vibration which can be used for damage detection using suitable data analyzer like Fast Fourier Transform (FFT) analyzer. This data from sensor can be analyzed to obtain the dynamic parameters which help in damage detection. For this method, the sensors should be in contact of the bridge so accessibility can prove to be a difficulty. Also, the effects of external noise also highly affect the outcome of the dynamic response. The wires also provide difficulty in handling of the equipment.

PHOTONICS

Using photonics for catching the dynamic response of the structure can be used where the obtained data can be further interpolated to obtain the modal parameters, which is used for damage detection or SHM. The photonics method can be used in any area or location as no contact is required for data acquisition. Photonics is highly sensitive as compared to other methods. Moreover, high number of data can be obtained in a very short interval of time. The removal of unwanted modal parameters obtained from noise or external factors can also be effectively implemented.

Finally, a significant challenge for SHM is to develop the capability to define the required sensing system properties before field deployment and, if possible, to demonstrate that the sensor system itself will not be damaged when deployed in the field. If the possibility of sensor damage exists, it will be necessary to monitor the sensors themselves. This monitoring can be accomplished either by developing appropriate self-validating sensors or by using the sensors to report on each other's condition. Sensor networks should also be 'fail-safe'. If a sensor fails, the damage identification algorithms must be able to adapt to the new network. This adaptive capability implies that a certain amount of redundancy must be built into the sensor network. *Therefore, it is not surprising that to date a robust and effective structural health monitoring system is still a Grand Challenge for the scientific and engineering community, as the techniques and technologies available for monitoring the health of a structures - be it bridges, buildings, or highways, have many constraints and limitations [Doebling et al., 1996; Farrar et al., 2001; Sohn et al., 2003; Brownjohn, 2007; Hayton et al., 2007; Lynch, 2007; Sohn, 2007; Farrar and Worden, 2007; Worden and Manson, 2007; Gunes and Gunes, 2012, 2013].*

Not surprisingly again, the industry's demand to detect damage in its structural and mechanical infrastructure at the earliest possible time is increasing every day based on the new insights and multi-dimensional perceptions being gained by stakeholders on the importance and safety of infrastructure (Roads, Bridges, Highways, Buildings and Installations) for the Nation's Commerce, Development, Economy, Transportation and additionally Defence and Disaster Preparedness for dealing with natural and man-made eventualities.

Against this backdrop, this report outlines indigenous innovative photonic technologies and systems which can perform structural health monitoring robustly from remote locations on a non-contact basis and which are free of the many constraints and limitations associated with conventional state of art systems.

Photonic Systems for Structural Health Monitoring – VEDA and VIDUR

Deflection and vibration play an important role in the health monitoring of bridges. Their limits are specified in design codes either for consideration or as requirements (Le and Hwang, 2016). The growing demand to quickly, and remotely monitor the health and condition of fixed and moving structures (civil, steel, FRP, glass, etc.) on land and sea for different applications, primarily requires rapid monitoring of vibrational displacements, velocities and accelerations remotely. Against the backdrop of the dire need for remote and accurate monitoring of vibrational displacements, velocities and accelerations for various applications in the real world across all industries, we have designed and developed innovative photonic systems (*patent pending)* capable of monitoring real time vibrations on bridges, platforms and highways from remote locations. The systems are compact, portable and can easily be deployed at any location for real time vibration and condition monitoring in a non-intrusive fashion even at inaccessible locations.

VIDUR and VEDA are Photonic Systems for Real Time Vibration and Condition Monitoring of bridges. The systems are *low powered*, *compact*, *portable* and can easily be deployed at any location for real time vibration and condition monitoring in a *non-intrusive* fashion, even at inaccessible locations. The innovative technologies and the algorithms employed in the development of the systems ensure the real time extraction of the following information:

1. Vibration and Condition of Structures/Bridges/Highways.
2. Vehicular and Pedestrian Traffic Statistics on a Bridge.
3. Vehicular Identification (Type, Size Tonnage and Number)
4. Structural Health Diagnostics.
5. Intrusion Detection

The uniqueness of these systems is that in addition to monitoring real time vibrations with high sensitivity (*nanometre resolution*), one can also listen to the sound at the observation location, remotely. Vibrational displacement, velocity and acceleration parameters can be simultaneously extracted in real time in both time as well as frequency domains from remote locations, non-intrusively. Figures 13 and 14 show the schematic details the principles of operation of VIDUR and VEDA. Figure 15 shows the prototype versions of VEDA, VIDUR1 and VIDUR2 deployed during the technology demonstration. The low cost systems were designed and developed indigenously at Visakhapatnam, and successfully deployed and demonstrated in the field during many trials to prove the higher sensitivities (compared to conventional systems) and efficacy of real time remote monitoring of structures. The technological and manufacturing readiness levels of the systems are TRL9 and MRL 9 (*as per NASA Standards*) respectively.

The present systems are capable of remotely monitoring vibrations and condition of structures simultaneously in the time and frequency domains. Technologies for integrating various spatially separated systems using fundamental communication concepts of Internet of Things are also in place for quick deployment.

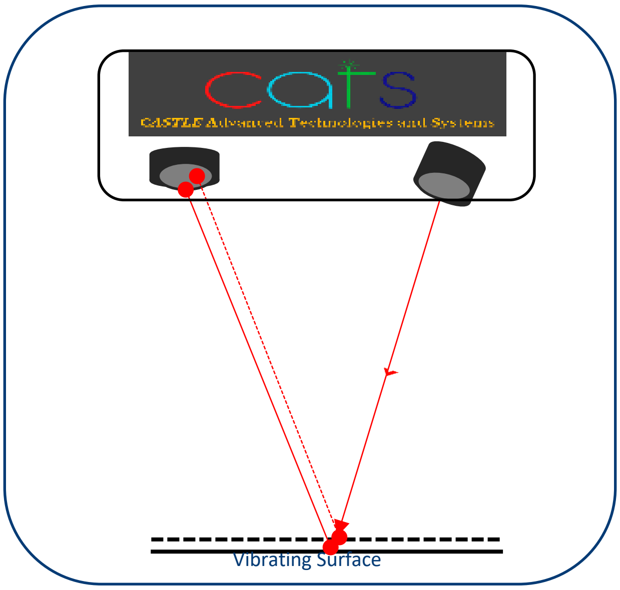


Figure 13: Schematic of VIDUR–Photonic System for vibration and condition monitoring.

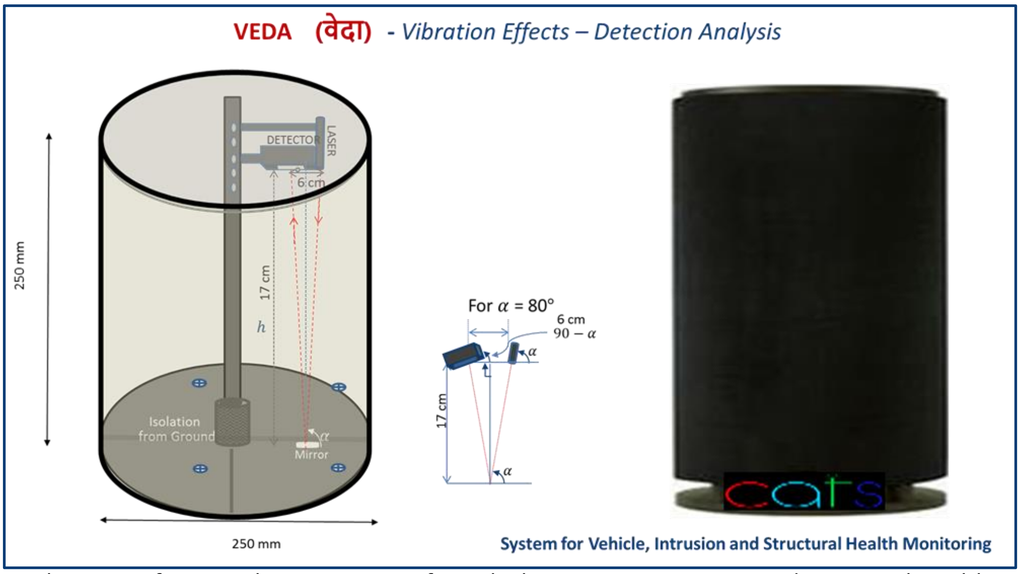


Figure 14: Schematic of VEDA–Photonic System for Vehicle Intrusion Detection and Structural Health Monitoring of Roads, Highways and Bridge

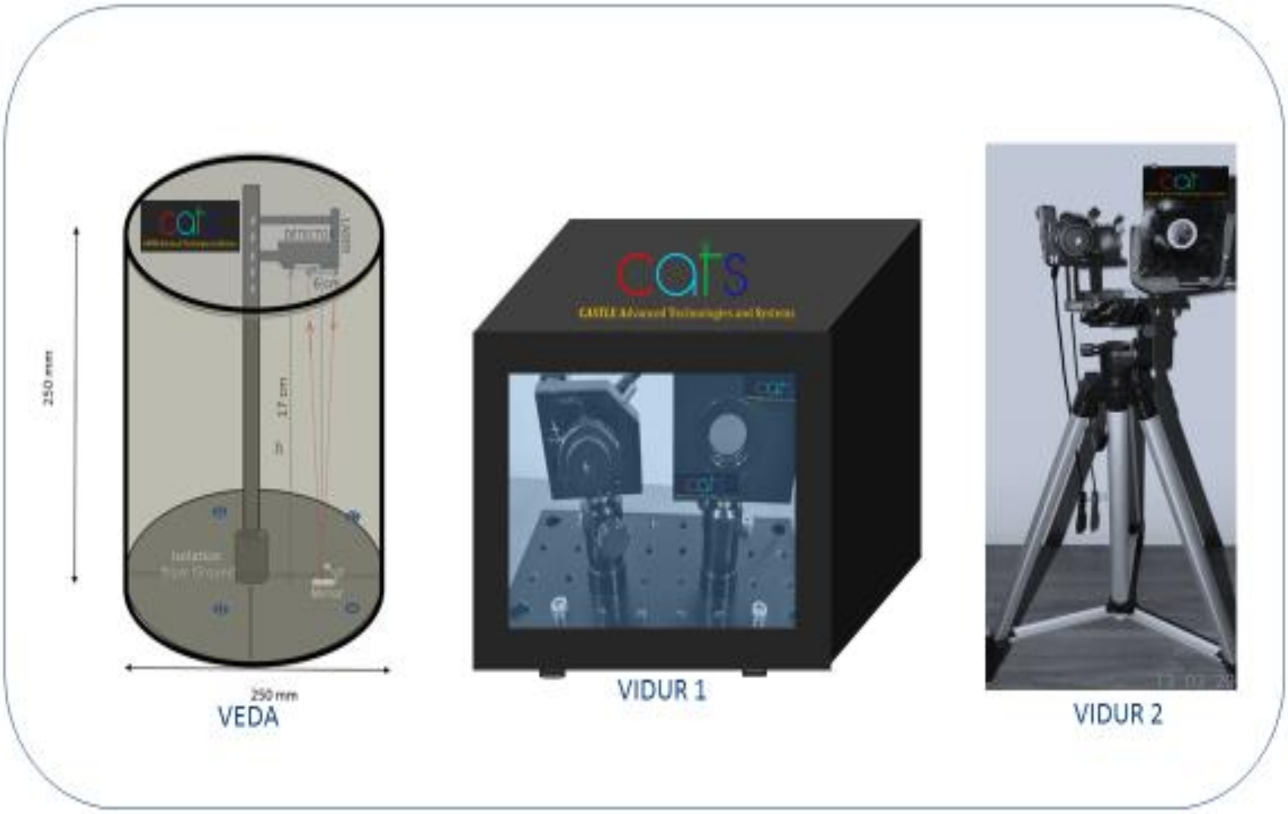


Figure 15: Photonic systems – VEDA, VIDUR1 and VIDUR2 deployed during the technology demonstration of structural health monitoring of a live bridge. The different versions were designed to pick up various vibrational signatures depending on the choice of locations of the systems and the geometries of the structures whose health needs monitoring. All systems are lightweight, portable and consume low power, and monitor vibrations remotely thus facilitating vibration monitoring even in the most inaccessible locations. The sensitivities of these systems are 3 orders of magnitude higher than the conventional systems commercially available.

Inter-comparison of various SHM Technologies with indigenous Photonic Technology

Tables 3 and 4 summarize the advantages and limitations of various structural health monitoring techniques commercially available and compare them with the indigenous photonics systems designed and developed by Prof. Tatavarti and team.

Mechanism	Type	Method	Advantages	Limitations
Non-contact	Non-destructive	Visual	• *Immediate results with minimum special skills*	• *Suitable only for surface, which can be viewed.* • *Generally, detects only larger defects* • *Misinterpretation of cracks and scratches.*
		Photonics	*Portable, Low Cost, Precise, Fast, and Continuous Remote Monitoring with High Sensitivity.*	*Line of sight to be free of obstructions, when operated from a remote location from target of measurement.*
Contact		X-Ray	• *Faster results* • *Does not require any special preparation.*	• *Low information* • *Difficult to apply to some part of the structure*
		Eddy Current	• *Portable* • *Moderate cost* • *Immediate results* • *Sensitive to small indications*	• *Essentially a surface inspection tool.* • *Suitable for inspection of metals only* • *Skill required in handling test equipment* • *Time consuming to scan large areas*
		Ultrasonic Techniques	• *Digital sensor has good accuracy.*	• *Have minimum sensing distance* • *Need to properly align the transducers.* • *Affected by ambient temperature, and humidity.*
		Rebound Hammer	• *Portable.* • *Fast result.* • *Questionable accuracy*	• *Careful attention is required.* • *Difficult to use on non-uniform surfaces.*
	Destructive	Core-cutter	• *Easily adaptable*	• *Less accuracy* • *Destroys the sample.*

Table 3: Various methods of Structural Health Monitoring

Methods of SHM based on different NDT methods	*Usable for global inspection*	*Detection of internal defects*	*Detection of defects far away from Sensors*	*Defects in areas with one surface accessible*	*Estimation of size and location of defect*	*Contact required*	*Identification of defects in inaccessible locations*
Visual	Yes	Partially	No	Yes	Partially	No	No
Magnetic	No	No	No	Yes	Partially	Yes	No
Radiography	No	Yes	No	No	Yes	Yes	No
Eddy current	No	No	No	Yes	Partially	Yes	No
Acoustic emission	Yes	Yes	Partially	Yes	No	Yes	No
Ultrasonic	No	Yes	No	Yes	Yes	Yes	No
Vibration	Yes	Yes	Partially	Yes	Partially	Yes	No
Photonics	***Yes***	***Yes***	***Yes***	***Yes***	***Yes***	***No***	***Yes***

Table 4: Inter-comparison of various NDT technologies vis-à-vis the indigenous photonic systems.

Structural Health Monitoring based on Vibrational Information

Variation of deflection with respect to natural and load of vehicles

Natural frequency $N_f = \frac{1}{2\pi}\sqrt{\frac{K}{m}} = \frac{1}{2\pi}\sqrt{\frac{Pg}{m\delta}}$

or $\delta = \frac{1}{4\pi^2}\,\frac{p}{mN_f{}^2}$

Where k = Stiffness N/m

m = Mass of structure =20000*26.5 = 530000 in kg

p = Load in N

δ = Deflection in m

Frequency (N_f) in Hz	Deflection (δ) in m		
	Bicycle(0.1 ton)	Car (1 ton)	Lorry (3 ton)
5	$1.91*10^{-6}$	$1.91*10^{-5}$	$5.74*10^{-5}$
10	$4.784*10^{-7}$	$4.77*10^{-6}$	$1.435*10^{-5}$

Thus, we understand that,

- Deflection is directly proportional to the weight of vehicles
- Deflection is inversely proportional to the natural frequency
- Deflection is directly proportional to the length of the member
- Deflection is directly proportional to the speed of the vehicle
- Deflection is directly proportional to the k/m ratio

Variation of natural frequency with structural material

Considering dimensions of simply supported member as width of 0.1m, depth of 0.1m and length of 1m

Material	Elasticity modulus (E) N/mm^2	Density in kg/m^3	Stiffness (k) = $\frac{48EI}{l^3}$ N/m	Mass (m) kg	K/m Ratio s^2	Frequency $N_f = \frac{1}{2\Pi}\sqrt{\frac{K}{m}}$ Hz
Wood	12.5	8000	5000	8	625	3.980
Reinforced concrete M_{30} grade	27386	2500	$1.095*10^7$	25	438000	105.38
Plane cement concrete M_{30} grade	27386	2400	$1.095*10^7$	24	456250	107.557
Steel	200000	7850	$8*10^7$	78.5	1019108.28	160.74

Table 5, elucidates how vibrational information observed by the photonic systems, VEDA and VIDUR, can be effectively used for assessing the structural integrity on a real time basis.

