



# Behaviour Inquiry of Floor Vibration on Composite Structures

S. Karunanidhi, G. Gajalakshmi, Y M S D Sastry

**Abstract:** *In contemporary times, building construction requires light weight with slender structures rather than using conventional materials like concrete. Now a day's Structural Engineers concentrate much more on such slender structures with longer span. The impact of vibration due to human rhythmic activities like aerobics, jumping and dancing on these slender structures is a notable phenomenon. As per the various researchers contemplate, the floor vibrations annoyance not only affect the structure and also its impact over the occupants of the buildings in health affecting aspects. The aim of this paper is to analyse the vibration behavior of composite steel floor structures under gymnastic activities like jumping as human rhythmic activities by FEM analysis. The Finite Element Method analysis is done by using ANSYS software. From the Transient analysis of Finite Element method, the peak acceleration values are found out. These peak acceleration values are compared with the recommended values of IS 800-2007 and ISO 2631 – part II. The annoyance of such acceleration values under human rhythmic activities may induce vibration in terms of resonance; the natural frequency of the structural floor may coincide with any of the frequency of such activities. When resonance occurs, even fatigue failure of structures may happen. Hence it is essential for the structural Engineer to undergo the vibration analysis of composite floor structures during design stage itself. In order to check over such problems, in this paper as a novelty; a mathematical model is developed using SPSS software. This mathematical model is for peak acceleration values which helps the structural designer to analyse vibration problems under human rhythmic activities.*

**Keywords :** *Vibration; Rhythmic activity; Composite structures; Acceleration; ANSYS; SPSS software*

## I. INTRODUCTION

Of late, the modern architecture and construction trends are motivating the structural engineer to search for challenging solutions. The recent evolution in building construction could be attributed to fast erection assembly with optimum weight duly supporting large spans with lesser columns facilitating greater space flexibility.

Owing to the impacts like human rhythmic activities, the structures floor systems are vulnerable to excess vibrations.

Vibrations due to this activity have created problems in office buildings, foot-bridges, shopping malls and sport stadia<sup>7</sup>. Recently the dynamic behavior of these composite floor systems is being investigated by various authors analytically using Finite Element Method is a modern computational analytical tool which is for structural dynamic analysis. In order to increase slender and lightness of the structural systems, designers continuously progress to safety margins. More and more composite floors, steel floors are constructed as light weight structures with low damping and low frequencies, but perceptible to vibration consequently changing the serviceability and ultimate limit state associated with their design.

Starting from Reiherand meister[12], Bruce Ellingwood<sup>3</sup> and more number of researchers attempted to find solution for vibration excitation. Allen [1], developed a design procedure by solving problems for different structural properties for different usage. S. Sanden de Silva et al [9] states that steel deck composite floor with increased acceleration cause discomfort to the occupants.

Nor Hayati and Abd Ghafer[11] made a research work on dynamic behaviour of LVL concrete composite floor system and concluded the natural frequency must exceed 8 Hz to prevent vibration problems.

The collapse of Hyatt Regency Hotel walkway in Kansas City US happened weekend tea dance in 1981 (McGrath and Foote 1981) [11] which caused many lives was a typical example for structural failure. As no information and appropriate theories were then available the people were kept in darkness regarding cause of the destruction.

Kromanis R and Kripakaran P[8] investigated the application of novel computational techniques for structural performance monitoring of National Physical Laboratory (NPL) footbridge bridges truss and concrete footbridge that enable quantification of temperature-induced response during the strain measurement interpretation process. The Results show that the methodology is capable of accurately predicting thermal response and can therefore help with interpreting measurements from continuous National Physical Laboratory (NPL) footbridge bridges truss and concrete footbridge monitoring.

It could be concluded from the above literature study that the understanding of human interaction to the structure is a complex phenomenon. Some equations and formula are arrived at by all researchers from their input data based on the corresponding human activities. Moreover many factors like the posture of the occupants, dynamic properties of the structure and the mass of the

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people which induce activities such as jumping; aerobics, walking etc determine the dynamic response.

