The Role of Low-cost Vibration Measurement Systems in Bridge Health Monitoring Applications

- Example of Pedestrian Bridges

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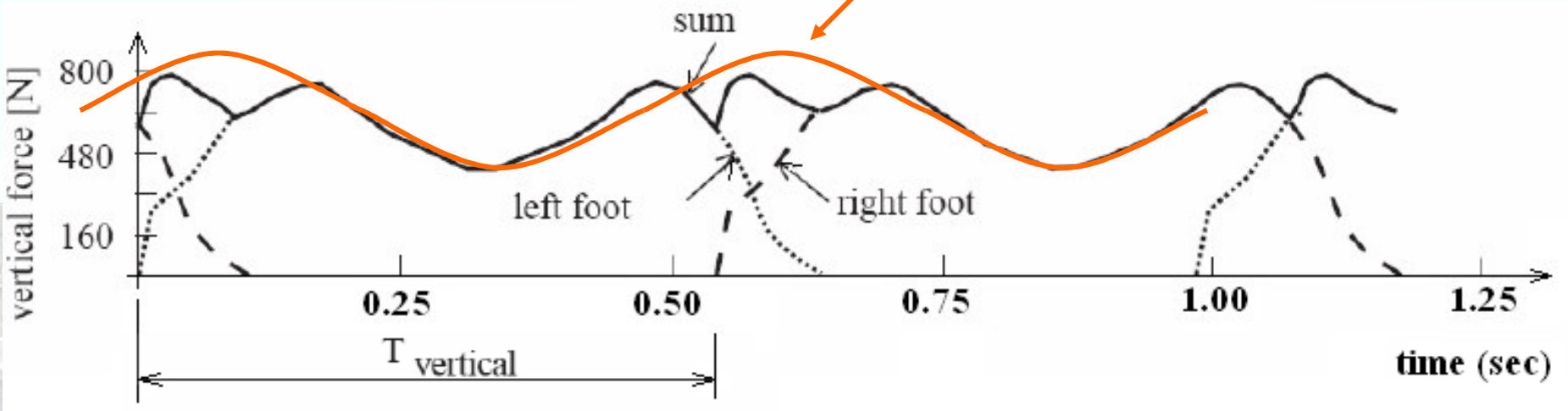
AS5100.2 (2004) Bridge Design - design loads quotes:

"For pedestrian bridges with resonant frequencies for vertical vibrations inside the range 1.5Hz to 3.5 Hz, the vibration of the superstructure shall be investigated as a serviceability limit state".

$$F_p(t) = G + 0.4G\sin(2\pi i f_p t)$$



Shape of human-induced vertical force trace from walking (Zivanovic et al. 2005)

$$F_p(t) = G + \sum_{i=1}^{n} G.\alpha_i.\sin(2\pi i f_p t - \phi_i)$$

More than one pedestrian ?

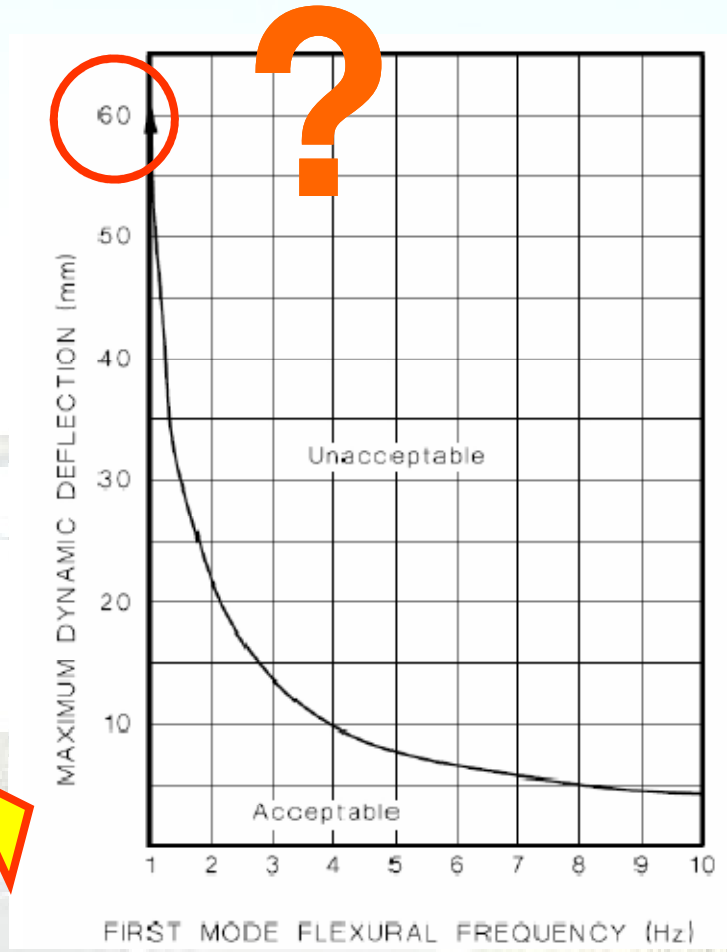
Synchronised ?

