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Vibration Effect on Steel Truss Bridge under Moving Loads

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Abstract: This paper presents vibration analysis of steel truss bridge under various moving loads by using STAAD.Pro Software. The proposed bridge is warren truss, through type. The bridge length is 240ft. The considered loadings on bridge are dead loads, live loads, wind load, impact effect, seismic effect and temperature effect. For vehicle live load, two types of loading (train and truck loadings) are considered. Truck is HS25-44 truck of AASHTO Specification and train is Meter Gauge train of IRS Specification. For the bridge model, AASHTO (2010) loading combination is used. Design calculation of structural steel members are considered according to the design criteria of AISC-ASD Specifications. Deflection checking is carried out in order to ensure that the structure is safe under the various loads. In the vibration analysis, moving loads are considered as harmonic loading and then, vibration effect is analyzed. Finally discussions and conclusions are made for this vibration analysis.

Keywords: Vibration Analysis, STAAD.Pro Software, AASHTO Specification, IRS Specification, AISC-ASD Specification.

I. INTRODUCTION

Construction of long span bridges has been very active in the world in the past few decades. Today, modern bridges tend to use high strength materials. Therefore, their structure is very slender. As a result, they are very sensitive to dynamic loadings such as wind, earthquake and vehicle movement. As bridge span gets longer, they become more flexible and prone to vibrate. Vibration can have several levels of consequences; from a potentially hazardous effect (causing immediate structural failure) to a more extended effect (structural fatigue). In addition, vibration can effect safety as well as comfort of users and limit serviceability of the bridge. Therefore, extensive studies have been carried out to understand mechanisms behind bridge vibration and to reduce this undesirable vibration effect.

II. OBJECTIVES

The following objectives serve as the guidelines for the research.

- To analyze and design a steel truss bridge that is capable of resisting various moving loads.
- To understand the behavior of the steel truss bridge when the structure is to be subjected to a set of moving loads.
- To analyze the vibration effect on steel truss bridge.

A. Analytical Procedure

The analytical procedure of the research is as follows.

- Analyse and design the proposed bridge by using STAAD. Pro Software.
- Analyse the vibration parameters of proposed steel truss bridge.
- Check for design satisfactory.

B. Case Study

Span Length	- 240ft (120ft each)
Number of Span	- Two
Truss Height	- 30ft from bottom chord to top chord
Truss Angle	- 56.31^0
Highway Width	- 24ft (12ft each)
Railway Width	- 3.28ft (1m)
Sidewalk Width	- 6ft (3ft each)
Number of Lane	- two lanes for highway and one lane for railway
Road Surface Type	- Through type
Frame Type	- Warren truss with vertical members

3D view and elevation view of the proposed bridge model are shown in Fig.1 and Fig.2 respectively.

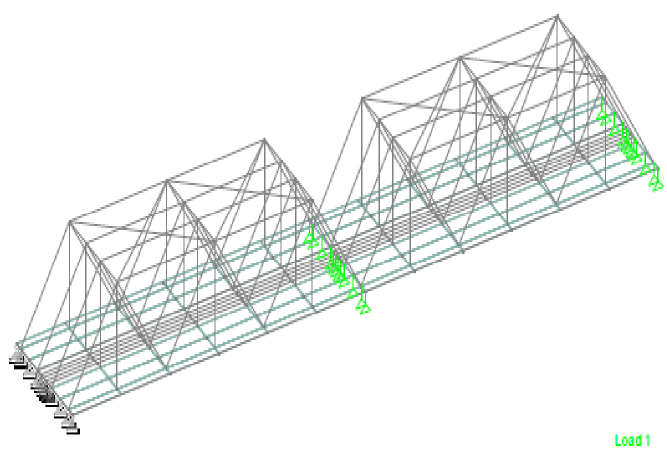

Fig.1. 3D view of proposed bridge.