Table 5: Rapid Assessment of Structural Health Integrity from the Photonics Systems' Vibrational Information

S No	Span *(l)*	Weight of Vehicle *(P)*	Bending Moment of the Structure *(M)*	Stiffness of Structure *(k)*	Speed of Vehicle V	Vibrational Amplitude or Deflection(δ)	Ranking of Vibrational Amplitudes	Frequency ratio (β)= Forcing frequency due to Vehicle, ω / Natural frequency of the Structure, N_f	Remarks
1	Long	High	High	Less	High	High	1 **Highest**	• For the resonance conditions (β=1), maximum vibration amplitude exists. • For β≠1, vibration amplitude will be less than resonance amplitude.	• Weight, Span and Bending Moment are related so in Case 1 and 2, as weight is varying bending moments are also varying. • Vehicle Speed and Vibrational Amplitudes are directly related. • All are considered constant except vehicle speed and structure stiffness, initially speed is varied, and later stiffness is varied.
2					Less	Less	2		
3		Case-1		High	High	High	3		
4					Less	Less	4		
5		Less	Less	Less	High	High	5		
6					Less	Less	6		
7		Case-2		High	High	High	7		
8					Less	Less	8		
9	Short	High	High	Less	High	High	9		
10					Less	Less	10		
11		Case-1		High	High	High	11		
12					Less	Less	12		
13		Less	Less	Less	High	High	13		
14					Less	Less	14		
15		Case-2		High	High	High	15		
16					Less	Less	16 **Lowest**		

Here, the amplitude of vibration for forced harmonic motion is assumed as,

$\delta = \delta_{st} * D$, where, y is forced vibration amplitude,

δ_{st} is static deflection i.e. $\delta_{st} = \frac{\omega}{k}$

ω is forcing frequency

k is stiffness of material

D is Dynamic Amplification Factor, *i.e.,* $D=\frac{1}{\sqrt{(1-\beta^2)^2*(2\xi\beta)^2}}$

where, β is the frequency ratio = $\frac{\omega}{N_f}$

ω is the forcing frequency

N_f is the natural frequency i.e. $N_f = \sqrt{\frac{k}{m}}$

where, k is the stiffness of material

m is the mass of the material

Technology Demonstration of VEDA and VIDUR - *Observations*

Technology demonstration of VEDA and VIDUR was planned by designing an experimental demonstration of six data runs spanning for *more than 36 minutes* duration during which the traffic was planned to be as is 'live' - unhindered on the bridge. However, the NHAI team, which came at the last minute on the day of demonstration, started controlling the traffic *apparently* to please the Director General and Special Secretary without knowing the import of the demonstration. Three systems - VEDA (*1 no.*) and VIDUR (*2 nos.*), were configured to record data autonomously at the designated time for a designated duration. The systems recorded autonomously with a data sampling frequency of 10 kHz, *i.e.*, 10000 data points each second. Each system recorded the laser beam modulations, which were manifestations of the vibrations in two orthogonal directions along with the laser beam's intensity modulations reflected off the vibrating surfaces of interest. The systems were located at crucial locations in order to sample data remotely from critical positions. Figure 15 shows the schematic location map of VEDA and VIDUR systems located between the Pier3 and Pier4. While VEDA was observing the vibrations at a location on the footpath as shown in the figure, VIDUR 1 was observing vibrations on the railing at the end of the

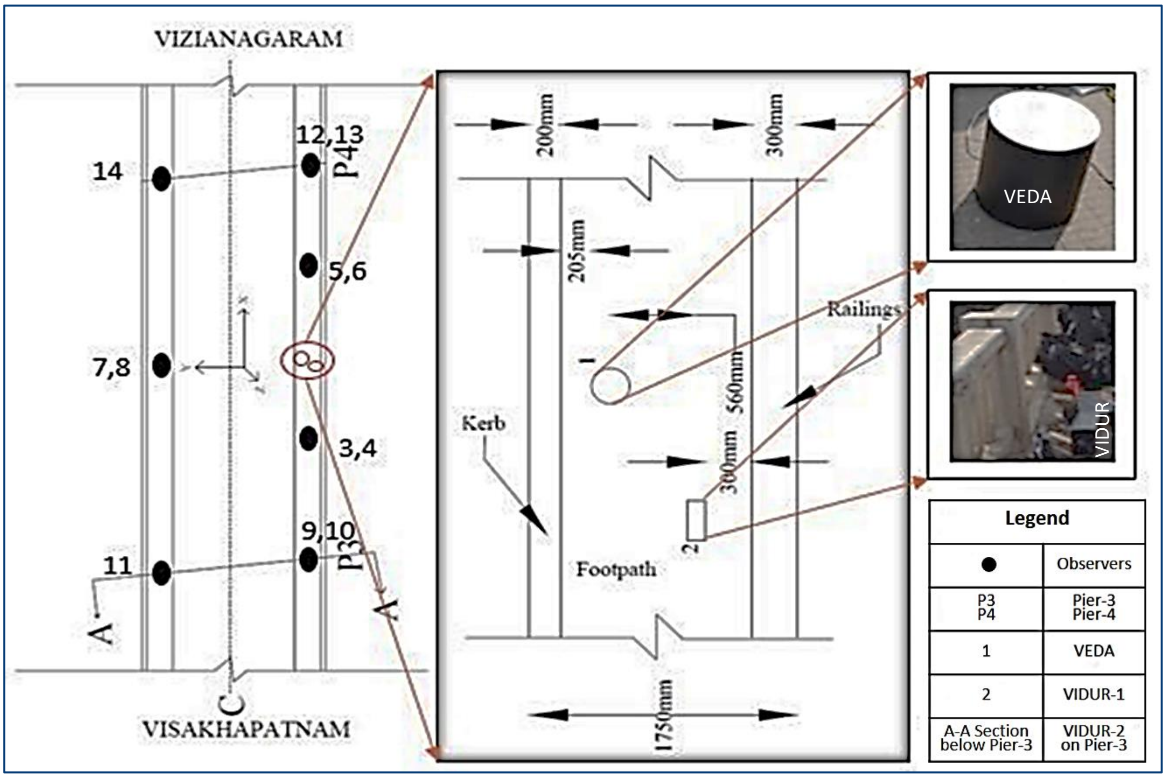
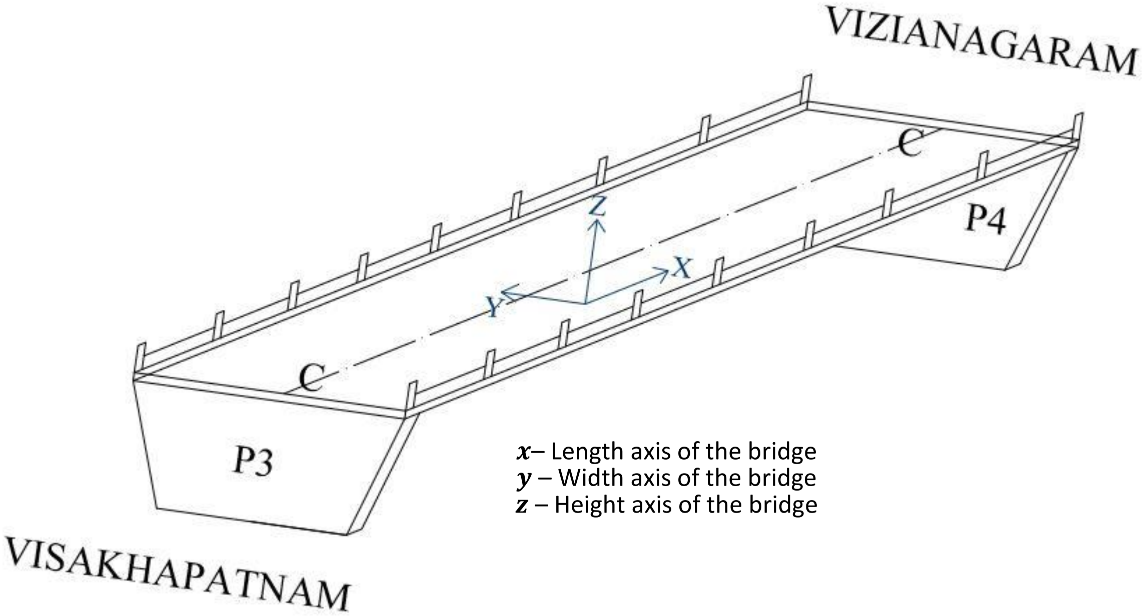


Figure 16: Technology demonstration of VEDA and VIDUR was carried out at three locations on the bridge.

footpath as shown in the figure above. VIDUR 2 was observing the vibrations on the Pier 3 below the bridge. All the observations were non-contact based remote observations. Vibrational isolators placed at the bottom of the systems ensured that all remote observations pertained to only the vibrations induced by the movements on the bridge caused by dynamic traffic on the bridge. The entire technology demonstration details spanning six data runs of 5-minute durations with Start and Stop times for VEDA, VIDUR 1 and VIDUR 2 are listed in Table 6. Technology demonstration lasted for a total duration of 36 minutes 40 sec, covering more than **0.594 billion data points**. Of these, only representative results were presented in this report. Observers located at different locations (*shown as numbers 1 to 14, in the Figure 16*) *on* the bridge (*observers 15* and *16 below* the bridge) made simultaneous visual observations. Video recordings at all observations posts were also made and documented.



x– Length axis of the bridge
y – Width axis of the bridge
z – Height axis of the bridge

System	δ_x	δ_y
VEDA	$-x$	y
VIDUR-1	x	z
VIDUR-2	z	y

Figure 17: Systems deployed and their pertinent data observations vis-à-vis the cartesian coordinate system adopted for the bridge

Run		**VIDUR-1** (*hr:min:sec*)	**VEDA** (*hr:min:sec*)	**VIDUR-2** (*hr:min:sec*)	**Common Start / Stop times for all systems** (*hr:min:sec*)
1	Start Time	9:46:01	9:48:36	9:48:35	***09:48:35 - 09:51:01 09:55:20 - 09:59:17 10:01:25 - 10:06:17 10:08:29 - 10:11:40 10:12:10 – 10:13:29 10:15:26 - 10:17:10 10:17:39 – 10:20:26***
	Stop Time	9:51:01	9:53:36	9:53:35	
2	Start Time	9:54:59	9:54:17	9:55:20	
	Stop Time	9:59:59	9:59:17	10:00:20	
3	Start Time	10:01:17	10:01:25	10:01:24	
	Stop Time	10:06:17	10:06:25	10:06:24	
4	Start Time	10:06:44	10:06:40	10:08:29	
	Stop Time	10:11:44	10:11:40	10:13:29	
5	Start Time	10:12:10	10:12:10	10:15:26	
	Stop Time	10:17:10	10:17:10	10:20:26	
6	Start Time	10:17:39	10:17:33	10:23:14	
	Stop Time	10:22:39	10:22:33	10:28:14	

Table 6: VEDA, VIDUR-1 and VIDUR-2 data runs details with Start and Stop times.

Vehicular Traffic Observations

All vehicular traffic were observed visually and with cameras by a team of 18 observers during the technology demonstration. Table 7 summarizes the traffic statistics during the technology demonstration period, where 916 different vehicles of varying sizes and weights, plied on the bridge with varying speeds. This information was used for validating the algorithms developed for VEDA and VIDUR. Figures 18 to 22, show case the pictures taken during observations.

Figure 18: *Observers at various locations monitoring the traffic and other parameters*.

Figure 19: Prof. Rao Tatavarti describing about the experiment to NHAI and MORTH team

Figure 20: Prof. Tatavarti explaining about vibration based structural health monitoring using photonic systems to Secretary, MORTH, GOI.

Figure 21: Project team along with MORTH, NHAI and IBMS personnel after successful completion of the technology demonstration to Director General and Special Secretary, MORTH, GOI.

Table 7 Visual Observations at various locations made to correlate with the systems recorded data.

				Time (in HH:MM:SS)				
S. No.	Vehicle	Speed	Lane	@Pier 3	5m from VEDA towards VSKP	At VEDA Location	5m from VEDA towards VZM	@Pier 4
1	Lorry1	B	LEFT	9:49:46		9:49:48		9:49:52
2	Car1	B	LEFT	9:49:48		9:49:50		9:49:54
3	Bike1	A	LEFT	9:49:50		9:49:52		9:49:56
4	Car2	B	LEFT	9:49:51		9:49:53	9:49:55	9:49:57
5	Bike2	A	LEFT	9:49:52		9:49:54	9:49:56	9:49:59
6	Bike3	B	LEFT	9:49:53		9:49:58	9:49:57	9:50:00
7	Car3	B	LEFT	9:49:56		9:50:00	9:50:00	9:50:04
8	Bike4	A	LEFT	9:49:57		9:50:03	9:50:01	9:50:05
9	Car4	B	LEFT	9:49:59		9:50:04	9:50:02	9:50:06
10	Bike5	B	LEFT	9:50:00		9:50:05		9:50:07
11	Bike6	B	LEFT	9:50:00		9:50:06	9:50:07	9:50:08
12	Bike7	B	LEFT	9:50:01		9:50:09		9:50:10
13	Car5	B	LEFT	9:50:03		9:50:10	10:50:07	9:50:11
14	Bike8	A	LEFT	9:50:04		9:50:12	10:50:12	9:50:12
15	Car6	A	LEFT	9:50:05		9:50:14		9:50:15
16	Truck1	A	LEFT	9:50:13		9:50:17	10:50:17	9:50:20
17	Car7	B	LEFT	9:50:16		9:50:19	10:50:20	9:50:23
18	Bike9	A	LEFT	9:50:17		9:50:22		9:50:25
19	Lorry 2	B	LEFT	9:50:23		9:50:26	10:50:26	9:50:30
20	Bike10	B	LEFT	9:50:24		9:50:27	10:50:28	9:50:32
21	Lorry 3	A	LEFT	9:50:30		9:50:33	9:50:34	9:50:37
22	Lorry 4	A	LEFT	9:50:34		9:50:37	9:50:38	9:50:41
23	Truck2	A	LEFT	9:50:41		9:50:44		9:50:46
24	Bus1	B	LEFT	9:50:47		9:50:48	9:50:52	9:50:53
25	Car8	B	LEFT	9:50:50		9:50:52	9:50:53	9:50:57
26	Car9	B	LEFT	9:50:52		9:50:54	9:50:57	9:51:00
27	Bike11	B	LEFT	9:50:54		9:50:56	9:50:58	9:51:03
28	Bike12	B	LEFT	9:50:55		9:50:58	9:50:59	9:51:06
29	Lorry5	A	LEFT	9:51:00		9:51:01		9:51:09
30	Bike13	B	LEFT	9:51:01		9:51:04	9:51:07	9:51:12
31	Bike14	B	LEFT	9:51:03		9:51:05		9:51:13
32	Auto1	B	LEFT	9:51:05		9:51:06	9:51:08	9:51:16
33	Bike15	B	LEFT	9:51:06		9:51:08		9:51:20
34	Car10	A	LEFT	9:51:07		9:51:11		9:51:23
35	Bike16	B	LEFT	9:51:10		9:51:13	9:51:13	
36	Bike17	B	LEFT	9:51:11		9:51:14	9:51:14	
37	Lorry6	A	LEFT	9:51:15		9:51:16	9:51:19	
38	Bike18	B	LEFT	9:51:16		9:51:17	9:51:21	
39	Auto2	B	LEFT	9:51:17		9:51:20	9:51:22	9:51:24

40	Car11	B	LEFT	9:51:21		9:51:22	9:51:25	9:51:28
41	Lorry7	A	LEFT	9:51:25		9:51:26	9:51:28	9:51:30
42	Auto3	A	LEFT	9:51:26		9:51:28	9:51:30	
43	Bike19	B	LEFT	9:51:27		9:51:30	9:51:32	9:51:33
44	Auto4	B	LEFT	9:51:28		9:51:31	9:51:33	9:51:36
45	Bike20	B	LEFT	9:51:29		9:51:32	9:51:34	9:51:37
46	Bike21	B	LEFT	9:51:30		9:51:33	9:51:35	9:51:38
47	Auto5	A	LEFT	9:51:33		9:51:36	9:51:37	9:51:41
48	TRACTOR1	A	LEFT	9:51:36		9:51:39	9:51:39	9:51:44
49	Bike22	A	LEFT	9:51:37		9:51:42	9:51:42	9:51:45
50	Bike23	A	LEFT	9:51:38		9:51:43	9:51:43	9:51:47
51	Bike24	A	LEFT	9:51:39		9:51:44	9:51:44	9:51:49
52	Auto6	A	LEFT	9:51:41		9:51:46	9:51:46	9:51:50
53	Auto7	A	LEFT	9:51:43		9:51:47	9:51:47	9:51:52
54	Bike25	A	LEFT	9:51:45		9:51:49	9:51:50	9:51:54
55	Car12	B	LEFT	9:51:46		9:51:50	9:51:51	9:51:55
56	Bike26	B	LEFT			9:51:52	9:51:53	9:51:57
57	Bike27	B	LEFT	9:51:48		9:51:55		
58	Car13	A	LEFT	9:51:51		9:51:57	9:51:54	9:51:58
59	Car14	A	LEFT	9:51:52		9:51:58	9:51:56	9:52:01
60	Bike28	A	LEFT	9:51:55		9:51:59	9:52:00	9:52:03
61	Bike29	A	LEFT			9:52:00	9:52:00	9:52:04
62	Bike30	A	LEFT	9:51:57		9:52:02	9:52:01	9:52:05
63	Bike31	A	LEFT	9:51:58		9:52:04	9:52:03	9:52:07
64	Lorry8	A	LEFT	9:52:03		9:52:06	9:52:07	9:52:09
65	Bike32		LEFT			9:52:10	9:52:10	9:52:13
66	Bike33	B	LEFT	9:52:04		9:52:11	9:52:11	9:52:13
67	Bike34	A	LEFT	9:52:06		9:52:11	9:52:11	9:52:15
68	Lorry9	A	LEFT	9:52:11		9:52:14	9:52:15	9:52:17
69	Auto8	A	LEFT	9:52:14		9:52:17	9:52:18	9:52:22
70	Car15	A	LEFT	9:52:17		9:52:20	9:52:21	9:52:23
71	Truck3	A	LEFT	9:52:26		9:52:28	9:52:29	9:52:33
72	Lorry10	A	LEFT	9:52:31		9:52:33	9:52:34	9:52:37
73	Auto9	B	LEFT	9:52:33		9:52:37	9:52:38	9:52:40
74	Bike35	B	LEFT	9:52:34		9:52:38	9:52:39	
75	Car16	B	LEFT	9:52:36		9:52:38	9:52:40	9:52:41
76	Bike36	A	LEFT	9:52:37		9:52:39	9:52:43	9:52:44
77	Car17	A	LEFT	9:52:40		9:52:44	9:52:45	9:52:46
78	Auto10	A	LEFT	9:52:42		9:52:46	9:52:47	
79	Car18	A	LEFT	9:52:45		9:52:48	9:52:49	9:52:50
80	Auto11	B,B	LEFT	9:52:46		9:52:49	9:52:52	9:52:55
81	Bike39		LEFT			9:52:50	9:52:52	9:52:57
82	Bike40	B	LEFT	9:52:47		9:52:53	9:52:53	
83	Car19	A	LEFT	9:52:50		9:52:54	9:52:55	9:52:58

84	Car20	A	LEFT	9:52:53		9:52:55	9:52:57	9:53:00
85	Bus2	A	LEFT	9:52:59		9:53:02	9:53:03	9:53:03
86	Bike41	B	LEFT	9:53:01		9:53:04	9:53:04	9:53:07
87	Car21	B	LEFT	9:53:02		9:53:05	9:53:05	9:53:08
88	Bike42	B	LEFT	9:53:03		9:53:08	9:53:08	9:53:10
89	Bike43		LEFT			9:53:11		
90	Lorry11	B	LEFT	9:53:07		9:53:12	9:53:12	9:53:13
91	Car22	A	LEFT	9:53:11		9:53:14	9:53:15	9:53:19
92	Car23	A	LEFT	9:53:13		9:53:15	9:53:17	9:53:23
93	Bike44	B	LEFT	9:53:14		9:53:18	9:53:18	
94	Car24	A	LEFT	9:53:17		9:53:21	9:53:22	9:53:25
95	Car25	B	LEFT	9:53:19		9:53:22	9:53:23	9:53:27
96	Car26	B	LEFT	9:53:21		9:53:25	9:53:25	
97	Auto12	B	LEFT	9:53:23		9:53:26	9:53:28	9:53:29
98	Bike45	A	LEFT	9:53:24		9:53:28	9:53:29	9:53:31
99	Car27	B	LEFT	9:53:26		9:53:30	9:53:31	9:53:33
100	Car28	A	LEFT	9:53:29		9:53:31	9:53:34	9:53:35
101	Car29	B	LEFT	9:53:31		9:53:34	9:53:35	
102	Bike46	B	LEFT	9:53:33		9:53:35	9:53:38	9:53:39
103	Car30	B	LEFT	9:53:34		9:53:38	9:53:39	9:53:41
104	Car31	A	LEFT	9:53:37		9:53:40	9:53:42	9:53:43
105	Car32	A	LEFT	9:53:40		9:53:43	9:53:43	9:53:45
106	Bike47	B	LEFT	9:53:41		9:53:44	9:53:45	9:53:48
107	Lorry12	A	LEFT				9:53:52	9:53:54
108	Auto13	A	LEFT	9:53:51		9:53:55	9:53:55	9:54:00
109	Lorry13	A	LEFT	9:53:57		9:53:58	9:53:59	9:54:03
110	Lorry14	A	LEFT	9:54:00		9:54:03	9:54:03	9:54:09
111	Bike48		LEFT			9:54:05	9:54:06	9:54:12
112	Bike49	B	LEFT	9:54:05		9:54:05	9:54:06	9:54:12
113	Bus3	A	LEFT	9:54:10		9:54:11	9:54:12	9:54:14
114	Car33	B	LEFT	9:54:12		9:54:14	9:54:15	9:54:19
115	Auto14	A	LEFT	9:54:14		9:54:18	9:54:19	9:54:20
116	Auto15	A	LEFT	9:54:16		9:54:19	9:54:21	9:54:22
117	Bus4	B	LEFT	9:54:20		9:54:20	9:54:22	9:54:23
118	Car34	B	LEFT	9:54:22		9:54:25	9:54:27	9:54:27
119	Auto16	B	LEFT	9:54:24		9:54:28	9:54:29	9:54:30
120	Car35	B	LEFT	9:54:27		9:54:30	9:54:32	9:54:32
121	Bike50	B	LEFT	9:54:28		9:54:32	9:54:34	9:54:34
122	Car36	A	LEFT	9:54:30		9:54:34	9:54:35	9:54:36
123	Car37	A	LEFT	9:54:34		9:54:36	9:54:38	9:54:39
124	Auto17	B	LEFT	9:54:35		9:54:37	9:54:40	9:54:41
125	Auto18	A	LEFT	9:54:38		9:54:40	9:54:42	9:54:43
126	Lorry15	A	LEFT	9:54:42		9:54:41	9:54:45	9:54:48
127	Car38	A,B	LEFT	9:54:46		9:54:48	9:54:50	9:54:52

