Finite Element Analysis of Footfall Function for Vibration Analysis of Floor System Using Ansys Workbench

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Abstract— Human footfalls are the main source of vibration in office building and 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. The objectives of the study are to determine the level of vibration on each floor of a multi-storey building due to footfalls and to perform structural response on the multi-storey building due to footfalls input. The scope of study is focused on the effect of vibration induced by footfalls on multi-storey building and analyzing the data using ANSYSv16.

Key words: Floor Vibration, Criteria, Modelling, Footfall, Force, High, Frequency, FE, Walking

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 and 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 centers affects in a relatively significant way the organization of urban space and the behaviors of city inhabitants and visitors.

The theoretical background and historical development of spatial interaction modelling is comprehensively discussed in the research literature, for example by Sheppard (1978), Senior (1979), Haynes, Fotheringham (1984), Fotheringham, O'Kelly (1989), Pooler (1994), Fotheringham, Brunsdon, Charlton (2000), and Wilson (2010), but we provide a basic insight into spatial interaction modelling approaches. In our argumentation, we aim only at cornerstone references specific for the issue (modelling of retail). A useful possibility to tackle the problems of acquiring the necessary data is to resort to spatial interaction modelling, that is able not only to represent with a greater or lesser accuracy the actual flows, but also able to anticipate the future development of intra-urban retail movements. Models of spatial interactions were further developed by Reilly (1931), who defined the law of retail gravitation.

Spatial interaction models generally show that the volume of spatial interaction increases with scale (i.e. either quantitative or qualitative "importance" "size", or "mass") of locations, and decreases with the distance separating them. To put it another way, the interaction (*Tij*) between two location *i* and *j* is a function of the measure v of propulsiveness of *i*, the measure *w* of attractiveness of *j*, and the measure *d* of distance between *i* and *j*:

$$Tij = f(\mu vi; \mathrm{a}wj; \mathrm{b}dij)$$

where μ, α, βare parameters reflecting the relation of variables *v*, *w* and *d* to the interaction patterns. The greatest importance is granted to the variable and parameter responsible for the formulation of the friction of distance and its expression in the models. The spatial separation between two spatial locations is expressed in the form of distance decay curves that have various forms and usually a non-linear shape (e.g. Taylor, 1971, 1983; Johnston, 1973; Wilson, 1974, or Sheppard, 1978). Negative Pareto and negative exponential functions with various values of parameters have been applied most frequently to express the spatial separation between two locations. The role of distance and the distance decay function is discussed for instance by Taylor (1971), Cliff et al. (1974), Wilson (1974), Fotheringham (1981), and De Vries et al. (2009).

Serviceability limit states are mainly related to vibrations and hence are governed by stiffness, masses, damping and the excitation mechanisms.

The excitation level at which vibrations cause problems is highly dependent on the sensitivity of the person exposed to the vibrations and to their circumstances when the vibration occurs.

Thus there is no clear distinction between acceptable and unacceptable levels of vibration since personal sensitivities and highly variable external environmental factors combine to produce, at best, a fuzzy boundary of 'acceptable' response.

In an attempt to rationalize these external factors, and to provide quantitative guidelines for design, BS-6472:1984 'Guide to Evaluation of Human Exposure to Vibration in Buildings' (BSI 1984) contains acceleration levels of 'equal annoyance' (the 'base curve'). Two such curves are published within that Standard, the first for acceleration in the foot-to-head direction and the second for the front-to-back direction.

In both cases the acceptance level varies with the frequency of vibration. In design, amplification factors are applied to these base curves to establish the nominally acceptable levels of acceleration below which vibration problems should be avoided.

These amplification factors consider various environmental factors which influence acceptable response levels including the following:
Surrounding environment tranquil or active surroundings (e.g. home, office or gymnasium).

Frequency of vibration higher frequency accelerations (<40 Hz) are noticed less Duration of vibration short duration vibrations with higher accelerations are more tolerable Expectation events which are forewarned are more acceptable (conversely the responder may become more aware of the event having had forewarning). Timing of vibration motion at night is more annoying than the same motion during the day. ISO 10137 (ISO 1992) brings together the combination of much of this work. Included in Annex C of this Standard are the amplification factors associated with the above environmental considerations, and these are reproduced in Table 7. The wide range of multipliers used indicate the diversity of acceptable vibration responses for the various occupancies. These multipliers are applied to a base acceleration curve also published in ISO 10137.

