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Dynamic response of bare steel concrete under human rhythmic activities

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Abstract - **Buildings built with light weight, longer span and high slenderness may possess adequate strength and stiffness for static loads. However, increase in slenderness may create problems associated with vibration under serviceability. The structures with human rhythmic activities are sensitive to dynamic excitation. The main aim of this paper is to predict and analyze the behavior of human rhythmic activities in Steel and Composite floors (Bare steel concrete). A typical floor plan of size 16mx12m which consists of an indoor recreation centre with an arena is considered for this study. ANSYS (ANSYS 11), a computational model is used for this study. Usual mesh refinement technique is adopted to study the transient dynamic performance. The results indicate that the peak acceleration values when compared with limits proposed by design code IS 800 2007 and ISO-2631(PART-II) are not satisfied. It is suggested that suitable stiffening or enhanced damping can be provided to counteract the rhythmic activities.**

Keywords - **Floor vibrations, human rhythmic activities, ANSYS, Peak Accelerations.**

I. Introduction

Lightweight, high-strength materials are used to construct flexible, long-span floors. These floors sometimes result in annoying levels of vibration even under ordinary loading situations. These vibrations do not possess any threat to the structural integrity of the floor, but they may render the floor unusable by the human occupants of the building in extreme cases.

The wide variety of scales and prediction techniques is an indication of the complex nature of floor vibrations. The increasing incidence of building vibration due to human rhythmic activities led to a specific design criterion for rhythmic excitations (Allen et al. 1985,Bachmann and Ammann, 1987,Faisca, 2003,Murray et al., 2003, Silva et al., 2008). Floor vibrations often leads 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 and Sample, 2002).This is the motivation for the development of a design methodology on the structural system subjected to dynamic loads due to human activities. But, it is very difficult to interpret the magnitude of the motion, the environment surrounding sensor and the human sensor in accounting the floor vibrations (Murray et al, 2003). In spite of its complexity, this paper emphasizes the human responses to floor vibration. The main objective of the paper is to study and compare the relationship between the maximum peak response acceleration and maximum displacement versus number of persons inducing dynamic excitation.

II. Structural Element Details

According to Hamdan et al ,2011, there are two types of floors in building namely, suspended floors and Ground floors. In this paper, suspended floors are considered due to the annoyance of vertical vibration. Floors are made of steel, timber, concrete and composite materials. Composite type is the most frequently used type of floor structure in modern commercial and residential building construction. For this reason, composite floors of long span (16m x 12m) which is used as an aerobic floor with adjacent stair openings are taken into analysis. The compression strength and Young's Modulus of concrete slab are 25N/mm^2 and 2.4x10^4 N/mm^2 respectively. The layout of the floor plan is shown in figure 1.The geometric properties of the structural model and the physical properties of members are illustrated in table 1 and 2 respectively.

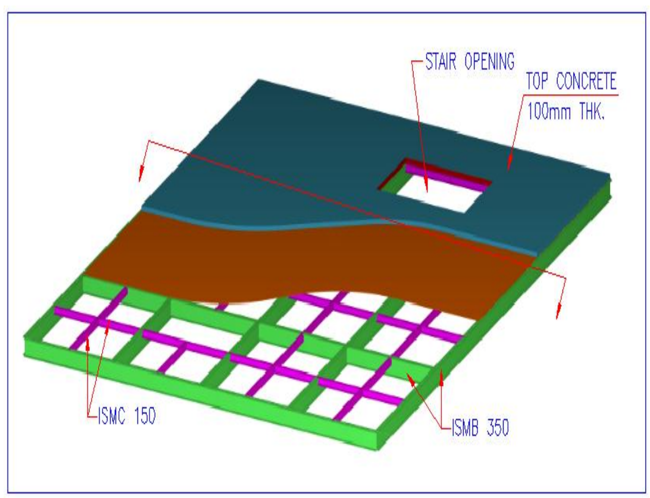

Figure 1. Structural model three-dimensional plan view

TABLE 1. STRUCTURAL MODEL GEOMETRIC PROPERTIES

FLOOR PLAN DIMENSION	MAIN MEMBER	SECONDARY MEMBER	CONCRETE TOPPING THK.
16m x 12m	ISMB 350	ISMC 150	100mm

TABLE 2. PROPERTIES OF MEMBERS (STEEL TABLE)

