SWINBURNE UNIVERSITY OF TECHNOLOGY

EMA and Other Dynamic Testing of a 2-Span Prestressed Concrete Floor

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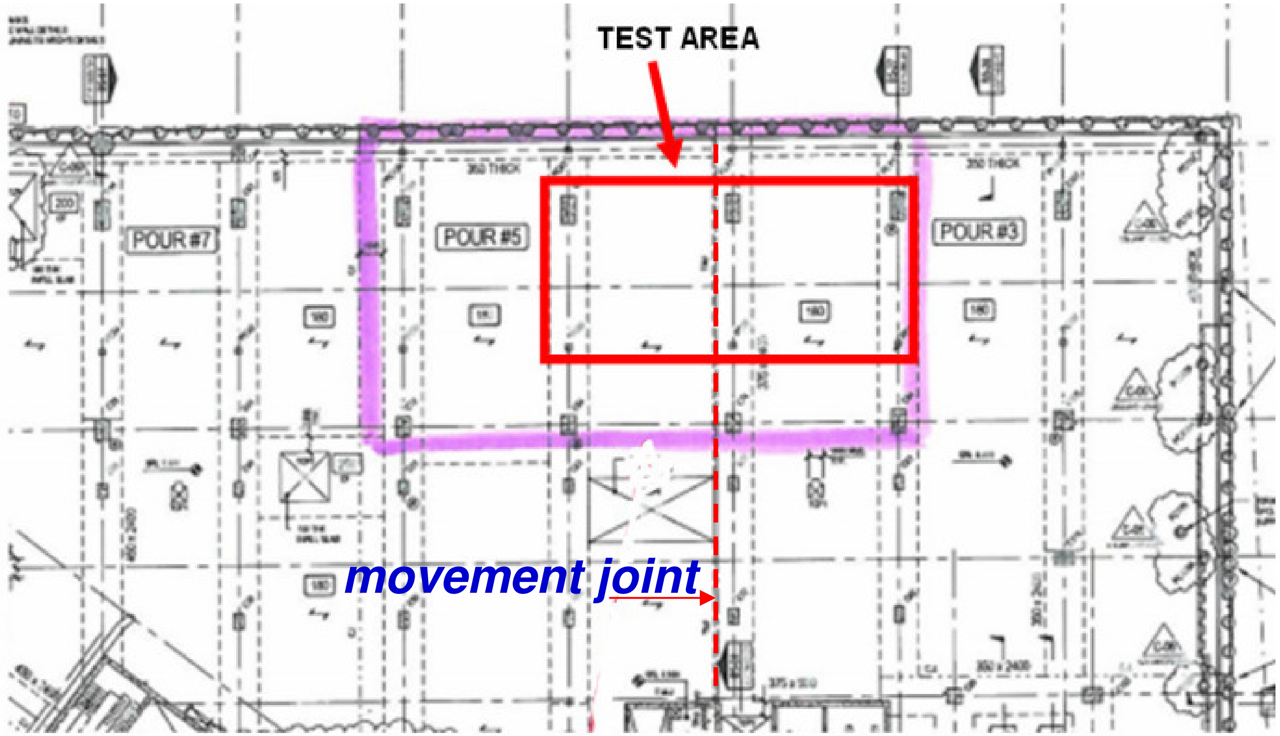
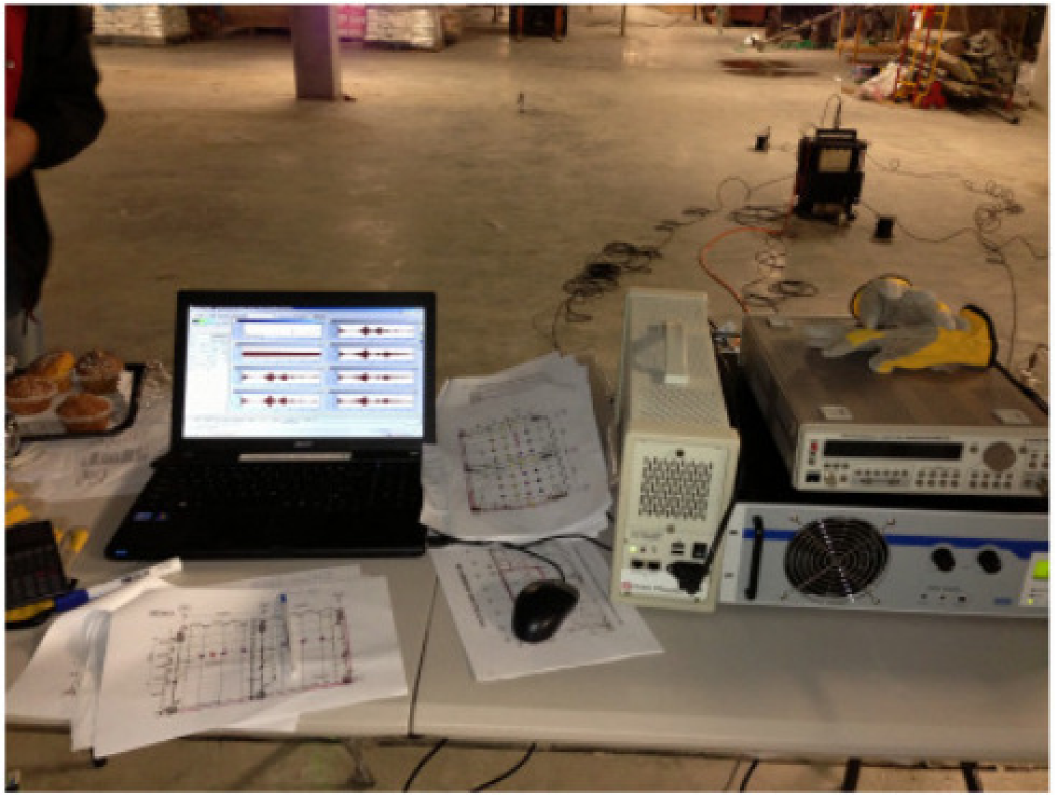
INTRODUCTION

This paper discusses experimental modal analysis (EMA) using swept sine wave forcing from a shaker, heel drop tests and walking tests performed on two bays of a prestressed concrete floor of a building under construction.