Vibration in buildings is a common problem and concern especially in big cities because of the daily activities such as road traffic, construction work and even from internal vibration, such as from machinery and human itself.

Modern floor systems can be more vibration-vulnerable due to trends in design and construction leading to longer spans, lighter weight and lower damping. Floor vibration design guidelines usually incorporate human comfort criteria and methodologies to determine the floor response to be checked against these criteria. Therefore, footfall analysis of multi-storey building floor is necessary.

A. Objectives

- To determine mode shapes and time period for different footfall rate.
- To find out remedial measures to reduce vibrations due to footfall for flat slab.
- To compare Flat slab, Composite flat slab for deformation, normal stress, normal strain, shear stress and shear strain for frequency (1.5–1.8, 1.8–2.0, 2.0–2.4) using ANSYS.

II. METHODOLOGY

A. Introduction

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.14 Workbench.

B. Material 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, hyperelasticity, 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. The geometrical representation of is show in SOLID186.

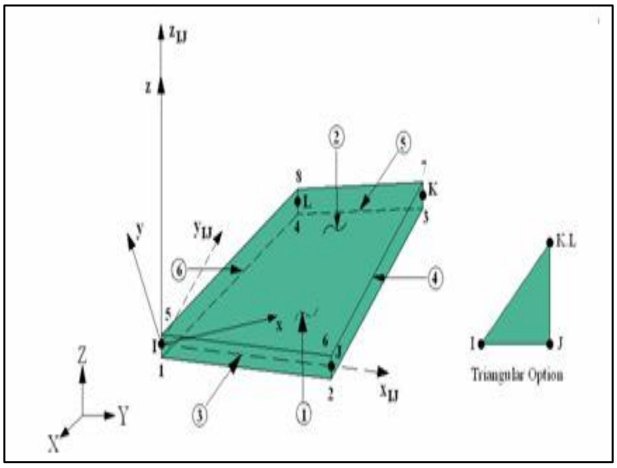


Fig. 1: Shell 43

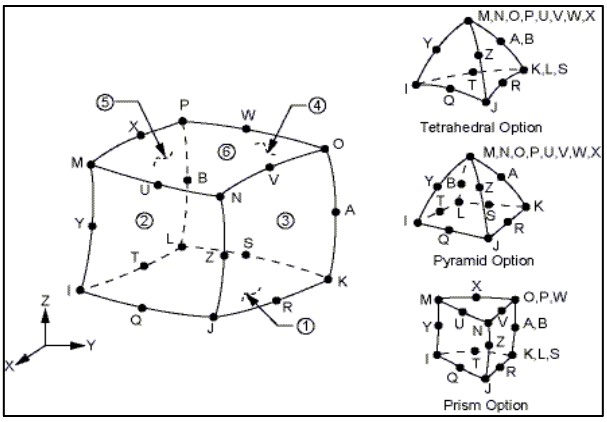


Fig. 2: Solid 186

C. 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.3. The finite element mesh developed for all elements followed the same methodology and degree of refinement presented in Figure3 shows the finite element mesh for the components cited, where (a) corresponds to the concrete slab,

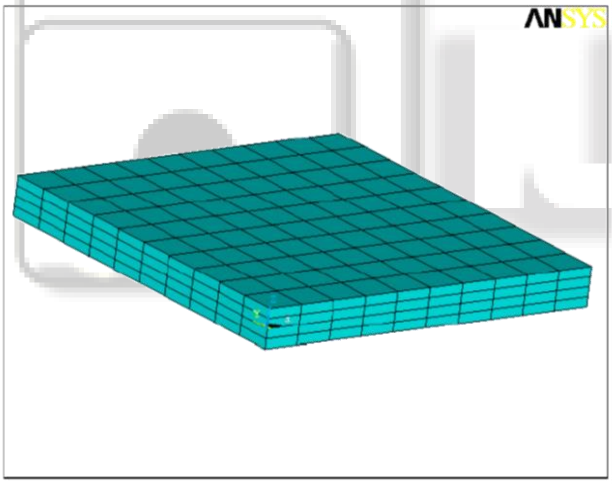


Fig. 3: Laminated composite plate modeled in ANSYS

III. PROBLEM STATEMENT

The typical floor system of 6m X 6m is adopted for vibration analysis of structures and following data is adopted

Size: 6m x 6m
Thickness: 150mm
Grade of Concrete: M30
Vibrational frequency: 2.4 Hz
Drop Panel thickness:100 mm
Epoxy FRP: 60mm
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.