128	Bike51		LEFT			9:54:49	9:54:52	9:54:54
129	Auto19	A,A	LEFT	9:54:48		9:54:50	9:54:52	9:54:56
130	Car39	A	LEFT	9:54:50		9:54:54	9:54:55	9:54:59
131	Car40	A	LEFT	9:54:54		9:54:58	9:54:59	9:55:02
132	Car41	A	LEFT	9:54:58		9:55:01	9:55:02	9:55:06
133	Car42	B	LEFT	9:55:00		9:55:04	9:55:05	9:55:07
134	Bike52	B	LEFT	9:55:01		9:55:05	9:55:06	9:55:09
135	Car43, Bike53	B,B	LEFT	9:55:03		9:55:07	9:55:07	9:55:10
136	Auto20	A	LEFT	9:55:07		9:55:10	9:55:12	9:55:14
137	Auto21	A	LEFT	9:55:09		9:55:13	9:55:13	9:55:16
138	Car44	B	LEFT	9:55:11		9:55:14	9:55:15	9:55:18
139	Car45	A	LEFT	9:55:14		9:55:16	9:55:18	9:55:20
140	Car46	A	LEFT	9:55:16		9:55:17	9:55:21	9:55:23
141	Bike54	B	LEFT	9:55:18		9:55:20	9:55:23	9:55:25
142	Bike55	B	LEFT	9:55:19		9:55:21	9:55:25	9:55:26
143	Car47	A	LEFT	9:55:21		9:55:24	9:55:26	9:55:31
144	Car48	A	LEFT	9:55:24		9:55:26	9:55:28	9:55:32
145	Car49	A	LEFT	9:55:27		9:55:29	9:55:31	9:55:35
146	Car50	A	LEFT	9:55:29		9:55:31	9:55:32	9:55:37
147	Car51	A	LEFT	9:55:32		9:55:34	9:55:37	9:55:39
148	Bike56	B	LEFT	9:55:33		9:55:35	9:55:39	9:55:40
149	Car52	A	LEFT	9:55:36		9:55:38	9:55:41	9:55:42
150	Car53	A	LEFT	9:55:39		9:55:41	9:55:44	9:55:46
151	Bike57	B	LEFT	9:55:41		9:55:43	9:55:46	9:55:48
152	Truck4	A	LEFT	9:55:51		9:55:53	9:55:52	9:55:55
153	Lorry16	A	LEFT	9:55:57		9:55:59	9:56:01	9:56:04
154	Car54	A	LEFT	9:56:00	9:56:01	9:56:02	9:56:04	9:56:08
155	Car55	B	LEFT	9:56:03	9:56:04	9:56:05	9:56:08	9:56:11
156	Truck5	A	LEFT	9:56:09	9:56:10	9:56:11	9:56:12	9:56:15
157	Lorry17	A	LEFT	9:56:14	9:56:14	9:56:15	9:56:14	9:56:19
158	Bike58	B	LEFT	9:56:15		9:56:18	9:56:20	9:56:22
159	Car56	B	LEFT	9:56:17	9:56:18	9:56:19	9:56:21	9:56:22
160	Bus5	A	LEFT	9:56:23	9:56:23	9:56:24	9:56:26	9:56:27
161	Bike59	B	LEFT	9:56:24		9:56:26	9:56:29	9:56:30
162	Car57	B	LEFT	9:56:25	9:56:27	9:56:28	9:56:30	9:56:31
163	Car58	B	LEFT	9:56:28	9:56:29	9:56:30	9:56:32	9:56:37
164	Car59	B	LEFT	9:56:30	9:56:32	9:56:33	9:56:35	9:56:39
165	Bike60	B	LEFT	9:56:31		9:56:34	9:56:37	9:56:40
166	Car60	B	LEFT	9:56:33	9:56:35	9:56:35	9:56:38	9:56:41
167	Bike61	B	LEFT	9:56:34		9:56:35	9:56:39	9:56:42
168	Car61	B	LEFT	9:56:35	9:56:37	9:56:38	9:56:40	9:56:45
169	Car62	A	LEFT	9:56:38	9:56:40	9:56:44	9:56:46	9:56:50
170	Car63	A	LEFT	9:56:41	9:56:43	9:56:46	9:56:47	9:56:51
171	Car64	A	LEFT	9:56:44	9:56:47	9:56:48	9:56:48	9:56:52

172	Car65	A	LEFT	9:56:48	9:56:50	9:56:50	9:56:51	9:56:55
173	Car66	A	LEFT	9:56:51	9:56:53	9:56:51	9:56:55	9:56:57
174	Car67	A	LEFT	9:56:54	9:56:54	9:56:55	9:56:58	9:57:01
175	Truck6	A	LEFT	9:57:01	9:57:02	9:57:02	9:57:03	9:57:06
176	Bike62	B	LEFT	9:57:02	9:57:03	9:57:04	9:57:07	9:57:09
177	Auto22	B	LEFT	9:57:03	9:57:04	9:57:06	9:57:08	9:57:12
178	Car68, Bike63	A,A	LEFT	9:57:06	9:57:07	9:57:08	9:57:11	9:57:13
179	Bike64,65, 66	A,A,A	LEFT	9:57:08	9:57:09	9:57:10	9:57:12	9:57:18
180	BikeS67,68	A,A	LEFT	9:57:09	9:57:10	9:57:11	9:57:13	9:57:19
181	Bike69	B	LEFT	9:57:10	9:57:11	9:57:11	9:57:14	9:57:20
182	Bike70	B	LEFT	9:57:11	9:57:14	9:57:14	9:57:15	9:57:21
183	Lorry18	A	LEFT	9:57:17	9:57:18	9:57:20	9:57:22	9:57:26
184	Bus6	A	LEFT	9:57:25	9:57:26	9:57:27	9:57:29	9:57:30
185	BikeS71,72	B	LEFT	9:57:26		9:57:30	9:57:31	9:57:34
186	Bike73	B	LEFT	9:57:27		9:57:31	9:57:32	9:57:35
187	Car69	B	LEFT	9:57:29	9:57:32	9:57:33	9:57:33	9:57:37
188	BikeS73,74	B,B	LEFT	9:57:31		9:57:34	9:57:35	9:57:38
189	Bike75	B	LEFT	9:57:32		9:57:36	9:57:36	9:57:40
190	Car70	B	LEFT	9:57:34	9:57:37	9:57:39	9:57:39	9:57:42
191	Bike76	B	LEFT	9:57:36	9:57:38	9:57:40	9:57:41	9:57:44
192	Bike77	A	LEFT	9:57:37		9:57:41	9:57:42	9:57:46
193	Car71	B	LEFT	9:57:39	9:57:42	9:57:44	9:57:45	9:57:47
194	Bus7	A	LEFT	9:57:44	9:57:44	9:57:46	9:57:47	9:57:50
195	BikeS78,79	B	LEFT	9:57:46	9:57:47	9:57:49	9:57:51	9:57:52
196	Bike80	B	LEFT	9:57:47	9:57:48	9:57:50	9:57:52	9:57:53
197	Bike81	B	LEFT	9:57:48	9:57:49	9:57:51	9:57:53	9:57:54
198	Bike82	B	LEFT	9:57:49		9:57:52	9:57:54	9:57:56
199	Bus8	A	LEFT	9:57:54	9:57:55	9:57:55	9:57:56	9:57:58
200	Car72	A	LEFT	9:57:57	9:57:58	9:57:59	9:58:01	9:58:02
201	Bike83	A	LEFT	9:57:59		9:58:00	9:58:02	9:58:03
202	Car73	B	LEFT	9:58:00		9:58:02	9:58:04	9:58:05
203	Car74	A	LEFT	9:58:02		9:58:04	9:58:06	9:58:07
204	Car75	B	LEFT	9:58:03	9:58:05	9:58:07	9:58:08	9:58:08
205	Car76	A	LEFT	9:58:06	9:58:08	9:58:10	9:58:10	9:58:12
206	Car77	A	LEFT	9:58:08		9:58:12	9:58:13	9:58:14
207	Car78	A	LEFT	9:58:11	9:58:12	9:58:15	9:58:15	9:58:16
208	Car79	B	LEFT	9:58:12	9:58:14	9:58:16	9:58:17	9:58:18
209	Auto23	B	LEFT	9:58:14	9:58:15	9:58:17	9:58:19	9:58:20
210	Bike84	B	LEFT	9:58:16		9:58:18	9:58:21	9:58:21
211	Car80	B	LEFT	9:58:17		9:58:19	9:58:22	9:58:23
212	Auto24	A	LEFT	9:58:19		9:58:22	9:58:24	9:58:26
213	Bike85,86	B,B	LEFT	9:58:20		9:58:24	9:58:25	9:58:27
214	Car81, Cycle1, 1man walking	A,A,A	LEFT	9:58:22		9:58:26	9:58:27	9:58:29

215	2 men walking	A,A	LEFT	9:58:24		9:58:27	9:58:28	9:58:30
216	Bus9	B	LEFT	9:58:27	9:58:28	9:58:29	9:58:32	9:58:33
217	Bike87	B	LEFT	9:58:28		9:58:32	9:58:35	9:58:36
218	Bike88, Car82	B,B	LEFT	9:58:30	9:58:33	9:58:33		
219	Bike89	B	LEFT	9:58:32		9:58:35	9:58:37	9:58:38
220	Bike90	B	LEFT	9:58:33		9:58:36	9:58:38	9:58:39
221	Bike91	C	LEFT	9:58:34	9:58:37	9:58:36	9:58:39	9:58:41
222	Car83	B	LEFT	9:58:35	9:58:37	9:58:38	9:58:40	9:58:42
223	Car84	B	LEFT	9:58:38		9:58:40	9:58:43	9:58:45
224	Bike92	B	LEFT	9:58:39		9:58:43	9:58:44	9:58:44
225	Car85	C	LEFT	9:58:40	9:58:43	9:58:44	9:58:46	9:58:46
226	Cycle2, Bike93	A,A	LEFT	9:58:42		9:58:44	9:58:47	9:58:47
227	Car86	B	LEFT	9:58:44	9:58:48	9:58:47	9:58:49	9:58:49
228	Car87	B	LEFT	9:58:47		9:58:50	9:58:52	9:58:52
229	Lorry19	A	LEFT	9:58:52	9:58:53	9:58:53	9:58:55	9:58:56
230	Bike94	B	LEFT	9:58:54		9:58:54	9:58:59	9:58:59
231	Car88	C	LEFT	9:58:55	9:58:57	9:58:57	9:59:00	9:59:00
232	Bus10	A	LEFT	9:59:01	9:59:02	9:59:03	9:59:04	9:59:04
233	Auto25	A	LEFT	9:59:03		9:59:06	9:59:08	9:59:08
234	Auto26	A	LEFT	9:59:04		9:59:07	9:59:09	9:59:11
235	Bike95	B	LEFT	9:59:06		9:59:09	9:59:11	9:59:13
236	Car89	B	LEFT	9:59:07		9:59:11	9:59:12	9:59:14
237	Car90	B	LEFT	9:59:09		9:59:12	9:59:14	9:59:16
238	Car91	B	LEFT	9:59:11		9:59:14	9:59:16	9:59:18
239	Lorry20	B	LEFT	9:59:15		9:59:18	9:59:18	9:59:20
240	Auto27	A	LEFT	9:59:18		9:59:21	9:59:23	9:59:24
241	Lorry21	A	LEFT	9:59:22		9:59:24	9:59:24	9:59:26
242	Bus11	B	LEFT	9:59:26		9:59:28	9:59:29	9:59:29
243	Bike96,97	B,B	LEFT	9:59:27		9:59:30	9:59:31	9:59:34
244	Bike98,99	B,B	LEFT	9:59:28		9:59:31	9:59:32	9:59:35
245	Bike100, 101	B,B	LEFT	9:59:29		9:59:32	9:59:33	9:59:35
246	Lorry22	B	LEFT	9:59:32		9:59:34	9:59:36	9:59:37
247	Bike102	B	LEFT	9:59:33		9:59:33	9:59:38	9:59:39
248	Car92	B	LEFT	9:59:36		9:59:38	9:59:40	9:59:40
249	Car93	B	LEFT	9:59:38		9:59:40	9:59:42	9:59:43
250	Bike103	B	LEFT	9:59:39		9:59:42	9:59:44	9:59:44
251	Bike104	B	LEFT	9:59:40		9:59:43	9:59:45	9:59:46
252	Lorry23	B	LEFT	9:59:41		9:59:44	9:59:47	9:59:48
253	Lorry24	B	LEFT	9:59:43		9:59:47	9:59:50	9:59:51
254	Car94	A	LEFT	9:59:47		9:59:49	9:59:51	9:59:53
255	Car95	A	LEFT	9:59:49		9:59:52	9:59:54	9:59:55
256	Bike105	B	LEFT	9:59:51		9:59:54	9:59:56	9:59:57
257	Bus12	A	LEFT	9:59:56		9:59:58	9:59:59	10:00:00

258	Car96	B	LEFT	9:59:58		10:00:01	10:00:03	10:00:03
259	Lorry25	B	LEFT	10:00:05		10:00:07	10:00:08	10:00:10
260	Bike106	B	LEFT	10:00:06		10:00:08	10:00:11	10:00:11
261	Car97, 1man walking	B	LEFT	10:00:09		10:00:11	10:00:13	10:00:14
262	Car98, Cycle3, 1man walking	B	LEFT	10:00:12		10:00:15	10:00:17	10:00:17
263	Lorry26	B	LEFT	10:00:18		10:00:21	10:00:23	10:00:24
264	Car99	B	LEFT	10:00:20		10:00:24	10:00:25	10:00:28
265	BikeS107, 108	B	LEFT	10:00:22		10:00:25	10:00:26	10:00:29
266	Lorry27	B	LEFT	10:00:28		10:00:30	10:00:31	10:00:33
267	Auto28	B	LEFT	10:00:30		10:00:33	10:00:35	10:00:36
268	Auto29	B	LEFT	10:00:32		10:00:35	10:00:36	10:00:37
269	Car100	B	LEFT	10:00:35		10:00:38	10:00:40	10:00:42
270	Car101	B	LEFT	10:00:39		10:00:43	10:00:45	10:00:46
271	**Tractor1**	B	LEFT	10:00:45		10:00:47	10:00:47	10:00:49
272	Bike109	B	LEFT	10:00:47		10:00:50	10:00:52	10:00:52
273	Lorry28	B	LEFT	10:00:50		10:00:53	10:00:53	10:00:55
274	Car102	B	LEFT	10:00:54		10:00:56	10:00:59	10:00:59
275	Bike110	B	LEFT	10:00:55		10:00:58	10:01:00	10:01:01
276	Bike111	B	LEFT	10:00:56		10:00:59	10:01:01	10:01:02
277	Car103	B	LEFT	10:00:58		10:01:01	10:01:02	10:01:03
278	Bike112	B	LEFT	10:00:59		10:01:03	10:01:04	10:01:06
279	Car104	B	LEFT	10:01:05		10:01:08	10:01:09	10:01:12
280	Bike113	B	LEFT	10:01:06		10:01:09	10:01:10	10:01:14
281	Bus13	B	LEFT	10:01:13		10:01:15	10:01:15	10:01:18
282	Auto30, 1 man walking	B	LEFT	10:01:14		10:01:18	10:01:20	10:01:22
283	Auto31	B	LEFT	10:01:17		10:01:20	10:01:21	10:01:24
284	Bike114	B	LEFT	10:01:19		10:01:23	10:01:24	10:01:26
285	Car105	B	LEFT	10:01:20		10:01:24	10:01:25	10:01:27
286	Car106	B	LEFT	10:01:24		10:01:27	10:01:28	10:01:30
287	Lorry29	B	LEFT	10:01:29		10:01:31	10:01:32	10:01:34
288	Bike115	B	LEFT	10:01:30		10:01:33	10:01:35	10:01:37
289	Auto32	B	LEFT	10:01:31		10:01:34	10:01:36	10:01:38
290	Bike116	B	LEFT	10:01:32		10:01:36	10:01:37	10:01:39
291	Bike117	B	LEFT	10:01:35		10:01:38	10:01:40	10:01:41
292	Car107	B	LEFT	10:01:39		10:01:41	10:01:42	10:01:44
293	Car108	B	LEFT	10:01:41		10:01:44	10:01:46	10:01:46
294	Car109	B	LEFT	10:01:47		10:01:49	10:01:49	10:01:53
295	Car110	B	LEFT	10:01:49		10:01:52	10:01:52	10:01:55
296	Car111	B	LEFT	10:01:53		10:01:55	10:01:55	10:01:58
297	Car112	B	LEFT	10:01:56		10:01:59	10:02:00	10:02:03
298	Car113	B	LEFT	10:01:59		10:02:01	10:02:04	10:02:06
299	Truck7	B	LEFT	10:02:08		10:02:08	10:02:10	10:02:13

