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MATHEMATICAL MODEL OF HUMAN RHYTHMIC ACTIVITY ONSTEEL FLOOR SLAB

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ABSTRACT

Analyzing vibration concert of civil engineering structures due to human induced rhythmic loading is more and more critical aspect of design process of structures such as sports amphitheaters used for pop/rock concerts, floors accommodating fitness Centre and aerobic classes, and foot over bridges used as viewer walkways during social events like fireworks demonstrations. This paper is to investigate the dynamic analysis of steel floor when subjected to human rhythmic activities (Jumping) and to frame a mathematical model based on the parameters related to the properties of steel materials. The investigated structural model is taken as a steel typical floor bay of a similar steel floor like Industrial steel structure, a wide-ranging parametric study is developed concentrating on the determination of the steel floor peak accelerations because of human rhythmic activities. This paper is concerned with the dynamic study of a Steel floor slab of size 3m x 24m. The analysis is done using ANSYS. The human rhythmic activity is been lead on the slab and the Modal and Harmonic analysis are carried out. The outcomes are associated with IS 800-2007 code recommendations. A recent progress presented in this paper is a step towards more systematic and realistic using SPSS, mathematical models of group/crowd rhythmic loading that can be used to simulate more reliably dynamic response.

Keywords: floor vibration, rhythmic activity, modal, harmonic, transient, frequency, amplitude, ansys, spss.

INTRODUCTION

In the recent years, the trend in the model of steel structure design has been towards greater spans and increased flexibility and lightness. As a result, decrease in the stiffness and mass leads to smaller natural frequencies that in order to results of higher degree of sensitivity for dynamic loads.

The reaction of people who feel vibration depends very strongly on what they are doing. People in offices or residences do not like "distinctly observable" vibration (peak acceleration of about 0.5% of the acceleration of gravity, *g*), whereas people taking part in an activity will accept vibrations approximately 10 times greater (5percent *g* or more).

People dining beside a dance floor, lifting weights beside an aerobics fitness centre, or standing in a shopping mall, will accept around (about 1.5% *g*). Sensitivity within each occupant also varies with duration of vibration and remoteness of source. The above limits are for vibration frequencies between 4 Hz and 8 Hz. This slender slab creates irritating vibration. This unwarranted floor vibration can make people feel unclear and uncomfortable. Sometimes, the vibration makes people get frightened of a structural failure also.

This fright, of course is unnecessary since the displacement and stress induced by floor vibration are generally small in view of the design criteria for structural safety. These facts have led to very slender floors, sensitive to dynamic excitation, and subsequently changed the serviceability and ultimate limit states related to their design. The extensive range of measures and analysing techniques is a warning of the multipart environment of floor sensations. The cumulative frequency of building shaking due to human rhythmic activities led to a exact design standard for rhythmic excitations (Allen *et al*. 1985, Bachmann and Ammann, 1987, Faisca, 2003, Murray *et al*., 2003, Silva *et al*., 2008). Floor vibrations often lead to structural failure as demonstrated by the Hyatt Regency Hotel Walkway in Kansas City, US, (McGrath and Foote, 1981) and London Millennium Footbridge (BBC news, 2000).

This paper deals with the dynamic behavior of steel floor subjected to the human rhythmic activity (Jumping). The floor dynamic response in terms of peak accelerations is obtained by numerical simulations and compared to the limiting values proposed by several authors and design codes.

BACKGROUND AND PURPOSE

Stiffness and Resonance are dominant considerations in the design of steel floor structures and footbridges. The first known stiffness criterion appeared nearly 170 years ago. Tredgold (1828) wrote that girders over long spans should be "made deep to avoid the inconvenience of not being able to move on the floor without shaking everything in the room". Traditionally, soldiers "break step" when marching across bridges to avoid large, potentially dangerous, resonant vibration.

Resonance has been ignored in the design of floors and footbridges until recently. Approximately 30 years ago, problems arose with vibrations induced by walking on steel-joist supported floors that satisfied

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traditional stiffness criteria. Since that time much has been learned about the loading function due to walking and the potential for resonance. More recently, rhythmic activities, such as aerobics and high-impact dancing, have caused serious floor vibration problems due to resonance.