Matsumoto:
If arrival times of pedestrians on bridge is random
***n* pedestrians on the bridge →** $m = \sqrt{n}$
pedestrians synchronised to the bridge

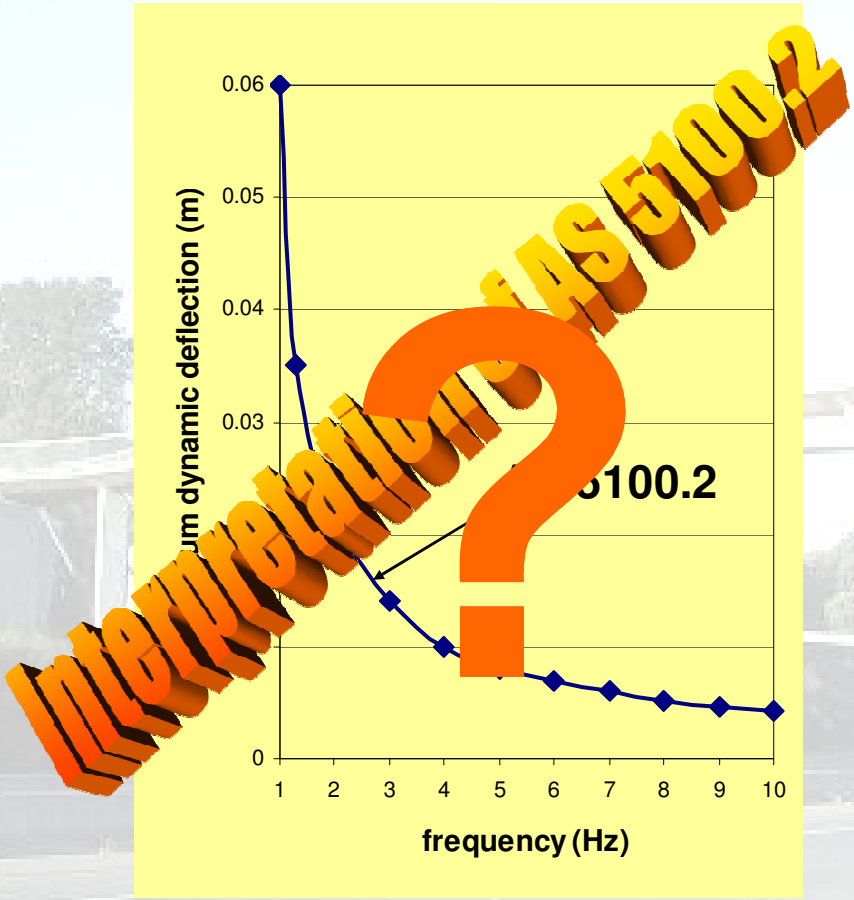
Vibration Acceptability Limits ?