300	Lorry30	B	LEFT	10:02:12		10:02:15	10:02:16	10:02:18
301	Lorry31	B	LEFT	10:02:17		10:02:18	10:02:21	10:02:23
302	Bus14	B	LEFT	10:02:24		10:02:24	10:02:26	10:02:29
303	Car114	B	LEFT	10:02:26		10:02:28	10:02:30	10:02:33
304	Bike118,119	B	LEFT	10:02:28		10:02:32	10:02:33	10:02:35
305	Bike120	B	LEFT	10:02:29		10:02:34	10:02:34	10:02:36
306	Bike121	B	LEFT	10:02:30		10:02:35	10:02:35	10:02:37
307	Bike122	B	LEFT	10:02:31		10:02:36	10:02:36	10:02:38
308	Bike123	B	LEFT	10:02:35		10:02:39	10:02:42	10:02:43
309	Bike124	B	LEFT	10:02:37		10:02:41	10:02:43	10:02:44
310	Car115	B	LEFT	10:02:38		10:02:42	10:02:44	10:02:45
311	Auto33	B	LEFT	10:02:40		10:02:44	10:02:45	10:02:48
312	Bus15	B	LEFT	10:02:47		10:02:47	10:02:50	10:02:52
313	Car116	B	LEFT	10:02:49		10:02:52	10:02:54	10:02:55
314	Bike125	B	LEFT	10:02:52		10:02:55	10:02:57	10:02:59
315	Car117	B	LEFT	10:02:54		10:02:57	10:02:58	10:03:03
316	Car118	B	LEFT	10:03:00		10:02:59	10:03:02	10:03:06
317	Bike126	B	LEFT	10:03:01		10:03:02	10:03:06	10:03:07
318	Car119	B	LEFT	10:03:03		10:03:05	10:03:08	10:03:08
319	Car120	B	LEFT	10:03:06		10:03:07	10:03:11	10:03:11
320	Car121	B	LEFT	10:03:08		10:03:09	10:03:13	10:03:13
321	Bike127	B	LEFT	10:03:09		10:03:11	10:03:14	10:03:15
322	Car122	B	LEFT	10:03:18		10:03:19	10:03:21	10:03:23
323	Bike128	B	LEFT	10:03:19		10:03:21	10:03:24	10:03:26
324	Car123	B	LEFT	10:03:22		10:03:22	10:03:25	10:03:27
325	Bike129	B	LEFT	10:03:23		10:03:24	10:03:29	10:03:29
326	Car124	B	LEFT	10:03:27		10:03:28	10:03:32	10:03:33
327	Bike130	B	LEFT	10:03:28		10:03:30	10:03:34	10:03:34
328	Car125	B	LEFT	10:03:31		10:03:31	10:03:35	10:03:36
329	Car126	B	LEFT	10:03:38		10:03:39	10:03:42	10:03:43
330	**Truck8**	B	LEFT	10:03:44		10:03:44	10:03:46	10:03:48
331	Bike131	B	LEFT	10:03:45		10:03:47	10:03:50	10:03:52
332	Car127	B	LEFT	10:03:48		10:03:50	10:03:53	10:03:53
333	Bus16	B	LEFT	10:03:52		10:03:52	10:03:55	10:03:56
334	Bike132	B	LEFT	10:03:54		10:03:55	10:03:59	10:03:59
335	Bus17	B	LEFT	10:03:57		10:03:58	10:04:01	10:04:01
336	Bus18	B	LEFT	10:04:01		10:04:02	10:04:05	10:04:04
337	Auto34	B	LEFT	10:04:04		10:04:05	10:04:08	10:04:09
338	Auto35	B	LEFT	10:04:05		10:04:07	10:04:10	10:04:10
339	Car128	B	LEFT	10:04:07		10:04:11	10:04:13	10:04:13
340	Bike133	B	LEFT	10:04:09		10:04:12	10:04:14	10:04:15
341	Car129	B	LEFT	10:04:12	10:04:13	10:04:14	10:04:17	10:04:19
342	Car130	B	LEFT	10:04:14	10:04:15	10:04:15	10:04:18	10:04:20
343	Bike134	B	LEFT	10:04:15		10:04:12	10:04:14	10:04:15

344	Car131	B	LEFT	10:04:17	10:04:18	10:04:14	10:04:17	10:04:19
345	Car132	B	LEFT	10:04:23	10:04:24	10:04:15	10:04:18	10:04:20
346	Bike135	B	LEFT	10:04:24	10:04:25	10:04:27	10:04:30	10:04:30
347	Bike136	B	LEFT	10:04:24	10:04:25	10:04:29	10:04:31	10:04:30
348	Bike137	B	LEFT	10:04:25	10:04:25	10:04:30		10:04:32
349	Bus19	B	LEFT	10:04:33	10:04:31	10:04:33	10:04:35	10:04:36
350	Bike138	B	LEFT	10:04:35	10:04:35	10:04:34	10:04:39	10:04:39
351	Bike139	B	LEFT	10:04:35	10:04:35	10:04:34	10:04:40	10:04:39
352	Bike140	B	LEFT	10:04:35	10:04:35	10:04:36	10:04:41	10:04:40
353	Car133	B	LEFT	10:04:37	10:04:38	10:04:39	10:04:42	10:04:42
354	Car134	B	LEFT	10:04:40	10:04:40	10:04:40	10:04:44	10:04:45
355	Car135	B	LEFT	10:04:42	10:04:43	10:04:44	10:04:47	10:04:48
356	Lorry33	B	LEFT	10:04:48	10:04:46	10:04:48	10:04:52	10:04:52
357	Bus20	B	LEFT	No Data	10:04:52	10:04:53	10:04:54	10:04:58
358	Bike141	B	LEFT			10:04:59	10:04:59	10:05:02
359	Bus21	B	LEFT		10:04:58	10:05:00	10:05:02	10:05:04
360	Bike142	B	LEFT		10:05:03	10:05:04	10:05:05	10:05:07
361	Bike143	B	LEFT		10:05:03	10:05:05	10:05:05	10:05:07
362	Bike144	B	LEFT		10:05:03	10:05:05	10:05:06	10:05:08
363	Bike145	B	LEFT		10:05:03	10:05:06	10:05:07	10:05:09
364	Bus22	B	LEFT		10:05:09	10:05:09	10:05:11	10:05:13
365	Car136	B	LEFT		10:05:13	10:05:14	10:05:16	10:05:18
366	Lorry34	B	LEFT		10:05:15	10:05:17	10:05:19	10:05:21
367	Car137	B	LEFT		10:05:19	10:05:20	10:05:21	10:05:23
368	Lorry35	B	LEFT		10:05:22	10:05:23	10:05:24	10:05:27
369	Car138	B	LEFT			10:05:26	10:05:28	10:05:30
370	Auto36	B	LEFT		10:05:29	10:05:30	10:05:30	10:05:32
371	Lorry36	B	LEFT		10:05:32	10:05:33	10:05:35	10:05:37
372	Bike146	B	LEFT		10:05:37	10:05:37	10:05:38	10:05:39
373	Auto37	B	LEFT		10:05:38	10:05:40	10:05:40	10:05:43
374	Car139	B	LEFT		10:05:47	10:05:47	10:05:47	
375	Lorry37	B	LEFT		10:05:50	10:05:52	10:05:52	10:05:55
376	Car140	B	LEFT		10:05:53	10:05:54	10:05:56	10:05:57
377	Car141	B	LEFT		10:05:55	10:05:57	10:05:59	10:06:00
378	Car142	B	LEFT		10:05:59	10:06:00	10:06:01	10:06:02
379	Bike147	B	LEFT		10:06:00	10:06:02		10:06:05
380	Lorry38	B	LEFT	10:06:02	10:06:03	10:06:06	10:06:04	10:06:08
381	Lorry39	B	LEFT	10:06:05	10:06:06	10:06:08	10:06:05	10:06:12
382	Bicycle4	B	LEFT	10:06:07	10:06:08	10:06:11	10:06:14	10:06:17
383	Lorry40	B	LEFT	10:06:13	10:06:16	10:06:16	10:06:20	10:06:23
384	BICycle5	B	LEFT		10:06:22	10:06:23	10:06:25	10:06:28
385	Bike148	B	LEFT	10:06:22	10:06:22	10:06:24	10:06:25	10:06:29
386	Lorry41	B	LEFT	10:06:23	10:06:26	10:06:26	10:06:29	10:06:33
387	Car143	B	LEFT	10:06:28	10:06:30	10:06:29	10:06:32	10:06:34

388	Bike149	B	LEFT	10:06:29	10:06:32	10:06:32	10:06:35	10:06:37
389	Auto38	B	LEFT	10:06:30	10:06:33	10:06:33	10:06:36	10:06:38
390	Car144	B	LEFT	10:06:33	10:06:35	10:06:35	10:06:39	10:06:42
391	Auto39	B	LEFT	10:06:35	10:06:38	10:06:40	10:06:40	10:06:44
392	Bike150	B	LEFT	10:06:39	10:06:41	10:06:43	10:06:44	10:06:48
393	Bike151	B	LEFT	10:06:39	10:06:41	10:06:43	10:06:44	10:06:50
394	Bike152	B	LEFT	10:06:41	10:06:42	10:06:46	10:06:46	10:06:51
395	Bike153	B	LEFT	10:06:41	10:06:43	10:06:46	10:06:46	10:06:51
396	Bike154	B	LEFT	10:06:43	10:06:43	10:06:47	10:06:47	10:06:52
397	Bike155	B	LEFT	10:06:43	10:06:46	10:06:47		10:06:53
398	Car145	B	LEFT	10:06:43	10:06:46	10:06:00	10:06:52	10:06:55
399	Car146	B	LEFT	10:06:47	10:06:48	10:06:54	10:06:56	10:07:00
400	Bike156	B	LEFT	10:06:52	10:06:55	10:06:56	10:06:57	10:07:01
401	Car147	B	LEFT	10:06:53	10:06:56	10:06:56	10:06:58	
402	Car148	B	LEFT	10:06:55	10:06:59	10:06:59	10:07:01	10:07:05
403	Lorry42	B	LEFT	10:06:59	10:07:02	10:07:03	10:07:05	10:07:09
404	Auto40	B	LEFT	10:07:04	10:07:07	10:07:08	10:07:09	10:07:12
405	Auto41	B	LEFT	10:07:05	10:07:08	10:07:09	10:07:11	10:07:14
406	Auto42	B	LEFT	10:07:08	10:07:10	10:07:11	10:07:13	10:07:16
407	Lorry43	B	LEFT	10:07:12	10:07:14	10:07:15	10:07:18	10:07:19
408	Bike157	B	LEFT	10:07:15		10:07:16	10:07:21	10:07:22
409	Car149	B	LEFT	10:07:17	10:07:18	10:07:17	10:07:23	10:07:24
410	Bike158	B	LEFT	10:07:18	10:07:22	10:07:18	10:07:24	10:07:26
411	Car150	B	LEFT	10:07:21	10:07:23	10:07:19	10:07:25	10:07:29
412	Lorry44	B	LEFT	10:07:24	10:07:25	10:07:28	10:07:31	10:07:32
413	Car151	B	LEFT	10:07:29	10:07:31	10:07:32	10:07:35	10:07:35
414	Auto43	B	LEFT	10:07:30	10:07:32	10:07:33	10:07:35	10:07:37
415	Auto44	B	LEFT	10:07:32		10:07:34	10:07:37	10:07:38
416	Auto45	B	LEFT	10:07:32	10:07:33	10:07:35	10:07:37	10:07:39
417	Auto46	B	LEFT	10:07:34	10:07:35	10:07:36	10:07:40	10:07:41
418	Auto47	B	LEFT	10:07:35	10:07:36	10:07:37	10:07:41	10:07:43
419	Auto48	B	LEFT	10:07:37	10:07:39	10:07:38	10:07:42	10:07:45
420	Car152	B	LEFT	10:07:39	10:07:42	10:07:42	10:07:44	
421	Bike159	B	LEFT	10:07:39	10:07:42	10:07:42	10:07:44	10:07:46
422	Bike160	B	LEFT	10:07:41		10:07:43	10:07:46	10:07:48
423	Bike161	B	LEFT	10:07:42	10:07:45	10:07:44	10:07:47	10:07:49
424	Bike162	B	LEFT	10:07:43	10:07:45	10:07:45	10:07:48	10:07:51
425	Lorry45	B	LEFT	10:07:46	10:07:48	10:07:49	10:07:52	10:07:55
426	Lorry46	B	LEFT	10:07:52	10:07:54	10:07:53	10:07:56	10:08:00
427	Bike163	B	LEFT	10:07:55	10:07:57	10:07:54	10:08:00	10:08:03
428	Lorry47	B	LEFT	10:07:57		10:07:55	10:08:03	10:08:05
429	Car153	B	LEFT	10:08:02		10:08:05	10:08:07	10:08:09
430	Car154	B	LEFT	10:08:04	10:08:15	10:08:06	10:08:10	10:08:10
431	Car155	B	LEFT	10:08:06	10:08:17	10:08:07	10:08:11	10:08:11

432	Lorry48	B	LEFT	10:08:09	10:08:09	10:08:12	10:08:15	10:08:15
433	Auto49	B	LEFT	10:08:13		10:08:15	10:08:18	10:08:18
434	Car156	B	LEFT	10:08:14	10:08:17	10:08:16	10:08:20	10:08:20
435	Bike164	B	LEFT	10:08:20		10:08:23	10:08:25	10:08:26
436	Lorry49	B	LEFT	10:08:23	10:08:23	10:08:26	10:08:28	10:08:30
437	Car157	B	LEFT	10:08:28	10:08:27	10:08:30	10:08:33	10:08:34
438	Lorry50	B	LEFT	10:08:30	10:08:30	10:08:31	10:08:36	10:08:37
439	Bike165	B	LEFT	10:08:33	10:08:33	10:08:32	10:08:38	10:08:39
440	Bus23	B	LEFT	10:08:36	10:08:37	10:08:38	10:08:43	10:08:42
441	Bike166	B	LEFT	10:08:39	10:08:39	10:08:41	10:08:45	10:08:45
442	Car158	B	LEFT	10:08:46	10:08:47	10:08:50	10:08:51	10:08:55
443	Car159	B	LEFT	10:08:49	10:08:51	10:08:52	10:08:55	10:08:57
444	Bike167	B	LEFT	10:08:52		10:08:53	10:08:58	10:08:58
445	Lorry51	B	LEFT	10:09:03	10:09:04	10:09:06	10:09:09	10:09:11
446	Car160	B	LEFT	10:09:08	10:09:09	10:09:12	10:09:14	10:09:16
447	Bike168	B	LEFT	10:09:10		10:09:13	10:09:16	10:09:18
448	Bike169	B	LEFT	10:09:11		10:09:15	10:09:17	10:09:19
449	Lorry52	B	LEFT	10:09:13		10:09:16	10:09:18	10:09:20
450	Lorry53	B	LEFT	10:09:21	10:09:23	10:09:25	10:09:27	10:09:29
451	Bike170	B	LEFT	10:09:24		10:09:25	10:09:28	10:09:29
452	Car161	B	LEFT	10:09:26		10:09:29	10:09:32	10:09:33
453	Bus24	B	LEFT	10:09:31	10:09:31	10:09:33	10:09:37	10:09:36
454	Car162	B	LEFT	10:09:35	10:09:36	10:09:38		
455	Car163	B	LEFT	10:09:37	10:09:37	10:09:38	10:09:41	10:09:42
456	Lorry54	B	LEFT	10:09:40	10:09:40	10:09:43	10:09:46	10:09:48
457	Auto50	B	LEFT	10:09:43	10:09:43	10:09:46	10:09:49	10:09:52
458	Auto51	B	LEFT	10:09:44	10:09:45	10:09:47	10:09:50	10:09:54
459	Car164	B	LEFT	10:09:47	10:09:47	10:09:49	10:09:54	
460	Auto52	B	LEFT	10:09:48	10:09:49	10:09:51	10:09:55	
461	Car165	B	LEFT	10:09:50	10:09:51	10:09:52	10:09:56	
462	Auto53	B	LEFT	10:09:52	10:09:53	10:09:55	10:09:58	10:09:59
463	Bike171	B	LEFT	10:09:54	10:09:53	10:09:57		10:10:01
464	Bike172	B	LEFT	10:09:55	10:09:54	10:09:58	10:09:59	10:10:01
465	Bike173	B	LEFT	10:09:55	10:09:54	10:09:58	10:09:59	10:10:02
466	Car166	B	LEFT	10:09:56	10:09:58	10:10:00	10:10:03	10:10:04
467	Car167	B	LEFT	10:09:59	10:10:01	10:10:03		10:10:05
468	Car168	B	LEFT	10:10:03	10:10:03	10:10:06		10:10:09
469	Lorry55	B	LEFT	10:10:06		10:10:10	10:10:11	10:10:11
470	Bike174	B	LEFT	10:10:08		10:10:11	10:10:12	10:10:12
471	Bike175	B	LEFT	10:10:09		10:10:12	10:10:13	10:10:13
472	Bike176	B	LEFT	10:10:10	10:10:11	10:10:12	10:10:13	10:10:15
473	Bike177	B	LEFT	10:10:10	10:10:11	10:10:13	10:10:13	10:10:16
474	Car169	B	LEFT	10:10:12	10:10:13	10:10:17	10:10:18	10:10:18
475	Bus25	B	LEFT	10:10:15	10:10:15	10:10:18	10:10:20	10:10:20

476	Auto54	B	CENTRE	10:10:19	10:10:19	10:10:22	10:10:24	10:10:24
477	Lorry56	B	LEFT	10:10:24	10:10:25	10:10:27	10:10:30	10:10:29
478	Car170	B	LEFT	10:10:28	10:10:29	10:10:30	10:10:34	10:10:32
479	Car171	B	LEFT	10:10:31	10:10:32	10:10:32	10:10:36	10:10:34
480	Lorry57	B	LEFT	10:10:34	10:10:34	10:10:37	10:10:40	10:10:39
481	Car172	B	LEFT	10:10:38	10:10:39	10:10:41	10:10:44	10:10:41
482	Lorry58	B	LEFT	10:10:43	10:10:43	10:10:46	10:10:49	
483	Car173	B	LEFT	10:10:46	10:10:47	10:10:49	10:10:52	10:10:52
484	Car174	B	LEFT	10:10:48	10:10:50	10:10:50	10:10:54	
485	Car175	B	LEFT	10:10:51	10:10:52	10:10:54		10:10:55
486	Auto55	B	LEFT	10:10:52	10:10:53		10:10:58	10:10:59
487	Auto56	B	LEFT	10:10:54	10:10:54	10:10:56	10:10:59	10:10:59
488	Bike178	B	LEFT	10:10:54				10:10:59
489	Car176	B	LEFT	10:10:57	10:10:57	10:10:58		10:11:01
490	Car177	B	LEFT	10:10:58	10:11:00			
491	Auto57	B	LEFT	10:10:59			10:11:03	10:11:03
492	Car178	B	LEFT	10:11:01		10:11:02	10:11:06	10:11:06
493	Auto58	B	LEFT	10:11:03	10:11:03	10:11:04	10:11:08	10:11:08
494	Auto59	B	LEFT	10:11:05	10:11:05	10:11:06	10:11:10	10:11:10
495	Car179	B	LEFT	10:11:07	10:11:08		10:11:12	10:11:12
496	Lorry59	B	LEFT	10:11:10	10:11:11	10:11:14	10:11:15	10:11:17
497	Car180	B	LEFT	10:11:14			10:11:20	10:11:21
498	Lorry60	B	LEFT	10:11:18	10:11:20	10:11:21	10:11:23	10:11:24
499	Bus26	B	LEFT					10:11:28
500	Car181	B	LEFT					10:11:30
501	Lorry61	B	LEFT	10:11:25			10:11:32	10:11:34
502	Bike179	B	LEFT	10:11:32	10:11:34	10:11:35	10:11:35	10:11:36
503	Car182	B	LEFT	10:11:34			10:11:37	10:11:39
504	Bike180	B	LEFT	10:11:34	10:11:35	10:11:36	10:11:38	10:11:40
505	Auto60	B	CENTRE	10:11:39	10:11:39	10:11:39		10:11:42
506	Bike181	B	LEFT	10:11:41			10:11:45	10:11:43
507	Auto61	B	LEFT	10:11:42	10:11:42	10:11:45	10:11:48	10:11:47
508	Car183	B	LEFT	10:11:44	10:11:44	10:11:46	10:11:49	10:11:49
509	Bike182	B	LEFT	10:11:45	10:11:47	10:11:47	10:11:51	10:11:51
510	Bike183	B	LEFT	10:11:47	10:11:48	10:11:49	10:11:52	10:11:53
511	Auto62	B	LEFT	10:11:48	10:11:49	10:11:50	10:11:54	10:11:55
512	Lorry62	B	RIGHT	10:11:51	10:11:51	10:11:55	10:11:55	10:11:55
513	Car184	B	LEFT	10:11:54	10:11:54	10:11:56	10:11:59	10:11:59
514	Car185	B	CENTRE	10:11:54	10:11:54	10:11:57	10:12:00	
515	Car186	B	LEFT	10:11:56	10:11:56	10:11:58	10:12:01	
516	Bike184	B	LEFT	10:11:56		10:11:58	10:12:02	
517	Bike185	B	RIGHT	10:11:57		10:11:59	10:12:03	
518	Car187	B	LEFT	10:11:59	10:12:00	10:12:01	10:12:04	
519	Car188, Bike186	B	LEFT	10:12:01	10:12:03	10:12:02	10:12:05	