This is the main purpose to motivate the development of a design methodology on the structural system dynamical response submitted to dynamic loads because of human activities.

EQUATION GOVERNING THE MODEL FROM FAISCA

This paper has considered the dynamic loads obtained by Faisca, based on the results achieved through a long series of experimental tests with individuals carrying out rhythmic and non-rhythmic activities. The dynamic loads generated by human rhythmic activities, such as jumps, aerobics and dancing were investigated by Faisca. The loading modelling was able to emulate human activities like aerobic gymnastics, dancing and free jumps.

In this paper, the Hanning function was used to represent the human dynamic actions, because it was verified that this mathematical representation is very similar to the signal force obtained through experimental tests developed by Faisca. The mathematical representation of the human dynamic loading using the Hanning function is given below.

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

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

Where

F(t) = dynamic loading (N)
t = time (s)
T = activity period (s)
Tc = activity contact period (s)
P = person's weight (N)
Kp = impact coefficient
CD = phase coefficient.

Finite element modelling

Dynamic analysis for simple structures can be carried out manually, but for complex structures Finite Element Analysis can be used to calculate the mode shapes and frequencies.

Finite element features

The main elements used in the Finite Element Modeling are as follows:

BEAM 44, this is a uniaxial element with tension, compression, torsion, and bending capabilities. The element has six degrees of freedom at each node, translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes.

SHELL 63, this has both bending and membrane capabilities. Both in-plane and normal loads are permitted. The element has six degrees of freedom at each node translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes. Stress stiffening and large deflection capabilities are Included. A consistent tangent stiffness matrix option is available for use in large deflection.

The proposed mathematical model, developed for the steel floor dynamic analysis, adopted the usual mesh refinement techniques present in finite element method simulations implemented in the ANSYS program. In this model, all steel beams and columns were represented by three-dimensional beam elements, where flexural and torsion effects are considered. The steel floor slab was represented by shell finite elements.

Loading scheme for the analysis

The live load considered in this analysis corresponds to one individual for each 4.0m2 (0.25person/m2). The load distribution is considered symmetrically cantered on the slab panel. The present investigation also assumed that an individual person weight is equal to 800 N (0.8 KN) (Bachmann and Ammann, 1987) and that the adopted damping ratio is equal to, ξ=3% (ξ = 0.03). (IS 800-2007).

The human-induced dynamic action is applied to the jumping area. The steel floor dynamical responses are obtained on the sensor or observer node A to verify the influence of the dynamical loads on the adjacent slab floor. In the current investigation, the human rhythmic dynamic loads are applied to the structural model corresponding to the effect of 2, 4, 6, 8, and 10 individuals practicing aerobics. Hence, 10 individual practicing is the full load condition for the model.

Human induced loading position diagram

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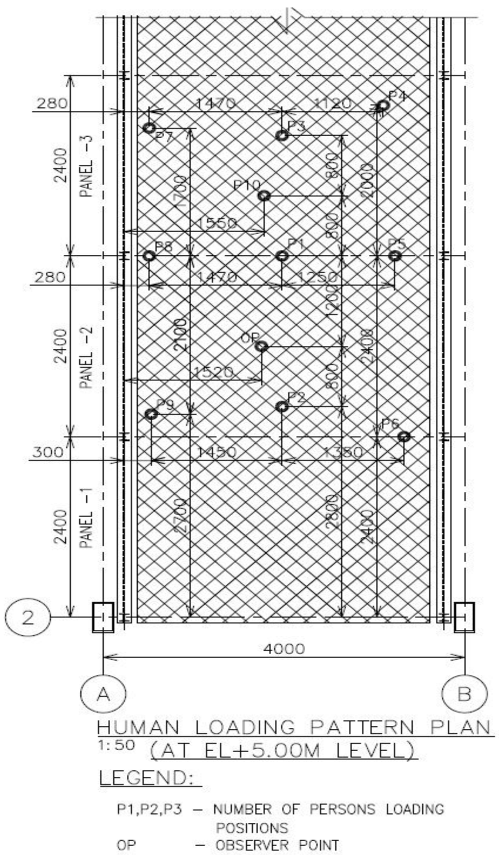

Figure-1. Human induced loading position diagram.