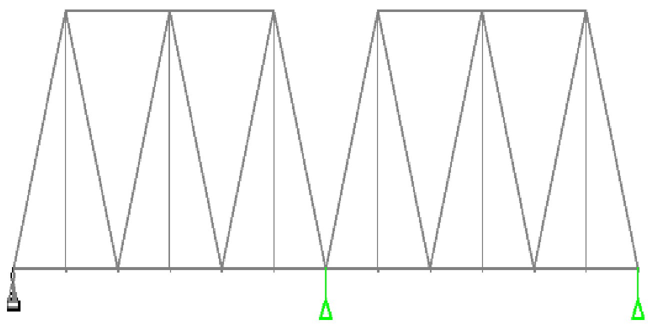

Fig.2. Elevation view of proposed bridge.

C. Material Properties

The strength of a structure depends on the strength of the materials from which it is made. So, the properties of materials are always important.

Type of steel - A709, Grade 70W
Minimum tensile strength, F_u - 90ksi
Minimum yield strength, F_y - 70ksi
Modulus of elasticity, E - 29000ksi
Poisson's ratio, μ - 0.3
Unit weight of steel - 490pcf
Unit weight of concrete - 150pcf

III. LOAD CONSIDERATION

Considered loadings for the proposed bridge are as follows.

1. Dead Load

Concrete slab weight - 100psf
Handrail and utility - 200lb/ft
Railway rail and fastening - 200lb/ft
Asphalt plank, 2in thick - 18psf

2. Live Load

Truck - HS25-44 truck of AASHTO
Train - Meter Gauge train of IRS
Sidewalk - 75psf

3. Seismic Load

Seismic parameter type - UBC 1997
Seismic zone - zone 4
Seismic zone factor - 0.4
Soil profile type - 4
Seismic importance factor, I - 1.25
Over strength factor, R - 8.5
Near source factor, N_A - 1
Near source factor, N_V - 1

4. Temperature Effect

Temperature change for axial elongation - 16^0F
Temperature difference from top to bottom - 10^0F
Temperature difference from side to side - 10^0F

5. Wind Effect

Exposure type - Type C
Basic wind velocity - 100mph
Category - Category I
Structure Type - Lattice Framework
Common Data - ASCE-7, 2002

A. Moving Load Cases

For the bridge model, considered moving load cases are as follows.

1. Moving Load Case 1

Lane 1 - Forward for HS25-44 Trucks
Lane 3 - Backward for HS25-44 Trucks

2. Moving Load Case 2

Lane 1 - Forward for HS25-44 Trucks
Lane 2 - Forward for Meter Gauge Train

3. Moving Load Case 3

Lane 2 - Forward for Meter Gauge Train
Lane 3 - Backward for HS25-44 Trucks

4. Moving Load Case 4

Lane 1 - Forward for HS25-44 Trucks
Lane 2 - Forward for Meter Gauge Train
Lane 3 - Backward for HS25-44 Trucks

B. Load Combination

According to AASHTO (2010), load combination for design of the proposed bridge structure is as follows.

1. DL+LL+T
2. DL+T+W
3. DL+LL+TH
4. DL+LL+T+L1
5. DL+LL+T+L2
6. DL+LL+T+L3
7. DL+LL+T+(L1+L2)
8. DL+LL+T+(L1+L3)
9. DL+LL+T+(L2+L3)
10. DL+LL+T+(L1+L2+L3)
11. DL+LL+TH+L1
12. DL+LL+TH+L2
13. DL+LL+TH+L3
14. DL+LL+TH+(L1+L2)
15. DL+LL+TH+(L1+L3)
16. DL+LL+TH+(L2+L3)
17. DL+LL+TH+(L1+L2+L3)
18. DL+LL+T+(TL1+TL2)+TL5
19. DL+LL+T+(TL3+TL4)+TL5
20. DL+LL+T+(TL1+TL2+TL3+TL4)+TL5
21. DL+LL+T+TL5
22. DL+LL+TH+(TL1+TL2)+TL5
23. DL+LL+TH+(TL3+TL4)+TL5
24. DL+LL+TH+(TL1+TL2+TL3+TL4)+TL5
25. DL+LL+TH+TL5

DL = Dead Load
LL = Sidewalk Live Load
L = Lane Load
T = Temperature Effect
TH = Time History
W =Wind Load
TL5 = Railway Truck Load
TL 1-4 = Highway Truck Load

Design sections of proposed bridge model are shown in Table I.

