Scientific Journal of Impact Factor (SJIF): 5.71

e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 5, Issue 04, April -2018

EFFECT OF HUMAN STRUCTURE INTERACTION ON BEHAVIOUR OF STADIUM STRUCTURE

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Abstract — *As more modern stadia structures built by making use of new high strength materials, makes the structure lighter than the before. The result is that structures become more flexible, and thus they become susceptible to undergone vibration problems due to the action of dynamic loading that can cause problems with the serviceability limit state. In the stadium structure, the significant dynamic responses such as resonance or similar behavior can be occurred by spectator rhythmical activities. Thus, accurate analysis and precise investigation of stadium structure that is subjected to dynamic loads are required for practical design and serviceability check of stadium structures. Moreover, it is desirable to measure and analyze the dynamic loads of spectator activities because these dynamic loads cannot be easily expressed in a numerical formula. In this study, various dynamic loads induced by spectator activities like seating, walking, jumping etc. are considered. These dynamic loads induced by spectators' movement at stadium structure can be classified into the impact load and the periodic load. These dynamic loads can be expressed as a harmonic load. And, these dynamic loads could be applied for the accurate vibration analysis of a stadium structure considering human structure interaction.*
In this study, floor vibration made by spectators' movement at stadium structure will be considered by jumping of a single person at each particular point and time history was made. This time history data were applied to the particular point of jumping for vibration analysis and analysis of stadium structure part was carried out using SAP2000 software.

Keywords *– Stadium structure, Spectator rhythmical activities, Harmonic load, Vibration analysis, Human structure interaction, Floor vibration, Time history data.*

I. INTRODUCTION

As more and more modern stadia structures nowadays are being built by making use of new high strength materials which makes the structure lighter than the before. Now a day all tries to optimize a structure as much as possible, in terms of minimal materials used, there is an inevitable side effect that comes with this. The result is that structures become more flexible, and thus they become susceptible to undergone vibration problems due to the action of dynamic loading that can cause problems with the serviceability limit state. Pop/rock concerts, exhibitions, boxing matches, and so forth are staged to supplement the football/ sports seasons. Consequently, stadia structures must resist not only static loading but also dynamic loadings, such as the human-induced loads from various activities of the spectators which include, standing, jumping, stamping, clapping and dancing, particularly in response to touchdowns (in football matches) or musical beats (during concerts).

A stadium is a place or venue for outdoor sports, concerts, or other events and consists of a field or stage either partly or completely surrounded by a tiered structure designed to allow spectators to stand or sit and view the event. Problematic levels of vibration are being reported in several stadiums around the world, especially during cricket matches, football matches, and music concerts due to excitations by rhythmic crowd motions such as sudden seating, clapping, foot stamping, bobbing or jumping. A few examples are given here. Firstly, the Maracanã football stadium in Brazil (Batista and Magluta 1993), with a capacity of 150,000 people, is a reinforced concrete structure with a cantilever stand 21 m long. The natural frequencies of the cantilever stand when empty were 4.6, 6.6 and 17.0 Hz. It was reported that high levels of acceleration and large displacements could be felt during football games. Cracks were found in the cantilever beams, most probably due to large displacements and hence over-stressing of the structure. Another example, the Feyenoord Stadium in the Netherlands (van Staalduinen and Courage 1994), with a capacity of 61,000 people, had also experienced strong vibrations during pop concerts. The grandstand had natural frequencies of 2.3, 4.6 and 5.8 Hz. Strong vibrations were reported on the upper tier during pop concerts. To reduce the vibration level, the displacement of the stand was monitored during pop concerts and the audio system was turned down when there was excessive vibration. The Morumbi Stadium in Brazil (Almeida and Rodrigues

1998), with a capacity of 80,000, had a few modes ranging from 2.2 to 4.0 Hz. Complaints were received from the crowds on the vibration of the structure. Tuned mass dampers were fitted to the stadium to reduce the vibration level (GERB Vibration Control Systems 2005).

The dynamic vibration of the stadium is generally difficult to stimulate and determine the design of structures. It is due to unpredictable behavior of spectators. For the current study, Active and passive models of humans are studied to see how they influence the response in Stadium for different Passive conditions, by performing dynamic analyses and comparing the results with the ones obtained from the static analysis. In this study, floor vibration made by spectators' movement at stadium structure will be considered by jumping of a single person at each particular point and time history was made. This time history data were applied to the particular point of jumping for vibration analysis and analysis of stadium structure part was carried out using SAP2000 software.

