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VIBRATION AND FOOTFALL ANALYSIS OF FOOTOVER Z BRIDGE

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***ABSTRACT**— As the population is increasing day by day, need for pedestrian bridges is also increasing day by day. With all the new technology and material quality improvement, the cross sections of the bridges are decreasing day by day. This is leading to lighter bridges with higher flexibility. In the past footbridges have always been designed for static loads only. People considered the dynamic effect of pedestrian walking as quite insignificant but after the incident of London's Millennium Bridge, this dynamic effect has been considered significant as well.*

In the present study, an effort has been made to study dynamic effects on an old Footover Bridge located in Mumbai. The overall length of the bridge is about 330 m having 21.6 m span length. Two types of bridge decks are considered namely Steel deck and Steel Deck plus concrete overlay. These two types of bridge decks are modelled in ETABS along with the rest of the supporting system of the bridge. Four load cases are considered for each type of bridge, namely: Single person walking on single path, three persons walking on a single path, three persons walking on three paths and finally crowd loading was considered over the entire span. All these Load cases are studied and compared for both types of bridge models. For the analysis, only vertical vibrations for the entire span length are considered. Horizontal vibrations are neglected because the bridge's natural frequency is higher than 2.5 Hz. EUROCODE EN 1990 part 0, part 1 and part 3 was followed as well as limits from ISO 10137 is also considered.

KEYWORDS— Vertical Vibrations, Footover Bridge, Steel vs Steel plus concrete overlay decks, EN 1990, Natural Frequency.

I. INTRODUCTION

The general trend in footbridge design has been towards greater spans and increased flexibility and lightness. Improvement in quality of construction materials has led to more slender structures which have lesser cross-sectional dimensions and greater spans. As a result of this, mass and stiffness has significantly decreased which leads to smaller natural frequencies resulting in more sensitivity to dynamic loads. Many footbridges have natural frequencies within the range of walking frequencies of human footsteps, thus leading to a case where excessive vertical vibrations may occur. Excessive vibrations can be caused by resonance between pedestrian loading and one or more natural frequencies of the structure. Thus, if the footbridges are only designed to withstand static loads, they may be susceptible to vertical as well as horizontal vibrations. A good example of that phenomenon is the London Millennium Bridge. It has shown the world; how important dynamic analysis is.

Several cases of footbridges experiencing excessive vibrations due to pedestrian induced loading have been reported in the past. The specific case of London Millennium Bridge attracted the most attention of the world. The London Millennium Bridge, as shown in figure 1.1, is located across the Thames River in Central London. On the inaugural day of 10 June 2000, roughly 80,000 and 100,000 people crossed the bridge, which resulted in a maximum crowd density of between 1.3 – 1.5 persons m^2 at single point of time. The vibrations took place mainly on the south span, which was at a frequency of around 0.8 Hz and on the central span, at frequencies of just under 0.5 Hz and 0.9 Hz. By observations, it was seen that the central span has been displaced by 70 mm. Just within two days after the opening of the bridge, it had to be closed down to investigate the root causes of such vibrations and to implement a solution on the matter in hand.