Methods of dynamic analysis

- Modal Analysis
- Harmonic analysis
- Transient analysis

Modal analysis

It is a fundamental analysis for more detailed dynamic analysis, such as Harmonic response analysis, Transient dynamic analysis.

The steel floor's natural frequency is going to determine with the aid of the numerical simulations. It pays much attention to the physical content of the simulation and highlights the goal that, from the numerical results of the simulation, knowledge of background processes and physical understanding of the simulation region can be obtained.

In fact, numerical simulation uses the values that can best represent the real environment. The evolution of the system also strictly obeys the physical laws that govern the real physical processes in the simulation region. Then the result of such simulation can have a good representation of the real environment. From the result of such simulation we can safely draw proper conclusions and have a better understanding of the system.

The structural system vibration mode shapes and the natural frequency values are tabulated.

Harmonic analysis

The FE model Steel floor is subjected to human activities such as jumping, walking. The mode-superposition method available in ANSYS computer program is adopted for the harmonic analysis, which is advantageous in tracing the harmonic response curve. The FE Model subjected to the forcing frequency of range 0 to 50Hz and corresponding Amplitudes are measured.

The mode-superposition method available in ANSYS computer program is adopted for the Harmonic analysis, which is advantageous in tracing the harmonic response curve. The FE Model subjected to the forcing frequency of range 0 to 50Hz and corresponding Amplitudes are measured.

The dynamic response of FE model floor Amplitudes are compared by varying number of person's activities.

Transient analysis

The linear time-domain analysis (Transient Analysis) is performed throughout this study. The evaluation of the vibration levels when subjected to dynamic excitations from human rhythmic activity (jumping).

The FE model of the steel floor is subjected to transient dynamic loading for a period of 5.3 second (10 cycles).

MATHEMATICAL MODEL BY SPSS SOFTWARE

Application of Taguchi Method in the optimization of harmonic analysis parameters

This paper presents a study in which an attempt has been made to improve the harmonic characteristic by optimizing the harmonic parameters using the Taguchi method.

The performance of the parameters is evaluated in terms of its orthogonal array; main effect, signal-to-noise (S/N) ratio and analysis of variance are employed to analyze the effect of no of persons and frequency.

Orthogonal array formulation

In this study, since each parameter has five levels. five levels of two parameters were selected as shown in Table-1. Therefore, an L25 (2 factor and 5 level - 1 ^{f}) orthogonal array the experimental layout for the injection moulding parameters using the L25 OA is shown in Table-2.

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Table-1. Harmonic parameters and their levels.

Factor	Unit	Level 1	Level 2	Level 3	Level 4	Level 5
Frequency	Hz	1	2	3	4	5
No. of Persons	---	2	4	6	8	10

Table-2. Experimental plan using an L25 Orthogonal array.

Trial	Frequency(Hz)	No. of Persons	Amplitude(mm)
	Factors (input)		Response (output)
1	1	2	2.74E-26
2	2	2	1.26E-25
3	3	2	1.58E-25
4	4	2	5.95E-26
5	5	2	3.86E-26
6	1	4	4.55E-26
7	2	4	2.08E-25
8	3	4	2.67E-25
9	4	4	9.96E-26
10	5	4	6.46E-26
11	1	6	4.37E-26
12	2	6	2.01E-25
13	3	6	2.50E-25
14	4	6	9.46E-26
15	5	6	6.15E-26
16	1	8	6.19E-26
17	2	8	2.85E-25
18	3	8	3.54E-25
19	4	8	1.34E-25
20	5	8	8.71E-26
21	1	10	7.28E-26
22	2	10	3.35E-25
23	3	10	4.16E-25
24	4	10	1.58E-25
25	5	10	1.02E-25

Signal to noise ratio (S/N)

The signal to noise ratio (S/N ratio) was used to measure the sensitivity of the quality characteristic being investigated in a controlled manner. In Taguchi method, the term ‘signal' represents the desirable effect (mean) for the output characteristic and the term ‘noise' represents the undesirable effect (Signal Disturbance, S.D) for the output characteristic which influence the outcome. Smaller are Best Characteristics: Data sequences for Amplitude (mm), which is lower-the-better performance characteristic. Since the objective function Amplitude (mm),) is smaller-the-better type of control function, was used in calculating the S/N ratio. The S/N ratios of all the experiments were calculated and tabulated as shown in Table-3 using the formula S/N ratio, $\eta = -10 \log (amp^2)$.

