

# Parametric Study on Dynamic Behaviour of Waffle Slab

<sup>1</sup>Vinit P. Thakor <sup>2</sup>Tushar N. Patel

<sup>1</sup>P.G. Research Scholar

<sup>2</sup>Department of Civil Engineering

<sup>1,2</sup> Sardar Vallabhbhai Patel Institute of Technology Vasad, India

## Abstract

Nowadays, Multistorey Building which include Fitness centers, Parking garages, Super markets, offices, Food centers are trending worldwide. In which, Simple activities like walking, running skipping, jumping can generate vibration in the slab. This vibration can cause inconvenience in persons and questions about safety of structures and risk of collapse that is determined by its intensity of vibration. The objective of this paper is evaluating the behaviour of reinforced concrete waffle slab due to human rhythmic activities and resonance. Waffle slab are modeled by element meshing method with ETABS with different plan aspect ratio. Here two types of dynamic analysis are performed: free vibration analysis for obtaining natural frequencies and mode shapes and forced vibration analysis to obtain Maximum displacement.

**Keyword-** Building Flexibility, Dynamic Behaviour

## I. INTRODUCTION

A floor is an integral part of practically every modern industrial, commercial or residential building. As expectation of building user, who is in everyday contact with the floors, rise, so the performance of floor structure in day-to-day service is becoming increasingly important. When a large space within a building needs to be covered without hindrance and supports, architects often deploy waffle slab to construct floor and ceiling. Waffle slab are generally used for heavy loads.

Waffle slab system consists of beams or ribs spaced at regular intervals in perpendicular direction and monolithic with slab. In these types of slab, a mesh or grid of beams running in both the directions is the main structure, and the slab is of nominal thickness. Grids (beams) are found to be very efficient in transferring load. Normally the sizes of grids running in perpendicular directions are generally kept the same. Waffle slab are generally employed for architectural reasons for large rooms such as auditoriums, vestibules, theatre halls, show rooms of shops where column free space is often the main requirement. They are used for heavy loads and large span structures as they exhibit higher stiffness and smaller deflection. Void formed in the ceiling leads to reduction in dead load and is advantageously utilized for concealed architectural lighting. These slabs are also used as the foundation for many different types of buildings and structures, but are most commonly used in commercial or industrial buildings. Waffle foundations are resistant to cracking and sagging and can hold a much greater amount of weight than traditional concrete slabs.

The waffle slab behaviour is intermediary between plate (concrete slab), grillage of beams (ribbed), and shell behaviour (diaphragm rigid and ribbed), which results in a difficult and complex analysis. There is a concern among researchers to evaluate the dynamic behaviour of the waffle slab under the human activity effects, because these actions are considered like static load in structural design. The human actions study on slabs gained impetus in the 1980s[1], when the first mathematical formulations to model these actions emerged. These formulations are based on Fourier series and assuming that induced force by persons is periodic in time.

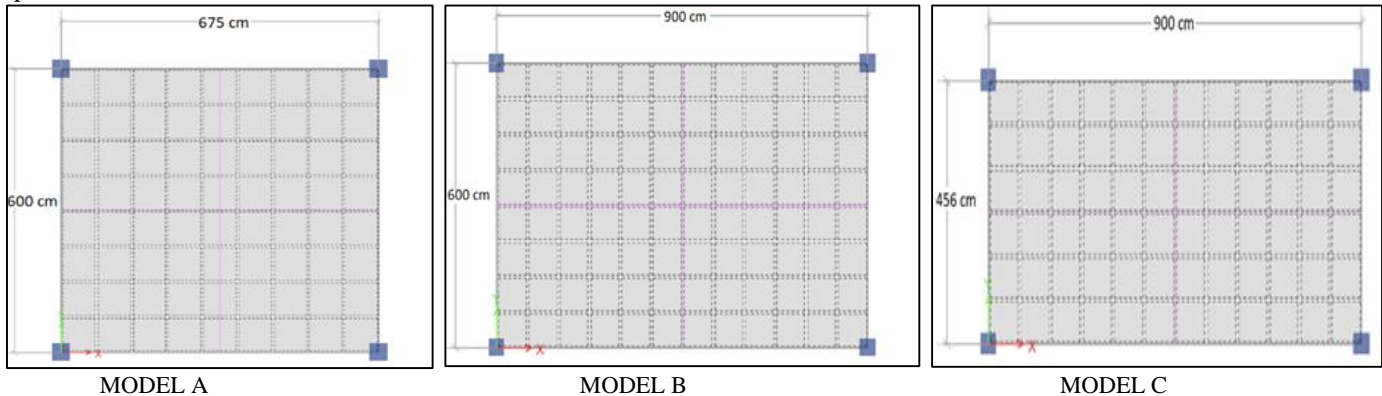
The aim of this job is to evaluate the reinforced concrete waffle slab behaviour due to the rhythmic human actions. Three-dimensional analyses are performed using the computer program ETABS in order to get the natural frequencies and mode shapes and compared to requirements provided by NBR 6118 (ABNT, 2003)