520	Bike187	B	RIGHT	10:12:01		10:12:03	10:12:06	
521	Bike188	B	RIGHT	10:12:02		10:12:05	10:12:07	
522	Car189	B	LEFT	10:12:04	10:12:04	10:12:07	10:12:09	
523	Car190	B	LEFT	10:12:05	10:12:05	10:12:07	10:12:10	
524	Auto63	B	LEFT	10:12:07	10:12:07	10:12:09	10:12:12	
525	Auto64	B	LEFT	10:12:08	10:12:08	10:12:11	10:12:13	
526	Cars191	B	LEFT	10:12:11	10:12:13	10:12:13	10:12:16	
527	Car192	B	LEFT	10:12:11		10:12:13	10:12:16	
528	Car193	B	LEFT	10:12:13		10:12:15	10:12:18	
529	Cars 194	B	RIGHT	10:12:14		10:12:16	10:12:19	
530	Bike189	B	RIGHT	10:12:15		10:12:17	10:12:20	
531	Car195	B	LEFT	10:12:16	10:12:16	10:12:18	10:12:21	
532	Car196	B	LEFT	10:12:21		10:12:24	10:12:26	
533	Lorry63	B	LEFT	10:12:23	10:12:23	10:12:25	10:12:28	
534	Bike190	B	LEFT	10:12:27		10:12:28	10:12:32	
535	Car197	B	RIGHT	10:12:28		10:12:30	10:12:33	
536	Auto65	B	LEFT	10:12:30	10:12:31	10:12:32	10:12:35	
537	Car198	B	LEFT	10:12:32	10:12:34	10:12:34	10:12:37	
538	Car199	B	LEFT	10:12:33	10:12:35	10:12:36	10:12:39	
539	Auto66	B	RIGHT	10:12:35		10:12:37	10:12:40	
540	Car200	B	CENTRE	11:12:35		10:12:38	10:12:41	
541	Car201	B	LEFT	10:12:37		10:12:39	10:12:42	
542	Bike191	B	LEFT	10:12:38		10:12:40	10:12:43	
543	Auto67	B	CENTRE	10:12:41	10:12:41	10:12:43	10:12:46	
544	Bike192	B	LEFT	10:12:42	10:12:42	10:12:46	10:12:49	
545	Lorry64	B	LEFT	10:12:47	10:12:48	10:12:49	10:12:53	
546	Car202	B	LEFT	10:12:49	10:12:49	10:12:52	10:12:55	
547	Lorry65	B	RIGHT	10:12:56	10:12:56	10:12:59	10:13:02	
548	Auto68	B	LEFT	10:13:02	10:13:03	10:13:05	10:13:08	
549	Lorry66	B	LEFT	10:13:05		10:13:08	10:13:11	
550	Bike193	B	RIGHT	10:13:05		10:13:08	10:13:12	
551	Car203	B	LEFT	10:13:07	10:13:08	10:13:11	10:13:13	
552	Bike194	B	LEFT	10:13:09		10:13:13	10:13:16	
553	Bike195	B	LEFT	10:13:12	10:13:13	10:13:15	10:13:18	
554	Lorry67	B	RIGHT	10:13:19	10:13:19	10:13:22	10:13:24	
555	Car204	B	LEFT	10:13:22	10:13:23	10:13:26	10:13:25	
556	Bus27	B	RIGHT	10:13:24	10:13:26	10:13:27	10:13:30	
557	Car205	B	LEFT	10:13:27	10:13:27	10:13:29	10:13:32	
558	Cars206	B	LEFT	10:13:29		10:13:30	10:13:33	
559	Car207	B	LEFT	10:13:29		10:13:32	10:13:34	
560	Car208	B	LEFT	10:13:31	10:13:33	10:13:33	10:13:37	
561	Car209	B	LEFT	10:13:32	11:13:33	10:13:34	10:13:38	
562	Car210	B	LEFT	10:13:33		10:13:35	10:13:39	
563	Car211	B	LEFT	10:13:35		10:13:38	10:13:41	

564	Auto69	B	LEFT	10:13:38	10:13:38	10:13:41	10:13:44	
565	Lorry68	B	RIGHT	10:13:43	10:13:43	10:13:48	10:13:50	10:13:52
566	Bike196	B	LEFT	10:13:44			10:13:51	
567	Car212	B	LEFT	10:13:47	10:13:47	10:13:49	10:13:52	10:13:54
568	Car213	B	LEFT	10:13:47	11:13:47	10:13:50	10:13:53	10:13:55
569	Car214	B	CENTRE	10:13:48		10:13:51	10:13:54	
570	Car215	B	LEFT	10:13:49		10:13:52	10:13:55	10:13:56
571	Car216	B	CENTRE	10:13:50		10:13:54	10:13:57	10:13:58
572	Bike197	B	LEFT	10:13:52	10:13:53	10:13:56	10:13:59	10:14:01
573	Car217	B	CENTRE	10:13:54				
574	Car218	B	LEFT	10:13:56	10:13:58	10:13:59		
575	Car219	B	CENTRE	10:13:58	10:13:58	10:14:02		
576	Car220	B	RIGHT	10:14:00	10:14:02	10:14:03		
577	Bike198	B	LEFT	10:14:00			10:14:05	
578	Car221	B	LEFT	10:14:04	10:14:05	10:14:07	10:14:10	
579	Bike199	B	LEFT	10:14:07		10:14:10	10:14:13	
580	Car222	B	LEFT	10:14:07		10:14:10	10:14:14	
581	Auto70	B	LEFT	10:14:09		10:14:12	10:14:15	
582	Auto71	B	LEFT	10:14:10		10:14:13	10:14:16	
583	Car223	B	LEFT	10:14:12	10:14:14			
584	Bike200	B	LEFT	10:14:12	10:14:16	10:14:16		
585	Bike201	B	LEFT	10:14:13		10:14:17		
586	Bike202	C	LEFT	10:14:14			10:14:18	
587	Bike203	B	CENTR E	10:14:15			10:14:19	
588	Bike204	C	CENTRE	10:14:15		10:14:19	10:14:20	
589	Car224	B	LEFT	10:14:15				
590	Lorry69	B	LEFT	10:14:27	10:14:29		10:14:33	
591	Car225	B	LEFT	10:14:27				
592	Auto72	B	LEFT	10:14:28			10:14:35	
593	Bike205	B	LEFT	10:14:30		10:14:33	10:14:37	
594	Car226	B	LEFT	10:14:31	10:14:32	10:14:34	10:14:38	
595	Car227	B	LEFT	10:14:32	10:14:34		10:14:39	
596	Bike206	B	LEFT	10:14:34		10:14:37	10:14:41	
597	Bike207	B	RIGHT	10:14:34		10:14:38		
598	Car228	B	LEFT	10:14:35	10:14:37	10:14:39	10:14:42	
599	Car229	B	LEFT	10:14:37		10:14:41	10:14:43	
600	Car230	B	LEFT	10:14:39		10:14:42	10:14:45	
601	Bike208	B	LEFT	10:14:41		10:14:44	10:14:47	
602	Bus28	B	LEFT	10:14:43	10:14:43	10:14:46	10:14:50	
603	Bike209	B	LEFT	10:14:47		10:14:49	10:14:53	
604	Auto73	B	LEFT	10:14:47	10:14:49	10:14:49	10:14:53	
605	Bike210	B	LEFT	10:14:48		10:14:50	10:14:54	
606	Car231	B	LEFT	10:14:50		10:14:51	10:14:56	
607	Bike211	B	LEFT	10:14:52		10:14:55	10:14:58	

608	Auto74	B	LEFT	10:14:53	10:14:54	10:14:57	10:14:59	
609	Bike212	B	LEFT	10:14:53		10:14:55	10:15:00	
610	Bike213	B	LEFT	10:14:55		10:14:58	10:15:01	
611	Auto75	B	LEFT	10:14:56	10:14:56	10:14:59	10:15:02	
612	Bike214	B	CENTRE	10:14:56		10:14:59	10:15:03	
613	Auto76	B	LEFT	10:14:58	10:14:59	10:15:01	10:15:04	
614	Lorry70	B	LEFT	10:15:04	10:15:04	10:15:07	10:15:11	
615	Car232	B	LEFT			10:15:09	10:15:14	
616	Car233	B	LEFT			10:15:10	10:15:16	
617	Car234	B	LEFT	10:15:12		10:15:13	10:15:18	
618	Lorry71	B	LEFT	10:15:17		10:15:17	10:15:23	
619	Bike215	B	LEFT	10:15:18		10:15:20	10:15:25	
620	Car235	B	LEFT	10:15:19	10:15:22	10:15:20	10:15:22	10:15:26
621	Car236	B	LEFT	10:15:23		10:15:24	10:15:24	10:15:29
622	Lorry72	B	LEFT	10:15:31		10:15:33	10:15:35	10:15:37
623	Auto77	B	LEFT	10:15:32		10:15:33	10:15:36	10:15:38
624	Bike216	B	LEFT	10:15:33		10:15:35	10:15:37	10:15:40
625	Car237	B	CENTRE	10:15:36	10:15:37	10:15:37	10:15:42	
626	Car238	B	LEFT	10:15:38	10:15:38	10:15:39	10:15:40	10:15:46
627	Lorry73	B	LEFT	10:15:42	10:15:43	10:15:45	10:15:46	10:15:48
628	Bike217	B	LEFT	10:15:43	10:15:43	10:15:47	10:15:48	10:15:50
629	Auto78	B	LEFT	10:15:45		10:15:48	10:15:50	10:15:51
630	Bike218	B	LEFT	10:15:46		10:15:50	10:15:52	10:15:53
631	Lorry74	B	CENTRE	10:15:47	10:15:48	10:15:51	10:15:54	
632	Car239	B	LEFT	10:15:51	10:15:52	10:15:53	10:15:57	
633	Bike219	B	LEFT	10:15:51		10:15:54	10:15:58	
634	Auto79	B	LEFT	10:15:52	10:15:54	10:15:55	10:15:56	10:15:59
635	Bike220	B	LEFT	10:15:54		10:15:58	10:15:59	10:16:00
636	Bike221	B	LEFT	10:15:55		10:15:58	10:16:00	10:16:01
637	Bike222	B	LEFT	10:15:55		10:15:59	10:16:01	10:16:02
638	Bike223	B	LEFT	10:15:56		10:15:59	10:16:01	
639	Lorry75	B	LEFT	10:16:00	10:16:00	10:16:03	10:16:07	
640	Bike224	B	LEFT	10:16:02		10:16:04	10:16:08	
641	Car240	B	LEFT	10:16:03		10:16:07	10:16:09	10:16:11
642	Bike225	B	LEFT	10:16:03		10:16:07	10:16:09	10:16:12
643	Car241	B	LEFT	10:16:06		10:16:09	10:16:12	10:16:13
644	Bike226	B	LEFT	10:16:07		10:16:10	10:16:13	10:16:14
645	Car242	B	LEFT	10:16:08		10:16:11		10:16:15
646	Bike227	B	LEFT	10:16:08		10:16:12	10:16:14	
647	Auto80	B	LEFT	10:16:11		10:16:13	10:16:18	10:16:19
648	Car243	B	LEFT	10:16:14	10:16:14	10:16:17	10:16:21	
649	Lorry76	B	LEFT	10:16:14		10:16:18	10:16:21	10:16:22
650	Auto81	B	LEFT	10:16:17		10:16:19	10:16:24	10:16:24
651	Car244	B	CENTRE	10:16:18		10:16:19	10:16:23	10:16:24

652	Bike228	B	LEFT	10:16:19		10:16:23	10:16:24	10:16:25
653	Car245	B	CENTRE	10:16:20		10:16:23	10:16:24	10:16:26
654	Auto82	B	RIGHT	10:16:22	10:16:23	10:16:25	10:16:27	10:16:28
655	Car246	B	LEFT	10:16:22		10:16:27	10:16:28	
656	Car247	B	RIGHT	10:16:26		10:16:28	10:16:29	10:16:31
657	Lorry77	B	LEFT	10:16:30	10:16:31	10:16:32	10:16:33	10:16:35
658	Auto83	B	RIGHT	10:16:32	10:16:33	10:16:34	10:16:35	10:16:37
659	Auto84	B	LEFT	10:16:33		10:16:35	10:16:36	
660	Car248	B	LEFT	10:16:37	10:16:38	10:16:39	10:16:39	10:16:42
661	Car249	B	LEFT	10:16:41		10:16:43	10:16:44	10:16:47
662	Lorry78	B	RIGHT	10:16:45	10:16:46	10:16:46	10:16:48	10:16:51
663	Car250	B	RIGHT	10:16:49	10:16:49	10:16:51	10:16:53	10:16:54
664	Car251	B	CENTRE	10:16:49	10:16:49	10:16:51	10:16:54	10:16:55
665	Bike229	B	LEFT	10:16:50		10:16:53	10:16:56	10:16:57
666	Car252	B	RIGHT	10:16:54		10:16:55	10:16:59	10:17:00
667	Bike230	B	LEFT	10:16:55	10:16:56	10:16:57	10:17:01	10:17:01
668	Bike231	B	LEFT	10:16:55	10:16:56	10:16:57	10:17:01	10:17:02
669	Car253	B	LEFT	10:16:57	10:16:58	10:17:00	10:17:03	10:17:04
670	Lorry79	B	LEFT	10:17:04	10:17:04	10:17:06	10:17:10	
671	Lorry80	B	LEFT	10:17:09	10:17:10	10:17:10	10:17:15	10:17:16
672	Car254	B	LEFT	10:17:12	10:17:14	10:17:14	10:17:16	
673	Bike232	B	LEFT	10:17:14	10:17:15	10:17:15	10:17:18	10:17:20
674	Bike233	B	LEFT	10:17:14	10:17:15	10:17:17	10:17:20	10:17:20
675	Auto85	B	LEFT	10:17:16	10:17:17	10:17:18	10:17:21	10:17:22
676	Auto86	B	LEFT	10:17:18	10:17:19	10:17:20	10:17:22	
677	Lorry81	B	LEFT	10:17:21	10:17:22	10:17:23	10:17:25	10:17:26
678	Car255	B	LEFT	10:17:25	10:17:25	10:17:24	10:17:27	10:17:30
679	Car256	B	LEFT	10:17:27	10:17:28	10:17:28	10:17:31	10:17:33
680	Bike234	B	LEFT	10:17:28		10:17:29	10:17:33	10:17:34
681	Auto87	B	LEFT	10:17:30	10:17:31	10:17:32	10:17:36	
682	Bike235	B	LEFT	10:17:33	10:17:33	10:17:34	10:17:36	10:17:38
683	Lorry82	B	LEFT	10:17:35	10:17:36	10:17:37	10:17:38	10:17:40
684	Bike235	B	RIGHT	10:17:37	10:17:38	10:17:39	10:17:40	10:17:41
685	Car257	B	LEFT	10:17:39		10:17:41	10:17:43	10:17:44
686	Bike236	B	RIGHT	10:17:41	10:17:42	10:17:42	10:17:46	10:17:46
687	Car258	B	LEFT	10:17:41	10:17:42	10:17:42	10:17:47	10:17:47
688	Auto88	B	LEFT	10:17:43		10:17:45	10:17:49	10:17:49
689	Car259	B	LEFT	10:17:45		10:17:49	10:17:49	10:17:51
690	Lorry83	B	LEFT	10:17:50	10:17:50	10:17:51	10:17:52	10:17:56
691	Car260	B	RIGHT	10:17:53		10:17:54	10:17:56	10:17:58
692	Auto89	B	LEFT	10:17:54		10:17:55	10:17:58	10:17:59
693	Car261	B	RIGHT	10:17:56	10:17:57	10:17:58	10:18:01	10:18:02
694	Car262	B	LEFT	10:17:59	10:17:59	10:18:00	10:18:04	10:18:05
695	Car263	B	LEFT	10:17:59	10:18:00	10:18:01	10:18:07	10:18:08