As the type of activity carried out by a single person might generate perceptible levels of vibration in a number of floors, no straight calculation is in existence for fundamental frequency. As such all the results obtained in various applications are not specific, ambiguous since the data are sparse, incoherent and devoid of continuity.

## A. Objective

The aim of this paper is to analyse the dynamic behavior for composite steel construction like steel floors with concrete topping for different occupancy usage under serviceable condition for human rhythmic activity (Jumping). The various structure models are to be analysed using Finite Element Method -ANSYS2 software. The analytical values obtained were compared with code recommendations.

## B. Novelty

In order to mitigate the setbacks relating to the vibration problem, a novel mathematical model based on software SPSS has been arrived with reference for composite steel structures.

## II. DYNAMIC ANALYSIS OF STRUCTURAL MEMBERS

### A. Loads generated by human activities

The dynamic loads have considered by Faisca (2003)<sup>4</sup> who achieved the same through a long series of various experiments executed with human activities as dynamic loads are described as jumps with and without stimulation, aerobics, soccer, rock concert audiences and dancing. based on results achieved through a long series of experimental tests made with individuals carrying out rhythmic and non-rhythmic activities. Human activities such as aerobics, Gymnastics dancing and free jumps can be simulated by the load modelling.

The mathematical representation is very much analogous to the signal force generated through experiments and it is described by the equation(2.1). Some parameters like the activity period T, contact period with the structure T<sub>c</sub>, period without contact with the model T<sub>s</sub>, impact coefficient K<sub>p</sub>, and phase coefficient CD are required for this equation.

$$F(t) = CD \left\{ K_p P \left[ 0.5 - 0.5 \cos \left( \frac{2\pi}{T_c} t \right) \right] \right\}, \text{ for } t \leq T_c$$

$$F(t) = 0, \text{ for } T_c < t \leq T \quad (2.1)$$

- Where
- F(t) - Dynamic loading, in (N);
  - t - Time, in (s);
  - T - Activity period (s);
  - T<sub>c</sub> - Activity contact period (s);
  - P - Weight of the individual (N);
  - K<sub>p</sub> - Impact coefficient;
  - CD - Phase coefficient.

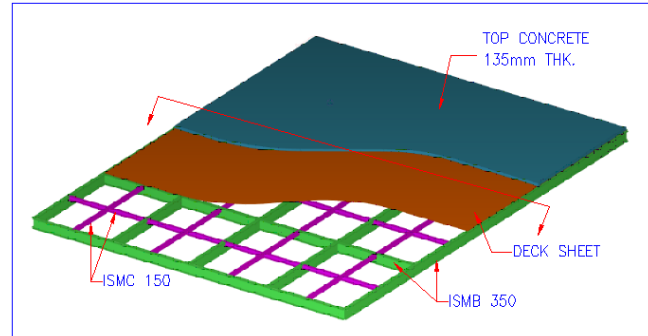
### B. Structural Configuration Details

#### Structural Floor Details:

- Span of the Composite floor systems are: 16m x 12m, 8m x 6m, 4m x 3m, 8m x 12m, 6m x 10m, 2m x 1m
- Youngs Modulus for the steel beams : 2.4 x 10<sup>5</sup> Mpa.
- Density of Steel: 7850 kg/m<sup>3</sup>.
- Density of Concrete: 2500 kg/m<sup>3</sup>
- Yield stress: 300 Mpa.

The above composite floor system panels are analysed using FEM are

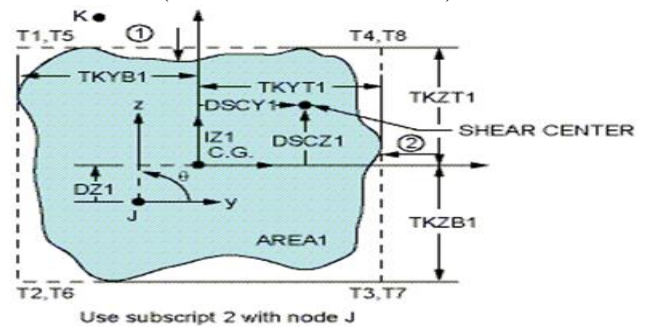
- a) Modal analysis b) Harmonic analysis and c) Transient analysis.