Several analytical and parametric studies were carried out in past to demonstrate the behaviour of waffle slab. D.E. Allen et.al. [2] Presented a design procedure based on user acceptability of vibration for floor structures that are subjected to rhythmic activities such as dancing and jumping exercises. Aleksendar Pavic et.al. [3] Have studied dynamic modeling of post tensioned concrete floor with the help of finite element modeling method and presented the lateral bending stiffness of ribs in post tensioned ribbed floors. G.Pernica et.al. [4] Presented that large vibration that have sometimes resulted the annoyed occupants and owner and occasionally have been of concern for reason of safety. C.M.R. Gaspar et.al. [5] Presented study on steel-concrete composite floors submitted to human rhythmic activity, aerobic exercise in the group of 32 and analyse the natural frequency with resonance condition. C.J.Middleton et.al. [6] Discussed the response of HFF to a footfall and shown that the analysis of a HFF possesses many unknowns, which make the response prediction from different activities is difficult there for a single force model, which is suitable for all floor type is desired. Indrajit Chaudhary et.al. [7] Proposed a semi analytical method for the analysis of waffle slab

with any arbitrary boundary conditions; fixed, free and simply supported. Dr. A.C. Galeb et.al. [8] Conducted studies to find the optimum dimensions waffle slabs by conducting two Case studies –Waffle slab with solid heads, Waffle slab with band beams. Anjaly Somsekhar et.al. [9] Studied on the structural behaviour of Waffle slab with and without opening and the effect of opening size and locations on the ultimate load. For that they considered a waffle slab with three square opening at different location with and without stiffening ribs.

## II. MODEL ANALYSIS

The structural system of waffle slab is of concrete slab, ribbed slab and board beams, which is analysed in three different models. I.e. Model A , Model B and Model C as shown in figure below. These models are different in the ratio of longer span to shorter span for different models.



This slab model have the geometric characteristics: concrete slab thickness is 4 cm, thickness of ribbed is 7 cm at the bottom and 13 cm on the top, and distance between ribbed is 48 cm at the top and 54 cm on the bottom. The ribbed are bidirectional and inclined. The board beams have 14 cm of width and 50 cm of height and are considered simply supported. Characteristic compressive strength ( $f_{ck}$ ) with 28 days curing is 35 Mpa and damping coefficient is 0.5 %.Element mesh analysis for waffle slab is done using ETABS for chosen to be faithful to real structure and get the natural eccentricity between the structural elements (concrete slab, ribbed, and board beams).The model A, model B and model C have the following masses: 13905 kg, 18540 kg and 14091 kg respectively.

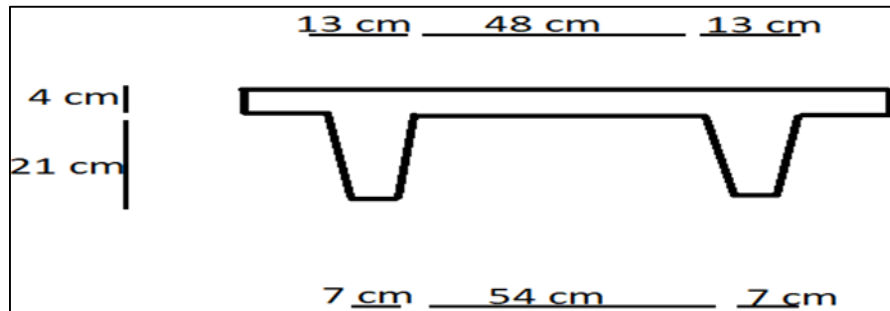


Fig. 1: Waffle slab geometric characteristic

## III.DYNAMIC LOADING

Design loads for the slabs are classified in permanent dead load and accidental loads. Dead loads are applied statically throughout the design life of the structure which includes self weight of slab, beams and floor finish. The self weight for reinforced concrete weight value is 25 kN/m<sup>3</sup> and floor finish is 1 kN/m<sup>3</sup>. This loads are applied on the slab surface. This load is represented by periodical mathematic functions in Fourier series. Bachmann et.al. [10] suggested the function, Expression is given as:

$$P(t) = w_p + \sum_{i=1}^n w_p \cdot \alpha_i \cdot \sin(2 \cdot \pi \cdot i \cdot f_p \cdot t - \varphi_i)$$