Figure 1 London Millennium Bridge

II. METHODOLOGY

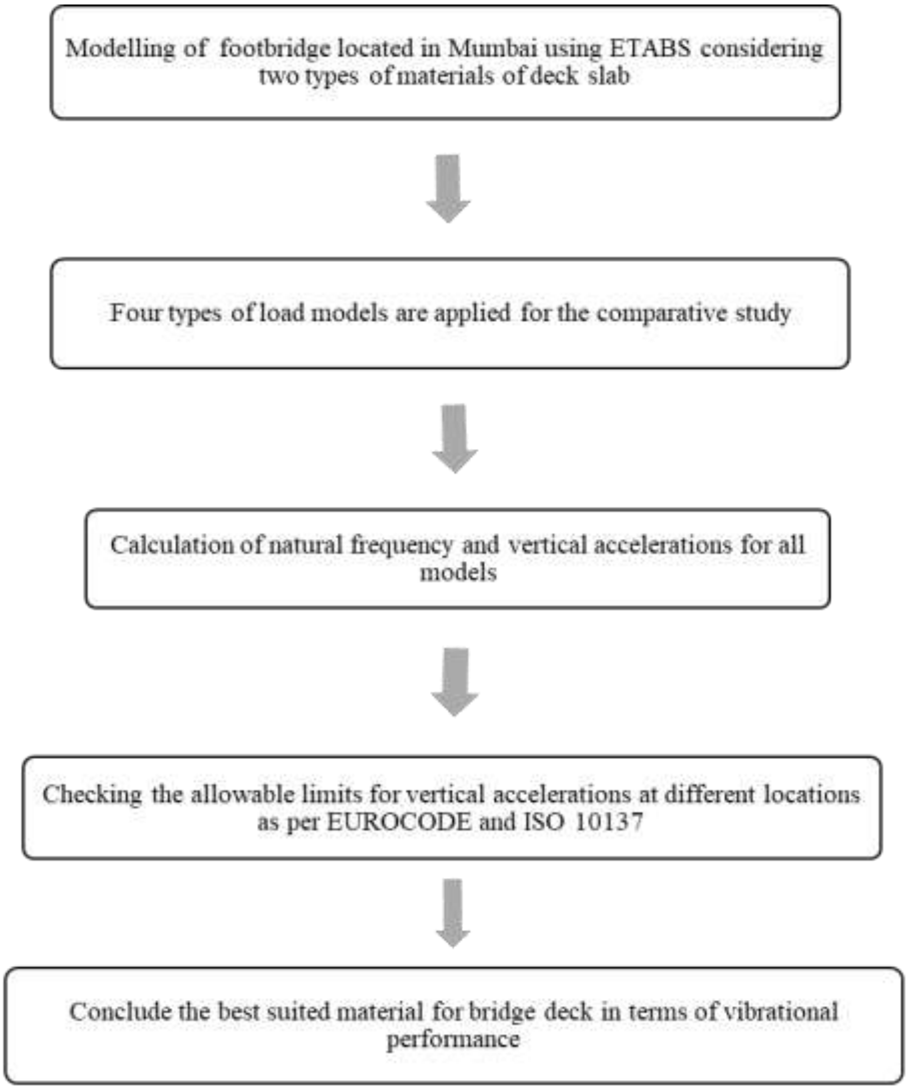


Figure 2 Flow Chart Showing the Methodology Adopted in the Present Study

III. PROBLEM STATEMENT

The Bridge was built in the year 1912 by the British.The depth of bridge truss is 2.4 m and the deck height from ground level is about 5.1 m. It consists of 10 spans of 24.3 m, 1 span of 16.2 m, 1 span of 13.5 m & 1 span of 21.6 m of the bridge, as shown in figure 4.2, total length is 294.3 m. Out of all the spans, the simply supported span of length 21.6 m was selected. This span is supported only at 4 points as pin supports.

Component	Section dimensions	Material
Deck	30 mm	Steel Fe250
Concrete Overlay	30 mm	Concrete M15
Bottom Chord	Angle 200 x 200 x 20	Steel Fe250
Top Chord	Built up section Double channel b/b : 300 x 90 x10	Steel Fe250
Inclined Members	I section 220 x 180 x 20	Steel Fe250
Inclined Members	Plate section 140 x 40	Steel Fe250
Bottom Plan Truss	Angle 65 x 65 x 6	Steel Fe250
Bottom Transverse Beams	I section 75 x 75 x 8	Steel Fe250

