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THE VIBRATION RESPONSE OF A NOVEL COMPOSITE FLOORING SYSTEM INCORPORATING PERFORATED STEEL ULTRA SHALLOW FLOOR BEAMS (USFBs) FOR SUSTAINABLE CONSTRUCTION

By: Richard Kansinally Dipl. Eng (Hons), B.Eng (Hons) Civil, MSc.
Supervisor: Dr. Konstantinos Tsavdaridis MEng (Hons) Civil, MSc, DIC, PhD, CEng TCG, M.ASCE

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1.0 INTRODUCTION

- Steel concrete composite (SCC) flooring solutions are widely used nowadays as they are lightweight and are quick to erect.
- Recent research initiatives seek to develop slim floors by minimising the structural depth of the floor section.
- Ultra Shallow Floor Beams (USFBs) are used to reduce structural depth compared to traditional slabs (Fig 1).
- USFBs provide an overall reduction in floor-floor height. Concept is shown in Fig 2.

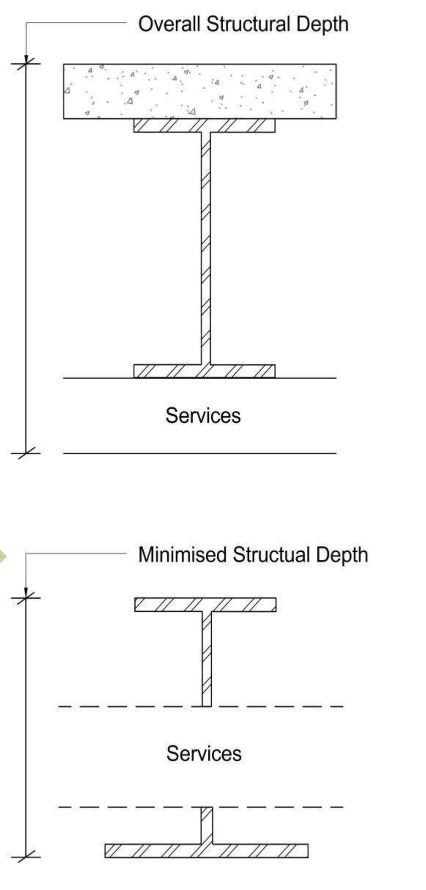


Fig 1: Reduced Depth

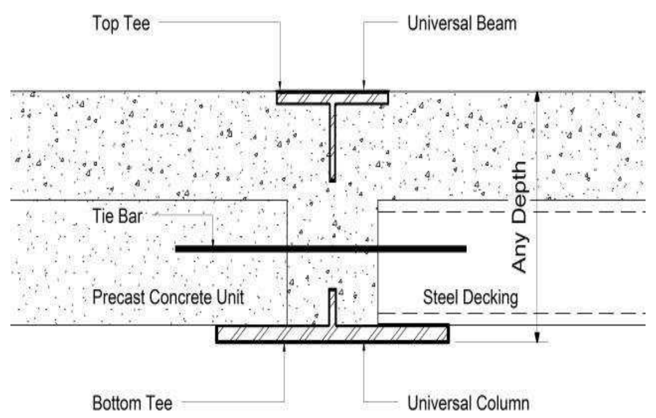


Fig 2: Concept of USFB

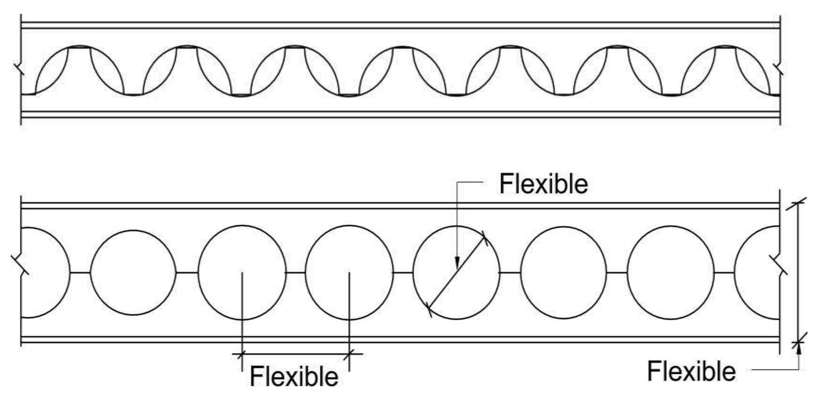


Fig 3: Fabrication Process

2.0 WHY USE PERFORATED USFBS

- A lighter flooring solution in the means of thinner and wider slabs (Fig 4).
- A section with greater second moment of inertia.
- Shear stud connectors in traditional SCC (i.e. concrete slab situated on top of steel beam) are not needed (Fig 5).
- Concrete encasement between structural depth offers a fire resistance of 60mins.
- Longitudinal shear resistance of composite section is enhanced.
- Possible service integration (Fig 6).