- *Modal properties*
- *Response to walking (single persons and people in pair)*
- *Calibrate FE models*



INTRODUCTION



Notebook PC Controlled Data Acquisition
System and Signal Generator
Controlled Shaker System

APS400 Shaker

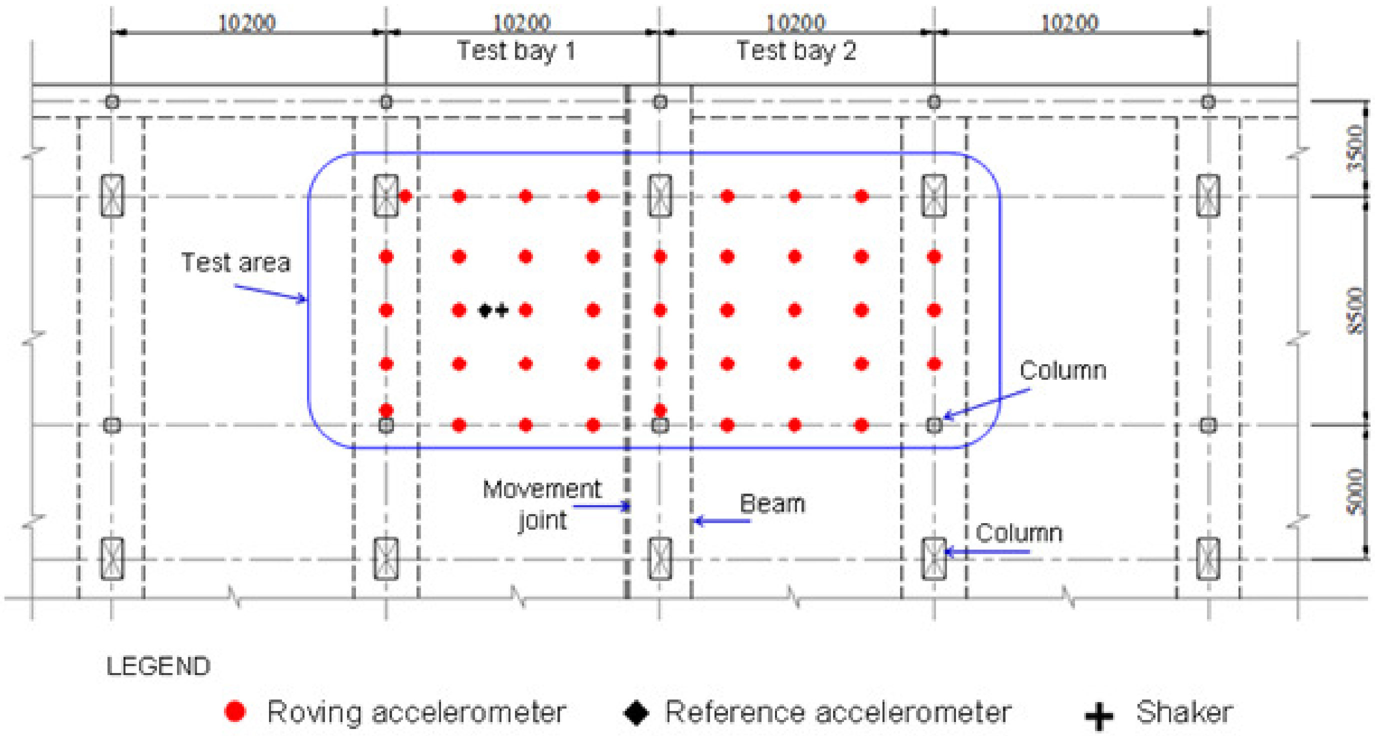
INTRODUCTION

View of test setup from Eastern to Western test spans (EMA testing)

Adhering grid-point location plates for accelerometers on test floor

MODAL TESTING WITH SHAKER

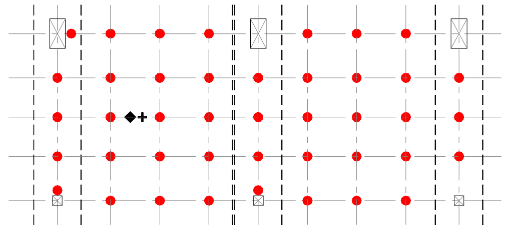
- *Swept sine signals, frequency range 5-13 Hz over a 64 second period.*
- *Dytran seismic accelerometers, 1-5 V/g sensitivity, 128 Hz sampling rate*
- *43 measurement points on floor*



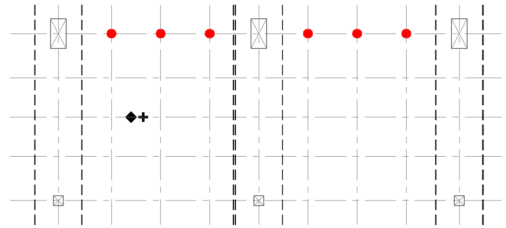
Plan view of floor showing EMA test setup with measurement points

MODAL TESTING WITH SHAKER

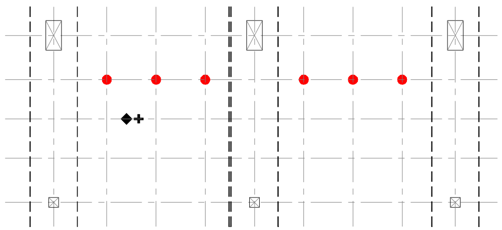
- *7 test setups (each with 1 reference sensor + 6 roving sensors)*
- *5 repeat tests in each setup → averaging*