Table 1 Sectional Properties of the given bridge

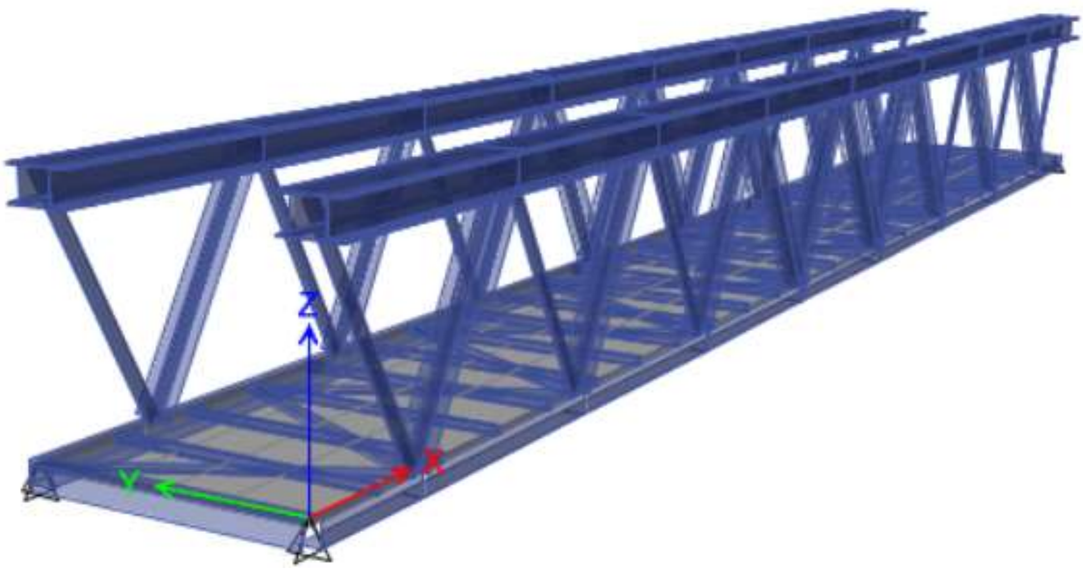


Figure 3 Rendered view of ETABS model

Two cases of deck were considered viz., deck consisting only steel plate and deck consisting steel plate with concrete overlay. The deck with only steel plate was modeled as thin shell element. The deck consisting of concrete overlay was modeled as layered shell element.

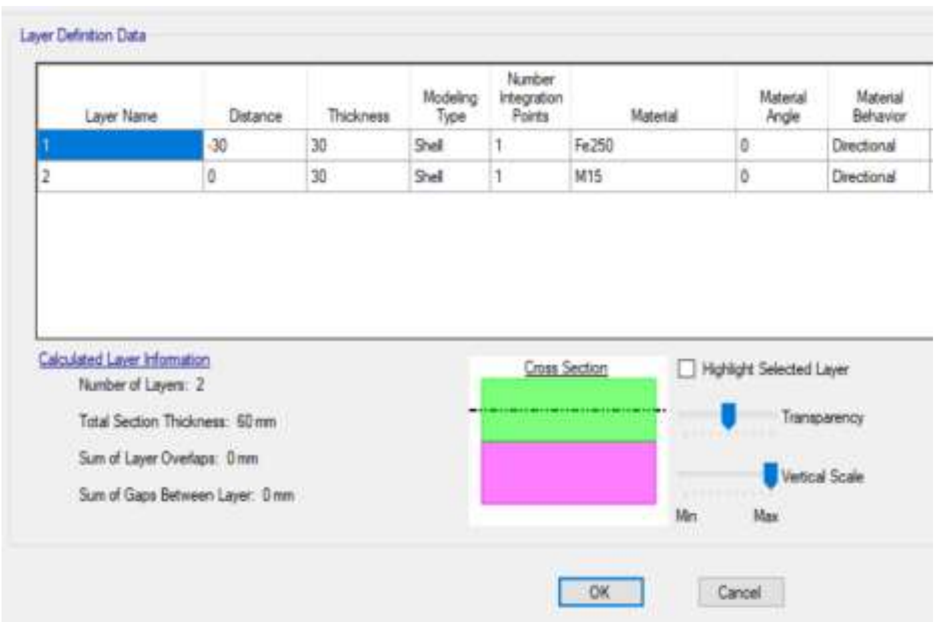


Figure 4 Layered Shell Modeling

IV. LOAD MODELS AND CODAL PROVISIONS

Two types of load models are used: Triangular pulse load type and Sine Load type model.
For triangular pulse load type model following data was considered:

- Weight = 734 N
- Pace = 2 Hz
- Speed = 1.5 m/s
- Stride = 0.75 m
- Load = 1.4 x Weight
- Pulse Duration = 0.45 s