DESCRIPTION	ISMB350	ISMC 150
WEIGHT	514.5 N	160.9 N
DEPTH	350mm	150mm
AREA	6671 mm^2	2085 mm^2
IXX	$13630.3x10^4$ mm^4	$779.1x10^4$ mm^4
IYY	$537.7x10^4$ mm^2	$102.3x10^4$ mm^2
WEB THICKNESS	8.1 mm	5.4 mm
FLANGE THICKNESS	14.2 mm	9.00mm

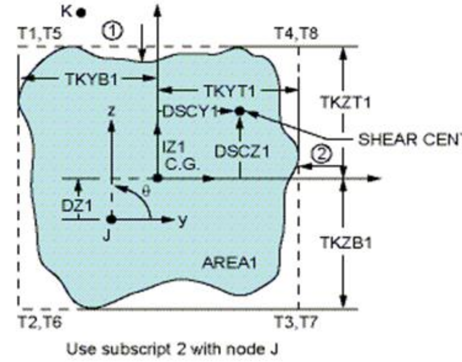

Figure 2. 3D elastic tapered unsymmetric beam

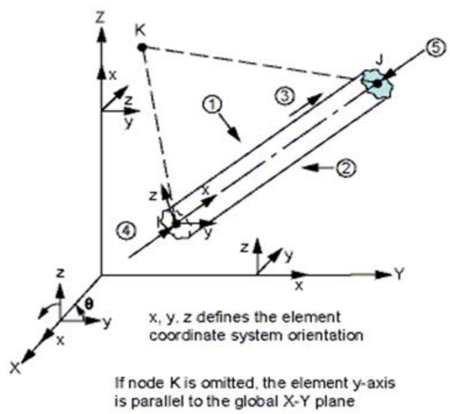

Figure 3. Beam 44 input summary

III.Materials and Methods

A. Finite element model using ANSYS

The proposed computational model, developed for the Bare steel with concrete floor dynamic analysis, adopted the usual mesh refinement techniques present in FEM simulations implemented in the ANSYS program (ANSYS 11). In the present computational model, floor joists are represented by BEAM44 which 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. The composite slab is characterized by SHELL63 which has both bending and membrane capabilities. Stress stiffening and large deflection capabilities are included. A consistent tangent stiffness matrix option is available for use in large deflection. In this analysis, it is considered that the composite materials gives the total interaction and behaves in an elastic manner

AREA1 - Cross-sectional area at end 1 (node I)

IZ1, IY1 - Moments of inertia at end 1 about the Z and Y axes

TKZB1, TKYB1 - Bottom thickness at end 1 in the Z and Y directions

IX1 - Torsional moment of inertia at end 1

AREA2 - Cross-sectional area at end 2 (node J)

IZ2, IY2 - Moments of inertia at end 2 about the Z and Y axes

TKZB2, TKYB2 - Bottom thickness at end 2 in the Z and Y directions

IX2 - Torsional moment of inertia at end 2

TKZT1, TKYT1 - Top thickness at end 1 (node I) in the Z and Y directions

TKZT2, TKYT2 - Top thickness at end 2 (node J) in the Z and Y directions

ARESZ1, ARESY1- Shear areas at end 1 (node I) in the Z and Y directions

ARESZ2, ARESY2- Shear areas at end 2 (node J) in the Z and Y directions

DSCZ1, DSCY1 - Shear center offset at end 1 (node I) in the Z and Y directions

DSCZ2, DSCY2 - Shear center offset at end 2 (node J) in the Z and Y directions

SHELL63 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.