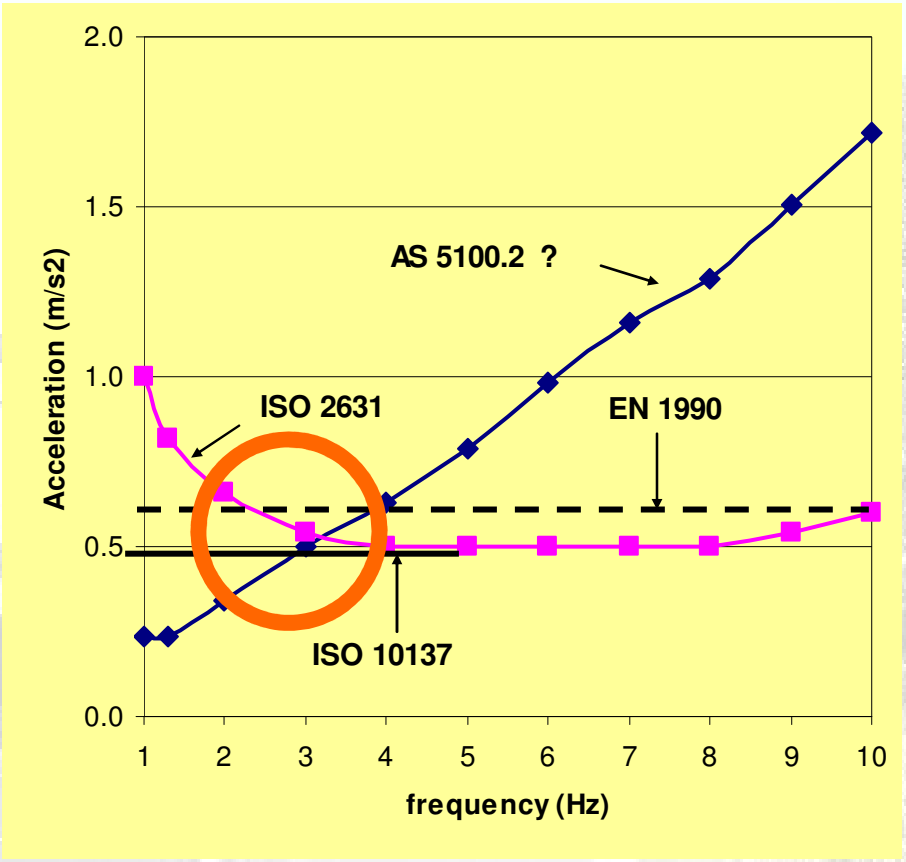
Design Standard Identification	Acceleration Limit a_{max}
ISO 10137	$a_{max} < 5\%g$ *(1-5Hz)*
ISO 2631	$a_{max} < 5\%g$ *(4-8Hz)* *logarithmic elsewhere*
Eurocode EN 1990	$a_{max} < 0.7$ m/s^2 *all frequencies*
BS 5400-2	$a_{max} < 0.5\sqrt{f_o}$ m/s^2 $f_o < 5$ Hz no limit for $f_o > 5$ Hz
AS 5100.2 (2004)	Deflection curve *(see Fig. 2)*

Table I Acceleration response limits for human-induced excitation of pedestrian bridges



Vibration Acceptability Limits ?





5%g – "rule of thumb" *(corresponds to ISO 10137)*

Questions ?

1. *What are the vibration characteristics like of the pedestrian bridges along Melbourne's Eastern freeway?*
2. *How well do their pedestrian-induced vibrations satisfy Acceptability Limits ?*

The 6 Pedestrian Bridges along the Eastern Freeway

The Six Bridges

Trenerry Cres. - Abottsford (Bridge#1)

Four span curved beam (slight) on pier

Estelle Street - Bulleen (Bridge#2)

Three span curved beam on pier

Heyington Ave. - Doncaster (Bridge#3)

Steel frame, timber deck cable stayed type

Eram Rd. - Doncaster (Bridge#4)

Single span tapered frame

Joseph St. - Blackburn Nth. (Bridge#5)