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Table-3. Tabulated S/N ratios.

Trial	Frequency (Hz)	No. of persons	Amplitude (mm)	S/N ratio for amplitude (mm)
1	1	1	2.74E-26	5.11E+02
2	2	1	1.26E-25	4.98E+02
3	3	1	1.58E-25	4.96E+02
4	4	1	5.95E-26	5.05E+02
5	5	1	3.86E-26	5.08E+02
6	1	2	4.55E-26	5.07E+02
7	2	2	2.08E-25	4.94E+02
8	3	2	2.67E-25	4.91E+02
9	4	2	9.96E-26	5.00E+02
10	5	2	6.46E-26	5.04E+02
11	1	3	4.37E-26	5.07E+02
12	2	3	2.01E-25	4.94E+02
13	3	3	2.50E-25	4.92E+02
14	4	3	9.46E-26	5.00E+02
15	5	3	6.15E-26	5.04E+02
16	1	4	6.19E-26	5.04E+02
17	2	4	2.85E-25	4.91E+02
18	3	4	3.54E-25	4.89E+02
19	4	4	1.34E-25	4.97E+02
20	5	4	8.71E-26	5.01E+02
21	1	5	7.28E-26	5.03E+02
22	2	5	3.35E-25	4.90E+02
23	3	5	4.16E-25	4.88E+02
24	4	5	1.58E-25	4.96E+02
25	5	5	1.02E-25	5.00E+02

Experimental details

The average S/N ratios of all the experiments were calculated and tabulated as shown in Table-4.

Table-4. Average S/N ratios for each factor.

Level	Average S/N ratios frequency (Hz)	Average S/N ratios No. of persons
1	5.06E+02	5.08E+02
2	4.93E+02	4.99E+02
3	4.91E+02	5.00E+02
4	5.00E+02	4.97E+02
5	5.03E+02	4.95E+02

Table-5. Optimum values of factors and their levels.

Parameters	Optimum values
Frequency(Hz)	3
No of Persons	10

Table-5 Optimum values of factors and their levels Parameter Optimum Value Frequency (Hz) 3 Hz No of Persons 10

Application of Taguchi Method in the optimization of transient analysis parameters

In this paper, transient parameters like time and no of persons are optimized with the considerations of multi responses such as displacement, velocity and acceleration. L9 orthogonal array (2 factors and 3 levels) was taken to conduct the experiments. The method shows

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a good convergence with the experimental and the optimum process parameters where the minimum displacement, velocity and acceleration are obtained.

Table-6. Transient parameters and domain of experiments.

S. No.	Operating parameter	Symbol	Unit	Levels		
				Low	Medium	High
1	Time	A	Sec	0.215	2.000	3.68
2	No of Persons	B	--	2	6	10

Table-7. Experimental results for L9 Orthogonal array (Actual values).

Trial No.	Time (Sec)	No. of Persons	Displacement (mm)	Velocity (m/sec)	Acceleration (m/sec^2)
1	0.215	2	-1.59E-04	-3.57E-04	0.960341
2	0.215	6	-1.89E-04	-1.19E-04	0.0543948
3	0.215	10	-0.000263186	-0.000263186	0.0827528
4	2	2	-1.48E-04	1.07E-02	0.796066
5	2	6	7.69641E-05	0.0161796	0.700232
6	2	10	1.14E-04	2.52E-02	1.13782
7	3.68	2	3.93E-05	-4.60E-03	-0.71479
8	3.68	6	7.55E-05	-0.00816946	-1.30839
9	3.68	10	0.000118305	-0.0105926	-1.8438

Factor analysis

Factor analysis is the most often used multi-variance technique in research studies. This technique is applicable when there is a systematic interdependence among a set of observed variables. Factor analysis aims at grouping the original input variables into factors which underlie the input variables. Each factor is accounted for one or more input variables. Principal Component Method (PCM) is a mathematical procedure that summarizes the information contains in a set up of original variables into a new and smaller set of uncorrelated combinations with a minimum loss of information. These analyses combine the variable that account for the largest amount of variance to form the first principal component. Second principal accounts for the next largest amount of the variance and so on, until the total sample variance is combined into components groups.