TABLE I: Sections of Proposed Bridge

Member	Section
Top chord	W 14×90
Top bracing	W 14×109
Strut	W 14×38
Vertical 1	W 14×61
Vertical 2	W 14×90
Inclined 1	W 14×90
Inclined 2	W 14×193
End post 1	W 14×211
End post 2	W 14×342
Stringer	W 14×74
Bottom chord 1	W 14×120
Bottom chord 2	W 14×132
Floor beam 1	W 14×145
Floor beam 2	W 14×211
Floor beam under the rail	W 14×90

C. Check for Deflection

Deflection checking is calculated as follows. Allowable Deflection,

$$\Delta_{all} = \frac{l}{800} \quad \textbf{(1)}$$

$\Delta_{all} = (120 \times 12/800)$

$= 1.8$ in

Maximum deflection = 0.1in < 1.8in

The deflection check is satisfied.

IV. TIME HISTORY ANALYSIS FOR BRIDGE VIBRATION

In this case, vehicle loadings are considered as harmonic loadings. The exciting period or forcing period applied the bridge model is 2.1824sec. For the vibration analysis, the influence of vehicle speed, and damping ratio are investigated. Firstly, 45mph, 60mph and 75mph vehicle speeds are considered to find the significant effect. Finally, the influence of damping ratio on the bridge model is investigated. In this case, damping ratio are assumed 1%, 2%, 3%, 4% and 5% respectively. And then, discussion and conclusion are made according to the analysis results. The values of vibration frequency and mode shape of the system are shown in Table II. The deformed shapes due to various vibration modes are shown in Figs. 3 to 7, and differences of time, velocity, acceleration, frequency is shown in figs .8 to 13.

TABLE II: Frequencies and Mode Shapes of the System

Mode	Frequency(Hz)	Period(sec)
1	12.008	0.08328
2	12.030	0.08313
3	12.228	0.08178
4	12.249	0.08164
5	16.865	0.05929
6	16.892	0.05920
7	19.504	0.05127
8	19.689	0.05079
9	19.723	0.05070
10	19.868	0.05033
11	19.892	0.05027
12	19.914	0.05022
13	20.219	0.04946
14	20.422	0.04897
15	20.725	0.04825
16	20.952	0.04773
17	23.792	0.04203
18	23.864	0.04190
19	23.929	0.04179
20	23.965	0.04173
21	24.357	0.04106
22	24.431	0.04093
23	24.535	0.04076
24	24.637	0.04059
25	27.032	0.03699
26	27.088	0.03692
27	27.274	0.03666
28	27.353	0.03656
29	27.406	0.03649
30	27.433	0.03645
31	27.467	0.03641
32	27.589	0.03625
33	28.806	0.03471
34	28.842	0.03467
35	28.959	0.03453
36	28.983	0.03450
37	29.940	0.03340
38	29.952	0.03339
39	30.204	0.03311
40	30.222	0.03309

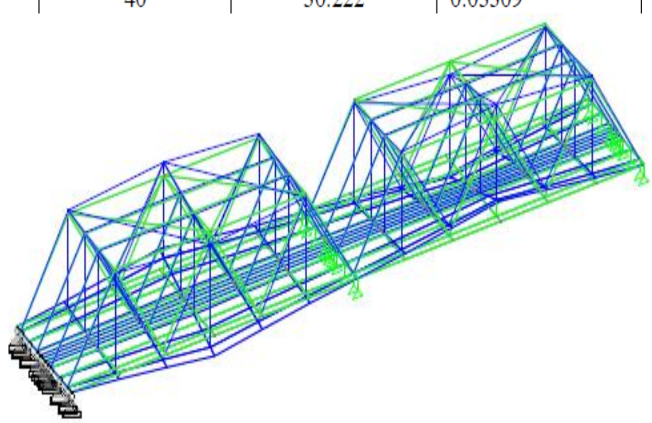

Fig.3. Deformation of mode shape 1.