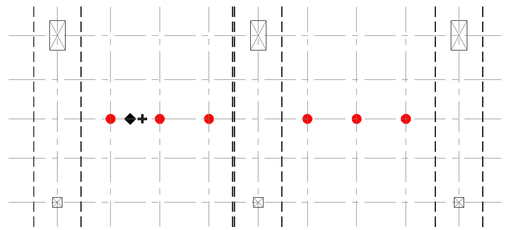
ALL TEST POINTS



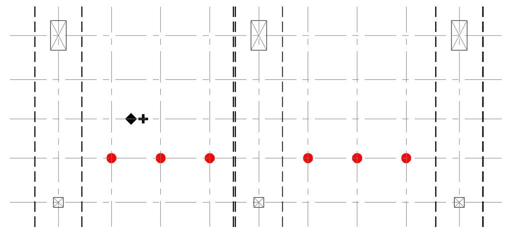
SETUP 1



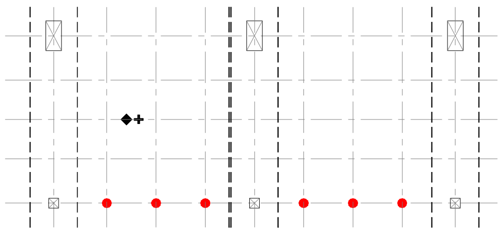
SETUP 2



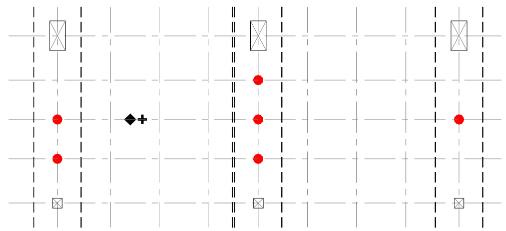
SETUP 3



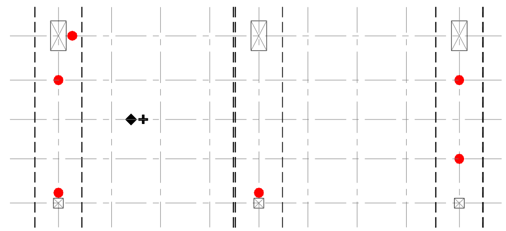
SETUP 4



SETUP 5

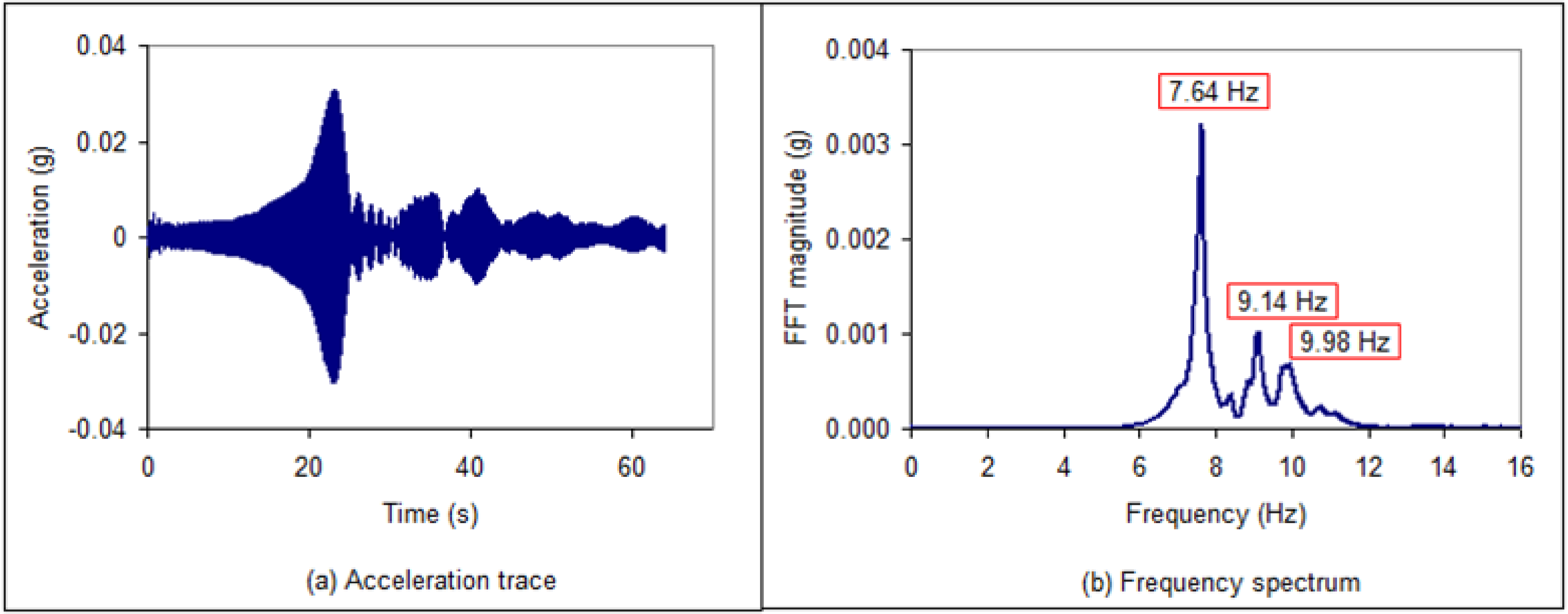


SETUP 6



SETUP 7

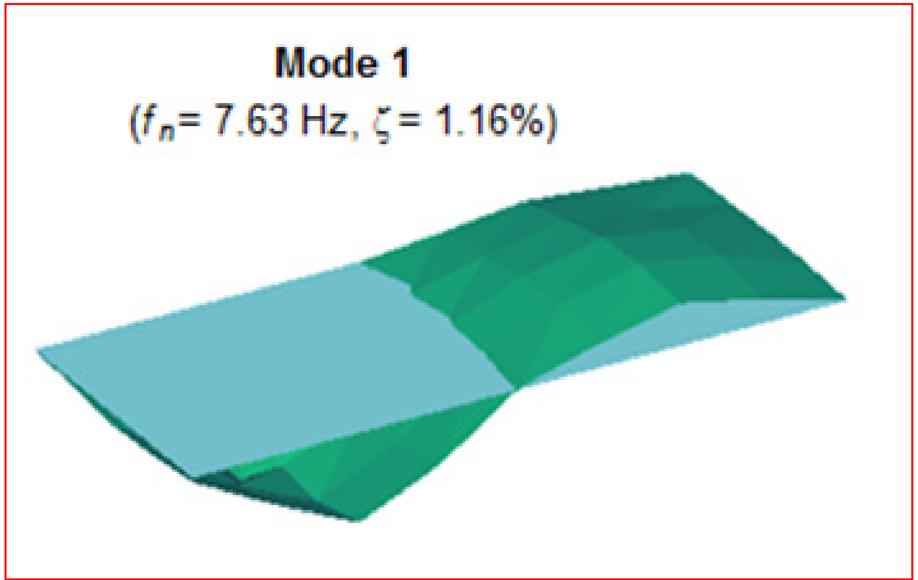
MODAL TESTING WITH SHAKER

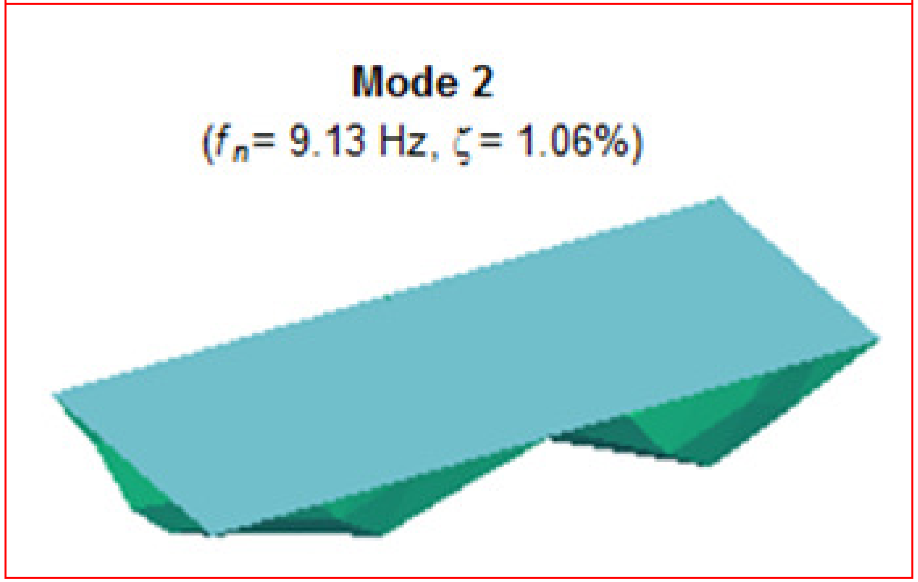


A typical floor response to shaker excitation measured by at the reference accelerometer (near the centre of the Western bay)

MODAL TESTING WITH SHAKER

To obtain the modal properties including mode shapes, natural frequencies and damping ratios; an extensive analysis of the data obtained from all 43 measurement channels was performed using the ARTeMIS experimental modal analysis program

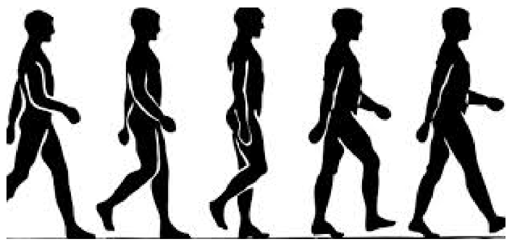




MODAL TESTING WITH SHAKER

- The temporary movement joints between the two floor bays did not fully prevent the transmission of vibration from the forced bay to the other bay
- The damping ratio of the test floor in bare condition without fittings and services is relatively low at approximately 1.1%.
- As the fundamental mode had a natural frequency of 7.6 Hz, i.e. less than 9–10Hz, the floor can be considered as a low-frequency floor which may be prone to resonant vibrations induced by human activities.

WHY RESONANCE?