II. HUMAN STRUCTURE INTERACTION

Generally, the crowds on a stadium can be classified into active and passive crowds. An active crowd moves rhythmically by jumping, bobbing or swaying, usually following a peak moment of matches, musical beat or crowd chanting. A passive crowd remains stationary by either sitting or standing on the structure. An analysis of the stadium structure involves the study of how each of these two crowds interacts with the structure. The active crowd is known to exert external dynamic loads on the structure by their rhythmic motions. For the passive crowd, modal tests on several stadiums have shown that it behaves as a dynamic system added to the main structural system.

The dynamic analysis of a stadium structure consists of four main tasks:
(a) Modeling the passive crowd.
(b) Defining the dynamic load induced by the active crowd.
(c) Analyzing the passive crowd-structure system subjected to the dynamic load.
(d) Assessing the resultant vibration level prediction for serviceability criteria.
Current knowledge and practice are deficient in all four main areas mentioned above. Therefore, no sensible analysis has yet been conducted on a cantilever grandstand of the stadium to estimate its response when subjected to a crowd rhythmic motion.

III. DYNAMIC LOAD INDUCED BY ACTIVE CROWD

In the stadium structure, the significant dynamic responses such as resonance or similar behavior can be occurred by spectator rhythmical activities. Thus, accurate analysis and precise investigation of stadium structure that is subjected to dynamic loads are required for practical design and serviceability check of stadium structures. Moreover, it is desirable to measure and analyze the dynamic loads of spectator activities like jumping, bobbing, swaying etc. because these dynamic loads cannot be easily expressed in a numerical formula. Even though many kinds of literature and code have adopted a numerical formula for calculation of load function due to individual jumping are mentioned below. Which is a basic model for the vertical loads produced by an individual moving cyclically is:

$$F_s(t) = G_s\left[1.0 + \sum_{n=1}^{\infty} r_n \sin\left(\frac{2n\pi}{T_p} t + \phi_n\right)\right]$$

F_s (t) = the time-varying load
G_s = the weight of the individual
n = number of Fourier terms
r_n = Fourier coefficient (or dynamic load factor)
T_p = the period of the cyclic load or the inverse of the cyclic frequency
φ_n = phase lag of the n^{th} term

A Load history is developed for the normal human jumping having the weight of 100kg and frequency of 2Hz. Contact ratio of human and structure during jumping has been considered 0.33 as per different kinds of literature. The developed load history is shown graphically in Figure 1.

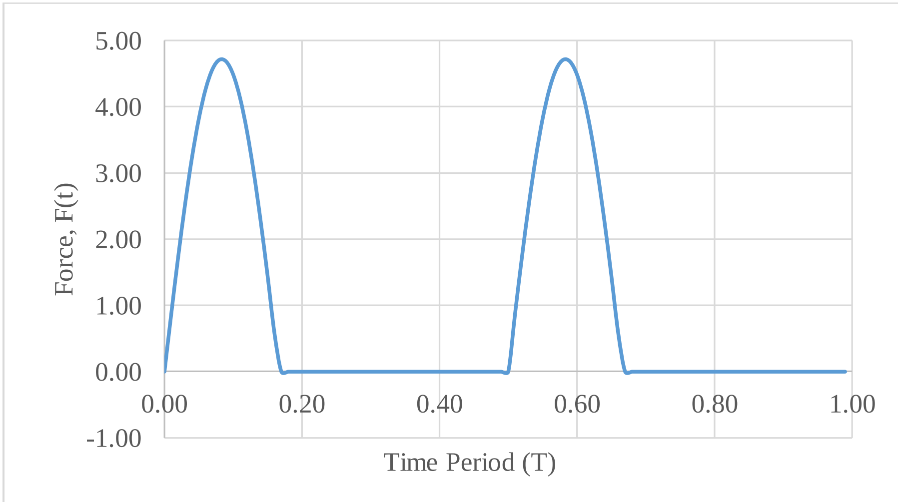

Figure 1. Load - Time History for normal jumping at 2 Hz

IV. PROBLEM DESCRIPTION

In the present study, a partial part of Khanderi Cricket Stadium – South block, which is located at Rajkot, is considered. For Study purpose analysis of the stadium structure are carried out for active live load, passive live load and possible combination of both, considering human structure interaction. Figure 2 Shows Plan and Sectional view of Stadium portion which considered for current work. The girders and the risers that make the upper and lower decks in addition to some columns in the lower deck were constructed using a reinforced concrete structural system. For this study, special consideration will be given to the South block lower deck of the stadium where the young people would be likely more involved in periodic or rhythmic motions such as jumping or dancing. The South lower deck is broken up into 6 typical sections. Each section having size 15.13m x 13.96 m is composed of seating single risers resting on concrete girders 350mmx600mm.