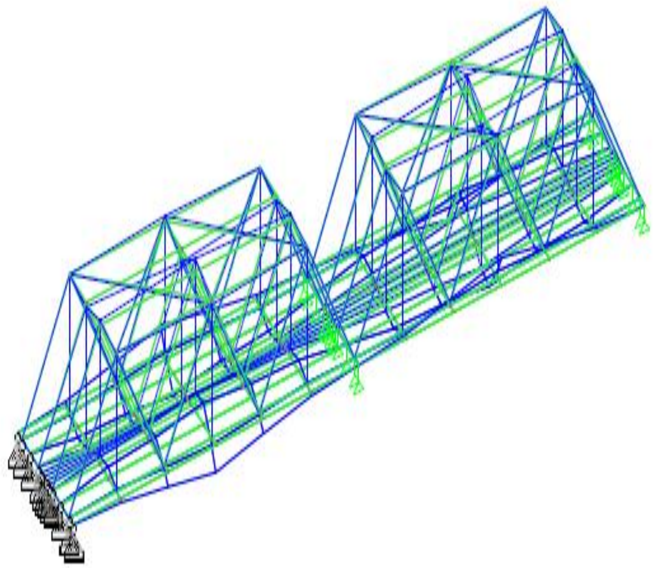

Fig.4. Deformation of mode shape 10.

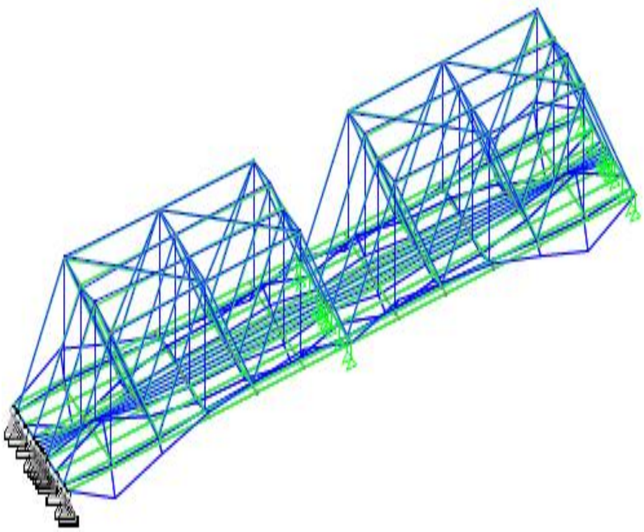

Fig.5. Deformation of mode shape 20.

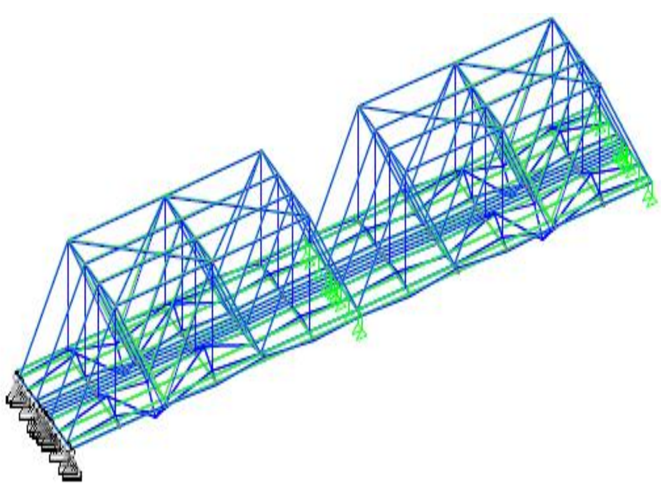

Fig.6. Deformation of mode shape 30.

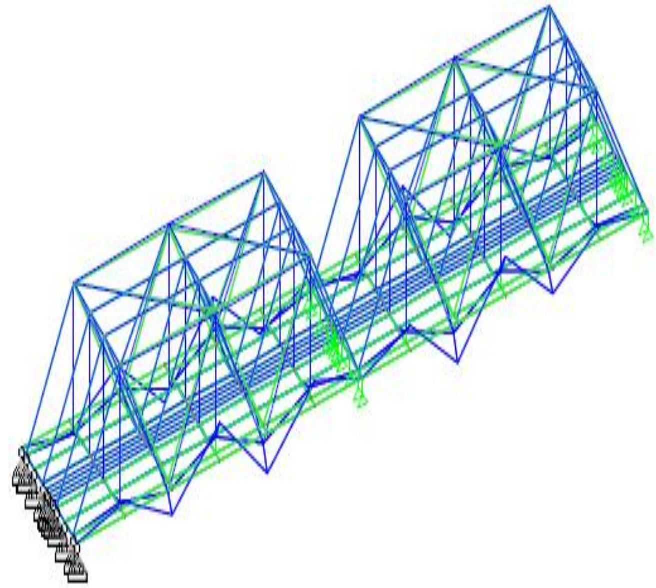

Fig.7. Deformation of mode shape 40.

