A study of Floor Vibration in commercial floors by Footfall Analysis

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Abstract-*Footfall analysis (or in full footfall induced vibration analysis) is a dynamic response analysis to evaluate the vertical responses of a building subjected to the action of human footfall loads. The responses from footfall analysis include nodal accelerations, nodal velocities and response factors etc.*

The human footfalls are considered as periodical dynamic loads that are decomposed into a number of harmonic components according to Fourier series theory. For each of the harmonic components of the footfall loads, a harmonic analysis is conducted using modal superposition method based on the results of modal dynamic analysis. Adding the responses obtained for each of the harmonic components of the footfall loads, the total responses of the form for the footfall loads can be obtained. For detailed description and theory of the footfall analysis, please refer to Footfall Analysis Theory section of GSA manual.

I. INTRODUCTION

For many years now, serviceability requirements have been a part of structural design. Initially, these were just deflection limits to prevent finishes from cracking and building occupants noticing the floors sagging. These proved adequate for decades, until advances began to be made into more efficient, lighter structures, such as composite beam or post-tensioned slab floors. The possibility of human footfall loading leading to excessive vibration of structures has long been recognized. Floor vibration problems are not restricted to steel/composite floors. Disturbing walking-induced vibrations have been observed more frequently in recent times on long span lightweight floor systems as evidenced by the development of a number of new design guidelines for floor vibration assessment. Consequently, the probability distribution of the floor response is determined with good agreement between the predicted and measured floor responses. However, response levels can be translated inconsistently in terms of human comfort by various acceptance criteria. Human footfalls are the main source of vibration in office building, commercial building and workshop it could affect the structure of the building as well as causing discomfort and annoyance to the occupants of the building when the vibration level inside the building exceeds the recommended level. Vibration in building could reach a level that may not be acceptable to the building occupants and may have an effect such as annoying physical sensations, interference with activities such as work, annoying noise caused by rattling of window panes, walls and loose objects and also interference with proper operation of sensitive instruments. The spatial location of shopping centre affects in a relatively significant way the organization of urban space and the behaviors of city inhabitants and visitors.

Commercial - on lively floors, computer users complain because their screens wobble, making it difficult to work.
Bridges – need to comply with BS5400

Laboratories - equipment, such as optical and electron microscopes and laser research systems, are very sensitive to vibrations. Such floors must comply with the BBN or ASHRAE standards.

Hospitals - operating theatres require the utmost stability for delicate operations, while night wards are nearly as onerous.
Airports - Airport owners require maximum response values for the waiting areas as floor vibrations can upset seated travelers in heavily trafficked areas.

Retail - many major retailers require a maximum liveliness for their display floors, such as where they are displaying glasses on glass shelves: if the floor is too lively then the glasses will rattle.

Two problems emerged with this solution however. The first was that floors are excited by the harmonics of the pedestrian's footstep frequency; the second was that while short spans had high natural frequencies, they had a low mass in ratio to the weight of a person, in comparison to long span floors that may have a low frequency but also a large floor area, making them more difficult to excite. What the industry needed was a solution for all materials and for all framing layouts.