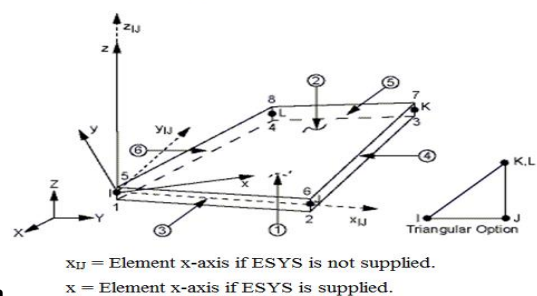
**Fig 2.1. Structural model three-dimensional plan view**

### C. Finite Element Analysis using Ansys

For dynamic floor analysis for the proposed computational model, adopted the usual mesh refinement techniques present in finite element method simulations implemented in the ANSYS program (ANSYS, 11). In this model, the floor beams are represented by three-dimensional beam elements (BEAM44), tension, compression, bending and torsion capabilities. The floor slab is represented by shell finite elements (SHELL63 and SHELL 99).



**Fig 2.2. 3-D Elastic Tapered Unsymmetric**



### Beam

**Fig 2.3. Elastic Shell**

Model results of ANSYS for 16mx 12m are- modal shape, natural frequency, harmonic analysis and transient analysis are given below.

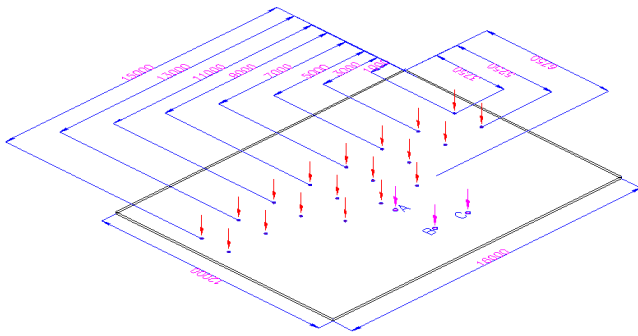


Fig 2.4. Load distribution Scheme associated to eighteen individuals practicing

D. Modal analysis and the mode shapes

Table 2.1. Mode shapes and natural frequencies

Mode shapes	1	2	3	4	5	6
Natural frequencies (Hz)	5.483	9.480	12.675	15.836	19.260	22.010

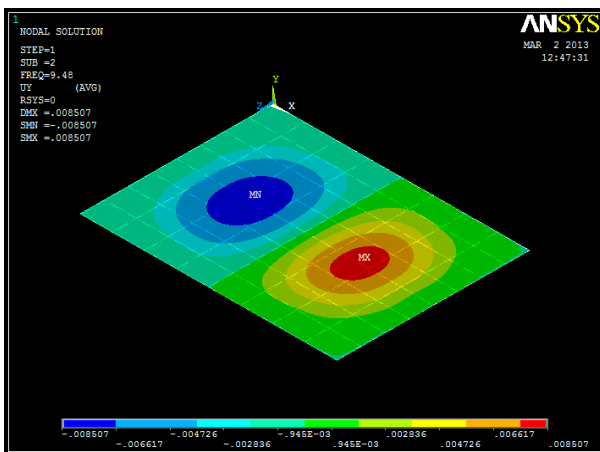


Fig 2.5. Vibration mode associated to the 2nd natural frequency: F02=9.480

E. Harmonic Analysis

• Results for three persons loading

The following graphs shows the dynamic response of FE model composite floor system with three persons loading