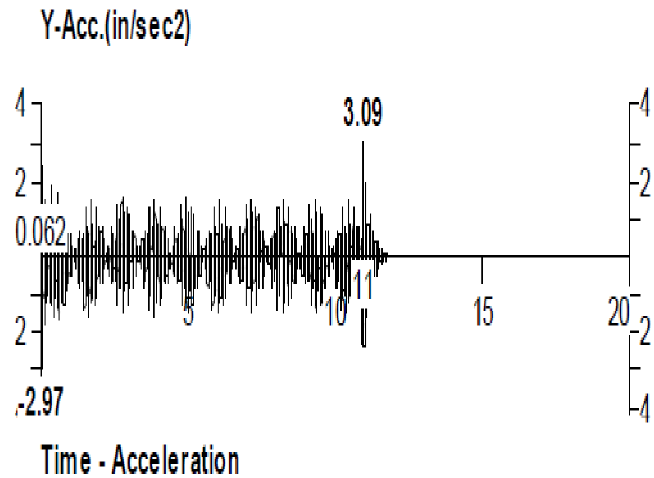

Fig.8. Time histories of vertical accelerations at node 95 (midpoint of outermost bottom chord).

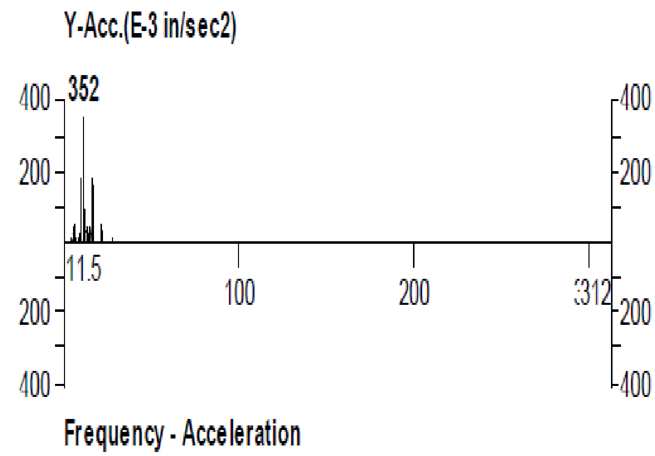

Fig.9. Frequency response of vertical accelerations at node 95 (midpoint of outermost bottom chord).

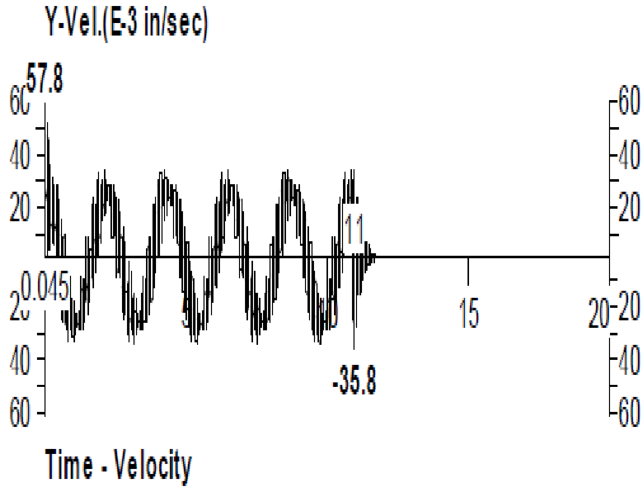

Fig.10.Time histories of velocity at node 95(midpoint of outermost bottom chord).