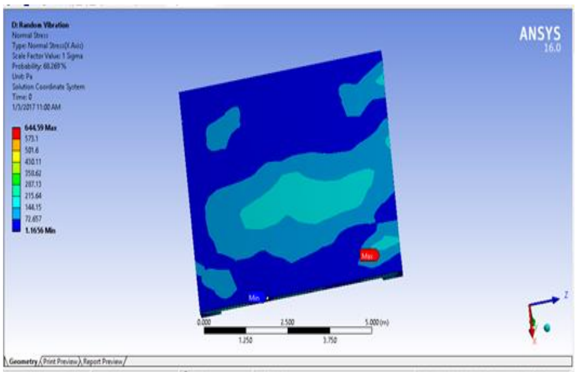


Fig. 3.1: Normal Stress of Flat Slab Model with epoxy material.

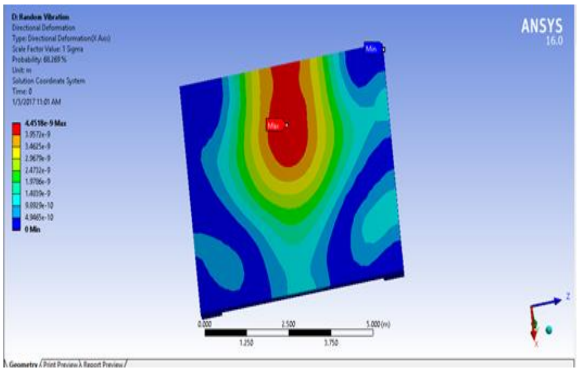


Fig. 3.2: Deformation of Flat Slab Model with epoxy material

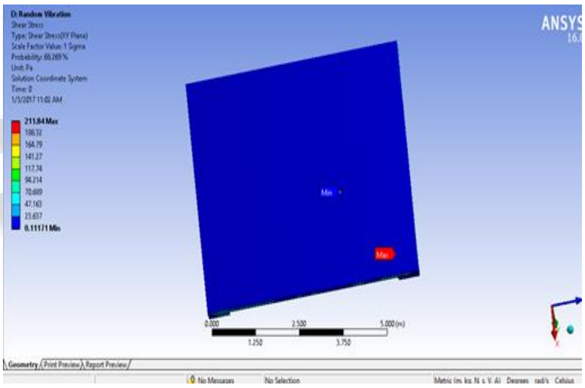


Fig. 3.3: Shear Stress of Flat Slab Model with epoxy material

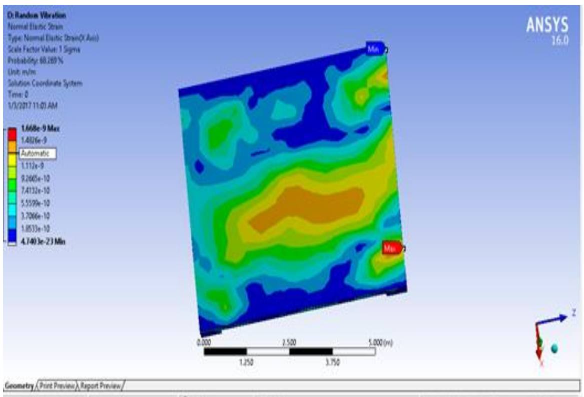


Fig. 3.4: Normal Strain of Flat Slab Model with epoxy material

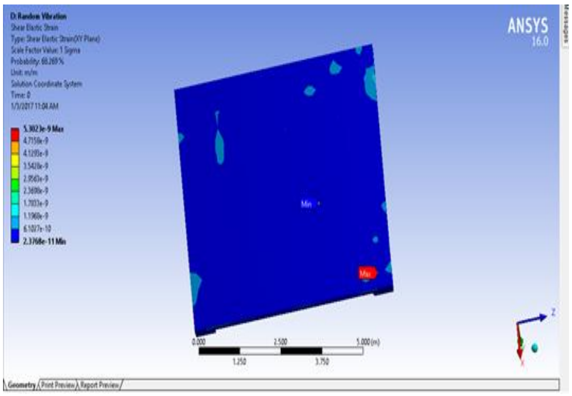


Fig. 3.5: Shear Strain of Flat slab Model with epoxy material

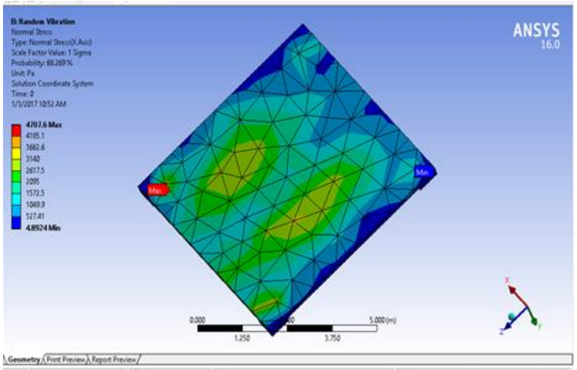


Fig. 3.6: Normal Stress of Flat Slab Model without epoxy material

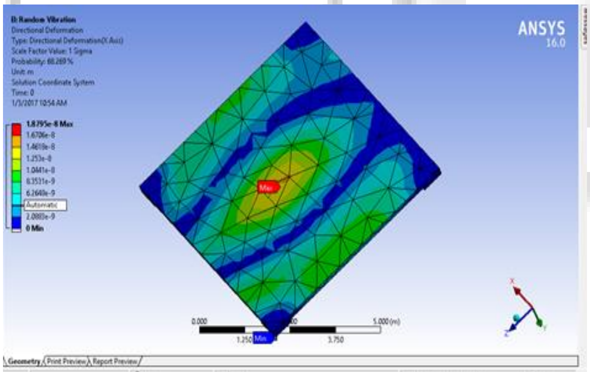


Fig. 3.7: Deformation of Flat slab Model without epoxy material

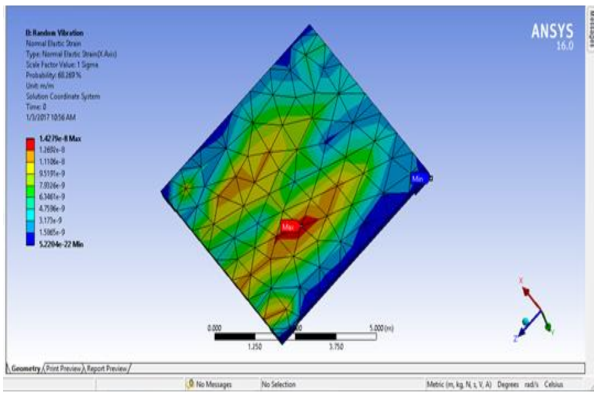


Fig. 3.8: Normal Strain of Flat Slab Model without epoxy material

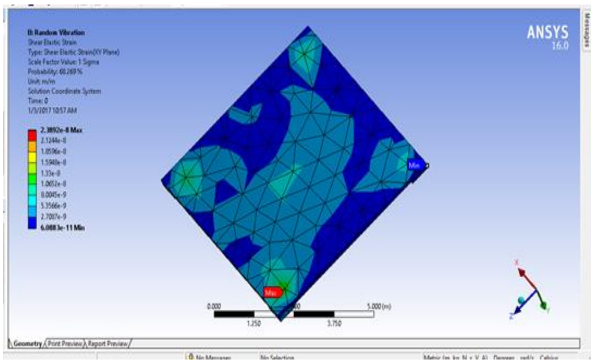


Fig. 3.9: Shear Strain of Flat slab Model without epoxy material