PCM of factor analysis is used for solving the multi -response Taguchi problems. Chao-Ton and Lee-Ing Tong (1997) have developed and effective procedure to transform a set of responses into a set of uncorrelated component such that the optimal conditions in the parameters design stage for the multi-response problem can be determined. They have proposed an effective procedure on the basis of PCM to optimize to multi-response problems in the Taguchi method (Pananeerselvam, 2004). Statistical software is used to perform factor analysis.

Step 1: Transform the original data from the Taguchi experiment into S/N ratio. S/N ratio for displacement and acceleration are computed form the following formula

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Table-8. Normalized S/N Ratio.

Trial	S/N Ratio values		Normalized S/N ratio values	
	Displacement	Acceleration	Displacement	Acceleration
1	7.59E+01	0.351490587	4.35E+00	5.665766799
2	7.45E+01	25.28885231	2.89E+00	30.60312853
3	7.16E+01	21.64434605	0.00E+00	26.95862227
4	7.66E+01	1.981018488	4.97E+00	7.295294701
5	8.23E+01	3.095160925	1.07E+01	8.409437137
6	7.88E+01	-1.121471266	7.23E+00	4.192804947
7	8.81E+01	2.916430639	1.65E+01	8.230706852
8	8.24E+01	-2.334744323	1.08E+01	2.97953189
9	7.85E+01	11.37	1	0

S/N ratio = $-10 \log \sum (Y_{ij}^2)$

Step 2: Normalized the S/N ratio are computed and presented in the Table-8.

Step 3: Factor analysis is performed based on principal component method. Here the components that are having Eigen value more than one are selected for analysis. The component values obtained after performing factor analysis based on PCM are given in the Table-9.

Table-9. Component Matrix[a].

Component Matrix[a]	
	Component
	1
Displacement	.883
Acceleration	-.883
Extraction Method: Principal Component Analysis.	

Table-10. Normalized S/N Ratio and MRPI for Response.

Trial	Normalized S/N Ratio values		MRPI
	Displacement	Acceleration	
1	4.35E+00	5.665766799	-1.159572813
2	2.89E+00	30.60312853	-24.47361683
3	0.00E+00	26.95862227	-23.80446346
4	4.97E+00	7.295294701	-2.049132478
5	1.07E+01	8.409437137	2.004458238
6	7.23E+00	4.192804947	2.68289787
7	1.65E+01	8.230706852	7.31701756
8	1.08E+01	2.97953189	6.944085619
9	1	0	6.132606014

Table-11 summarizes the main effect on MRPI. The controllable factor on MRPI value in the order of significance are time and no of persons. The larger MRPI value implies the better quality. Consequently the optimal condition is set as A1, B3.

Table-11. Main effect on MRPI.

A1	4.484246	B1	-16.47922
A2	-5.17502	B2	0.8794079
A3	-4.99632	B3	6.7979031

Table-12 Optimum values of factors and their levels Parameter Optimum Value time (sec) 0.215 No of Persons 10.

RESULTS AND DISCUSSIONS

Modal analysis results

The natural frequencies of the structural model due to its self-weight are obtained by using ANSYS software modal analysis for the first six modes.

Table-12. Mode shapes and natural frequencies.

Mode shapes	Natural frequencies (Hz)
1	0.971
2	0.971
3	1.722
4	2.505
5	2.505
6	2.676

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The natural frequencies ranges varies from0.971 Hz to 2.676Hz corresponding to the mode Shape one and the mode shape6.