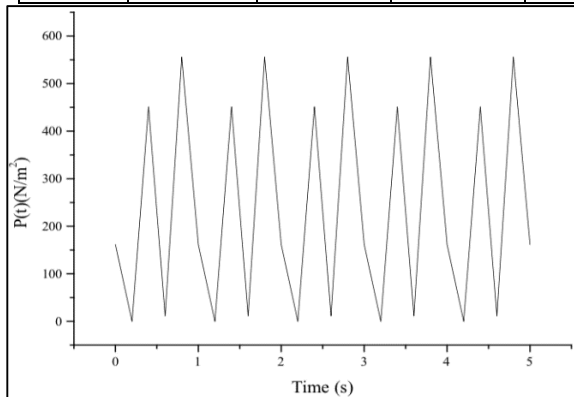
Where;  $P(t)$  is the dynamic loading function in time (N);  $w_p$  is the weight of the person considered as 800 N;  $\alpha_i$  is the Fourier coefficient of the  $i^{\text{th}}$  harmonic or dynamic load factor;  $f_p$  is the activity rate (Hz);  $i$  is the number of  $i^{\text{th}}$  harmonic;  $n$  is total number of contributing harmonics;  $t$  is time (s);  $\varphi_i$  is the phase lag of the  $i^{\text{th}}$  harmonic relative to the 1st harmonic.

Bachmann suggest values for design density of participants during different activity, for dynamic load factors ( $\alpha$ ) and phase lag ( $\varphi$ ). these values are shown in table below.

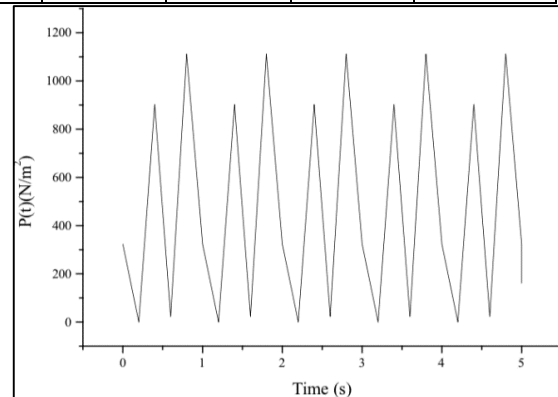
Representative type of activity	Activity Rate(Hz)		Fourier Coefficient and Phase Lag					Design Density(Person/m2)
			$\alpha_1$	$\alpha_2$	$\alpha_3$	$\phi_2$	$\phi_3$	
Walking	Vertical	2	0.4	0.1	0.1	$\pi/2$	$\pi/2$	~1
		2.4	0.5	0.1	0.2	-	-	
	Forward	2	0.2	0.1	-	-	-	
	Lateral	2	$\alpha_1/2=0.1$	$\alpha_3/2=0.1$	-	-	-	
			$\alpha_1/2=0.1$	-	-	-	-	
Running	2 to 3		1.6	0.7	-	-	-	~
Jumping	Normal	2	1.8	1.3	0.7	-	-	In Fitness Training ~0.25(in extreme cases up to 0.5)
		3	1.7	1.1	0.5	-	-	
	High	2	1.9	1.6	1.1	-	-	
		3	1.8	1.3	0.8	-	-	
Dancing	2 to 3		0.5	0.15	0.1	-	-	~4(in extreme cases up to 6)

Frequency of excitation applied on slab models is 3Hz and design density varies between 0.25-0.50 person/m<sup>2</sup>. Parameter values for high activity rate and normal activity rate for each dynamic load model as shown in table below.

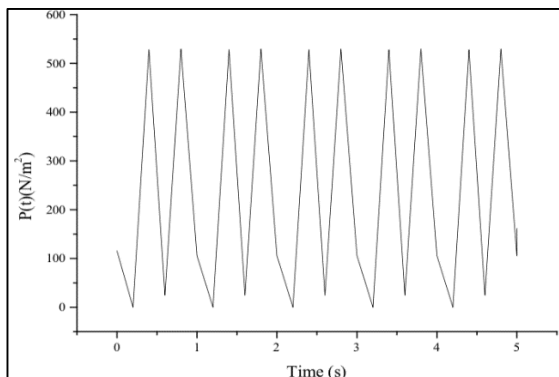
Loading	Fourier coefficient	Fourier Coefficient	Fourier Coefficient	Phase lag	Phase lag	Phase lag	frequency	Design Density
	$\alpha_1$	$\alpha_2$	$\alpha_3$	$\Phi_1$	$\Phi_2$	$\Phi_3$	Hz	(person/m <sup>2</sup> )
1	1.7	1.1	0.5	0	1.25664	1.25664	3	0.25
2	1.7	1.1	0.5	0	1.25664	1.25664	3	0.50
3	1.8	1.3	0.8	0	1.25664	1.25664	3	0.25
4	1.8	1.3	0.8	0	1.25664	1.25664	3	0.50