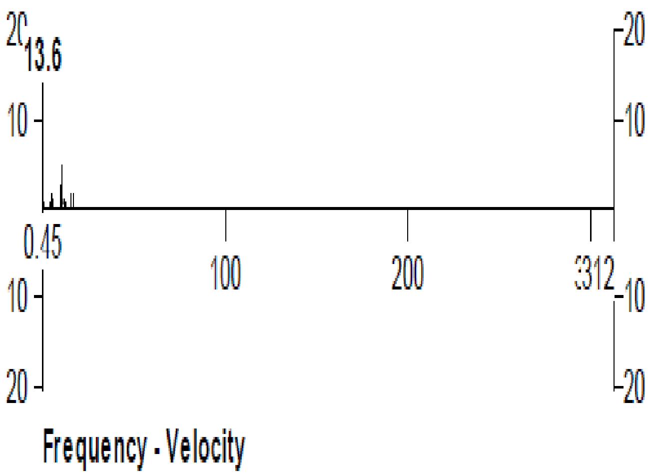

Fig.11. Frequency response of velocity at node 95(midpoint of outermost bottom chord).

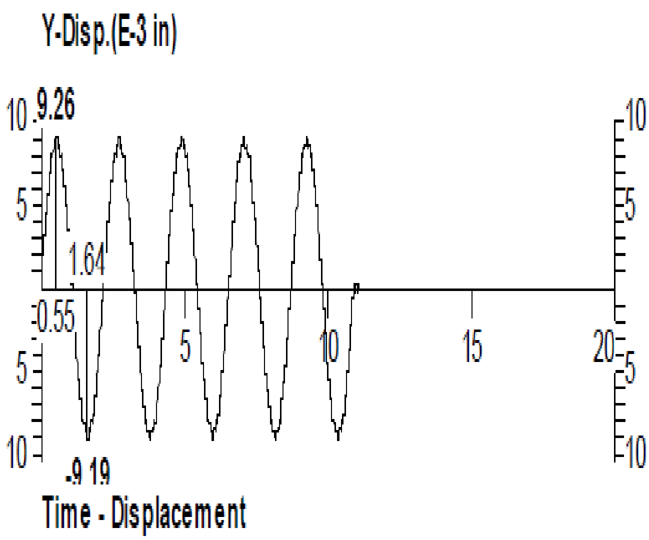

Fig.12. Time histories of vertical displacement at node 95(midpoint of outermost bottom chord).

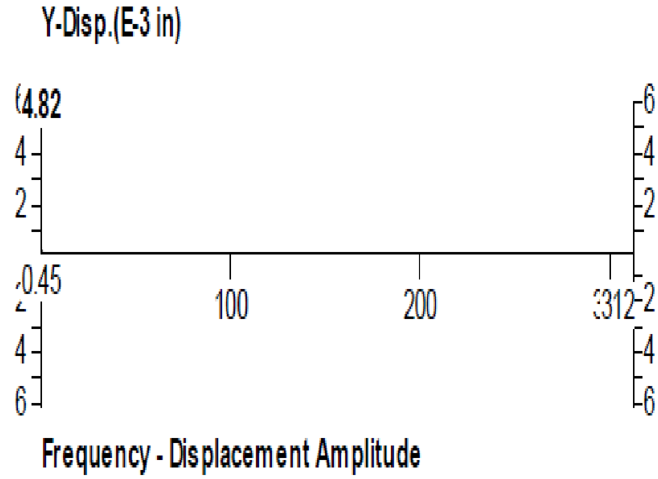

Fig.13. Frequency response of vertical displacement at node 95 (midpoint of outermost bottom chord).

V. DISCUSSION AND CONCLUSION

This study presents the vibration effect on steel truss bridge under moving loads. In this, the influence of vehicle speed and damping ratio are investigated along the bridge vibration. First, there is significant difference in bridge acceleration, velocity and displacement under changes of vehicle speed. The higher the speed, the greater the acceleration, velocity and displacement of the bridge. Also, it is observed that vehicle speed is the most significant factor in bridge vibration. The second investigated factor is the effect of damping ratio. In this case, the difference is occurred although it is small in magnitude. The higher the damping ratio, the lesser the acceleration, velocity and displacement of The bridge. Another interesting fact is that maximum displacement is occurred only at mid span (60ft from the support), especially at bottom chord. The maximum displacement is 0.1in. It is within the limiting values. According to above results, it can be concluded that the proposed steel truss bridge is satisfactory to service.

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