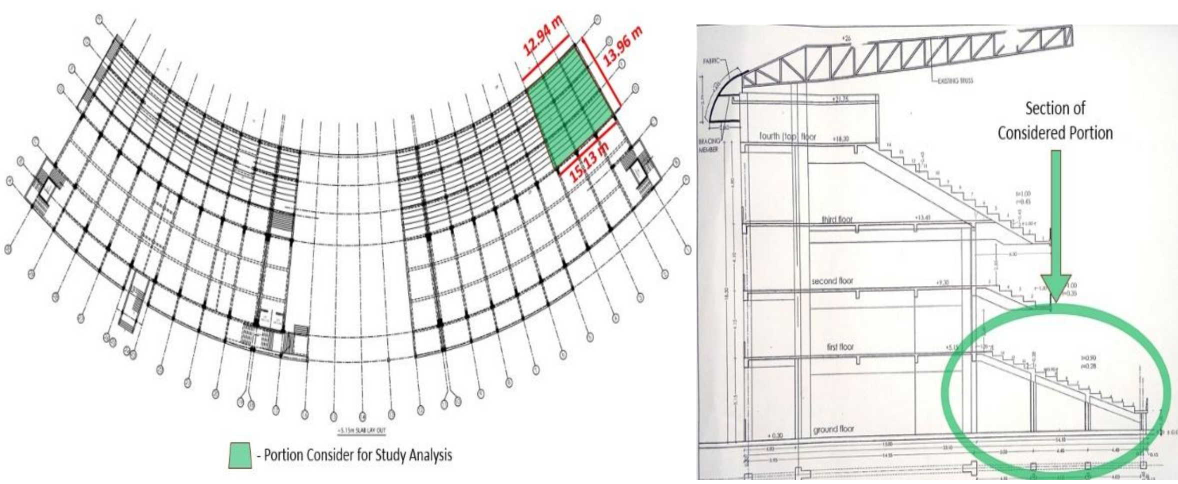

Figure 2. Plan and Section of a considered portion of the stadium

A three-dimensional finite element model is used to model the Stadium structure, using SAP2000 structural software. Beams and columns are modeled as frame elements (with six degrees of- freedom per node). Slabs are modeled with quadrilateral shell elements (with four nodes and six degrees-of-freedom per node). Figure 3 shown three dimensional model of Stadium structure.

Figure 3. Stadium Model in SAP2000

A. LOAD CONSIDERATION:

For the comparison, a static analysis is performed on the Stadium structure with the loading of $5kN/m^2$ of Passive live load specified in the IS875 (Part II). To consider the effect of rhythmic motions, time history for 1kN load has been generated and applied to the seating position.

In the current study, Active and passive models of humans are studied to see how they influence the response in Stadium for different Passive conditions, by performing dynamic analyses and comparing the results with the ones obtained from the static analysis. Here different possible combinations of Passive Load with Active Load is considered and are shown in Figure