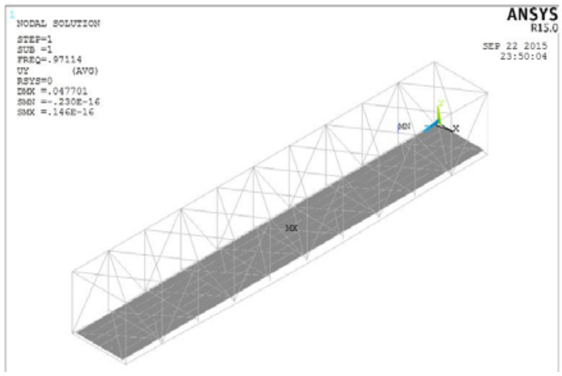

Figure-2. Mode shape 1 with natural frequency 0.97 Hz.

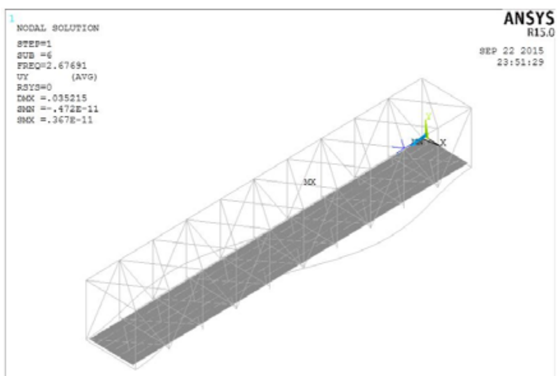

Figure-3. Mode shape 6 with natural frequency 2.68 Hz.

Harmonic analysis results

The amplitude for 2,4,6,8 and 10 people's loadings are obtained from harmonic analysis and shown as following Figures.

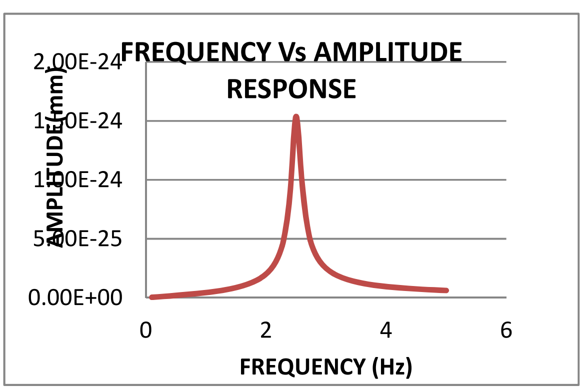

Figure-4. Frequency Vs Displacement for six persons at sensor point.

Transient analysis results

Results for two persons loading

The vertical displacement, velocity, and acceleration values are obtained from transient analysis and shown as following Figures.

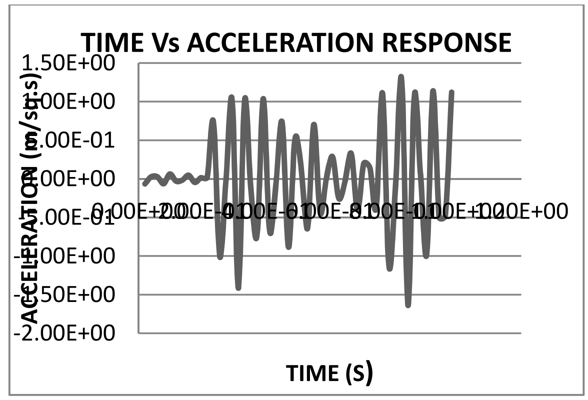

Figure-5. Time Vs Acceleration for two persons at sensor point.

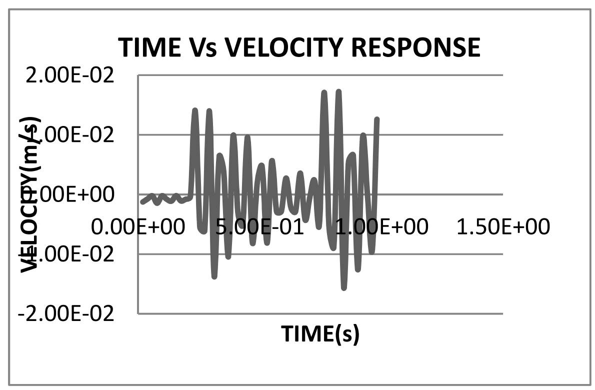

Figure-6. Time Vs Velocity for two persons at sensor point.