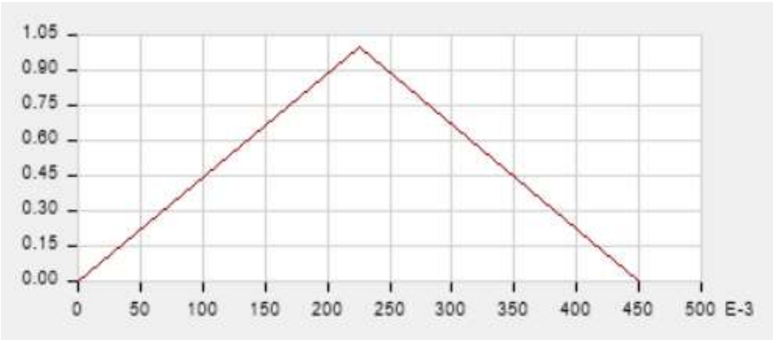


Figure 5 Triangular Pulse type load model

For Sine type Load model following data was considered:
Q_{pv}= 280 sin ($2\pi f_v t$)
Where, f_v= 3.41 Hz (Concrete overlay + steel deck case) and f_v = 2.44 Hz (Only steel deck case)

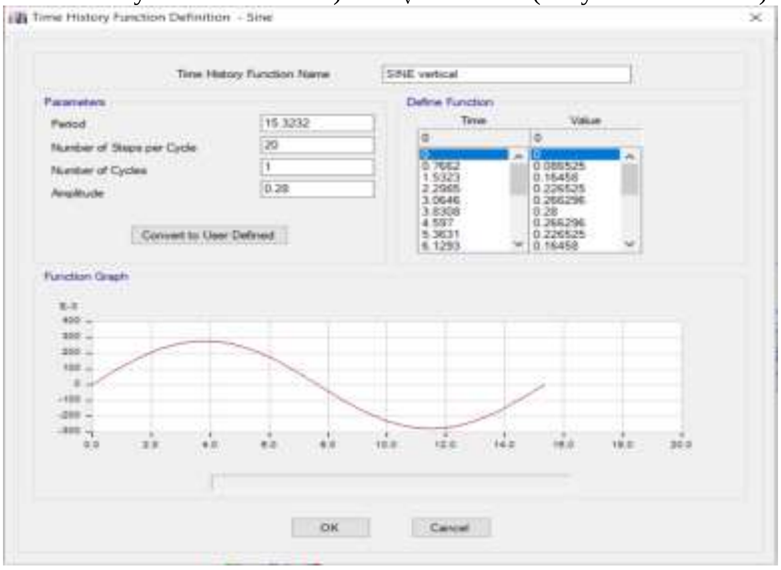


Figure 6 Sine Type Load model

Each load model type has been done for four iterations namely:

1. Single person walking on a single path
2. Three people walking on a single path
3. Three people walking on three paths
4. Crowd Loading

Codal Provisions:

EUROCODE's Recommendations:
Eurocode 0 defines the comfort criteria. As mentioned earlier, pedestrians are sensitive to vibrations, especially in vertical direction. The Eurocode therefore state a limit to these vibrations. Eurocode 0 also states when a dynamic analysis should be performed.

Vertical vibrations	0.7 m/s^2
Horizontal vibrations (Normal conditions)	0.2 m/s^2
Horizontal vibrations (Crowd conditions)	0.4 m/s^2

Table 2 Permissible acceleration values

Vertical vibrations	< 5 Hz
Horizontal and torsional vibrations	< 2.5 Hz

Table 3 Verification Criterion for comfort

ISO 10137 states that the designer shall decide on the serviceability criterion and its variability. Further, ISO 10137 states that pedestrian bridges shall be designed so that vibration amplitudes from applicable vibration sources do not alarm potential users. In Annex C, there are given some examples of vibration criteria for pedestrian bridges. There it is suggested to use the base curves for vibrations in both vertical and horizontal directions given in ISO 2631-2, multiplied by a factor of 60, except where one or more persons are standing still on the bridge, in which case a factor of 30 should be applicable.