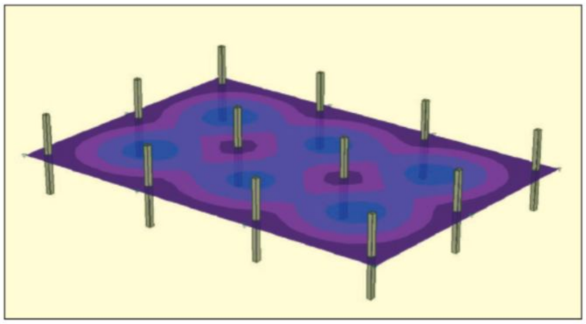

Fig: 1.1 Footfall Pattern Of Flat Slab

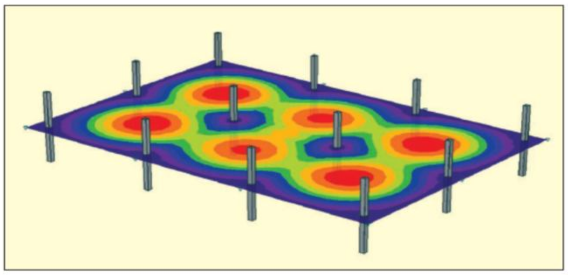

Fig: 1.2 Footfall Pattern Of Pt Slab

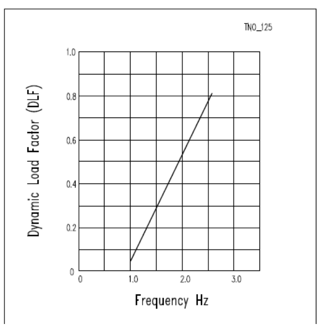

Fig: 1.3 Dynamic Load Factor For Walking Force

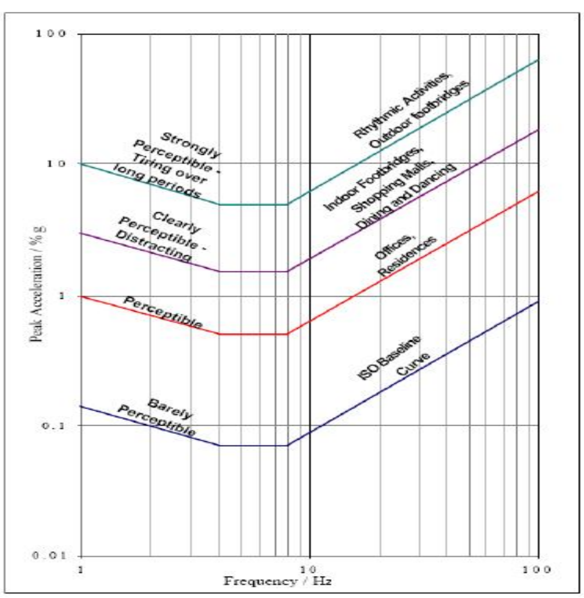

Fig: 1.4 Generate Indication Of Human Perception To Structural Acceleration

II. FOOTFALL FORCES

2.1 Single Step: Figure is an idealized representation of how the force that acts on a floor due to person's step varies with time. The dwell duration D, the rise time τ/2 (and the drop time, which is equal to the rise time), and the ratio of the plateau force Fm to the weight W of the walking person vary with the walking speed. Table 2, based on curves fit to available data [Galbraith and Barton, 1970; Mouring, 1992; Ebrahimpour, et al, 1996] and taken from [Ungar, Zapfe, and Kemp 2004] presents values of these parameters for three representative walking speeds.

Table No: 2.1 Footfall Rate

Frequency (Hz)	Designation
1.5–1.8	"Normal walking" for cellular areas
1.8–2.0	"Someone who is in hurry"
2.0–2.4	"A very brisk pace" considered likely in corridors

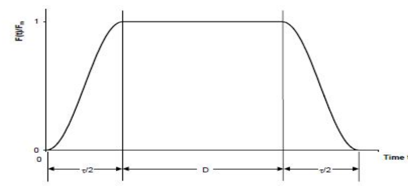

Fig: 2.1 Single Footstep Forcing Time History

2.2 Continuous Walking: Typical walking consists of a sequence of steps, with the force pulse from one step beginning before that from the previous step ends, as shown in idealized form in Figure. The total duration of a pulse, Tp=D+t/2, is greater than the step repetition period T=1/f.