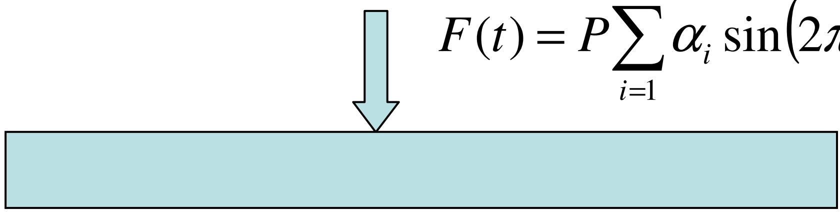


if $f_p = f_n$

f_p : *footstep frequency*

f_n : *floor frequency*

$$F(t) = P\sum_{i=1}^{4}\alpha_i \sin\left(2\pi i f_p t + \phi_i\right)$$

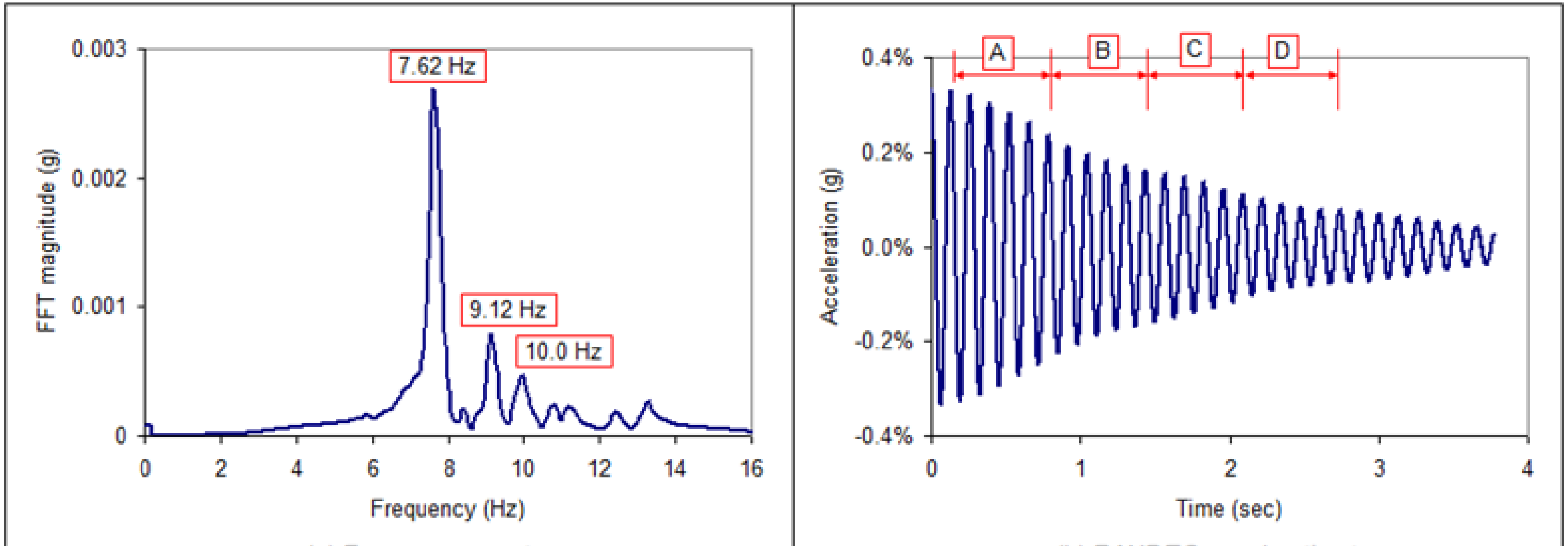


HEEL DROP TEST

- A standard heel drop impact is created by an 86-kg person rising onto their toes with their heels about 63 mm off the floor and suddenly dropping their heels to the floor.
- Only simple unreferenced heel drop tests were performed on the test floor (only the floor response is measured, rather than both the floor response and the impact force).

HEEL DROP TEST

- Relocation of accelerometers to cover the whole test area was not made and the floor response was recorded at only some locations close to the centre of the forced bay.
- A Random decrement (RANDEC) analysis was used to acquire an averaged acceleration history from the measured acceleration histories.



(a) Frequency spectrum (b) RANDEC acceleration trace

Floor response due to heel drop

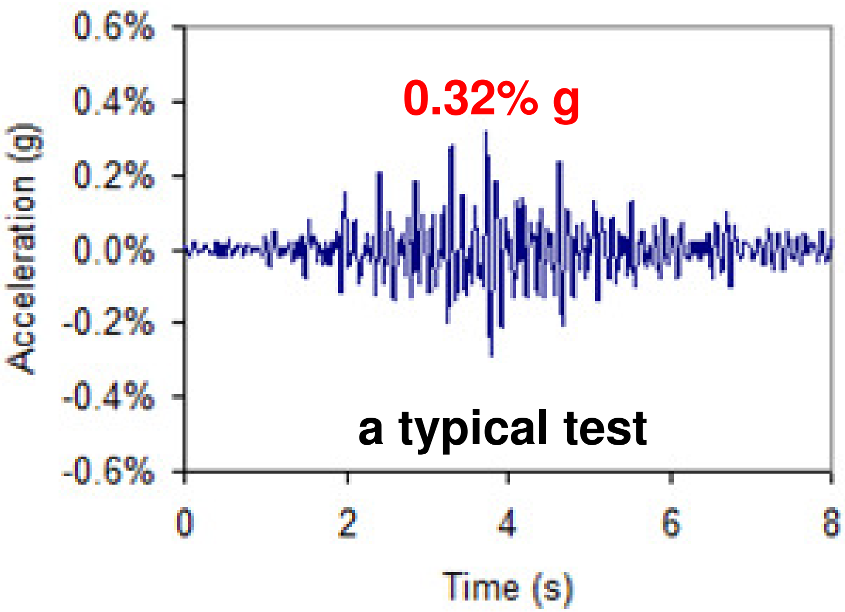
HEEL DROP TEST

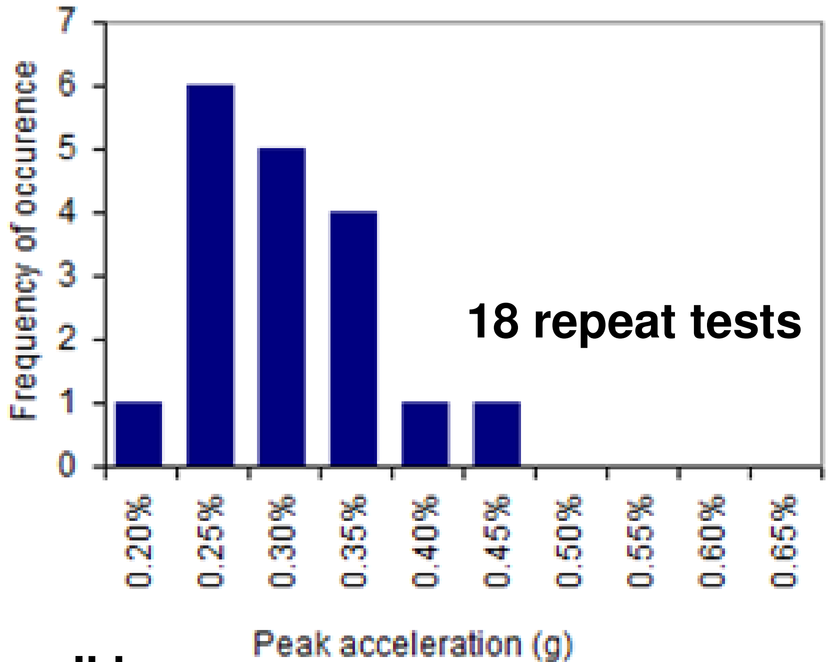
Acceleration amplitude (g)			Frequency (Hz)	Damping ratio (RANDEC)
Range	Upper limit	Lower limit		
A	0.33%	0.24%	7.64	1.05%
B	0.24%	0.16%	7.67	1.17%
C	0.16%	0.11%	7.66	1.26%
D	0.11%	0.08%	7.66	1.13%