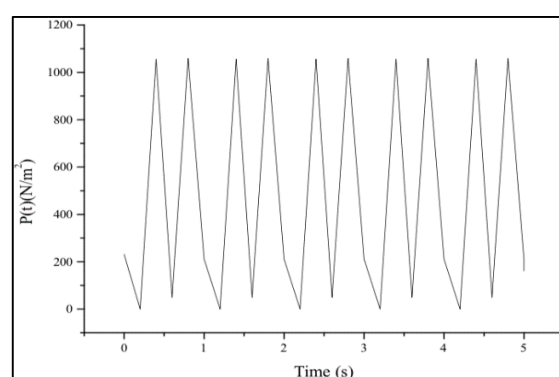
LOADING 1



LOADING 2



LOADING 3



LOADING 4

Fig. 2: Dynamic functions for each load model

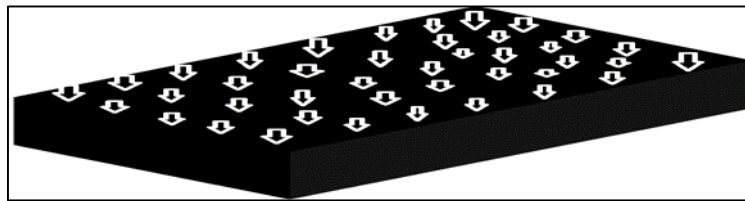


Fig. 3: Distributed loading on the slab

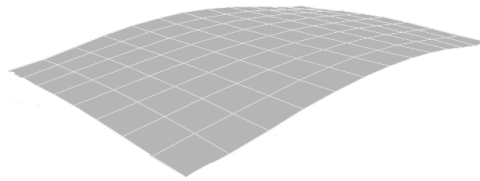
## IV. RESULTS

### A. Result of Natural Frequencies

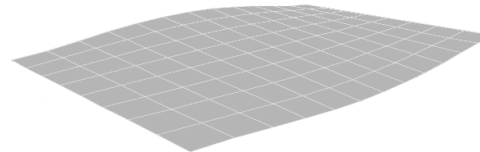
The natural frequencies and its respective mode shapes are obtained through a free undamped vibration analysis of three slab models.

MODE SHAPE

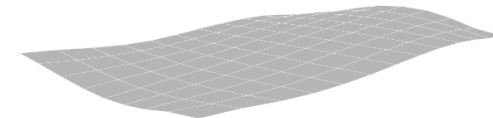
PERSPECTIVE VIEW



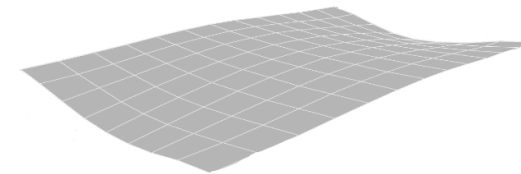
Mode 1 ( $f_1 = 4.52$  Hz)



Mode 2 ( $f_2 = 6.53$  Hz)



Mode 3 ( $f_3 = 10.84$  Hz)



Mode 4 ( $f_4 = 15.2$  Hz)

In accordance with these mode shapes, it is noticed that the first natural frequency is associated with first flexural mode; the second one corresponds to first torsional mode; the third one is related to the second bending mode; and fourth natural frequency refers to the second mode of torsion. Therefore, the lowest slab frequency is associated with the first mode shape in bending.

The natural frequencies of each models are shown in table below.

Slab	$f_1$	$f_2$	$f_3$	$f_4$	$f_5$	$f_6$	$f_7$	$f_8$	$f_9$	$f_{10}$
Model A (Hz)	6.91	10.77	12.64	18.91	24.99	30.16	37.36	43.48	46.30	50.70
Model B (Hz)	4.52	6.53	10.84	15.21	18.86	21.59	23.94	31.55	35.04	42.47
Model C (Hz)	4.71	7.20	14.75	20.11	22.60	29.62	34.01	39.58	41.21	45.46

The NBR 6118 (ABNT, 2003) establishes values for critical frequencies allowed. For example slab of commercial building, the critical frequency value refers to offices that is 4 Hz. This code states that the fundamental frequency of the structure, with certain activity, may not be less than 20% the critical frequency ( $f_1 > 1.2 \cdot f_{crit}$ ). In other words, the fundamental frequency of offices must be greater than 4.8 Hz to ensure performance stability in Excessive Vibration Limit State.