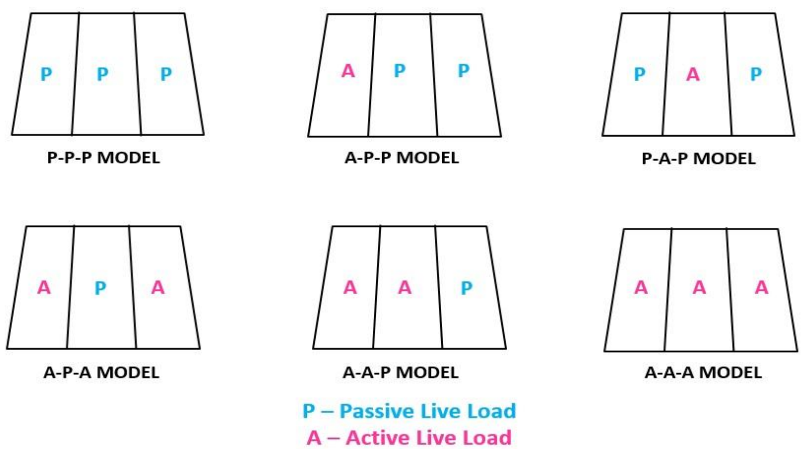

Figure 4.Active and Passive Live Load Combinations

B. DYNAMIC ANALYSIS:

For Dynamic analysis SAP, Structural Analysis Program is used, which is user-friendly generalized analysis and design software. SAP2000 Version 15.1.0 has a powerful graphical interface with modeling, analytical, and design procedures. It is a full-featured program that can be used for the simplest problems or the most complex projects. Dynamic analysis of stadium structure has been carried out for different combinations of active and passive live load for different jumping frequencies. The results obtained are compared in form of horizontal frequency, vertical frequency, acceleration, displacement, time period, shear force & bending moment.

V. RESULTS AND DISCUSSIONS

Dynamic analysis is carried out for 6 different load combination of active live load and passive live load of the stadium structure using SAP2000. The results are in form horizontal frequency, vertical frequency, acceleration, displacement, time period, shear force & bending moment values are taken from the software SAP2000. Earthquake force and any forces are not considered here because to understand the better effect of active live load.

A. HORIZONTAL FREQUENCY COMPARISON:

Frequency is an important parameter for any dynamic analysis and to prevent resonance condition. Frequency indicates cycles completed in unit time. The different horizontal frequencies obtained from the dynamic analysis is presented in Figure 5. Which indicated that the horizontal frequencies for all different combinations are greater than the 4.0 Hz that means it satisfies the codal requirement of BS 6399 – Part 1. Horizontal Frequency of Structure should be greater than 4.0 Hz as per codal provision BS 6399 – Part 1.

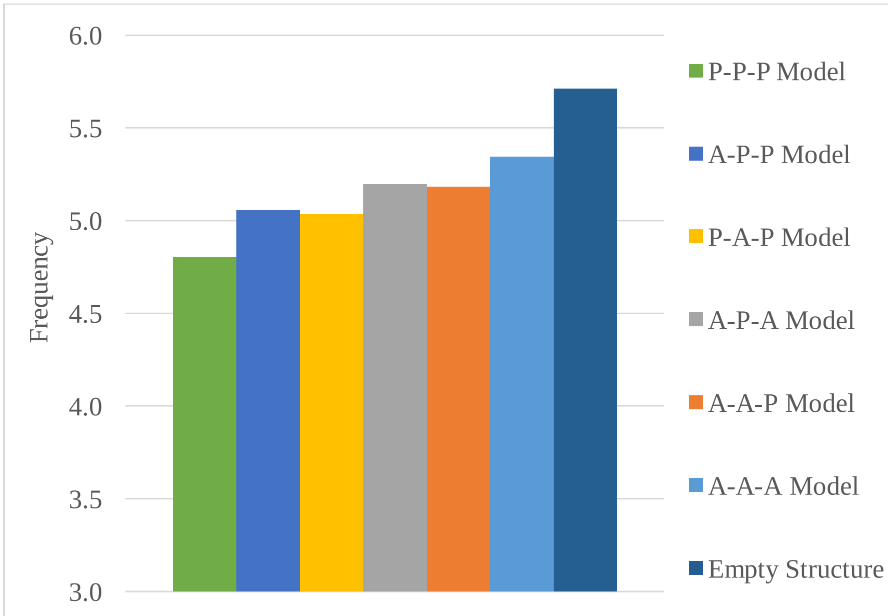

Figure 5.Horizontal Frequency Comparison

B. VERTICAL FREQUENCY COMPARISON:

The vertical frequency of Empty Structure should be higher than 8.4 Hz as per codal provision BS 6399 – Part 1.The graphical representation of vertical frequency is for all models shown in Figure 6. As per result comparison, only PPP Combination has a higher frequency than 8.4Hz.