- The modal frequencies and damping ratios acquired from the simple un-instrumented heel drop test compared well with those resulted from the shaker test (f_n~7.6 Hz, ζ ~ 1.1%)
- A slight non-linearity was observed in the damping ratio whereby damping values can vary slightly with different levels of vibration

WALKING TESTS

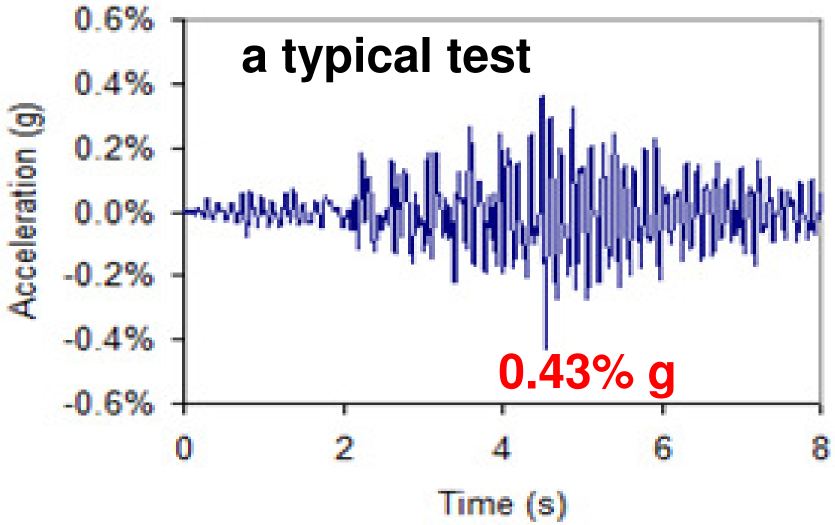
The floor response to footfall was evaluated in three conditions: single persons walking, two persons attempting to walk in-phase and two persons attempting to walk out-of-phase; at a pacing rate of about 1.8–2.0 Hz along the Western test bay. The filtered floor response was mass-weighted, assuming a typical body mass of 80-kg for an adult.