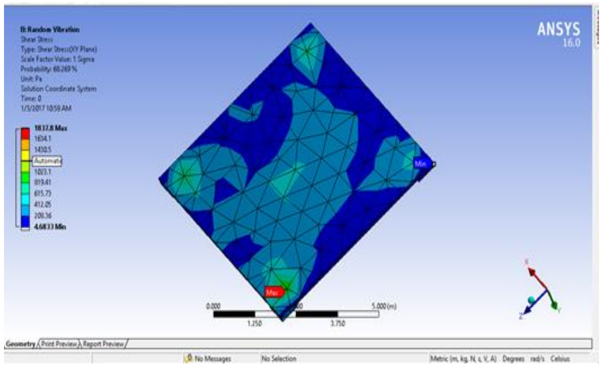


Fig. 3.10: Shear Stress of Flat slab Model without epoxy material

IV. RESULTS & DISCUSSION

A. Result of Flat Slab without Epoxy Laminate

NO.	Mode shape	Deformation(mm)
Mode No.	1	0
Mode No.	6	1.8795x 10^{-5}

Table 4.1: Deformation of flat slab

NO.	Mode shape	Normal stress(N/mm2)
Mode No.	1	4.8924x10^{-6}
Mode No.	6	4.7076x10^{-3}

Table 4.2: Normal stress of flat slab

NO.	Mode shape	Normal strain
Mode No.	1	5.2204x10^{-22}
Mode No.	6	1.4279x10^{-8}

Table 4.3: Normal strain of flat slab

NO.	Mode shape	Normal stress(N/mm2)
Mode No.	1	1.17x10-6
Mode No.	6	6.45x10-4

Table 4.4: Normal Stress of flat slab

B. Result for flat slab with Epoxy laminate

NO.	Mode shape	Deformation
Mode No.	1	0
Mode No.	6	4.45x10-6

Table 4.5: Deformation of flat slab

NO.	Mode shape	Shear Stress
Mode No.	1	1.12x10-7
Mode No.	6	2.12x10-4

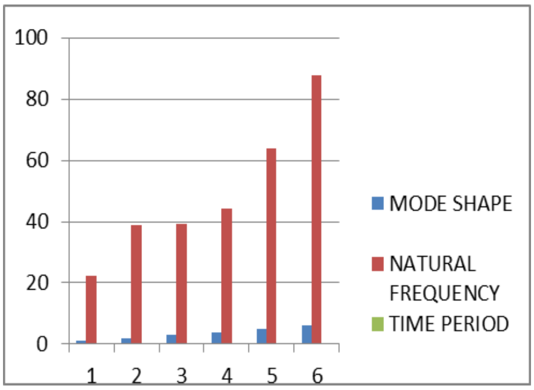