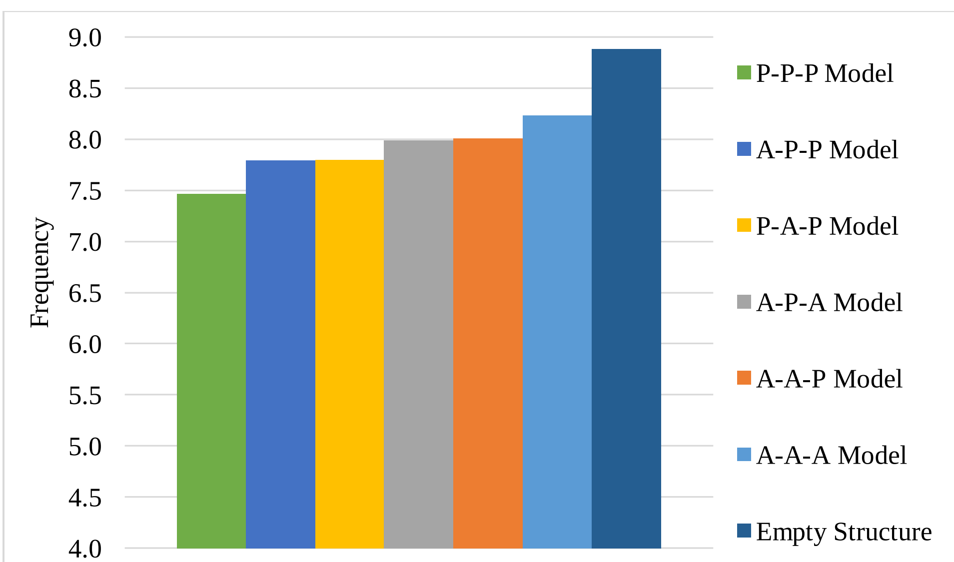

Figure 6.Vertical Frequency Comparison

C. MAXIMUM DISPLACEMENT COMPARISON:

The following figure 7 is showing the comparison for Maximum Displacement measured at the internal inclined frame of the considered portion. The Displacement has been measured for different active and passive combinations and for different jumping frequencies. Displacement comparison is graphically represented in Figure 7. The full Passive combination gives minimum displacement while Full PPP passive case generates maximum displacement.

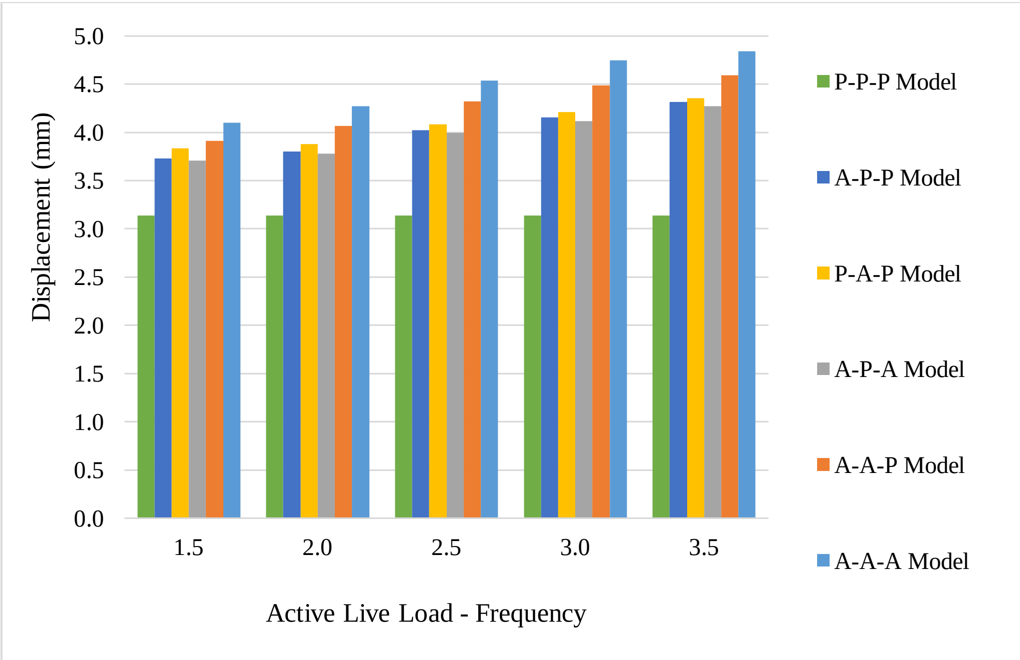

Figure 7.Maximum Displacement Comparison

D. ACCELERATION COMPARISON:

Acceleration is one of the criteria for serviceability. For better serviceability, the acceleration of structure should be less than 0.35xg = 3.4335. Figure 8 is showing the comparison of acceleration. For considered portion acceleration for all models is higher than the desired limit but, the Acceleration may within the desirable limit for the whole structure.