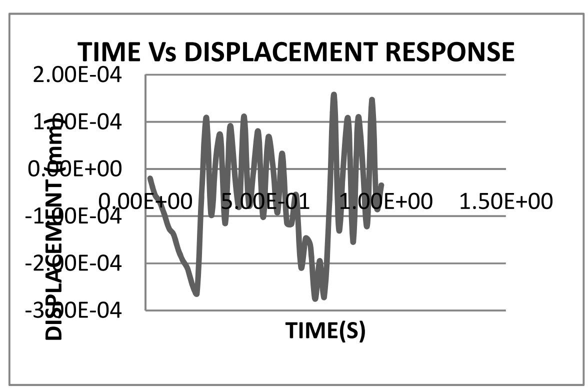

Figure-7. Time Vs Displacement for two persons at sensor point.

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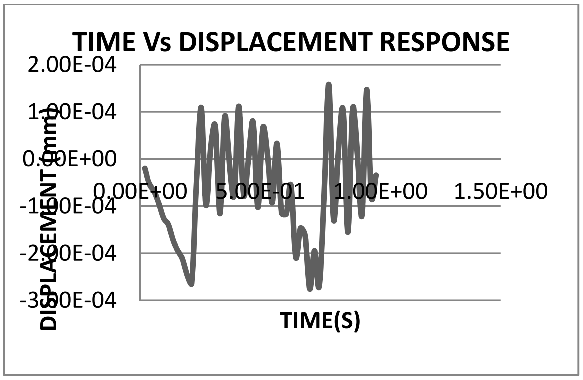

Figure-8. Time Vs Displacement for ten persons at sensor point.

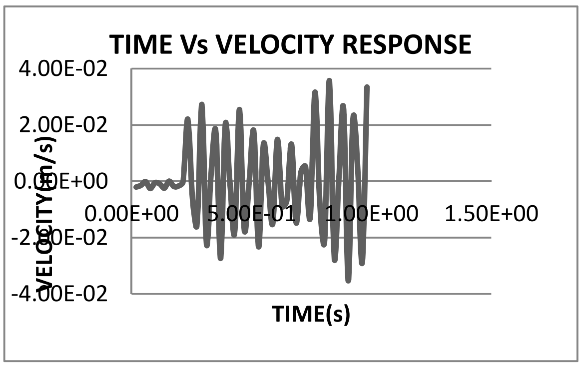

Figure-9. Time Vs Velocity for ten persons at sensor point.

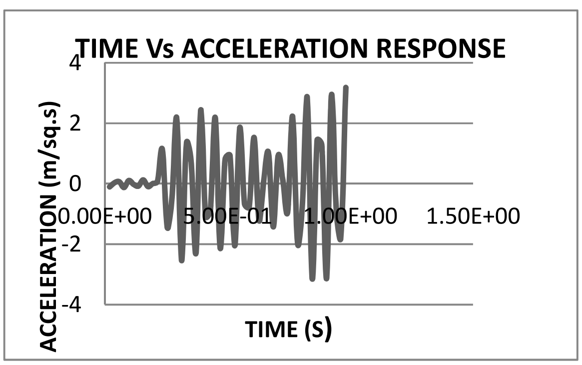

Figure-10. Time Vs Acceleration for ten persons at sensor point.

Comparison of actual and threshold acceleration values

Table-13. Comparison of actual and threshold acceleration values.

Number of persons loading	**Peak Acceleration** (m/sq.s) **at observer point**	**Threshold Limits** (a_{lim})
2	1.3	0.5% g as per IS800-2007
4	2.1	
6	2.25	
8	2.4	
10	3.1	

Comparison of harmonic and transient displacement values

Table-14. Comparison of harmonic and transient displacement values.