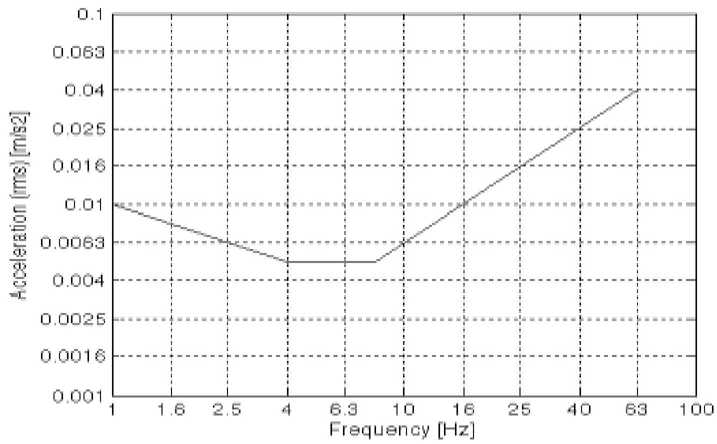


Figure 7 Vertical Vibration limits

V. RESULTS

The following tables show the comparison of accelerations for various load cases of Steel + Concrete overlay deck and comparison of accelerations for various load cases of Steel deck. The results were formulated in a tabular form.

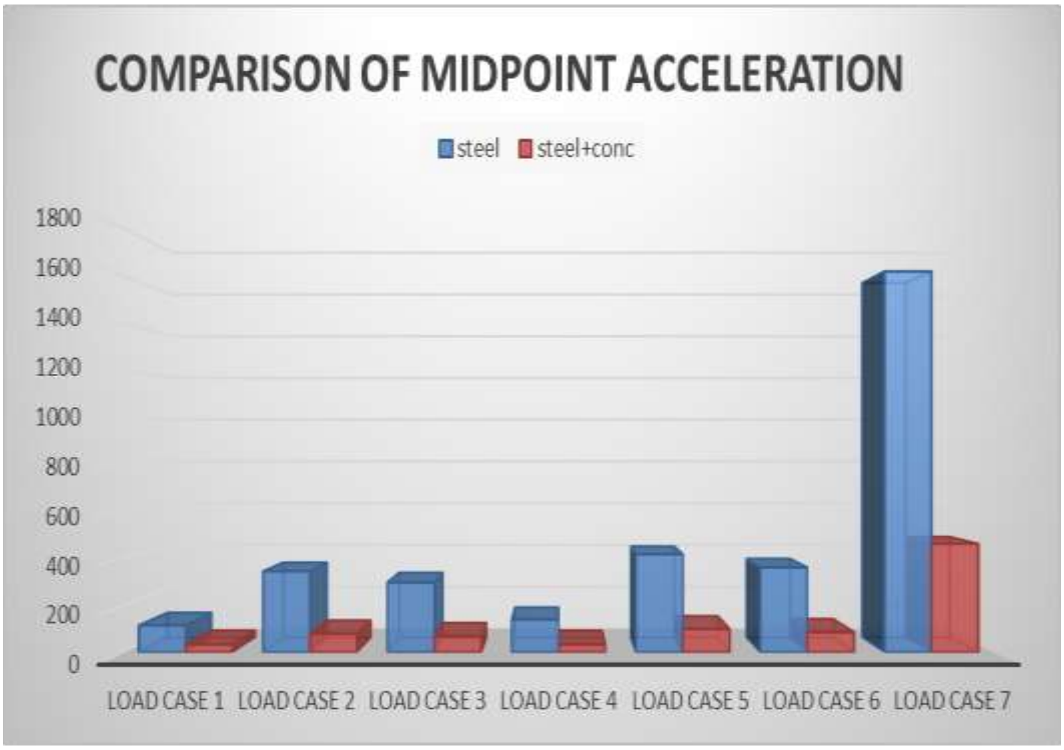
Load case number	Acceleration at joint 82 (centre node) [mm/sec^2]	Absolute max accn. [mm/sec^2]	Vertical acceleration limit [mm/sec^2]	ISO Standards
Load case 1	33.69	42.29	700	745
Load case 2	79.01	79.01	700	745
Load case 3	68.45	68.45	700	745
Load case 4	33.49	45.14	700	745
Load case 5	99.17	99.17	700	745
Load case 6	85.92	85.92	700	745
Load case 7	461	468.56	700	745