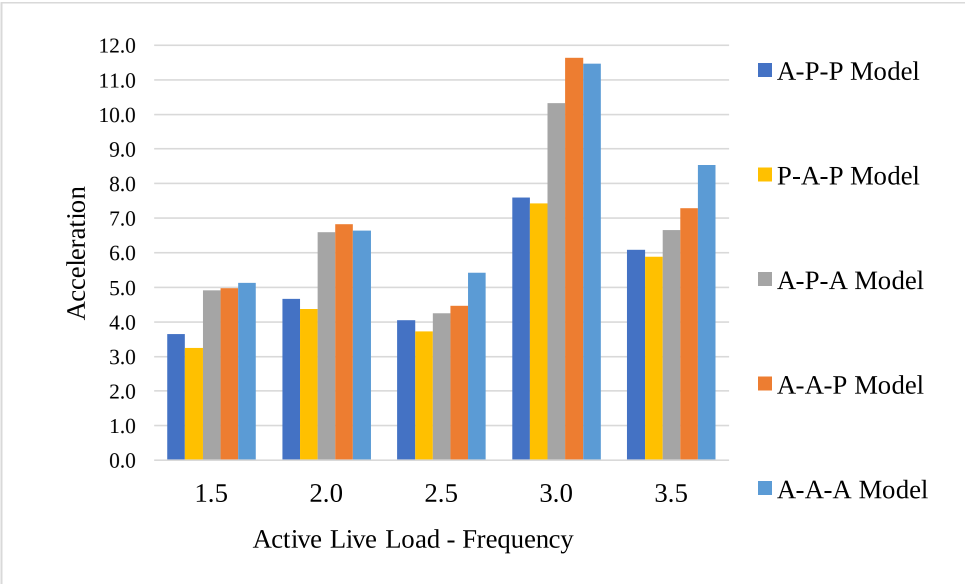

Figure 8.Acceleration Comparison

E. MEMBER FORCES

The following figure 9 is showing the comparison for Maximum Bending Moment at the internal inclined frame for different load combination models. For load combination A-A-A model and A-A-P model due to a combination of A-A live load bending moment is very nearer in both cases. Full active load A-A-A generates higher bending moment than all other cases while Full P-P-P passive load generates less bending moment among all cases.