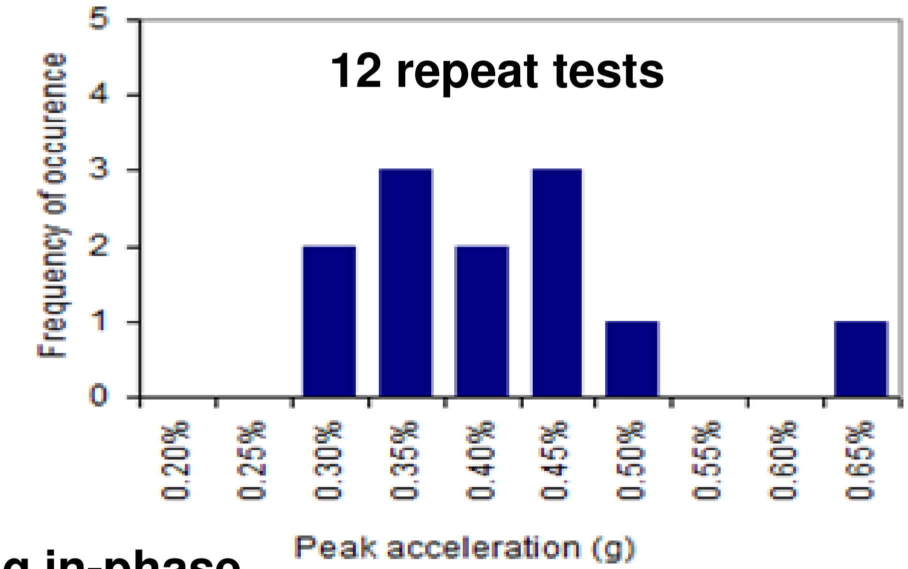




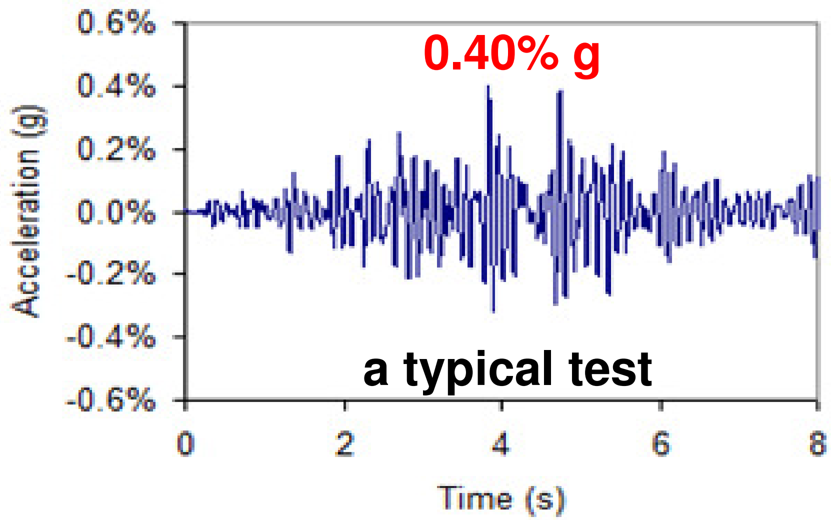
One 80-kg person walking

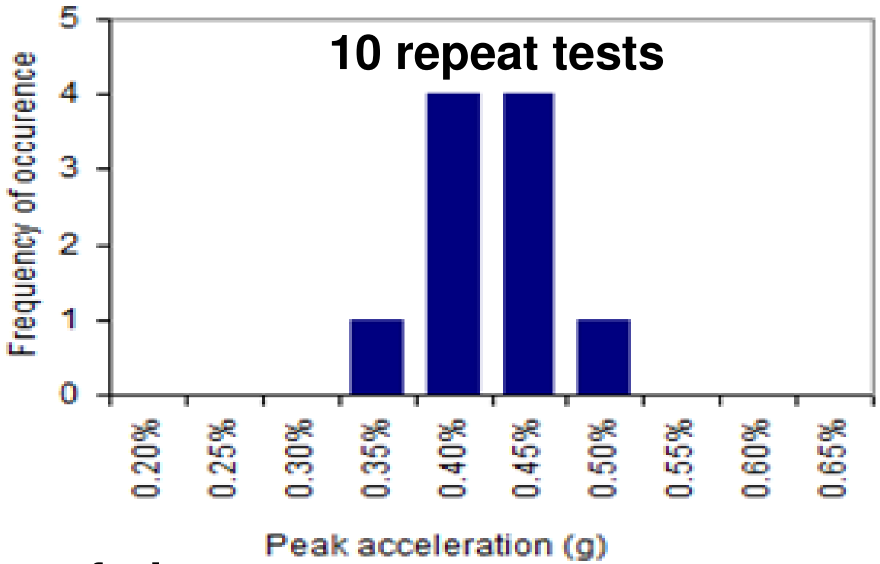
WALKING TESTS





Two 80-kg persons walking in-phase





Two 80-kg persons walking out-of-phase

WALKING TESTS

Peak floor response due to walking

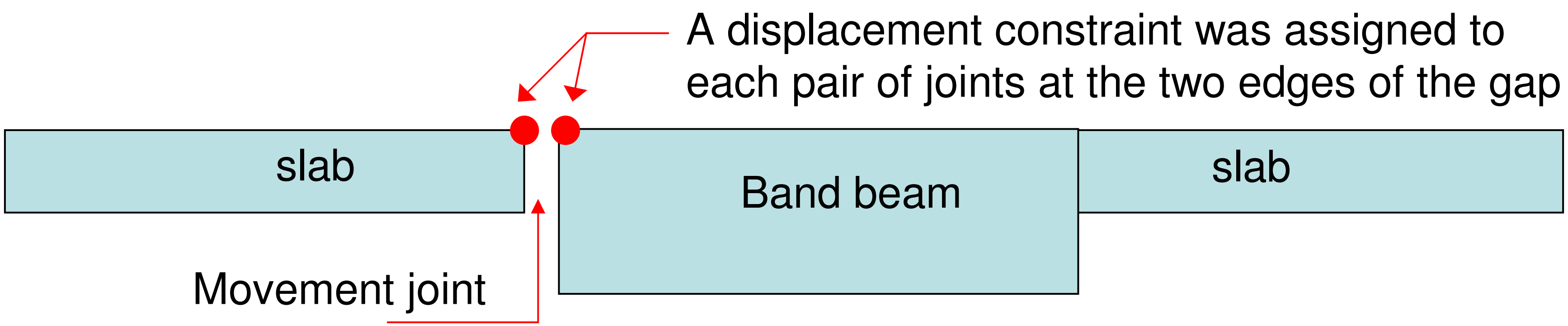
	One person	Two persons in-phase	Two persons out-of-phase
Average (g)	0.28%	0.39%	0.40%
Maximum (g)	0.40%	0.60%	0.47%