TK(I)	- Shell thickness at node I
TK(J)	- Shell thickness at node J
TK(K)	- Shell thickness at node K
TK(L)	- Shell thickness at node L
EFS	- Elastic foundation stiffness
THETA	- Element X-axis rotation
RMI	- Bending moment of inertia ratio
CTOP	- Distance from mid surface to top
CBOT	- Distance from mid surface to bottom

IV. Loads generated by human activities

The loads generated by human activities are not a simple job. Many investigations have been made aiming to launch parameters to describe human activity loads.

Faisca considered the dynamic loads, based on results achieved through a long series of experimental tests made with individuals carrying out rhythmic and non rhythmic activities.(qtd.in Silva, 2011 (234))

The dynamic loads generated by human activities were expressed as Jumps with and without stimulation, aerobics, rock concert audiences and dancing.

Faisca considered the dynamic loads, based on results achieved through a long series of experimental tests made with individuals carrying out rhythmic and non-rhythmic activities. These dynamic loads, generated by human activities, are described such as jumps with and without stimulation, aerobics, soccer, rock concert audiences and dancing. The load modeling is able to simulate human activities like aerobic gymnastics, dancing and free jumps. In this paper, the Hanning function is used to represent the human dynamic actions since it is verified that this mathematical representation is very similar to the signal force obtained through experimental tests (qtd .in Silva2011 (234))

Equation (1) describes the mathematical representation of the human dynamic loading. This expression requires some parameters like the activity period T, contact period with the structure Tc, period without contact with the model Ts, impact coefficient Kp, and phase coefficient CD.

$$F(t) = CD\left\{K_p P\left[0.5 - 0.5\cos\left(\frac{2\pi}{T_c}t\right)\right]\right\}, \text{for } t \le T_c \quad (1)$$

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

Where:

F (t)	- dynamic loading, in (N);
t	- time, in (s);
T	- activity period (s);
Tc	- activity contact period (s);
P	- weight of the individual (N);
Kp	- impact coefficient;
CD	- phase coefficient. .(qtd.in Silva2011 (234))

V. Analysis of floor model

The live load considered in this analysis corresponds to one individual for each 4.0m^2 (0.25person/m^2). The load distribution is considered symmetrically centered 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).

The human-induced dynamic action is applied to the dancing area. The composite floor dynamical response, are obtained on the nodes A, B and C, 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, 8, 10, and 18 individuals practicing aerobics. Hence, 18 individual practicing is the full load condition for the numerical model.

The modal analysis and Time domain analysis are carried out and the results are discussed below.

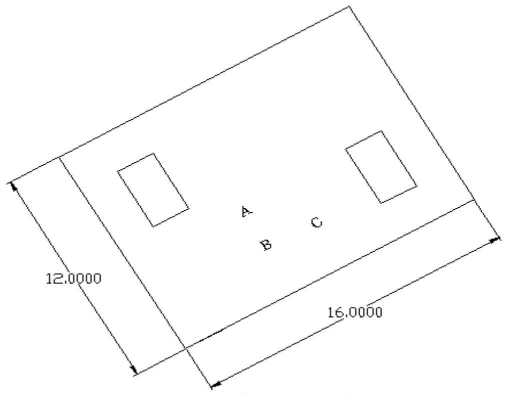

Figure 4. Layout of the typical floor plan

A. Modal Analysis

The Bare steel with concrete floor natural frequencies is determined with the aid of the numerical simulations. The structural system vibration mode shapes and the natural frequency values are tabulated. in Table 3.

TABLE 3. MODE SHAPES AND NATURAL FREQUENCIES

Mode shapes	1	2	3	4	5	6
Natural frequencies (Hz)	5.456	9.806	12.524	15.52	17.871	22.338

The natural frequencies values range from 5.456 to 22.338 corresponding to the mode shape one and mode shape six.

B. Time Domain Analysis

The linear time-domain analysis is performed throughout this study. The evaluation of the vibration levels when subjected to dynamic excitations from human rhythmic activities (aerobics and dancing).The FE model of the steel with concrete floor is subjected to transient dynamic loading for a period of 5.3 second (10 cycles).