Fig 4: Wider Spans

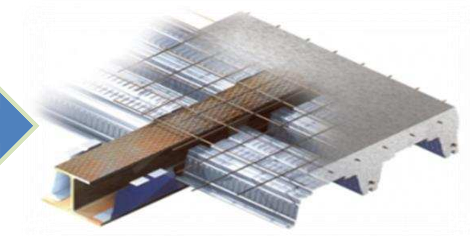


Fig 5: No Shear Studs

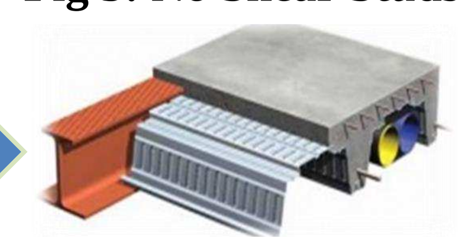


Fig 6: Service Integration

3.0 THE PROBLEM

- It is expected that lightweight, thin and long span slabs will vibrate under certain loads.
- Resonance creates excessive floor vibrations when the floor's natural frequency coincides with excitation frequencies e.g. walking, dancing, etc.

4.0 PROJECT AIM & OBJECTIVES

The main aim was:

- To provide design guidelines of slabs with perforated USFBs.

The objectives were as follows:

- To extract the dynamic properties of a bare steel perforated USFB.
- To generate the natural frequencies and modes shapes of the novel USFB slab by investigating the influence of concrete depth, support conditions and web opening spacing.
- To develop frequency design limits for various floor spans.
- To develop equivalent geometric properties for the USFB corresponding to the Euler Bernoulli beam of constant cross-section.

5.0 EXPERIMENTAL RESULTS

- Experimental test was performed on a bare steel 210x124/255x55 USFB.
- The testing found the 1st in plane natural frequency to be 11.77 Hz. Satisfactory performance is achieved as $f_{01} > 3$Hz.

a) b) c)

Fig 7: a) Isometric View. b) Cross Section. c) Accelerometers

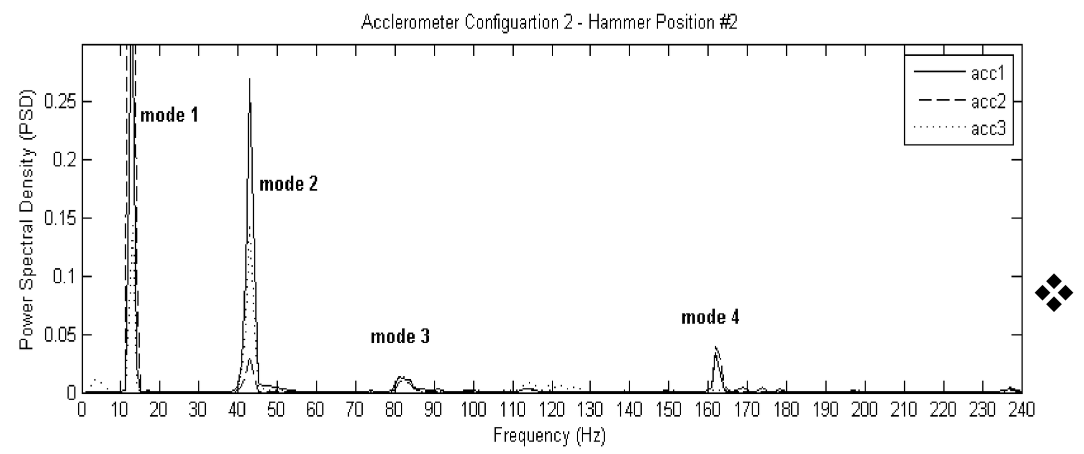


Fig 8: Matlab Results, f_{01} = 11.77Hz

6.0 VALIDATION OF FE MODELS

- Calibrating FE models was done against existing studies.
- 3D solid FE elements were built similar to Tsavdaridis and Giaralis (2011) and Mello et al. (2008).
- Good corroboration was observed thereby allowing the parametric models to be built and evaluated (Fig 9).