- On average, the peak acceleration due to two persons walking (either in-phase or out-of-phase) was found to be about 1.43 times of that due to one person walking.
- Perfect synchronization was unlikely to be achieved even when the walkers attempted to deliberately walk in-phase. Although the maximum peak acceleration from the two person walking in-phase scenario was 1.28 times greater than that from the out-of-phase scenario, the average values of peak acceleration were almost the same.

FE MODELLING

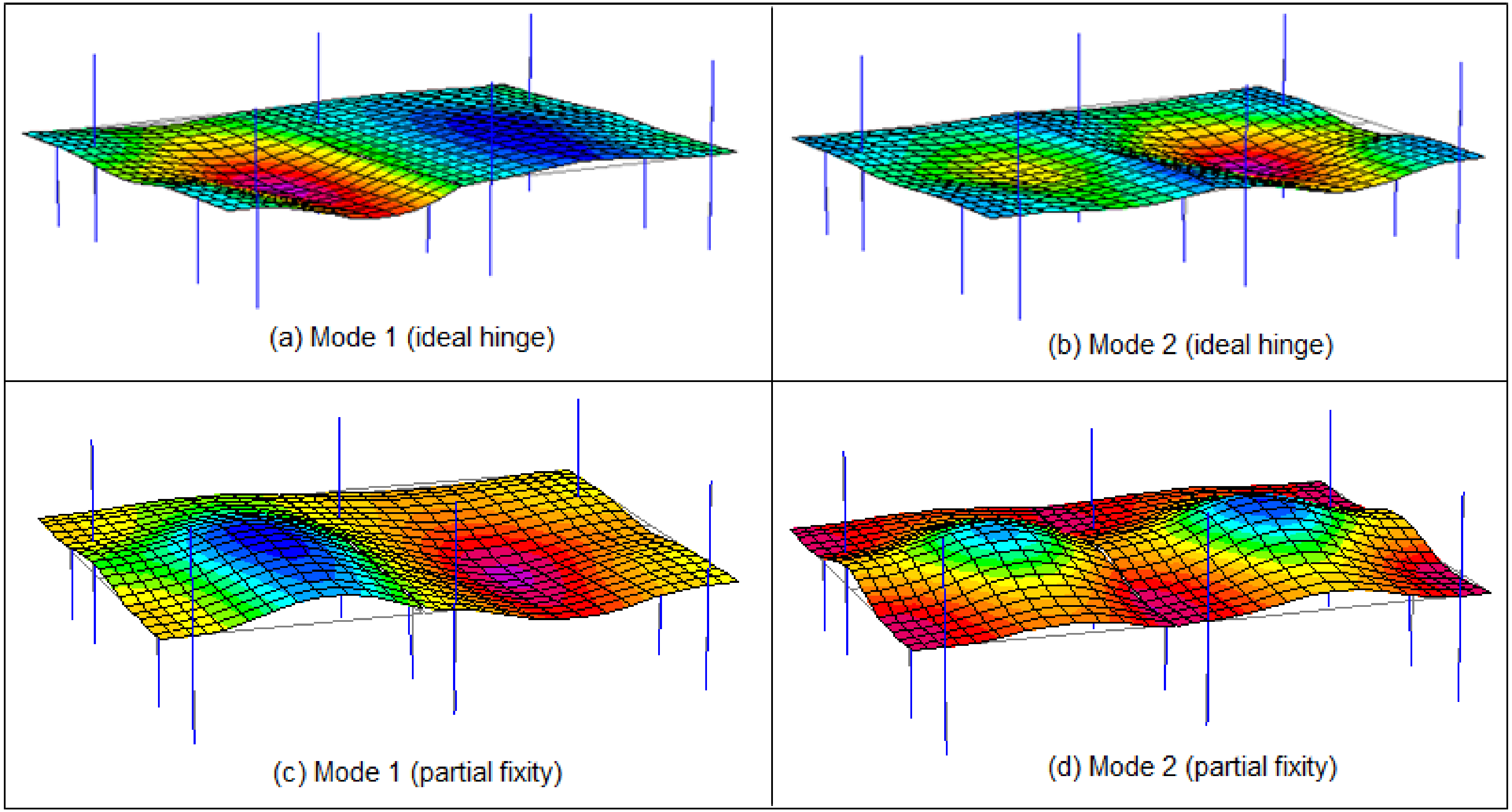
Two modelling features were investigated:

- Continuity conditions at movement joint: ideal hinge vs partial fixity
- Use of Young modulus of elasticity of concrete in dynamic analysis of floor systems.



- Ideal-hinge: all vertical-displacement constraints with no bending stiffness
- Partial-fixity: some vertical-displacement constraints were replaced by rigid-body constraints which allows for the transmission of bending moment

FE MODELLING



(a) Mode 1 (ideal hinge)
(b) Mode 2 (ideal hinge)
(c) Mode 1 (partial fixity)
(d) Mode 2 (partial fixity)

The mode shapes resultant from the FE models with partial fixity are more consistent with the measured mode shapes. The mode shapes acquired from the models with ideal hinges do not show a considerable transmission of vibration between the two bays, which is somewhat different from what was observed in the EMA testing.

FE MODELLING

Floor natural frequencies (Hz)

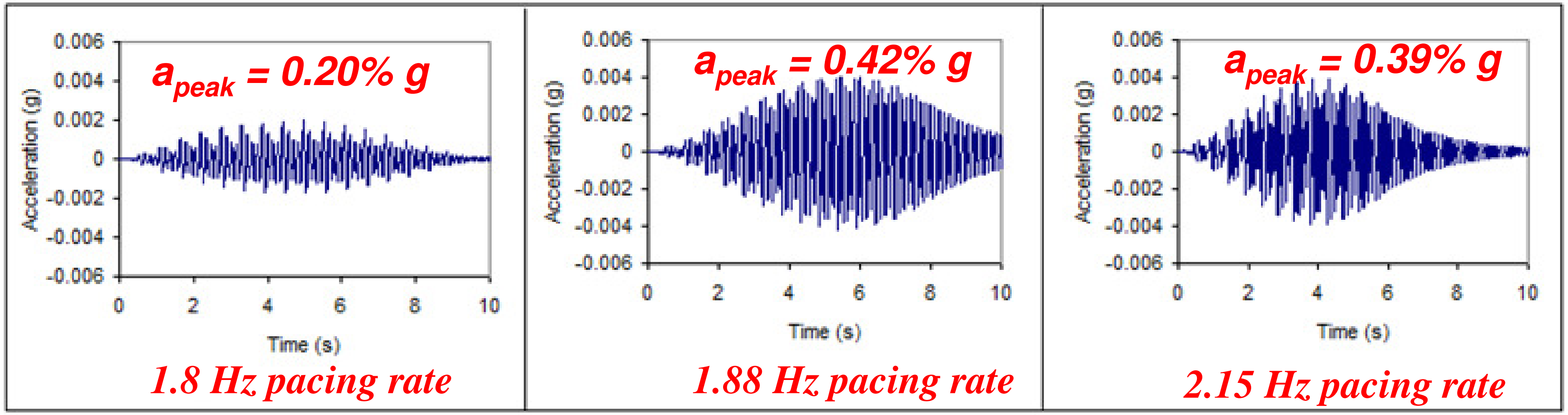
	FE modelling				Experiment
	Ideal hinge		Partial fixity		
	using E_c	using $E_{c,dyn}$	using E_c	using $E_{c,dyn}$	
Mode 1	6.45	7.42	6.57	7.53	7.63
Mode 2	7.04	8.08	7.45	8.58	9.13

- AS3600-2009: for 40 MPa concrete, E_c = 32800 MPa
- Floor vibration guide lines (e.g. AISC DG11): $E_{c,\,dyn} = (1.1\text{–}1.35)E_c$
- The FE-predicted natural frequencies given in the table above were based on E_c= 32800 MPa and $E_{c,dyn}$= 44000MPa

FE MODELLING

FLOOR RESPONSE TO SINGLE PERSONS WALKING

(using FE model with partial fixity and concrete dynamic modulus $E_{c,dyn}$)



ARBITRARY NORMAL PACING RATE

NORMAL PACING RATE WHOSE 4TH HARMONIC MATCHES FLOOR FIRST FREQUENCY (7.53 Hz)

FAST PACING RATE WHOSE 4TH HARMONIC MATCHES FLOOR SECOND FREQUENCY (8.58 Hz)

CONCLUDING REMARKS

- Whilst sophisticated modal testing with shaker excitations and accelerometer relocation can provide valuable information about the floor modal properties including the mode shapes, adoption of a much simpler heel drop test requiring only one or a few response measurement points can be very instructive.
- Whilst most current guidelines provide calculation methods for floors subjected to single persons walking, an opportunity to investigate people walking in pairs has been presented in this paper. People walking in pairs were found to increase the footfall response due to single persons by a factor of about 1.43
- An FE model that accounts for an increase in the concrete modulus of elasticity and the presence of partial bending stiffness at the movement joint appears to agree well with measurements.