696	Car264	B	CENTRE	10:18:01	10:18:03	10:18:04	10:18:07	10:18:08
697	Car265	B	CENTRE	10:18:02		10:18:05		10:18:08
698	Car266	B	LEFT	10:18:03		10:18:07	10:18:09	10:18:10
699	Auto90	B	CENTRE	10:18:03	10:18:04	10:18:06	10:18:09	10:18:12
700	Bike237	B	LEFT	10:18:06	10:18:06	10:18:09	10:18:11	
701	Bus29	B	LEFT	10:18:08		10:18:10	10:18:14	
702	Car267	B	LEFT	10:18:11		10:18:11	10:18:15	10:18:16
703	Bike238	B	CENTRE	10:18:12	10:18:12	10:18:13	10:18:17	10:18:20
704	Bike239	B	LEFT	10:18:12	10:18:12	10:18:13	10:18:18	10:18:17
705	Car268	B	LEFT	10:18:13	10:18:13	10:18:15	10:18:19	10:18:19
706	Bike240	B	LEFT	10:18:15	10:18:16	10:18:16	10:18:20	
707	Bike241	B	LEFT	10:18:16	10:18:16	10:18:17	10:18:20	10:18:21
708	Bike242	B	LEFT	10:18:17	10:18:17	11:18:17	10:18:21	10:18:22
709	Lorry84	B	CENTRE	10:18:17	10:18:18	10:18:20	10:18:21	10:18:23
710	Car269	B	LEFT	10:18:20	10:18:20	10:18:21	10:18:21	10:18:25
711	Car270	B	LEFT	10:18:24	10:18:24	10:18:26	10:18:25	10:18:30
712	Auto91	B	LEFT	10:18:28	10:18:28	10:18:30	10:18:29	10:18:33
713	Lorry85	B	LEFT	10:18:31	10:18:31	10:18:33	10:18:34	10:18:37
714	Bike243	B	LEFT	10:18:33	10:18:35	10:18:34	10:18:37	10:18:38
715	Bike244	B	LEFT	10:18:34	10:18:35	10:18:35	10:18:38	10:18:39
716	Bike245	B	LEFT	10:18:35	10:18:35	10:18:36	10:18:39	10:18:40
717	Car271	B	LEFT	10:18:37	10:18:38	10:18:39	10:18:40	10:18:43
718	Car272	B	LEFT	10:18:39	10:18:40	10:18:40	10:18:42	10:18:44
719	Car273	B	CENTRE	10:18:41		10:18:43	10:18:44	10:18:46
720	Auto92	B	LEFT	10:18:42	10:18:42	10:18:44	10:18:46	10:18:47
721	Bike246	B	CENTRE	10:18:49				10:18:47
722	Lorry86	B	CENTRE		10:18:48	10:18:49	10:18:53	10:18:53
723	Auto93	B	LEFT	10:18:50	10:18:52	10:18:53	10:18:56	
724	Auto94	B	LEFT	10:18:52	10:18:52	10:18:54	10:18:56	10:18:57
725	Bike247	B	LEFT	10:18:53		10:18:55	10:18:58	10:18:58
726	Car274	B	LEFT	10:18:54	10:18:55	10:18:57	10:18:59	10:19:00
727	Auto95	B	LEFT	10:18:56	10:18:58	10:18:59	10:19:00	10:19:01
728	Car275	B	LEFT	10:18:56	10:18:58	10:18:57	10:19:01	10:19:02
729	Auto96	B	LEFT	10:18:58		10:19:01	10:19:03	10:19:05
730	Car276	B	LEFT	10:18:59		10:19:01	10:19:05	10:19:06
731	Car277	B	LEFT	10:19:00		10:19:03	10:19:06	10:19:07
732	Bike248	B	LEFT	10:19:01	10:19:02	10:19:04	10:19:08	10:19:07
733	Bike249	B	LEFT	10:19:02	10:19:04	10:19:04	10:19:08	10:19:09
734	Auto97	B	LEFT	10:19:03	10:19:06	10:19:06	10:19:09	10:19:09
735	Bike250	B	LEFT	10:19:04	10:19:04	10:19:06		
736	Auto98	B	LEFT	10:19:05		10:19:07	10:19:10	10:19:11
737	Auto99	B	LEFT	10:19:07			10:19:12	10:19:13
738	Bike251	C	LEFT	10:19:08		10:19:08	10:19:12	10:19:18
739	Bike252	A	LEFT	10:19:08			10:19:13	

740	Auto100	C	LEFT	10:19:09	10:19:11	10:19:12	10:19:15	
741	Car278	C	LEFT	10:19:10			10:19:16	
742	Car279	C	LEFT	10:19:15	10:19:15		10:19:20	
743	Bike253	C	LEFT	10:19:16		10:19:19	10:19:22	
744	Lorry87	C	LEFT	10:19:19	10:19:19	10:19:21	10:19:25	10:19:26
745	Lorry88	C	CENTRE	10:19:24	10:19:24	10:19:26	10:19:30	
746	Bike254	A	LEFT	10:19:26		10:19:28	10:19:31	
747	Car280	C	CENTRE	10:19:28	10:19:29	10:19:30	10:19:31	10:19:33
748	Car281	B	LEFT	10:19:30	10:19:32	10:19:32	10:19:32	10:19:35
749	Car282	C	LEFT	10:19:33	10:19:34	10:19:35	10:19:34	10:19:38
750	Car283	C	LEFT	10:19:35	10:19:38	10:19:38	10:19:37	10:19:40
751	Lorry89	C	LEFT	10:19:38	10:19:41	10:19:43	10:19:47	10:19:48
752	Car284	B	LEFT	10:19:44			10:19:49	10:19:50
753	Auto101	B	CENTRE	10:19:46		10:19:48	10:19:51	10:19:51
754	Bike255	C	LEFT	10:19:47	10:19:48	10:19:50	10:19:53	10:19:53
755	Bike256	C	LEFT	10:19:49		10:19:51	10:19:54	10:19:55
756	Bike257	C	LEFT	10:19:52		10:19:54	10:19:57	10:19:58
757	Car285	B	LEFT	10:19:52		10:19:54	10:19:58	10:19:59
758	Bike258	B	LEFT	10:19:53		10:19:55	10:19:59	10:20:00
759	Car286	B	CENTRE	10:19:56	10:19:56	10:19:57	10:20:00	10:20:01
760	Bike259	B	LEFT	10:19:58		10:19:59	10:20:02	10:20:03
761	Bike260	B	LEFT	10:19:59	10:20:00	10:20:01	10:20:04	10:20:04
762	Bike261	B	RIGHT	10:20:00		10:20:02	10:20:05	10:20:06
763	Car287	B	LEFT	10:20:02	10:20:04	10:20:04	10:20:08	10:20:07
764	Bike262	B	LEFT	10:20:03				
765	Auto102	B	LEFT	10:20:03		10:20:05	10:20:09	10:20:10
766	Bike263	B	LEFT	10:20:05		10:20:07	10:20:10	
767	Auto103	B	CENTRE	10:20:06		10:20:08	10:20:11	10:20:14
768	Car288	B	LEFT	10:20:07		10:20:08	10:20:12	10:20:14
769	Bike264	B	CENTRE	10:20:11		10:20:12	10:20:16	10:20:17
770	Bike265	B	RIGHT	10:20:11		10:20:13	10:20:16	10:20:17
771	Bike266	B	LEFT	10:20:12		10:20:14	10:20:18	10:20:18
772	Bike267	B	LEFT	10:20:14	10:20:14	10:20:15	10:20:19	
773	Auto104	B	LEFT	10:20:14		10:20:16	10:20:20	
774	Bike268	B	LEFT	10:20:16		10:20:18	10:20:21	
775	Car289	B	LEFT	10:20:16				
776	Auto105	B	LEFT	10:20:24	10:20:24	10:20:25	10:20:29	10:20:30
777	Auto106	B	LEFT	10:20:25	10:20:26	10:20:27	10:20:30	10:20:31
778	Bike268	B	CENTRE	10:20:27		10:20:29	10:20:33	10:20:33
779	Bike269	B	LEFT	10:20:28		10:20:30	10:20:34	10:20:34
780	Bike270	B	LEFT	10:20:30	10:20:31	10:20:31	10:20:36	10:20:36
781	Bike280	B	LEFT	10:20:31	10:20:31	10:20:32	10:20:37	10:20:38
782	Bike290	B	CENTRE	10:20:32		10:20:34	10:20:38	10:20:38
783	Auto107	B	CENTRE	10:20:33	10:20:33	10:20:35	10:20:39	10:20:40

784	Car290	B	CENTRE	10:20:36	10:20:36	10:20:38	10:20:43	10:20:44
785	Car291	B	CENTRE	10:20:38	10:20:38	10:20:40	10:20:44	10:20:45
786	Car292	B	LEFT	10:20:40	10:20:40	10:20:42	10:20:46	10:20:47
787	Bike291	B	LEFT	10:20:42	10:20:42	10:20:44	10:20:47	10:20:49
788	Bike292	B	LEFT	10:20:46	10:20:47	10:20:48	10:20:51	10:20:52
789	Auto108	B	LEFT	10:20:50	10:20:51	10:20:51	10:20:56	10:20:58
790	Bike(Opp.)1	B	LEFT	10:20:57	10:20:58	10:20:59		
791	Bike293	B	LEFT	10:20:58		10:21:00	10:21:03	10:21:04
792	Car293	B	CENTRE	10:21:05	10:21:05	10:21:07	10:21:11	10:21:12
793	Bike294	B	LEFT	10:21:07		10:21:09	10:21:13	10:21:14
794	Car294	B	CENTRE	10:21:09		10:21:11	10:21:15	
795	Auto109	B	LEFT	10:21:20		10:21:21	10:21:25	10:21:28
796	Cycle6	B	LEFT	10:21:24		10:21:28	10:21:30	
797	Bike293	B	LEFT	10:21:25	10:21:25	10:21:27	10:21:31	10:21:34
798	Lorry90	B	LEFT	10:21:31	10:21:32	10:21:33	10:21:37	10:21:38
799	Lorry91	B	LEFT	10:21:35	10:21:36	10:21:36	10:21:40	10:21:42
800	Bike294	B	LEFT	10:21:37	10:21:38	10:21:38	10:21:43	10:21:44
801	Bike295	B	LEFT	10:21:40	10:21:38	10:21:40	10:21:45	
802	Car295	B	CENTRE	10:21:47	10:21:48	10:21:48	10:21:52	10:21:56
803	Bike296	B	LEFT	10:21:51	10:21:52	10:21:54		10:21:59
804	Lorry92	B	LEFT	10:21:56	10:21:57	10:21:58	10:22:01	10:22:03
805	Bus29	B	LEFT	10:22:01	10:22:02	10:22:02	10:22:06	10:22:06
806	Car296	B	LEFT	10:22:03	10:22:04	10:22:05	10:22:06	10:22:08
807	Car297	B	LEFT	10:22:04	10:22:04	10:22:07	10:22:07	10:22:09
808	Car298	B	LEFT	10:22:05	10:22:05	10:22:09	10:22:11	10:22:12
809	Car299	B	LEFT	10:22:08	10:22:08	10:22:10	10:22:12	10:22:13
810	Bike297	B	LEFT	10:22:09	10:22:09		10:22:14	10:22:13
811	Lorry93	B	LEFT	10:22:14	10:22:14	10:22:16	10:22:19	10:22:19
812	Bike298	B	LEFT	10:22:15	10:22:16	10:22:17	10:22:20	10:22:20
813	Bike299	B	LEFT	10:22:17	10:22:18		10:22:22	
814	Car300	B	LEFT	10:22:17		10:22:19	10:22:20	10:22:21
815	Bike300	B	LEFT	10:22:19		10:22:20	10:22:21	10:22:22
816	Lorry93	B	LEFT	10:22:23	10:22:24	10:22:25	10:22:29	10:22:30
817	Lorry94	B	LEFT	10:22:30	10:22:32	10:22:33	10:22:35	10:22:36
818	Bike301	B	LEFT	10:22:32		10:22:34	10:22:37	10:22:39
819	Cycle7	B	LEFT	10:22:33			10:22:38	
820	Bus30	B	CENTRE	10:22:34	10:22:35	10:22:37	10:22:39	10:22:41
821	Car301	B	RIGHT	10:22:37	10:22:40	10:22:38	10:22:42	10:22:42
822	Bike302	B	LEFT	10:22:38		10:22:41	10:22:43	10:22:45
823	Car302	B	CENTRE	10:22:41		10:22:43	10:22:46	10:22:48
824	Bike303	B	LEFT	10:22:43		10:22:45	10:22:48	10:22:49
825	Auto110			10:22:45	10:22:47	10:22:47	10:22:50	10:22:51
826	Auto111			10:22:46	10:22:48	10:22:48	10:22:52	10:22:53
827	Auto112			10:22:49		10:22:51	10:22:54	10:22:55

828	Bike304			10:22:50		10:22:52	10:22:55	10:22:57
829	Lorry95			10:22:51	10:22:52	10:22:54	10:22:56	10:22:57
830	Bike305			10:22:53		10:22:55	10:22:59	10:23:00
831	Auto113			10:22:57	10:22:58	10:22:59	10:23:03	10:23:06
832	Lorry96			10:23:02	10:23:02	10:23:04	10:23:07	10:23:08
833	Car303			10:23:04	10:23:07	10:23:07	10:23:10	10:23:12
834	Car304			10:23:06	10:23:07	10:23:08	10:23:12	10:23:13
835	Car305			10:23:08	10:23:09	10:23:10	10:23:13	10:23:15
836	Lorry97			10:23:10	10:23:10	10:23:12	10:23:15	10:23:17
837	Bike306			10:23:12	10:23:13	10:23:15	10:23:17	10:23:18
838	Car306			10:23:12	10:23:14	10:23:15	10:23:17	10:23:19
839	Bike307			10:23:13	10:23:15	10:23:17	10:23:19	10:23:19
840	Bike308			10:23:13	10:23:15	10:23:17	10:23:19	10:23:19
841	Bike309			10:23:14	10:23:16	10:23:17	10:23:20	10:23:21
842	Bike310			10:23:15			10:23:21	10:23:21
843	Bike311			10:23:15				10:23:22
844	Car307			10:23:16	10:23:17		10:23:22	10:23:23
845	Auto114			10:23:17	10:23:17	10:23:20	10:23:23	10:23:25
846	Auto115			10:23:19	10:23:21	10:23:22	10:23:24	10:23:27
847	Auto116			10:23:21				
848	Car308			10:23:23	10:23:23	10:23:24	10:23:27	10:23:28
849	Bike312			10:23:26	10:23:27	10:23:28		10:23:35
850	**Cycle8**			10:23:27	10:23:27			10:23:35
851	Lorry98			10:23:27		10:23:29	10:23:33	10:23:36
852	Bike313			10:23:29		10:23:32	10:23:35	
853	Bike314			10:23:30		10:23:32	10:23:36	10:23:37
854	Auto117			10:23:30		10:23:33		10:23:38
855	Auto118			10:23:32		10:23:35		
856	Lorry99			10:23:36	10:23:36	10:23:38	10:23:42	10:23:46
857	Lorry100			10:23:41	10:23:41	10:23:44	10:23:46	10:23:50
858	Lorry101			10:23:45	10:23:46	10:23:48	10:23:50	10:23:52
859	Lorry102			10:23:49	10:23:50	10:23:51	10:23:54	10:23:54
860	Car309			10:23:51	10:23:51	10:23:52	10:23:56	10:23:55
861	Bike315			10:23:52	10:23:52	10:23:53	10:23:57	10:23:57
862	Bike316			10:23:53	10:23:53	10:23:54	10:23:58	10:23:58
863	Bus31			10:23:56	10:23:57	10:23:57	10:24:02	10:23:59
864	Lorry103			10:24:02	10:24:02	10:24:04	10:24:08	10:24:10
865	Car310			10:24:05	10:24:05	10:24:06	10:24:10	10:24:11
866	Car311			10:24:07	10:24:07	10:24:09	10:24:12	10:24:15
867	Auto119			10:24:09	10:24:09	10:24:11	10:24:15	10:24:16
868	Car312			10:24:11	10:24:12	10:24:12	10:24:16	10:24:18
869	Auto120			10:24:14	10:24:14	10:24:14	10:24:17	10:24:19
870	Auto121			10:24:14	10:24:15	10:24:16	10:24:19	10:24:20
871	Bike317			10:24:15	10:24:17	10:24:18	10:24:21	10:24:21

872	Car313			10:24:16		10:24:18	10:24:22	
873	Bike318			10:24:18		10:24:19	10:24:23	
874	Car314			10:24:24		10:24:25		
875	Bike319			10:24:26	10:24:26	10:24:26		
876	Bike320			10:24:26	10:24:27	10:24:28		
877	Bike321			10:24:28	10:24:28	10:24:30		
878	Lorry104						10:24:37	
879	**Crane1**			10:24:42		10:24:45		
880	**Lorry105**			10:24:47		10:24:48	10:24:53	
881	**Car315**			10:24:47			10:24:52	
882	Bike322			10:24:50		10:24:50	10:24:54	
883	**Auto122**			10:24:51		10:24:53	10:24:57	
884	Bike323			10:24:53			10:24:58	
885	**Bus32**			10:24:55				
886	**Bike324**			10:24:55				

Total Vehicular Traffic = 916 (8 Cycles, 324 Bikes, 122 Autos, 315Cars, 1 Tractor, 1 Crane, 32 Buses, 105 Lorries, 8 Trucks)

Results from Photonic Systems – VEDA and VIDUR

As indicated in the earlier section information regarding the laser beam deflections (x and y components), the intensity of the laser beam modulation, the magnitude of vibration, the direction of vibration, the vibrational displacement, velocity and acceleration parameters; along with a time stamp are continuously recorded at a sampling frequency of 10 kHz, thus ensuring that more than half a billion data are generated by the three photonic systems in a span of 36 minutes and 40 seconds. The heavy traffic density (*916 vehicles in a time span of 36 minutes and 40 seconds*) ensured that the free vibrations generated due to the vehicle movements on the bridge did not dampen out fast, and with the arrival of the next vehicle and the subsequent vehicles, always kept the bridge under perennial vibration and increased fatigue loading.

Representative plots of time history and spectra of data from VEDA, VIDUR1 and VIDUR2 during conditions of no traffic and conditions with traffic, *on the span of the bridge*, where measurements were, made are shown in Figure 22 to Figure 28.

The unique feature of our embedded algorithms in VEDA and VIDUR, facilitate real time data processing and showcase digestible information on the console - *indicating the laser beam modulation characteristics, the vibrational displacement, velocity and acceleration in the time domain and the vibrational magnitude spectra along with information related to moving vehicles* (*the type and class of vehicles, the number of vehicles in a given time and the speed of vehicles*).

The snapshots of the live video console display that the operator sees in real time are shown in Figure 29 and Figure 30.

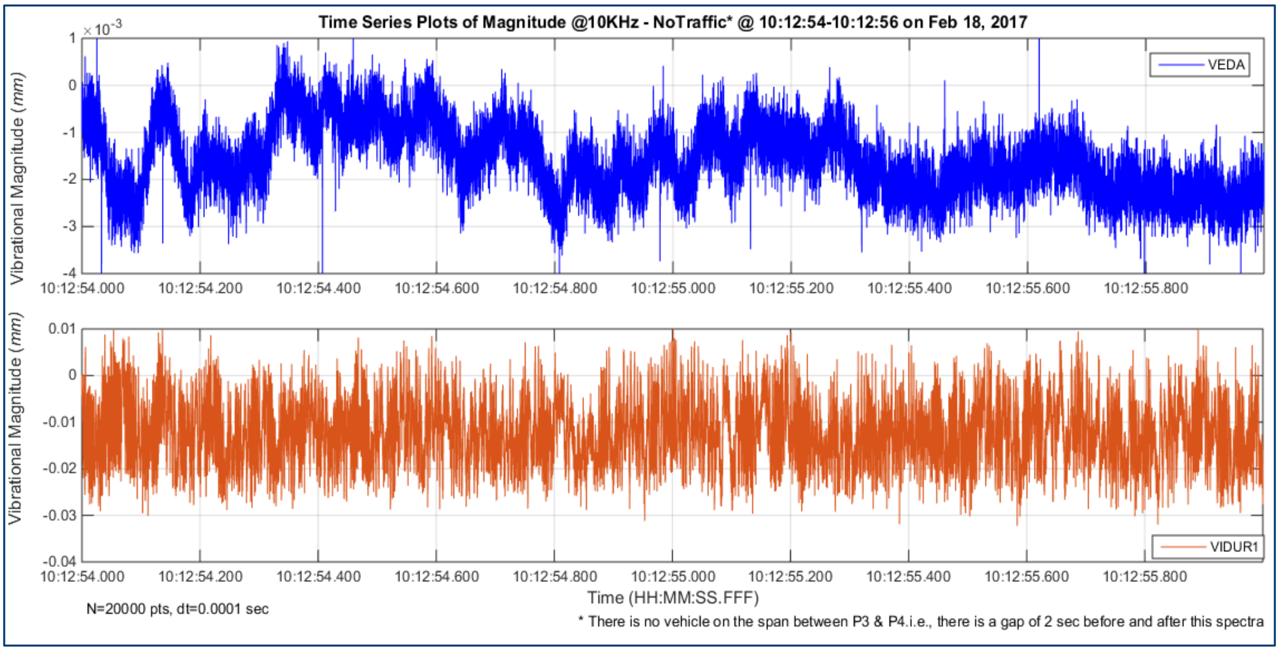


Figure 22: Time series of vibrational magnitude (in mm) data from VEDA (blue) and VIDUR 1 (orange) for a duration of 2 secs with data sampling interval of 10 kHz during which time there were no vehicles on the bridge span (i.e., between the deck on top of Pier P3 and Pier P4). Note that VEDA and VIDUR 1 were observing different components of the vibrations.