The Bare steel with concrete floor dynamic response are determined in terms of its displacements, velocity and accelerations with respect to time. The results of the dynamic analysis are obtained from an extensive numerical analysis, based on the finite element method using the ANSYS program (ANSYS 11). The results are tabulated and compared with design recommendations.

VI. RESULTS AND DISCUSSIONS

The composite floor is analyzed by considering the impacts measured at points A,B and C such that one, Two, Four, Eight, Ten and Eighteen persons' load are acting on the structural model. From this, the graphs are plotted for vertical displacement and acceleration versus time.

A. RESULTS FOR EIGHTEEN PERSONS LOADING

The maximum Displacement and acceleration are obtained for eighteen persons' loading measured at Points A, B and C.

Eighteen persons' loading at Measuring point A:

The maximum displacement and acceleration are 4.09 mm and 3.59 m/s^2 respectively.

Eighteen persons' loading at Measuring point B:

The maximum displacement and acceleration are 3.63 mm and 3.2 m/s^2.

Eighteen persons' loading at Measuring point C:

The maximum displacement and acceleration are 2.62 mm and 2.31 m/s^2.

The Figures 5,6,7,8,9,10 show that the vertical Displacement and acceleration, at point A,B and C of the numerical model, on the observation there is a gradual increase with time until the beginning of the Steady state response of the Bare steel with concrete floor, this is occurred at the time approximately.