Table 4.6: Shear Stress of flat slab

NO.	Mode shape	Normal strain
Mode No.	1	1.67x10-9
Mode No.	6	1.67x10-9

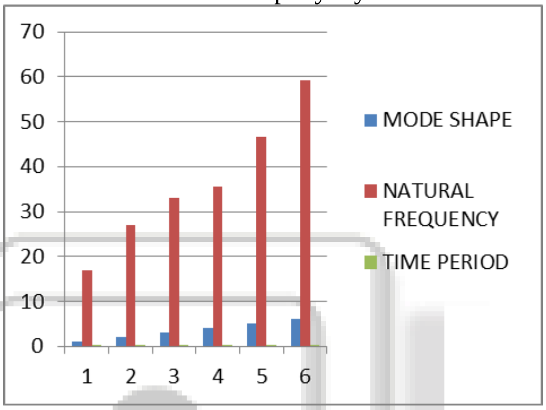
Table 4.7: Normal strain of flat slab

NO.	Mode shape	Normal strain
Mode No.	1	2.38x10-11
Mode No.	6	5.30x10-9

Table 4.8: Shear strain of flat slab



Graph. 1: of natural frequency vs mode shape for flat slab with epoxy layer



Graph. 2: of natural frequency vs mode shape for flat slab with epoxy layer

V. Conclusion

Following conclusions are obtained after modeling in ANSYS with epoxy FRP and without epoxy FRP.

1) The deformation of flat slab reduced by 24% by using epoxy FRP.
2) Vibration induced in flat slab are reduced by use of FRP but TMD should be used for severe conditions
3) Natural frequency and time period changed by using FRP.
4) Both normal and shear stress, strain are also reduced by 13% & 11.54% respectively.

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