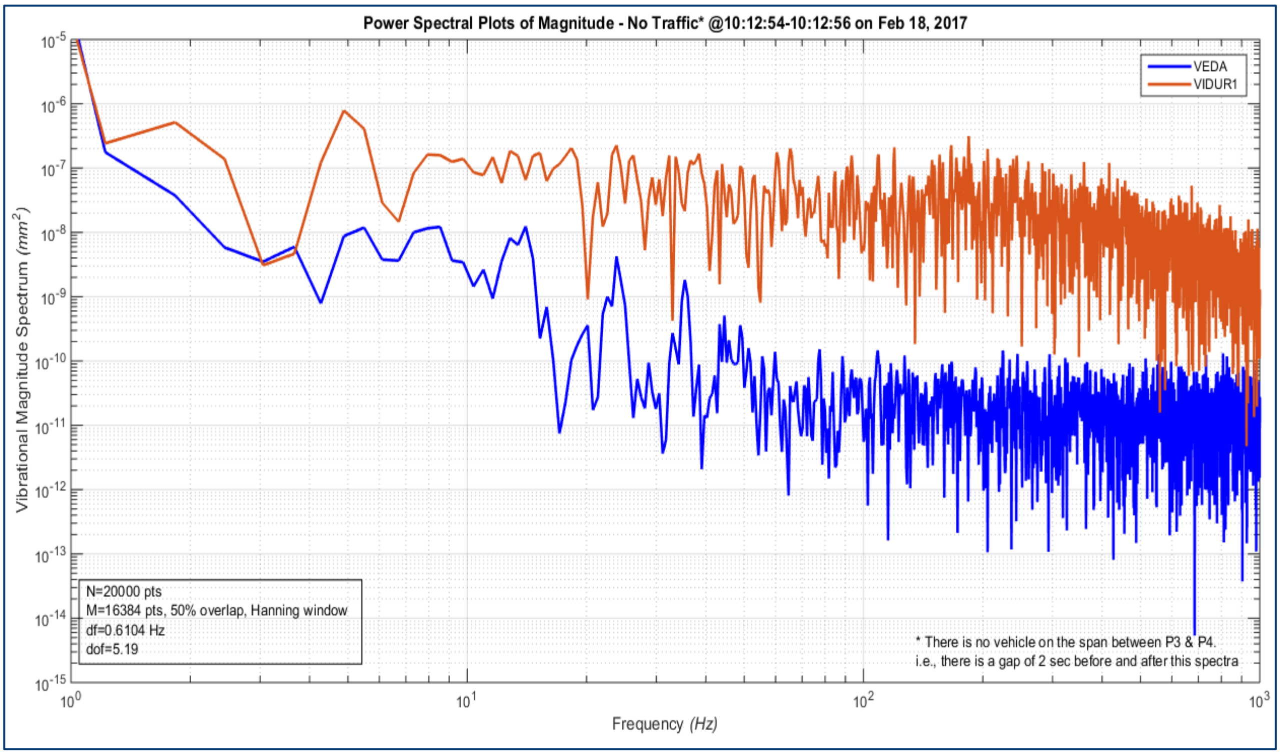


Figure 23: Spectral data from VEDA (blue) and VIDUR 1 (orange) for a duration of 2 secs with data sampling interval of 10 kHz during which time there were no vehicles on the bridge span (i.e., between the deck on top of Pier P3 and Pier P4). Note that VEDA and VIDUR 1 were recording different components of the vibrations.

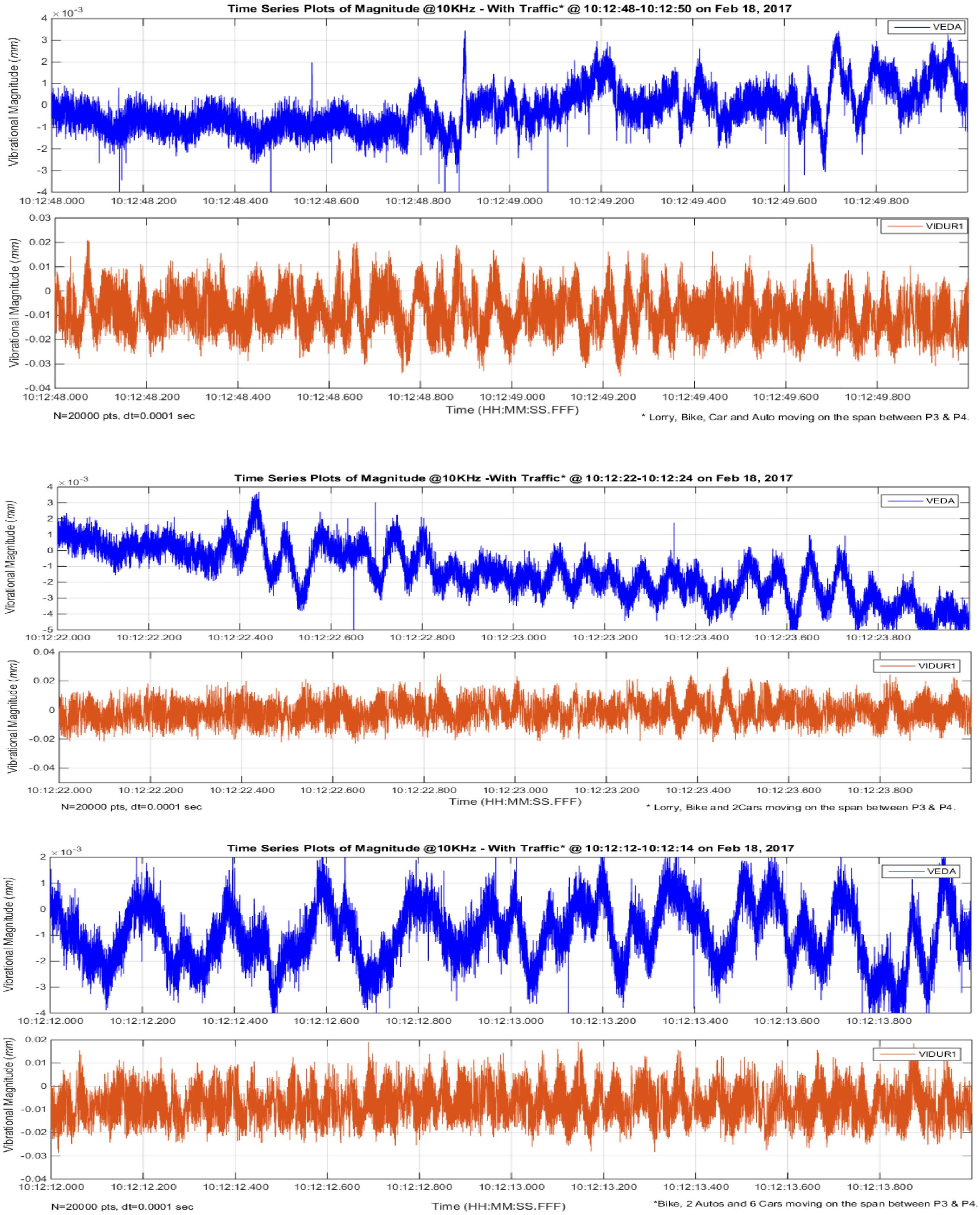


Figure 24: Time series data from VEDA (blue) and VIDUR 1 (orange) for a duration of 2 secs with data sampling interval of 10 kHz during which time there was traffic on the bridge span (at three different timings, under varying traffic conditions on the bridge deck between Pier P3 and Pier P4). Note that VEDA and VIDUR 1 were recording different components of the vibrations. The plots show varying conditions representing increasing traffic conditions in the three plots.

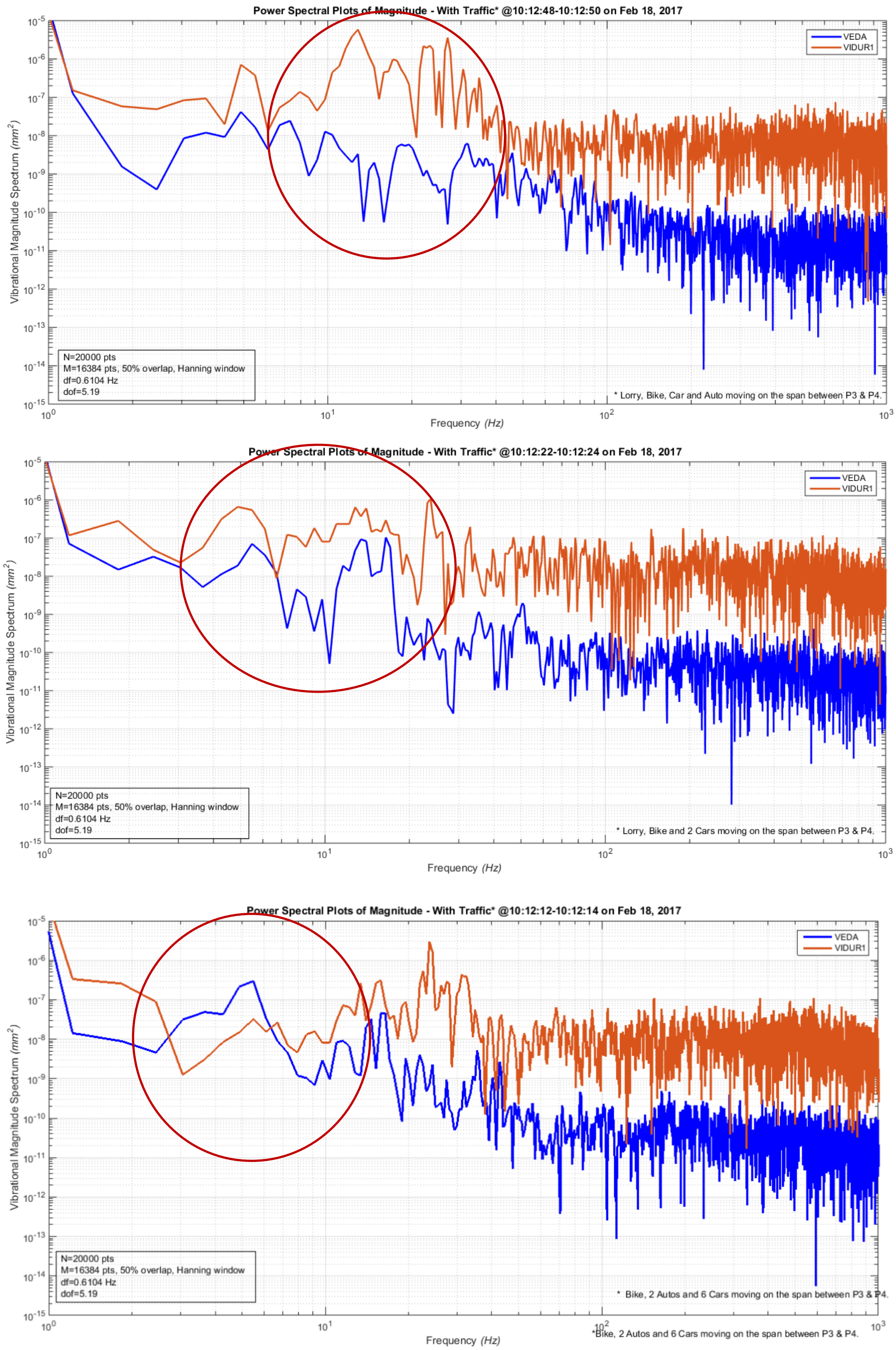


Figure 25: Spectral data from VEDA (blue) and VIDUR 1 (orange) for a duration of 2 secs with data sampling interval of 10 kHz during which time there was traffic on the bridge span (at three different timings, under varying traffic conditions on the bridge deck between Pier P3 and Pier P4). Note that VEDA and VIDUR 1 were recording different components of the vibrations. The plots show varying conditions representing increasing traffic conditions in the three plots.

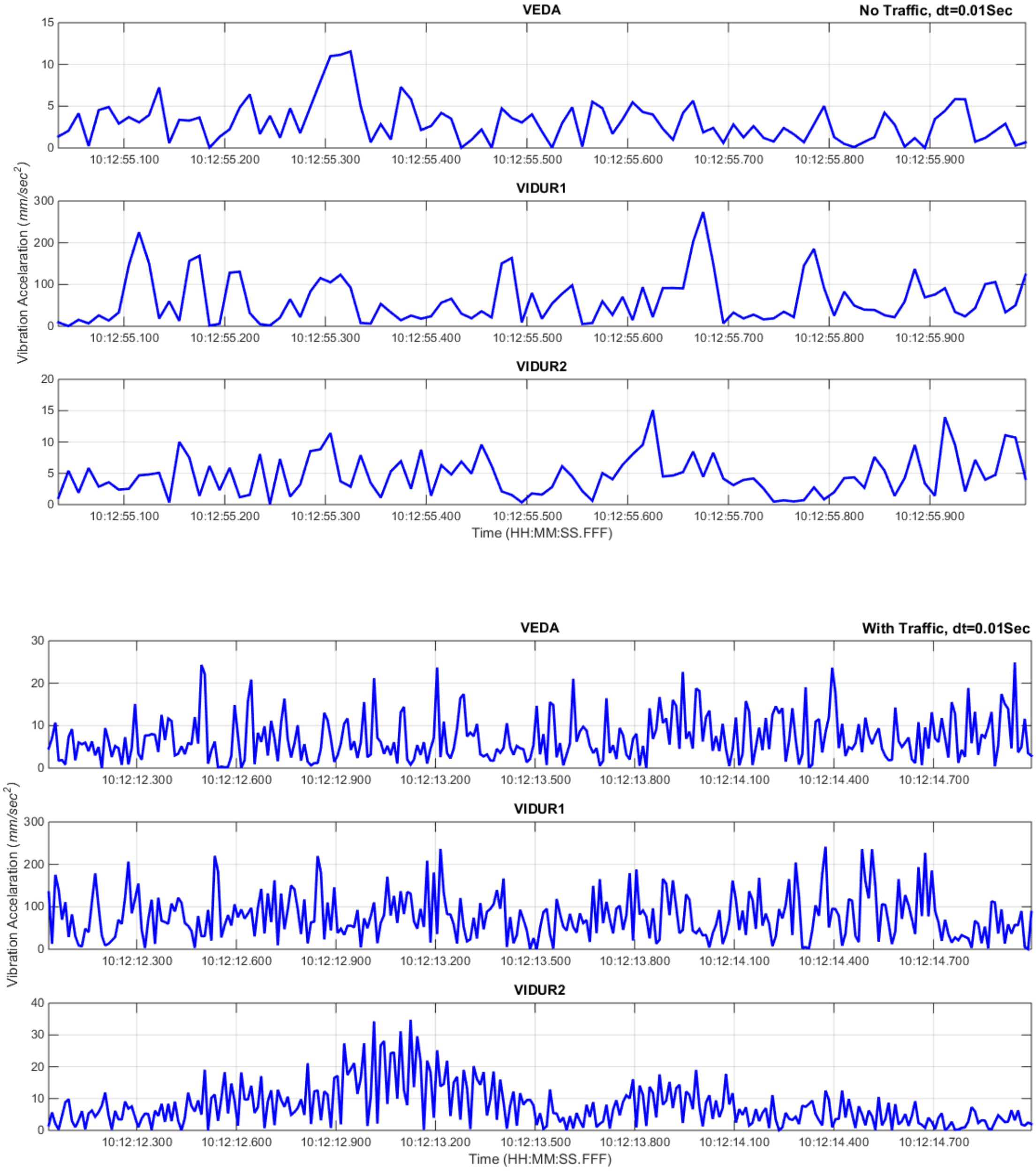


Figure 26: Time series of vibrational acceleration data from VEDA, VIDUR 1 and VIDUR 2 during no traffic condition on the bridge (top plot) for a duration of 1 sec and the time series of vibrational acceleration data from VEDA, VIDUR 1 and VIDUR 2 during traffic conditions for a duration of 3 secs with data sampling interval of 100 Hz demonstrates the feasibility of detecting traffic on bridges.

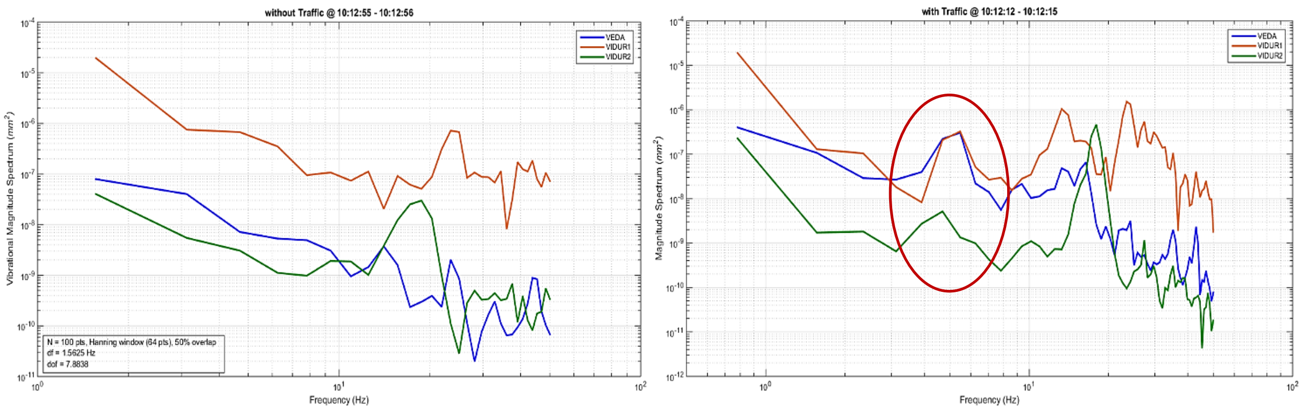


Figure 27A: Spectral data from VEDA (blue), VIDUR 1 (orange) and VIDUR 2 (green) for a duration of 3 secs with data sampling interval of 100 Hz during conditions - when traffic was present, i.e., from 10h:12m:12s to 10h:12m:15s, and when no traffic was present , i.e., from 10h:12m:54to 10h:12m:55s when there was no moving traffic on the bridge span (i.e., between the deck on top of Pier P3 and Pier P4). Note that VEDA ad VIDUR 1 were recording different components of the vibrations. The plots show varying conditions representing increasing traffic conditions in the three plots. Increase in traffic increases the vibrational amplitudes. Note that when there is traffic - the fundamental spectral frequency of 5.469Hz appears along with a higher frequency of 13.2 Hz, indicating the natural modal frequencies of the bridge. These values are in agreement with the theoretical calculation of 5.49Hz and 12.02 Hz respectively.