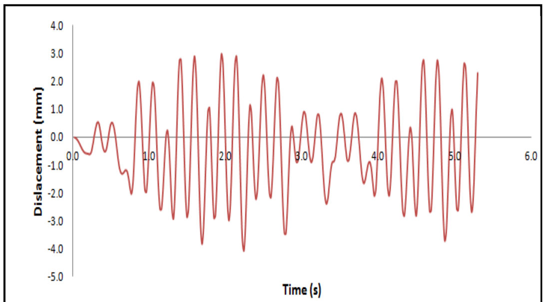

Figure 5. Time Vs Displacement response at point A

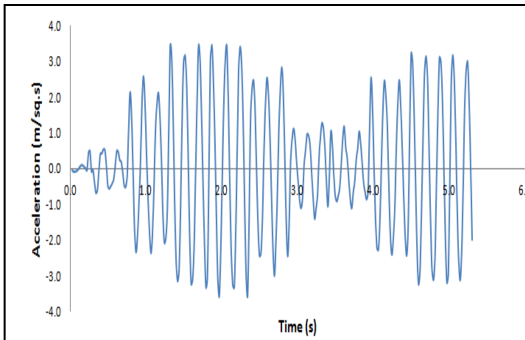

Figure 6. Time Vs acceleration response at point A

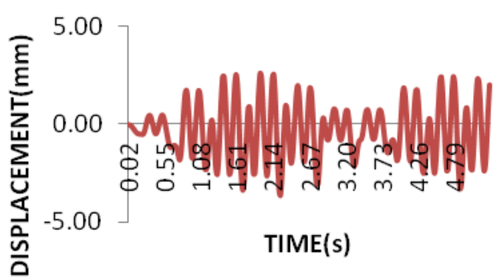

Figure 7. Time Vs Displacement response at point B

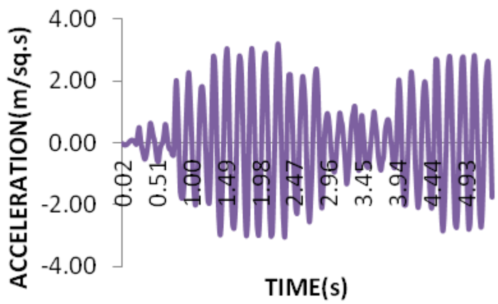

Figure 8. Time Vs acceleration response at point B

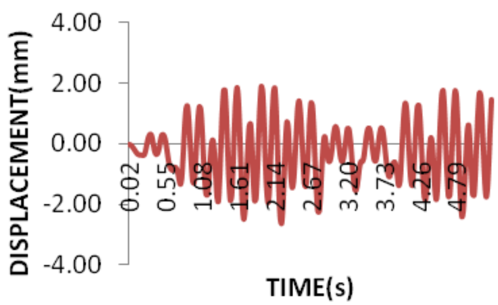

Figure 9. Time Vs Displacement response at point C

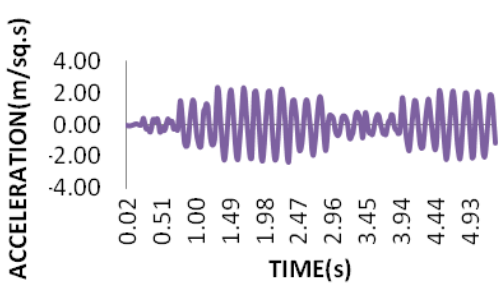

Figure 10. Time Vs acceleration response at point C

TABLE 4. TRANSIENT ANALYSIS MAXIMUM DISPLACEMENT

Number of Persons	**Maximum Displacement(mm)**		
	Point A	*Point B*	*Point C*
1	0.39	0.284	0.214
2	0.682	0.585	0.434
4	1.35	1.15	0.856
8	2.31	2.03	1.47
10	3.26	2.88	2.08
18	4.09	3.63	2.62

TABLE 5.TRANSIENT ANALYSIS PEAK ACCERELATION

No of Persons	**Maximum acceleration**			**Peak Acceleration**	**Thres hold Limit**
	Point A	*Point B*	*Point C*		
1	0.31	0.395	0.255	0.395	0.5%g as per IS 800-2007/ 5% g as per ISO2631 (PART II)
2	0.639	0.655	0.531	0.655	
4	1.28	1.05	1.00	1.28	
8	2.02	1.76	1.65	2.02	
10	3.01	2.62	2.28	3.01	
18	3.59	3.20	2.31	3.59	

CONCLUSIONS

The trend towards light flooring system with composite structural action has resulted in decreased stiffness and low frequencies of flooring system. Flooring system supporting aerobic activities with rhythmic jumping are increasing the vulnerability of such flexible floors to large deflection levels. The present code of practice in steel (IS 800-2007) limits the maximum acceleration levels to a value of 0.5% g = 0.05m/sec^2 which is a very stringent vibration criteria.

Towards, studying the actual vibration levels of rhythmic human jumping acting on an aerobics floor, a typical floor plan of 16 m x12 m is taken as modular floor plan and analyzed for dynamic action of human induced load. After performing the normal design procedure using the dead load and live loads on the floor, the suitable section details are arrived at and used in the dynamic analysis.

The force-time relationship of activity of jumping and rhythmic movements is complicated and difficult to measure, but have been successfully approximated by suitable for time function by various researches.

Modal Analysis involves only extraction of dynamic characteristics of the floor system, which is used as input in the harmonic and transient dynamic analysis. The first natural frequency of the floor system is computed as 5.438 (Hz) which is within the critical range of frequencies suggested by IS 800-2007. Since, such a system is having high flexibility and low frequency is found to be more vulnerable. The analysis is continued with the input. The transient analysis involves modeling the force-time history as exact and suggested by Faisca.

For the purpose of loading number of persons participating in the jumping is sequentially increased from 2, 4, 8, 10 and 18. A spacing of 1.5m between each person is assumed in the analysis. Following significant conclusions are drawn from this study;

- The maximum vertical response acceleration at critical measurement points in the floor system are found to be 0.395m/s^2 and for 2, 4, 8, 10 and 18 persons respectively from the results of transient dynamic analysis. This shows that, there is not a substantial increase due to cumulative loading of number of persons simultaneously jumping on the floor as compared to single person or a couple jumping. There is a non-linear relationship found from the study between the maximum peak response acceleration versus number of persons inducing dynamic excitation
- However it is concluded and cautioned that even for the two persons generally the rhythmic activity response acceleration is for higher than what is permitted in IS 800-2007 as the governing maximum acceleration. Hence, it is suggested that suitable stiffening or enhanced damping shall be available for floor system meant for these kinds of rhythmic activities.

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