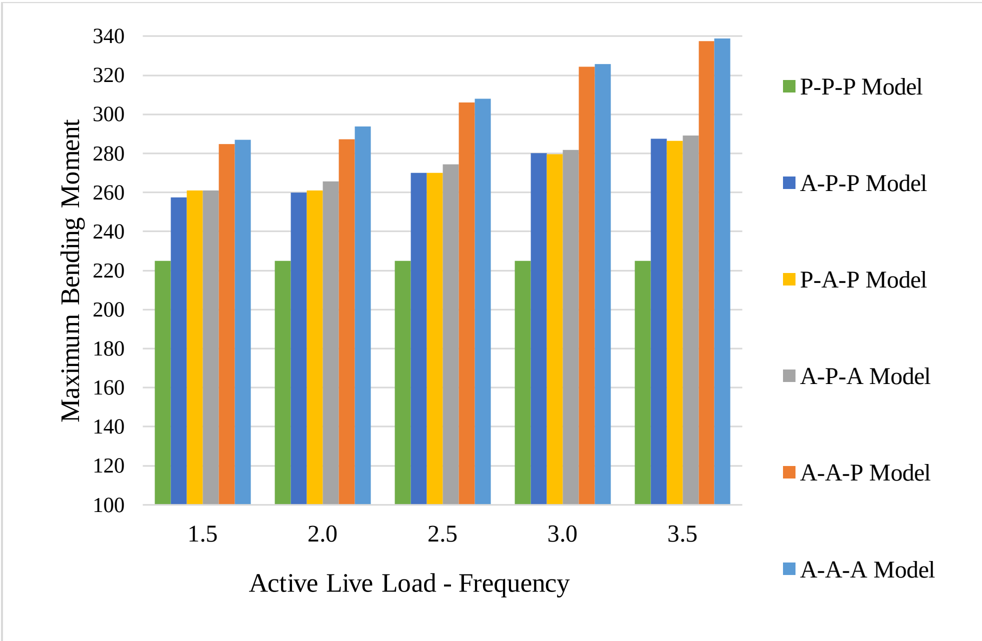

Figure 9.Maximum Bending Moment Comparison

Similar to Bending moment, full active load A-A-A generates higher Shear force than all other cases while Full P-P-P passive load generates less Shear force among all cases. Figure 10 shows the comparison of the Maximum shear force at the internal inclined frame for different load combination models.

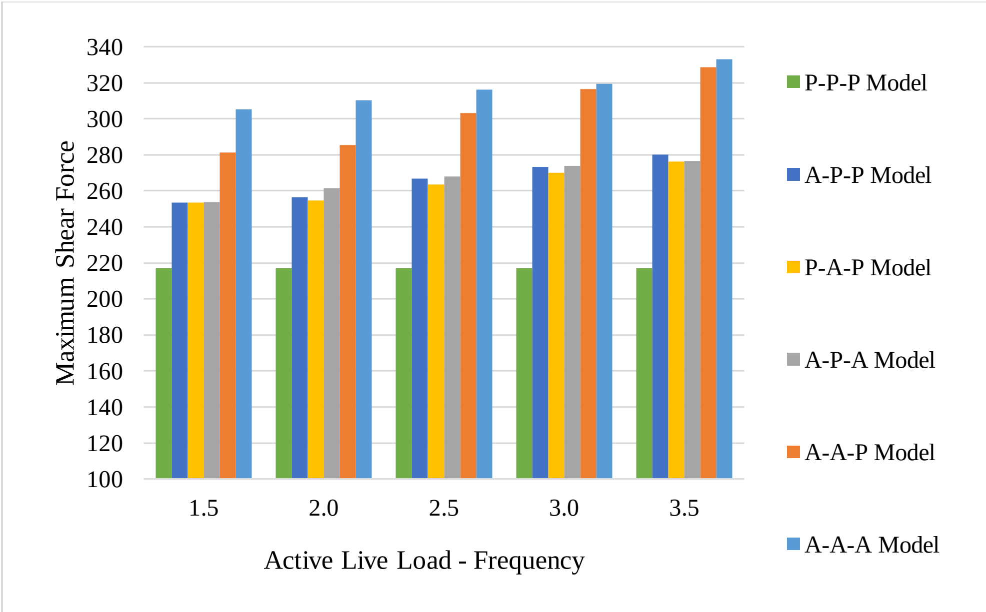

Figure 10.Maximum Shear Force Comparison

VI. CONCLUSIONS

An analysis of dynamic loads induced by spectators' movements is necessary for an accurate analysis of stadium structure. Thus, the dynamic loads induced by spectators' jumping are calculated by numerical model and analyzed. This study investigated the behavior of stadium structure considering different load combination of active live load and passive live load. Based on Study following conclusions are drawn.

- Generally, human-induced frequencies are in the range of 1.5 to 3.5Hz. So, the horizontal frequency of structure should be higher than 4Hz. while the vertical frequency should be more than 8.4 Hz. In current study full Passive Load satisfies this criteria.
- Static design for stadium structure is safe for loading but may fail in serviceability criteria so it is necessary to perform dynamic analysis considering human structure interaction.
- In this study comparative results for horizontal frequency, vertical frequency, maximum displacement, maximum bending moment, maximum shear force, and acceleration are measured higher in effect of active live load in compare to passive live load.
- The full Passive combination gives minimum displacement while Full PPP passive case generates 33 to 66% higher displacement.
- Acceleration is one of the criteria for serviceability. As per literature acceleration of structure should be less than 0.35g but in all cases acceleration is higher than the limits. Particularly for 3Hz loading frequency, the value of acceleration increases drastically.
- Full active load A-A-A generates 27% to 54% higher bending moment than Full P-P-P passive load combination.
- Similarly Full active load A-A-A generates higher Shear force than all other cases while Full P-P-P passive load generates less Shear force among all cases.
- As the frequency of Load increases, the response of structure in form of displacement and internal member forces increases.

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