Cases	$f_{critical}$ (Hz)
Gymnasium	8.0
Dance room or concrete without fixed seats	7.0
Offices	3.0 & 4.0
Concrete rooms with fixed seats	3.4
Pedestrian walkways or cyclists	1.6 & 4.5

The fundamental frequencies of models B and C are 4.52 Hz and 4.51 Hz, respectively. These frequencies are below the critical frequency increased in 20% (4.8 Hz). The model A does exceed these values (4.8 Hz).

### B. Displacement Analysis

The NBR 6118 (ABNT, 2003) determines limit values of displacements in order to avoid excessive deformation of structure. One of basic groups defined by this code is the acceptability sensorial that is characterized by unpleasant visual effect and undesirable vibrations. For unpleasant visual effect, the maximum vertical displacement is  $L/250$ , where  $L$  is the shorter length of slab; and for undesirable vibrations, the value limit is  $L/350$ . In this work, the maximum displacements of three models are compared with limit displacement value for unpleasant visual effect (2.4 cm for models A and B and 1.87 cm for model C). The maximum vertical displacements occur in the centre of each slab model for each analysis.

Loading	Model A	Model B	Model C
1	0.79	1.93	1.61
2	0.93	2.23	1.92
3	0.74	2.22	1.59
4	0.91	2.308	1.89

## V. CONCLUSION

After this effective study on dynamic behaviour of waffle slab with the different aspect ratio. Three slab models are analysed by ETABS software. By analysing these three models, it is concluded that model A is more stable than model B and model C. For loading 4, model B generates greater displacement among all three models, thus model B is more flexible. Among three models, model A is more rigid, because its fundamental frequency is higher. When the ratio of span increases of model A to model B, the mass raises and the fundamental frequency is reduced. When the ratio of span increases of model B to model C, the mass is reduced and the fundamental frequency is increased.

## REFERENCES

- [1] Yuri Cláudio Vieira da Costa Tereza Denyse de Araújo "Evaluation of dynamic behaviour of waffle slab to gym center" Latin American Journal of Solid and Structures 11 (2014) 1114-1131
- [2] Allen, D. E.; Rainer, J. H.; Pernica, G. "Vibration criteria for assembly occupancies" Canadian Journal of Civil Engineering, 12, 3, pp. 617-623, 1985-09
- [3] Pavic, A., Reynolds, P., Waldron, P., Bennet, K., (2001). "Dynamic modeling of post-tensioned concrete floors using finite element analysis" Finite Elements in Analysis and Design, 37: 305-323.
- [4] Rainer, J.H., Pernica, G., (1986) "Vertical dynamic forces from footsteps". Canadian Journal of Civil Engineering, Canadian Acoustics, 14: 12-21.
- [5] C.M.R. Gaspar , J.G. Santos da Silva , L.F. Costa-Neves "vibration control of building steel-concrete composite floors submitted to human rhythmic activities" Computers and structures 165 (2016) 107-12
- [6] C.J. Middleton, J.M.W. Brownjohn "Response of high frequency floors: A literature review" Engineering Structures 32 (2010) 337-35
- [7] Indrajit Chowdhury and Jitendra P. Singh, "Analysis and Design of Waffle Slab with Different Boundary Conditions", Indian Concrete Journal, vol.5, pp1-10 9, 2010
- [8] Alaa C. Galeb, Zainab F. Atiyah , " Optimum design of reinforced concrete waffle slabs", IJCSE, vol.1, n0 .4, pp862-880, 2011
- [9] Anjaly Somasekhar and Preetha Prabhakaran , "Analytical Investigation on Performance of Stiffened Waffle Slabs with Openings", IOSR- JMCE, vol.4,pp8-13,2016
- [10] Bachmann, H., Ammann, W.J., Deischl, F., Eisenmann, J., Floegl, I., Hirsch, G.H., Klein, G.H., Lande, G.J., Mahrenholtz, O., Natke, H.G., Nussbaumer, H., Pretlove, A., Rainer, J.H., Saemann, E., and Steinbeisser, L., (1995). "Vibration problems in structures. Practical guidelines." Berlin:Birkhauser
- [11] ABNT – Brazilian Association of Technical Codes (2003). NBR 6118: Projetos de estruturas de concreto: procedimentos. Rio de Janeiro, Brazil.