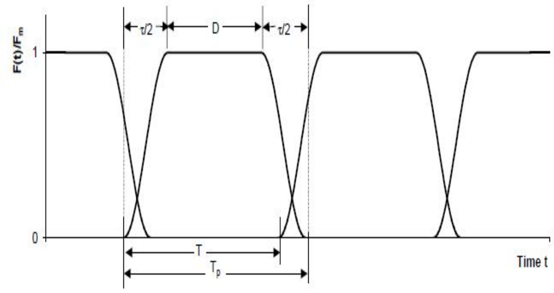

Fig: 2.2 Multiple Footstep Forcing Time History

III. OBJECTIVES

- To determine mode shapes and time period for different footfall rate and mechanical vibration for flat plate
- Comparison of flat plate with and without cut section period for different footfall rate and mechanical vibration
- To find out transient stresses and strains for different frequencies for footfall frequency range (1.5–1.8, 1.8–2.0, 2.0–2.4).

- To validate results of natural frequency and time period for flat plate with 4 drop panels using Eigen value Eigen vector.

IV. METHODOLOGY

The finite element method (FEM) is the most popular simulation method to predict the physical behavior of systems and structures. Since analytical solutions are in general not available for most daily problems in engineering sciences numerical methods like FEM have been evolved to find a solution for the governing equations of the individual problem. Much research work has been done in the field of numerical modeling during the last thirty years which enables engineers today to perform simulations close to reality. Nonlinear phenomena in structural mechanics such as nonlinear material behavior, large deformations or contact problems have become standard modeling tasks. Because of a rapid development in the hardware sector resulting in more and more powerful processors together with decreasing costs of memory it is nowadays possible to perform simulations even for models with millions of degrees of freedom. In a mathematical sense the finite element solution always just gives one an approximate numerical solution of the considered problem. Sometimes it is not always an easy task for an engineer to decide whether the obtained solution is a good or a bad one. If experimental or analytical results are available it is easily possible to verify any finite element result. However, to predict any structural behavior in a reliable way without experiments every user of a finite element package should have a certain background about the finite element method in general. In addition, he should have fundamental knowledge about the applied software to be able to judge the appropriateness of the chosen elements and algorithms. This paper is intended to show a summary of ANSYS capabilities to obtain results of finite element analyses as accurate as possible. Many features of ANSYS are shown and where it is possible we show what is already implemented in ANSYS Workbench.

4.1Material Modeling: The definition of the proposed numerical model was made by using finite elements available in the ANSYS code default library. SOLID186 is a higher order 3-D 20-node solid element that exhibits quadratic displacement behavior. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element supports plasticity, hyper elasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elasto-plastic materials, and fully incompressible hyper-elastic materials.