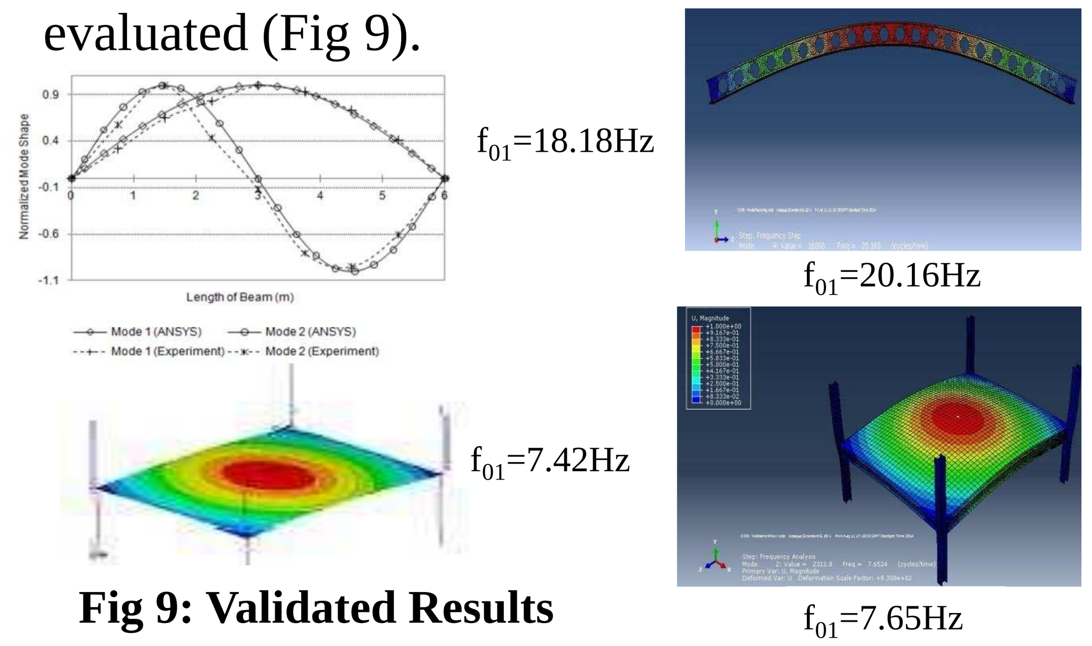


Fig 9: Validated Results

7.0 COMPARATIVE STUDY

- Economic savings are possible with USFBs whilst satisfying minimum floor frequency of 3Hz.

Mode	Comparative Model Natural Frequencies (Hz): Model 1 – Concrete on top Perforated USFB	Comparative Model Natural Frequencies (Hz): Model 2 – Concrete encasing Perforated USFB	(Mello et al., 2008) Natural Frequencies (Hz)
1	6.69	5.55	7.42
2	12.610	10.876	14.70
3	13.463	11.295	15.23
4	17.061	14.418	20.32
5	25.419	22.687	30.82
6	29.157	26.595	31.86

Table 1 : Results from Comparative Analyses

8.0 PARAMETRIC STUDY

The results from this study revealed that:

- Increasing concrete thicknesses resulted in a parabolic behaviour of the 1st vibration mode. Higher modes were linear (Fig 11a, 11b).
- Higher natural frequencies with fixed supports but similar results to pinned supports were seen in higher vibration modes (Fig 11c).
- Decreasing web opening spacing stiffened the section resulting in higher natural frequencies (Fig 11d).