Table 4 Comparison of accelerations for various load cases of Steel + Concrete overlay deck

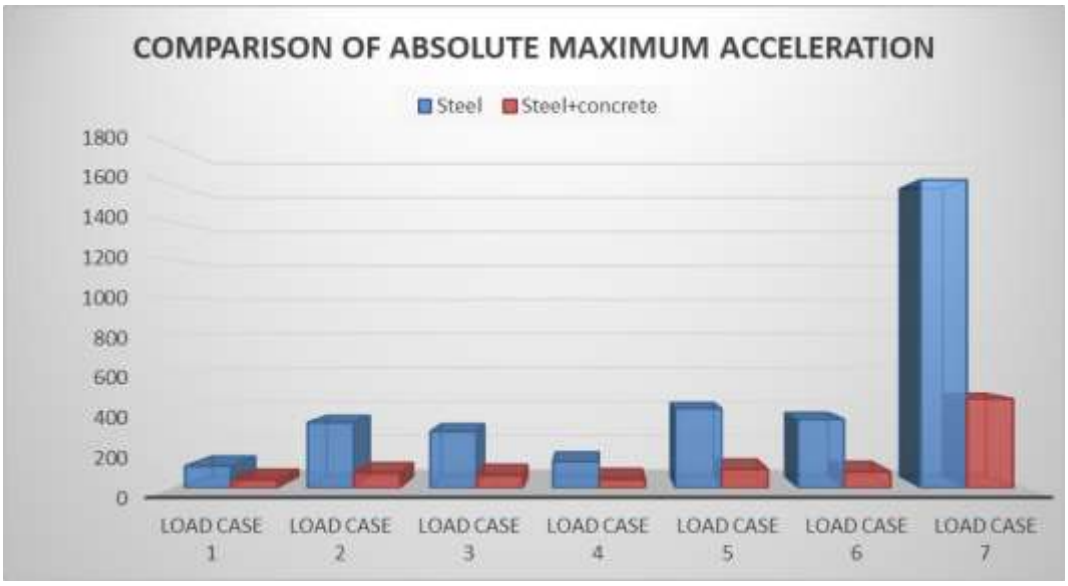
Load case number	Acceleration at joint 82 (centre node) [mm/sec^2]	Absolute max accn. [mm/sec^2]	Vertical acceleration limit [mm/sec^2]	ISO Standards
Load case 1	114.72	115.52	700	745
Load case 2	344.17	344.17	700	745
Load case 3	297.31	297.31	700	745
Load case 4	139.23	139.27	700	745
Load case 5	416.8	417	700	745
Load case 6	360.79	361.4	700	745
Load case 7	1619	1619	700	745

Table 5 Comparison of accelerations for various load cases of Steel deck

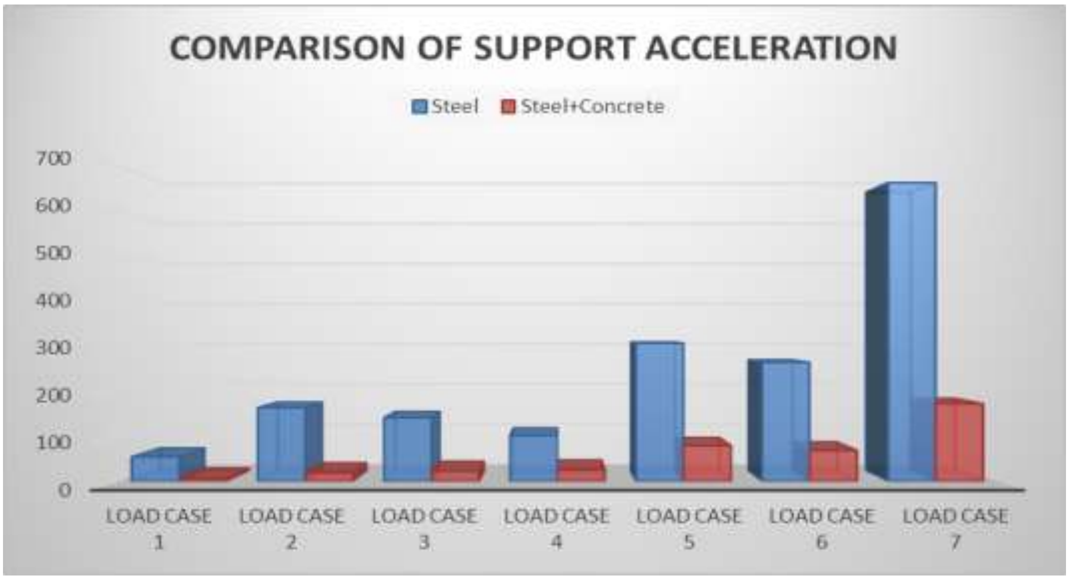
The comparison of midpoint accelerations shows that for crowd loading the maximum response in terms of vertical acceleration is achieved and hence works out to be a critical case. Also, by the introduction of even a thin concrete overlay the accelerations of the deck reduce drastically due to enhanced structural damping. The absolute maximum accelerations were observed near the midpoint of the span. Also, a similar trend of results is shown in absolute maximum accelerations.