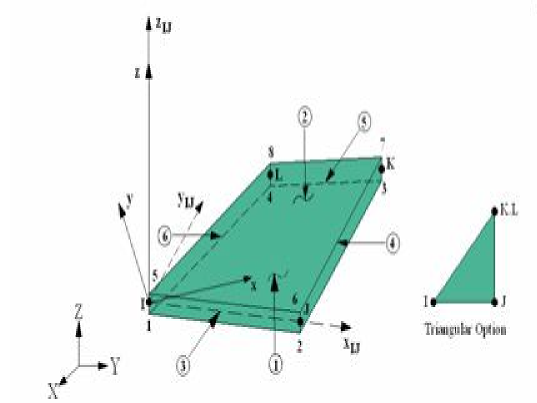

FIG: 4.1 SOLID 186

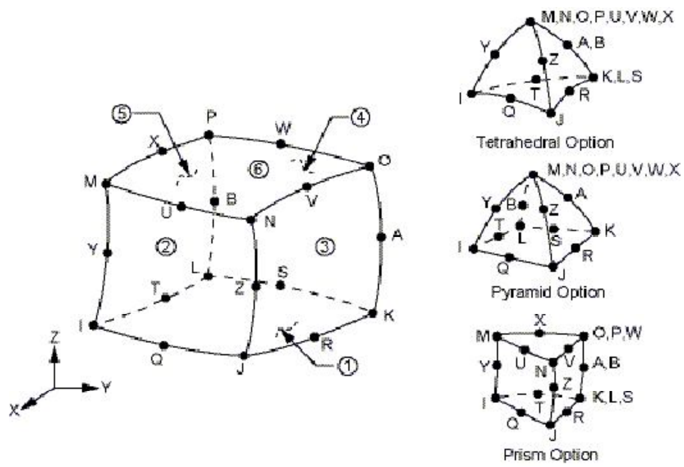

FIG: 4.2 3-D 20-NODE SOLID ELEMENTS

4.2 Finite elements mesh: The model designed for the numerical analysis was defined by four types of elements that form the concrete slab with added reinforcements, such as steel beam, shear connectors and the pair of contact at the slab-beam interface. The elements were established separately, but the nodes were one by one coupled on the interface between them as shown in fig. The finite element mesh developed for all elements followed the same methodology and degree of refinement presented in Figure shows the finite element mesh for the components cited, where (a) corresponds to the concrete slab.

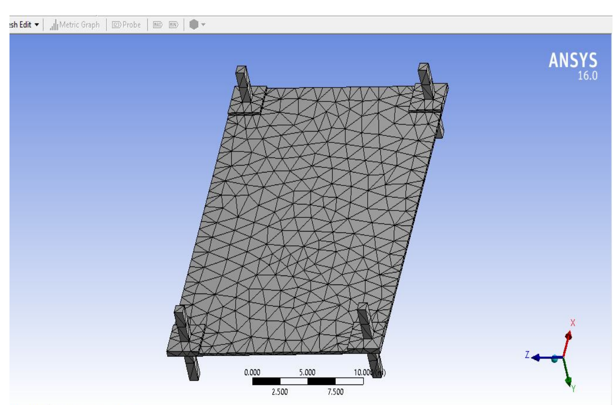

Fig: 4.3Finite Elements Mesh

V. PROBLEM STATEMENT

The typical floor system of 1200mm X 1000mm is adopted for vibration analysis of structures and following data is adopted.

Size: 1200mm x 1000mm, Thickness: 150mm, Grade of Concrete: M35, Drop Panel thickness: 150mm, Epoxy FRP: 50mm.

4.3 Acceleration Caused by Walking Person: Use the relationship (1) below to determine the peak acceleration ratio caused by the footfall on the floor (ap /g).

Formula to determine the peak ground acceleration as a result of footfall on a floor panel. The formula,

Gives the value as ratio of ground acceleration "g"

$$\left(\frac{a_p}{g}\right) = \frac{P_0 e^{-0.35 f_n}}{\beta W}$$

Where,

a_p = peak acceleration

g = gravitational acceleration [32.2 ft/sec$_2$; 9.81 m/sec$_2$]

P_o = constant force representing the walking force (from walking person)

β = modal damping ratio, recommended

W = effective weight of the panel and the superimposed dead load; and

f_n = first natural frequency (Hz).

With the natural frequency (Hz) from Step 1 and the peak acceleration ratio (ap/g) from Step 5 refer to the GSA chart to determine the acceptability of the vibration.

5.1 Following model is prepared:

Model 1: Vibrating model of flat plate without FRP laminate

Model 2: Vibrating model of flat plate with FRP laminate all edges constraint.