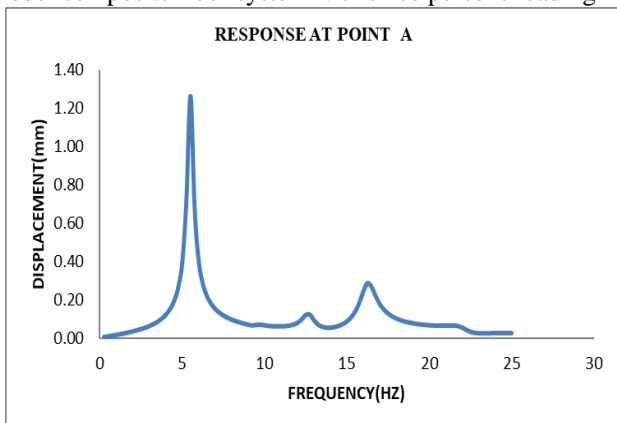


Fig 2.6. Frequency Vs Displacement for Three persons at Measuring Point A

Transient Analysis Results for five persons loading

The following Figure presents the Acceleration versus Time graphs for the analyzed Composite Concrete Floor at measuring point A , B, C, when only five persons load is acting on the structural Model(Aerobic).

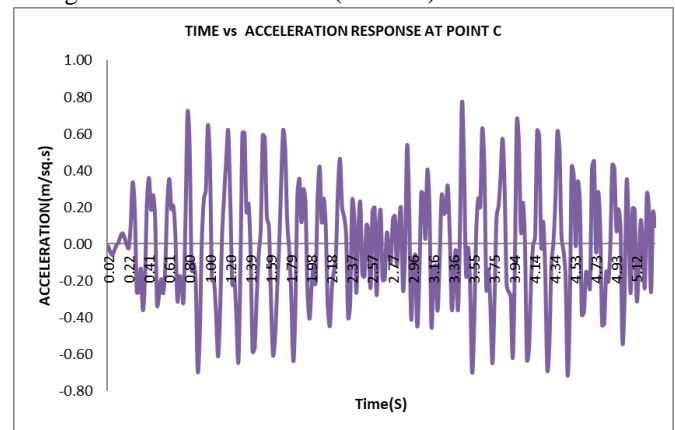


Fig 2. 7. Time Vs Acceleration Response for 5 persons at Measuring Point C

Table 2.2. Comparison of peak acceleration results with Threshold limits

Number of Persons	Peak Acceleration (m/sq.s)			Max peak acceleration	Threshold limits $a_{lim}$
	Poi nt A	Point B	Point C		
1	0.27	0.247	0.24	0.27	0.5% g as per IS800-2007 <sup>6</sup>
3	0.737	0.644	0.557	0.737	
5	0.94	0.824	0.767	0.94	
7	1.41	1.17	1.16	1.41	5% g as per ISO-2631 (PART-II) <sup>5</sup>
11	2.01	1.66	1.59	2.01	
19	3.54	2.95	2.69	3.54	

Likewise the dynamic analysis for other panels like 10mx 8m, 8mx 6m, 6mx 10m, 8mx 12m, 4mx 3m, 2m x 1m are analysed and their corresponding structural properties and results are given as inputs for generating a regression mathematical model using SPSS software.

III. RESULTS AND DISCUSSION ON ANALYTICAL RESULTS

From the results with reference to Table 2., the threshold limit for acceleration as per IS 800 2007 for human rhythmic activity is 0.5g. For one person loading condition for jumping activity, the peak acceleration value is 0.27m/sec<sup>2</sup>. Nearly 81% value is increased when compared with IS800-20075. Therefore composite steel floor is vulnerable to vibration due to the impact of jumping activity. The floor is not supported to jumping activity from 3 persons loading condition when compared to the threshold limit of 5% g as per ISO 2631(part II)<sup>6</sup>.