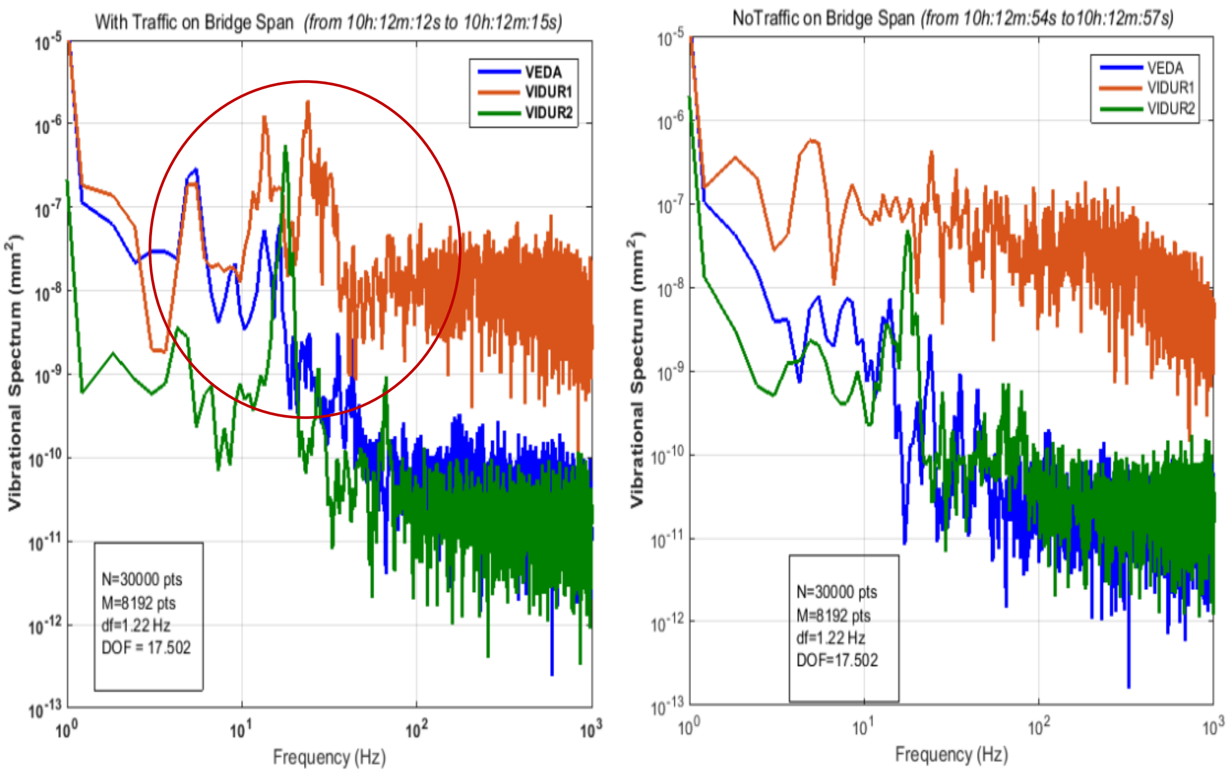


Figure 27B: Spectral data from VEDA (blue), VIDUR 1 (orange) and VIDUR 2 (green) for a duration of 3 secs with data sampling interval of 10 kHz during conditions - when traffic was present, i.e., from 10h:12m:12s to 10h:12m:15s, and when no traffic (or very less traffic) was present , i.e., from 10h:12m:54to 10h:12m:57s when there was no or very less moving traffic on the bridge span (i.e., between the deck on top of Pier P3 and Pier P4). Note that VEDA ad VIDUR 1 were recording different components of the vibrations. The plots show varying conditions representing increasing traffic conditions in the three plots. Increase in traffic increases the vibrational amplitudes.

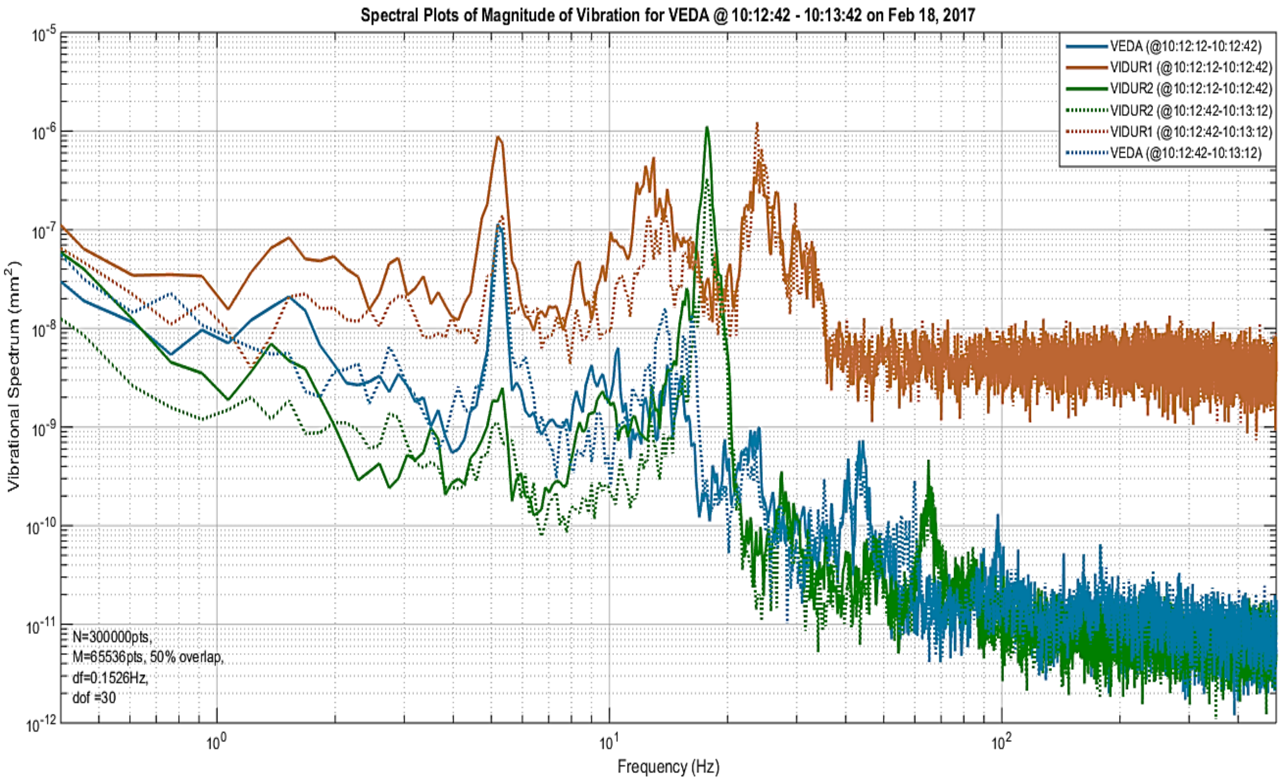


Figure 28: Spectral estimates from the vibrational data recorded by the photonic systems -VEDA, VIDUR 1 and VIDUR 2 under varying moving vehicular loads on the bridge. VEDA was positioned to pick up vibrations in the xy plane, while VIDUR 1 and VIDUR2 were positioned to pick up vibrations in the xz, and the yz planes of the bridge respectively. The data covers a time duration of 60 secs, during which time about 25 vehicles with varying loads and speeds passed on the bridge. The spectral estimates are sensitive their frequency resolution and statistically robust (df = 0.1526Hz with 30 degrees of freedom).

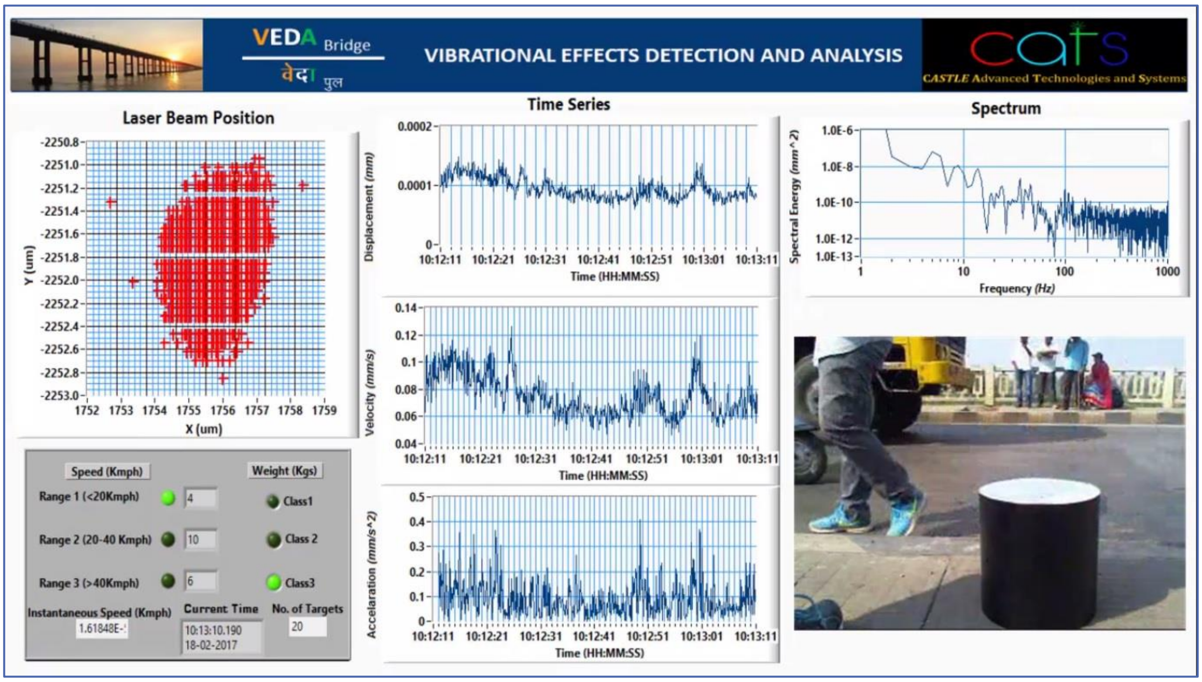


Figure 29: Snapshot of real time monitoring by VEDA taken approximately after 1 min duration of recording. Live video display of information in terms of vibrational displacement, velocity and acceleration in the time domains, as well as spectral information of vibrations is displayed on the console. In addition, on the left hand lower corner of the display live real time traffic statistics like loads (type and class) of the vehicles passing the system as well as speeds of the vehicles on the bridge, and also the number of vehicles passed so far, are recorded. Live video feed is displayed in the lower right hand corner of the display. Along with the video, the raw vibrational data however is stored @ 10 kHz sampling for further analyses.

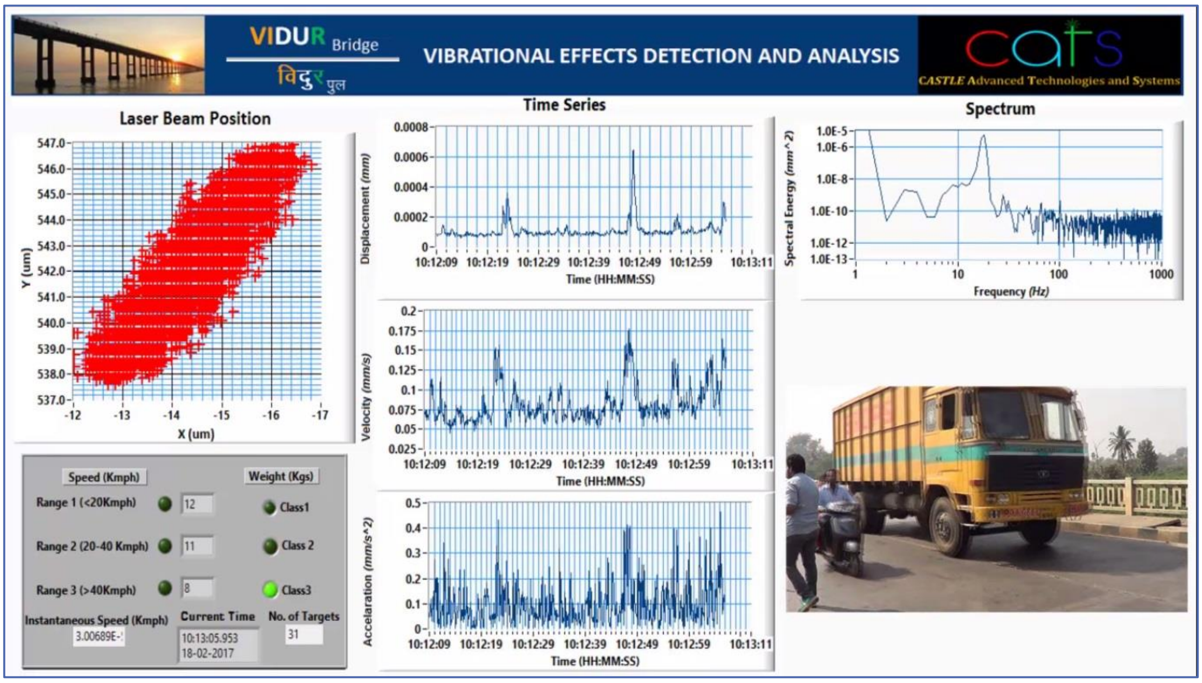


Figure 30: Snapshot of real time monitoring by VIDUR 1 taken approximately after 1 min duration of recording . Live video display of information in terms of vibrational displacement, velocity and acceleration in the time domains, as well as spectral information of vibrations is displayed on the console. In addition, on the left hand lower corner of the display live real time traffic statistics like loads (type and class) of the vehicles passing the system as well as speeds of the vehicles on the bridge, and also the number of vehicles passed so far, are recorded. Live video feed is displayed in the lower right hand corner of the display. Along with the video, the raw vibrational data however is stored @ 10 kHz sampling for further analyses.

Dynamic Effects of Moving Vehicles on the Bridge

Based on the huge data sets generated by the indigenous photonic systems- VEDA, VIDUR1 and VIDUR2, and validated by the physical observations by our team – we summarize the information as follows:

1. The static effects of moving loads are in accord with those as per the influence of a moving load with maximum bending moment and deflection occurring when the vehicle is mid-span and the maximum shear force, when the vehicle is near to the supports.
2. The vibration of the bridge due to the temporal variation in the position of the vehicle is superposed on the static effects.
3. Theoretically, the critical speed at which the dynamic deflection of the bridge is maximum is given by
$$V_{cr} = \alpha \left[\frac{Span\ of\ Bridge}{Time\ period\ of\ Bridge}\right]; with\ \alpha = 1\ to\ 2$$
4. The dynamic characteristics of the bridge, in terms of its natural frequency changes due to the position and weight of the moving vehicle. The magnitude of this change would be a good indicator for assessing the structural integrity. The structural integrity would be jeopardized if the magnitude of this change were high. *However, in the absence of any established code / standard, we are reserving our judgement on this aspect.*
5. The stiffness of the moving load (suspension and tire stiffness) play a role in altering the dynamic characteristics of the overall system.
6. The static and the dynamic displacements are proportional to the weight and speed of the moving vehicles.
7. The impact factor α (considering a smooth travelling surface) can have a value of 2.0. However, as generally the velocity of vehicle shall be less, compared to the critical velocity the value of impact factor can be chosen to be between 1.0 and 2.0 (Hung and Hwang, 2017). The presence of potholes, irregular topography, undulations and obstacles may increase the impact factor to large values.

Conclusions

The time series and spectral plots derived from the simultaneous recordings of the indigenous photonic systems of VEDA, VIDUR1 and VIDUR 2 located on one of the Bridge's Span and on one of the Pier supporting that Span respectively, during varying live traffic conditions clearly demonstrated that:

1. *The vibrational spectrum values are dependent on the size (tonnage) of the vehicle as well as the speed of the vehicle. VEDA and VIDUR were demonstrated to effectively obtain information related to traffic*
2. *There is a distinct spectral peak at around 5Hz, indicating the natural frequency of the bridge.*
3. *Varying spectral amplitudes and frequencies recorded by the three systems were a function of the size, type, weight and speed of the vehicles moving on the bridge.*
4. *The vibrational amplitudes in the frequency range of 1Hz-40Hz were dominant (as seen in the recordings by VIDUR 1 photonics system - which was aligned to pick up the vibrations in the vertical plane (xz plane) with higher sensitivity.*
5. *The vibrational amplitudes in the frequency range of 4Hz-100Hz were dominant (as seen in the recordings by VEDA photonics system - which was aligned to pick up the vibrations in the vertical plane (xy plane) with higher sensitivity.*
6. *The vibrational amplitudes in the frequency range of 4Hz-80Hz were dominant (as seen in the recordings by VIDUR 2 photonics system - which was aligned to pick up the vibrations in the vertical plane (yz plane) with higher sensitivity.*
7. *The slow moving heavier vehicular traffic was additionally inducing lower frequency vibrations, which may again seriously jeopardize the structural integrity, as they are likely to induce structural resonance of the bridge.*
8. *The higher the vehicle density and the vehicle speed, the higher the vibrational amplitudes at all frequencies were evident. The vibrations especially at the higher frequencies caused discomfort to pedestrians, in addition can seriously jeopardize the structural integrity.*
9. *Vibrations were observed to be more at midpoint of the first pier and second piers on either sides of the bridge.*
10. *Vibrations of the bridge under observation were higher, compared to those on the adjacent new bridge.*
11. *Wear and tear of bearings as evident, and were additionally inducing vibrations when vehicles were moving on the bridge.*
12. *All the three systems (whatever their alignment and location) are capable of picking up vibration signatures in the presence of dynamic moving loads –* ***thus indicating that parsimony in deployment of systems can be adopted without jeopardizing the efficacy and sensitivity of bridge monitoring****. This would greatly enhance the cost effectiveness of photonic systems.*
13. *The photonic systems can detect and discriminate traffic on the bridge along with generation vibration statistics in real time, to arrive at information related to the structural integrity of the bridge.*
14. *The photonic systems successfully demonstrated that they are very cost effective and have higher sensitivities and accuracies compared to commercially available systems.*

15. *Given the huge number of bridges in India, with varying shapes of structures with different materials, we recommend our indigenous cost effective and efficient photonic systems for structural health monitoring.*

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