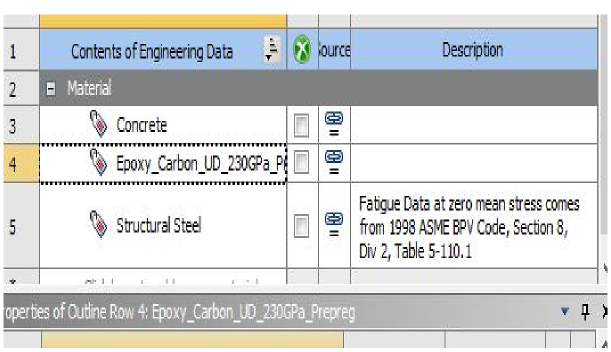

Fig: 5.1 Materials Modeling In Ansys

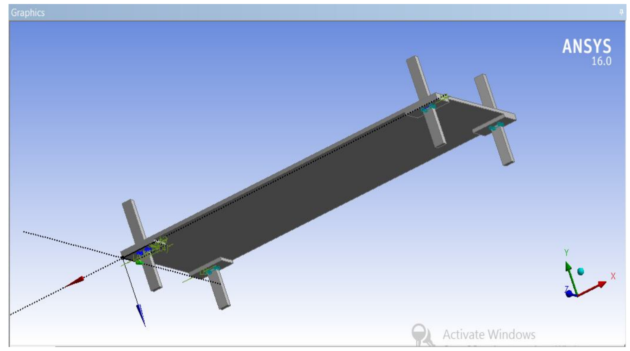

Fig: 5.2 Model On Ansys

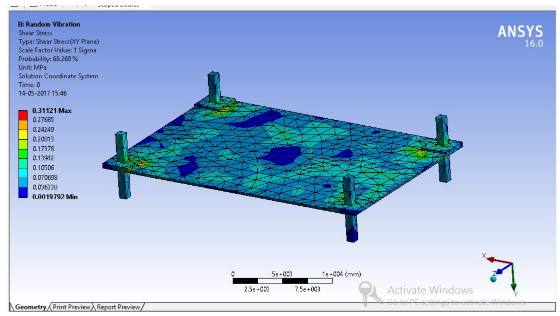

Fig: 5.3 Finite Element Vibration Mesh

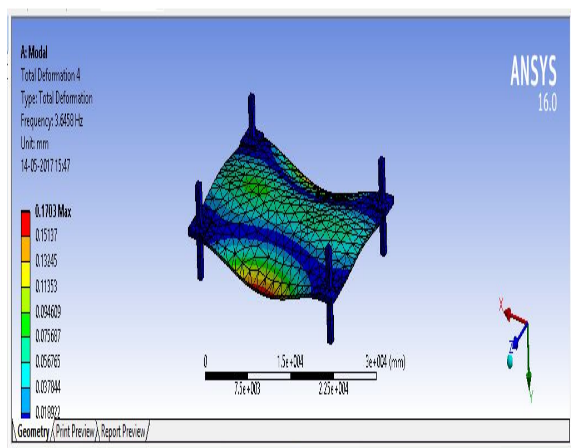

Fig: 5.4 Total Deformation Mode Shape (3.65hz)