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## • Mathematical model using SPSS software

SPSS software is used for data analysis using statistical techniques. There are many statistical packages available for data analysis Minitab, SAS, STATA. But SPSS is the most widely used software. This software can be used in all domains like finance, healthcare, bio engineering etc. SPSS (Statistical Package for the Social Sciences) is a software package used for statistical analysis. Long produced by SPSS Inc., it was acquired by IBM in 2009. The current versions (2015) are officially named IBM SPSS Statistics. Companion products in the same family are used for survey authoring and deployment (IBM SPSS Data Collection), data mining (IBM SPSS Modeler), text analytics, and collaboration and deployment (batch and automated scoring services). SPSS contains two views. They are two views in the SPSS such as data view and variable view. Data view is used to store data and variable view is used to define variables.

## • Multiple regression model development

Regression analysis is mathematical measure of average relationship between two or more variables in terms of original units of data. Regression is used to create an equation or transfer function from the measurements of the system's inputs or outputs acquired during a passive or active experiment. Multiple regression analysis was conducted using displacement (d) and Acceleration (a) as a dependent variable and area (A), Moment of Inertia (IZ1, IY1). Web thickness (TKyB1) as the independent variables.

### Regression Analysis

For acceleration

SPSS 16 was used to analyze the response of this study. Person correlation was used to analyze correlation among the 7 variables. All the variables were significantly correlated with one another at 0.001

$$d=f(A, IZ1, IY1, TKZB1, TKYB1) \quad (3.1)$$

TKZB1, TKYB1 are not significant in the explaining the variation in acceleration we developed the reduced regression that excluded the variables.

The reduced model has the following form:

$$d= f (A, IZ1, IY1) \quad (3.2)$$

Predictors: (Constant), TKYB1, IZ1, A

**Table 3.1. Correlations**

		A	ZI	IY1	IX1	TKZB1	TKYB1	displacement	acc
A	Pearson Correlation	1	.946**	.990**	.949**	.246*	.944**	.541**	.611**
	Sig. (2-tailed)		.000	.000	.000	.050	.000	.000	.000
	N	64	64	64	64	64	64	64	64
IZ1	Pearson Correlation	.946**	1	.969**	1.000**	.262*	.891**	.593**	.548**
	Sig. (2-tailed)	.000		.000	.000	.036	.000	.000	.000
	N	64	64	64	64	64	64	64	64

IY1	Pearson Correlation	.990**	.969**	1	.971**	.253*	.940**	.564**	.619**
	Sig. (2-tailed)	.000	.000		.000	.044	.000	.000	.000
	N	64	64	64	64	64	64	64	64
IX1	Pearson Correlation	.949**	.990**	.971**	1	.262*	.894**	.592**	.552**
	Sig. (2-tailed)	.000	.000	.000		.036	.000	.000	.000
	N	64	64	64	64	64	64	64	64
TKZB1	Pearson Correlation	.246*	.262*	.253*	.262*	1	.287*	.206	.247*
	Sig. (2-tailed)	.050	.036	.044	.036		.022	.103	.049
	N	64	64	64	64	64	64	64	64
TKYB1	Pearson Correlation	.944**	.891**	.940**	.894**	.287*	1	.590**	.720**
	Sig. (2-tailed)	.000	.000	.000	.000	.022		.000	.000
	N	64	64	64	64	64	64	64	64
displacement	Pearson Correlation	.541**	.593**	.564**	.592**	.206	.590**	1	.735**
	Sig. (2-tailed)	.000	.000	.000	.000	.103	.000		.000
	N	64	64	64	64	64	64	64	64
acc	Pearson Correlation	.611**	.548**	.619**	.552**	.247*	.720**	.735**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.049	.000	.000	
	N	64	64	64	64	64	64	64	64

\*\* . Correlation is significant at the 0.01 level (2-tailed).

\* . Correlation is significant at the 0.05 level (2-tailed).