No. of persons	**Max. Displacement** (mm)	
	Harmonic analysis	**Transient analysis**
2	9.60E-25	8.40E-05
4	1.55E-24	1.08E-04
6	1.54E-24	1.15E-04
8	2.18E-24	1.30E-04
10	1.62E-24	1.73E-04

SPSS Results

Components extracted

Using the values from the Table-15, the following MRPI equation is obtained, $MRPI_{i,j} = 0.883\ Z_{i1} - 0.883\ Z_{i2}$.

CONCLUSIONS

The fashion towards light weight structural systems has resulted decreased stiffness and low frequencies. The flooring system supporting human rhythmic jumping activity is increasing the vulnerable of floor to varying deflections.

As per IS 800-2007, In the annoyance range of 2 to 8Hz in which people are most sensitive to vibration, the threshold level corresponds approximately to 0.5 percent g, where g is the acceleration due to gravity. Continuous vibration is generally more annoying then decaying vibration due to damping. Floor systems with the natural frequency less than 8 Hz in the case of floors supporting rhythmic activity and 5 Hz in the case of floors supporting normal human activity should be avoided. Since, this structural model system has more flexibility and less frequency (2.67 Hz).

Hence from the modal analysis, this is suggested that, suitable stiffening or enhanced damping shall be

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available for the structural model for these kinds of human rhythmic activities.

The peak accelerations are compared with human activity at measurement point in the floor system is 3.1m/sq.s from the result of transient analysis.

There is not substantial increase to cumulative loading of number persons simultaneously jumping on the floor as compared as couple of person's jumping. There is a nonlinear relationship between peak acceleration and human induced rhythmic activity.

Hence from the transient analysis, this is concluded that, even for two persons response acceleration (1.3m/sq.s) is more than the IS Code recommendations 0.5%g, that is 0.005 m/sq.s.

REFERENCES

Allen D.E *et al*. 1985. Vibration criteria for assembly occupancies. Canadian Journal of Civil Engineering. 12: 617-623.

Allen D.E. 1990. Building vibration from human activities. ACI concrete International -Design and Construction.

Bachmann H and Ammann W. 1987. Vibrations in structures induced by man and machines. Structural Engineering Document 3e, International Association for Bridges and Structural Engineering.

BBC news dated on 10.6.2000. http://news.bbc.co.uk/on this day/hi/dates/stories/june/10/newssid 2510000/2510839.stm.

Da Silva, J.G.S. *et al.* 2006. Dynamical response of composite steel deck floors. Latin American Journal of Solids and Structures. p. 3.

Da Silva, J.G.S. *et al.* 2008. Vibration Analysis of orthotropic composite floors for human rhythmic activities. Journal of Brazilian Society of Mechanical Sciences and Engineering. pp. 56-65.

Da Silva, J.G.S. *et al.* 2011. Vibration Analysis of long span joist floors submitted to Human Rhythmic Activities. State University of Ride janeiro, ISBN 978-953-307-209-8, pp. 231-244.

Da Silva, J.G.S. *et al.* 2015. Influence of the Human Rhythmic Activities Modelling on the Composite Floors Dynamic Response. Journal of Civil Engineering and Architecture Research. 2(1, 2015): 429-437.

Faisca R.G. Caracterizaçãodecargasdinâmicasgeradasporatividadeshumanas (Characterization of Dynamic Loads due to Human Activities), PhD Thesis (in Portuguese), COPPE/UFRJ, Rio de Janeiro, RJ, Brazil. pp. 1-240, 2003.

Gajalakhsmi G *et al.* 2013. Proceeding of the International Conference on Future Trends in Structural, Civil, Environmental and Mechanical Engineering- FTSCEM.

Gajalakhsmi G *et al*. 2015. Analysis of Harmonic Behaviour of Human Rhythmic Activity in A RCC Roof Slab. International Journal of Innovative Science, Engineering and Technology. 2(5).

IS 800: 2007, Indian standard general construction in steel - code of practice- third revision?

ISO 2631-2: 2003. Mechanical vibration and shock-Evaluation of human exposure to whole-body vibration-Part 2: Vibration in buildings (1 Hz to 80 Hz).

Murray T.M *et al*. 2003. Floor vibrations due to human activity. Steel design guide series by American institute of steel Construction.