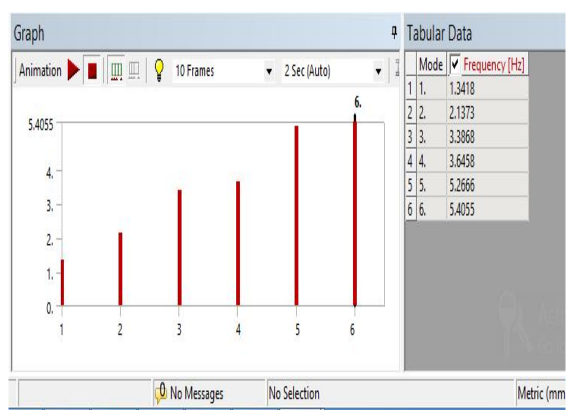

Fig: 5.5 Frequency Graph

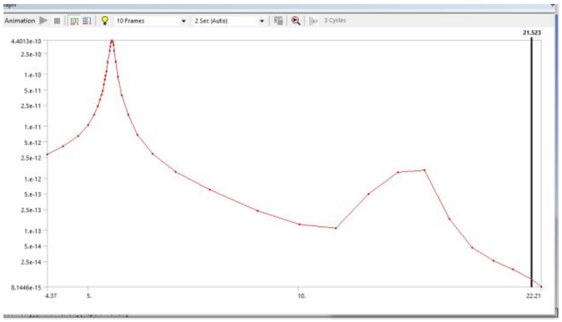

Fig: 5.6 Maximum Pick Hrs

VI. RESULTS & DISCUSSION

6.1 Multi person walking: The more critical situation may arise when multiple persons walk together with the same pacing rate. In normal practice, the effect of multi people walking can be taken care of by multiplying the single footfall force time history by an amplification factor. This factor can be calculated from Eqs.(2-4) by setting N equal to factor can be calculated from Eqs. _2_–_4_ by setting N equal to the number of people. For example, for a case of four persons walking, a factor of 3.8 is needed. Because of the linear analysis used, the method is equivalent to multiplying the response of a single person walking by the same factor the number of people. For example, for a case of four persons walking, a factor of 3.8 is needed. Because of the linear analysis used, the method is univalent to multiplying the response of a single person walking by the same factor.

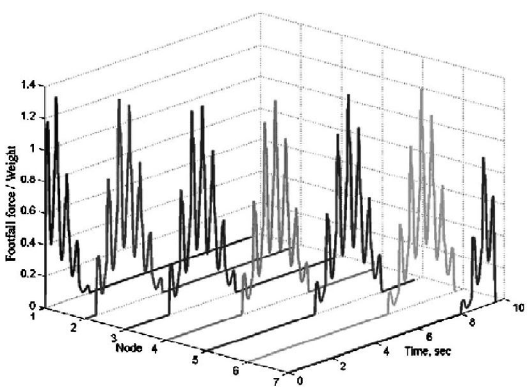

FIG: 6.1 Nodal Loading Time Histories For Continuous 2 Hz Walking

Ddt Frequency Reading Table: 6.1

Sr.No.	Frequency [Hz]	Response PSD [(m²)/Hz]
1	4.37	2.85E-12
2	4.6043	4.06E-12
3	4.838	6.50E-12
4	4.9941	1.05E-11
5	5.0954	1.64E-11
6	5.1598	2.40E-11
7	5.2003	3.22E-11
8	5.2256	4.00E-11
9	5.2412	4.68E-11
10	5.2666	6.29E-11
11	5.2822	7.73E-11
12	5.296	9.33E-11
13	5.3079	1.11E-10
14	5.3337	1.67E-10
15	5.3634	2.78E-10
16	5.3755	3.36E-10
17	5.3895	4.03E-10
18	5.4055	4.40E-10
19	5.4216	4.06E-10
20	5.4317	3.59E-10
21	5.448	2.76E-10
22	5.4744	1.72E-10
23	5.5174	8.71E-11
24	5.5872	3.87E-11
25	5.7004	1.62E-11
26	5.8844	6.81E-12
27	6.1831	2.94E-12
28	6.6681	1.34E-12
29	7.4557	5.93E-13
30	8.7345	2.36E-13
31	10.013	1.27E-13
32	11.292	1.09E-13
33	12.571	4.99E-13
34	13.85	1.30E-12
35	15.129	1.41E-12
36	16.408	1.63E-13
37	17.686	4.63E-14
38	18.965	2.60E-14
39	20.244	1.77E-14
40	21.523	1.15E-14
41	22.21	8.14E-15

A. Result of flat slab without epoxy laminate:

Table No: 6.2 Total Deformation Of Flat Slab

NO.	Mode shape	Deformation(mm)
Mode No.	1	0.15

Mode No.	6	0.196

VII. CONCLUSION

Following conclusions are obtained after modeling in ANSYS with footfall vibration inputs

- The deformation of flat slab was observed during for first mode shape was 0.15mm and 0.196 mm for mode shape 6.
- Peak response during footfall pattern was 4.06E-10 [(m^2)/Hz] for frequency 5.4216Hz, 3.65Hz.

FUTURE SCOPE

- Various comparative studies should be carried out to reduce footfall vibration analysis. Limit state of vibrations needs to be upgraded in design codes.
- Officially shopping malls are defined as “one or more buildings forming a complex of shops representing merchandisers, with interconnected walkways enabling visitors to walk from unit to unit.”1 Unofficially, they are the heart and soul of communities, the foundation of retail economies, and a social sanctuary for teenagers everywhere.

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