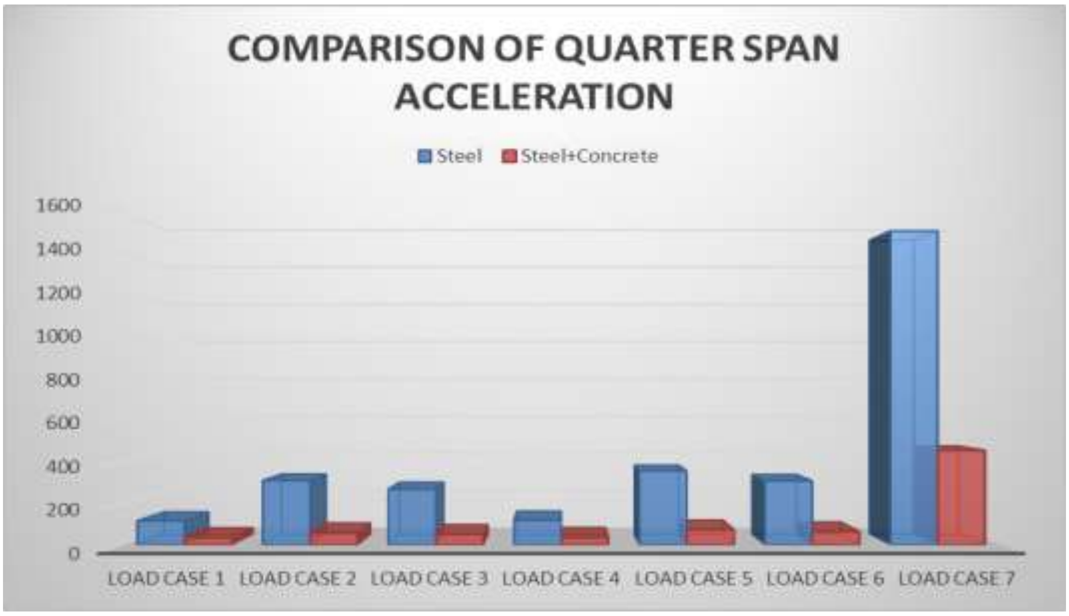
Graph 1 comparison of midpoint acceleration



Graph 2 comparison of maximum acceleration



Graph 3 Comparison of support acceleration



Graph 4 Comparison of quarter span acceleration

VI. CONCLUSIONS

- ✓ More critical accelerations were seen in sine type of load as compared to triangular loads.
- ✓ Accelerations at supports were negligible as compared to central nodes.
- ✓ Maximum accelerations were seen in load case 5 (Dynamic Sine load with three persons on same path)
- ✓ Even with a crowd load the bridge is under safe conditions
- ✓ In case of steel deck, the vertical accelerations shoot up. This proves that the concrete provides enough damping to reduce the vertical accelerations
- ✓ Providing a thin Layer of concrete actually reduces the response drastically

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