Acceleration - Regression Full model

Acceleration full model

**Table 3.2. Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.878 <sup>a</sup>	.771	.747	.65743038408

**Table 3.3. ANOVA<sup>b</sup>**

Model	Sum of Squares	df	Mean Square	F	Sig.
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1	Regression	82.920	6	13.820	31.975	.000 <sup>a</sup>
	Residual	24.636	57	.432		
	Total	107.556	63			

a. Predictors: (Constant), displacement, TKZB1, A, TKYB1, IZ1, IY1

b. Dependent Variable: acc

**Table 3.4 Coefficients<sup>a</sup>**

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-1.756	.804		-2.185	.033
A	-602.190	341.613	-.871	-1.763	.083
IZ1	-41399.111	9928.032	-1.206	-4.170	.000
IY1	1229817.785	494641.797	1.598	2.486	.016
TKZB1	.605	1.079	.037	.561	.577
TKYB1	1490.666	398.890	.776	3.737	.000
displacement	.851	.127	.555	6.703	.000

a. Dependent Variable: acc

ACC reduced

**Table 3.5. Model Summary**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.767 <sup>a</sup>	.589	.561	.86586205000

a. Predictors: (Constant), TKYB1, IZ1, A, IY1

**Table 3.6. ANOVA<sup>b</sup>**

Model	Sum of Squares	df	Mean Square	F	Sig.	
1	Regression	63.323	4	15.831	21.116	.000 <sup>a</sup>
	Residual	44.233	59	.750		
	Total	107.556	63			

a. Predictors: (Constant), TKYB1, IZ1, A, IY1

b. Dependent Variable: acc

**Table 3.7. Coefficients<sup>a</sup>**

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-2.911	1.034		-2.814	.007
A	-915.125	445.620	-1.324	-2.054	.044

IZ1	-25051.631	12646.276	-.730	-1.981	.052
IY1	1155100.942	650877.390	1.500	1.775	.081
TKYB1	2321.652	494.234	1.209	4.697	.000

a. Dependent Variable: acc

**Regression Full model**

$$Acceleration = -602.190A - 41399.111IZ1 + 1229817.785IY1 + 0.605TKZB1 + 1490.666TKYB1 + 0.851D - 1.756$$

**Regression Reduced model**

$$Acceleration = -915.125A - 25051.631IZ1 + 1155100.94IY1 + 2321.65TKYB1 - 2.911 \quad (3.4)$$

Model Validation:

In the above Equation, the significant error is at and TKZB1 as 0.577. Hence the Equation is reduced as shown in Equation, in which significant errors are at 0.01 level. The reduced regression model has explained the variation accounts for 58.9% which is the best model for validation.

The resulting multiple regression model is From above Equation and, there is a positive relationship between Acceleration with IY1 and TKZB1. But there is a negative relationship between the area and acceleration.

**IV. CONCLUSION**

The floor vibration of composite steel structures are analysed using Finite Element method under ANSYS software for human rhythmic activities. The peak acceleration values are obtained from transient analysis and they are compared with IS 800-2007 and ISO 2631.

The resonance formation under deviated acceleration values lead occupancy health problems and also fatigue failure to structures. To mitigate such vibration resonance problems, a mathematical model for acceleration parameter is developed using SPSS software. This mathematical model incorporates the various properties of composite steel structures and helps the structural Engineer to check and control the vibration problems due to human rhythmic activities at the design process itself.

Some of the suggestions to control the vibration problems over engineering structures for human rhythmic activities are summarized below:

- To install a steel girder as a supporting structure underneath the existing floor
- To increase damping, it is recommended to use partition walls and planters with low cost method to increase damping.
- By providing separate ceilings and partitions immediately below the jumping floor by supporting the ceiling on its own framing and by not extending partition to the floor above.

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conferences. Now he is working as Assistant Professor in the department of civil Engineering, Bonam Venkata Chalamayya Engineering College, Autonomous, Odalarevu, Allavaram Mandal, Affiliated to JNTUK, Kakinada, East Godavari District, Andhra Pradesh, with more than 18 years of teaching, research and industrial experience. He is a life time member of ISTE, CSI and Institute of Engineers (India).

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