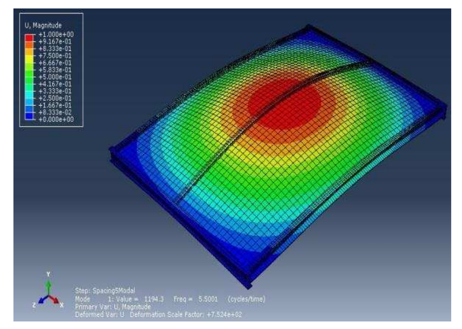
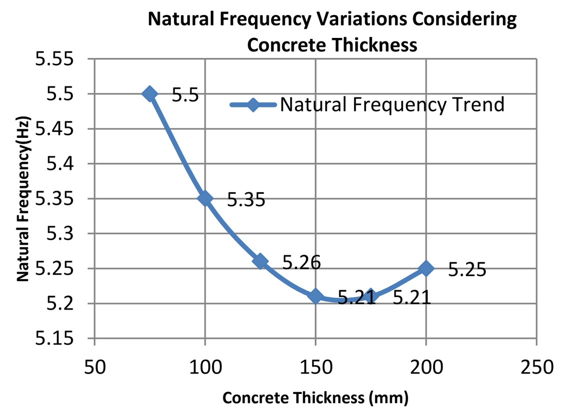
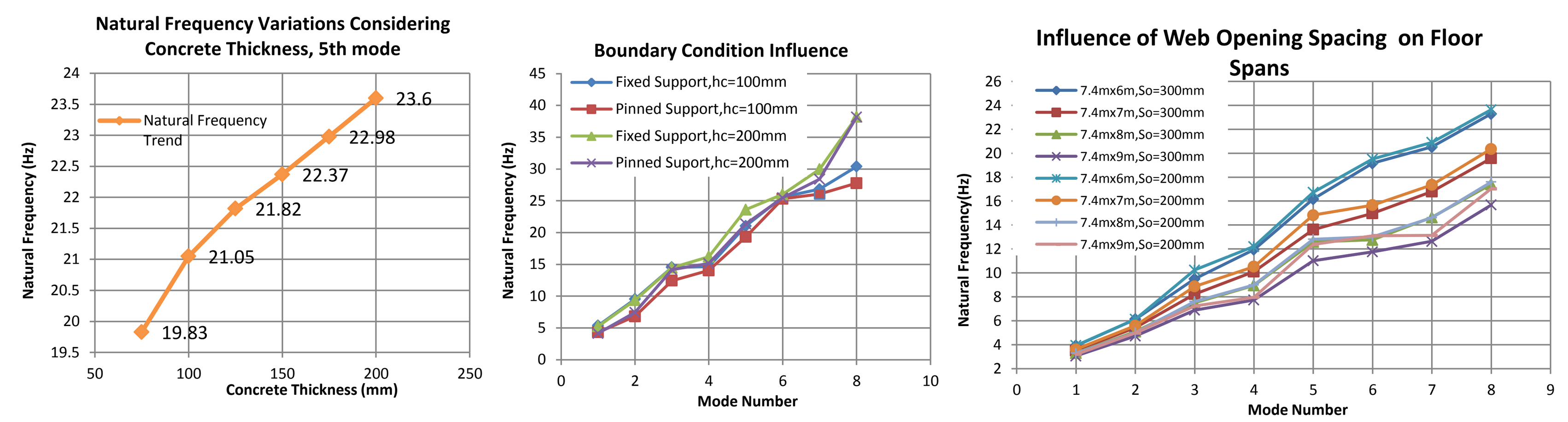


Fig 10: Typical 1st mode shape



a)



b) c) d)

Fig 11a,b,c,d: Parametric Results

9.0 EQUIVALENT GEOMETRIC PROPERTIES

- Favourable results were obtained with equivalent geometric properties corresponding to Euler Bernoulli beam (Table 2).

Floor Dimension (mxm)	Concrete Thickness (m)	1st In Plane Natural Frequency(FE) (Hz)	Equivalent Composite Area A_{eq} (m^2)	Equivalent Composite Moment of Inertia I_{eq}(m^4)	1st In-Plane Natural Frequency with equivalent.properties (Hz) Eq1.	Percentage of error (%)
7.4x9	0.075	3.17	0.0324	$1.54*10^{-5}$	3.11	1.9
	0.100	3.06	0.0412	$1.83*10^{-5}$	3.06	0
	0.125	3.02	0.0500	$2.16*10^{-5}$	3.05	0.99
	0.150	3.02	0.0588	$2.53*10^{-5}$	3.07	1.7
	0.175	3.05	0.0676	$2.92*10^{-5}$	3.10	1.6
	0.200	3.10	0.0764	$3.48*10^{-5}$	3.20	3.2

Table 2: Results with Equivalent Properties

- Slabs 7.4mx5m & 7.4mx9m have natural frequencies of 5.07Hz and 3.02Hz.
- Increasing slab spans reduced the natural frequencies.
- Great potential for SCC slabs with perforated USFBs as results were greater than 3Hz.

10.0 FINAL REMARKS

The research concluded:

- Less participation of increased mass in the 1st mode.
- Slabs modelled with fixed supports are preferable.
- Reduced web opening spacing improves the slab response.

11.0 FURTHER WORK

- Consider influence of beam-column joints.
- Influence of various size and shape of web openings.
- Influence of shear studs welded to the web and re-bars through web openings.
- Determining response factor (R).
- Testing of the system in its bare, construction and final states.

12.0 REFERENCES

- Mello,A.V.A. et al., 2008. Dynamic Analysis of Composite Systems made of Concrete Slabs and Steel Beams. Journal of Constructional Steel Research, Volume 64, pp. 1142-1151.
- Tsavdaridis, K.D. and Giaralis,A., 2011. Derivation of the Dynamic Properties of Steel Asymmetric Perforated Ultra Shallow Floor Beams via Finite Element Modal Analysis and Experimental Verification. Greece, City University London