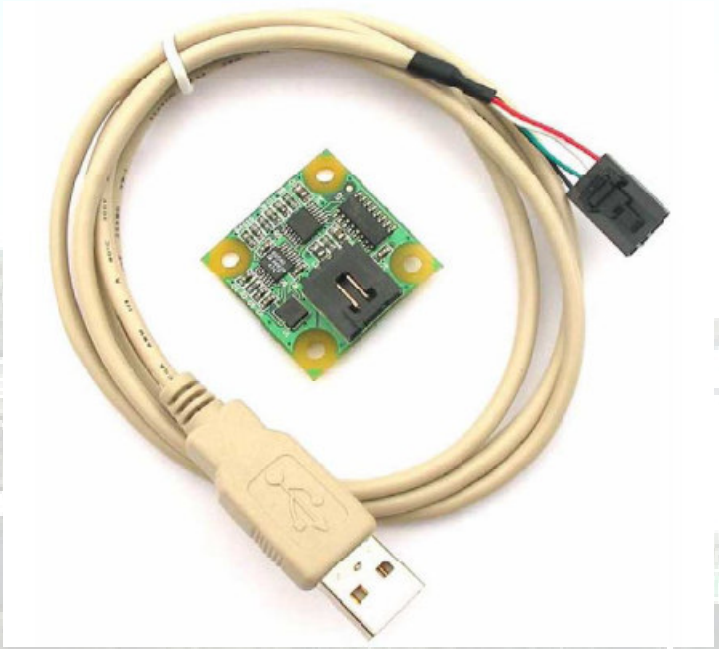
Arch over, inclined stringers

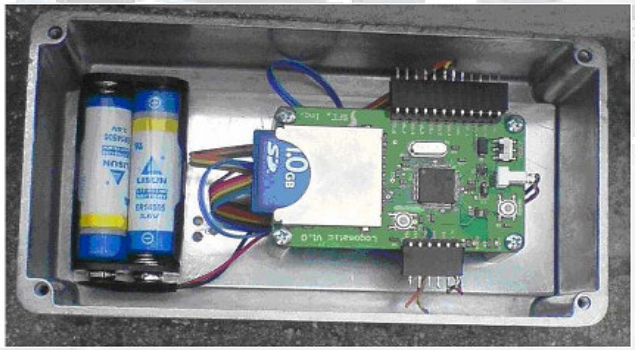
Cabena St. - Donvale (Bridge#6)

Arch under, braced vertical deck support

Instrumentation

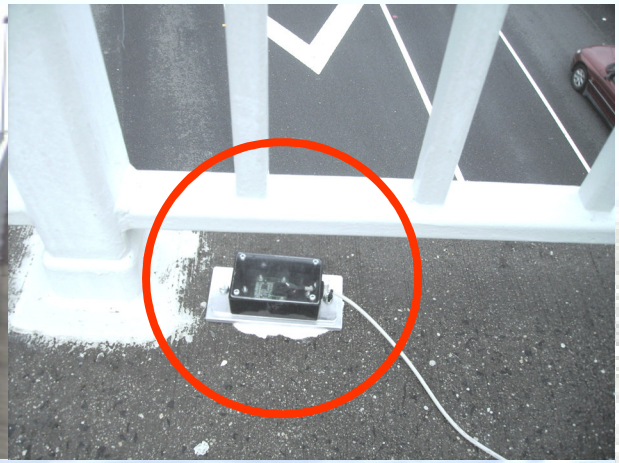
Phidgets 3-axis accelerometer



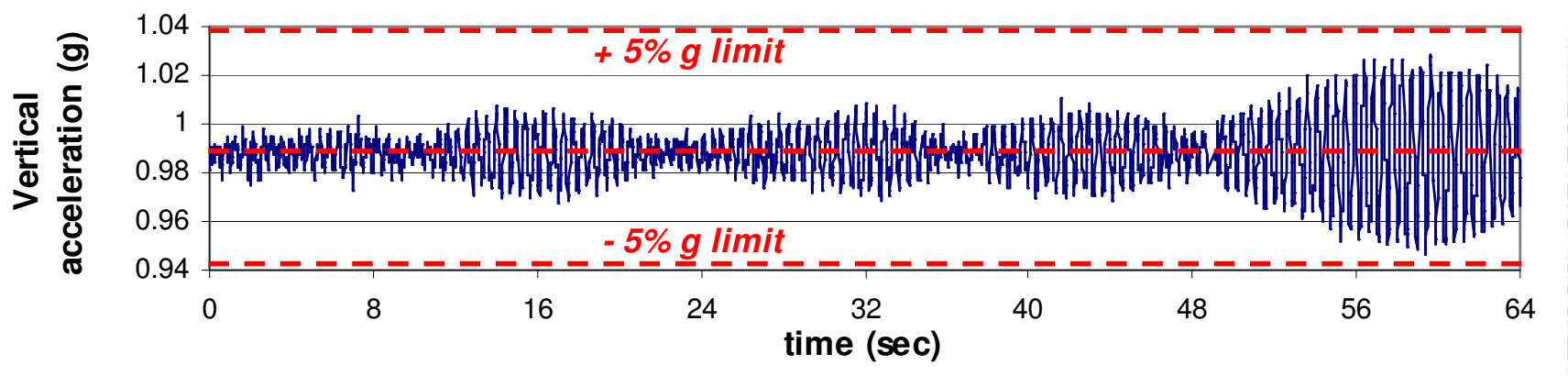


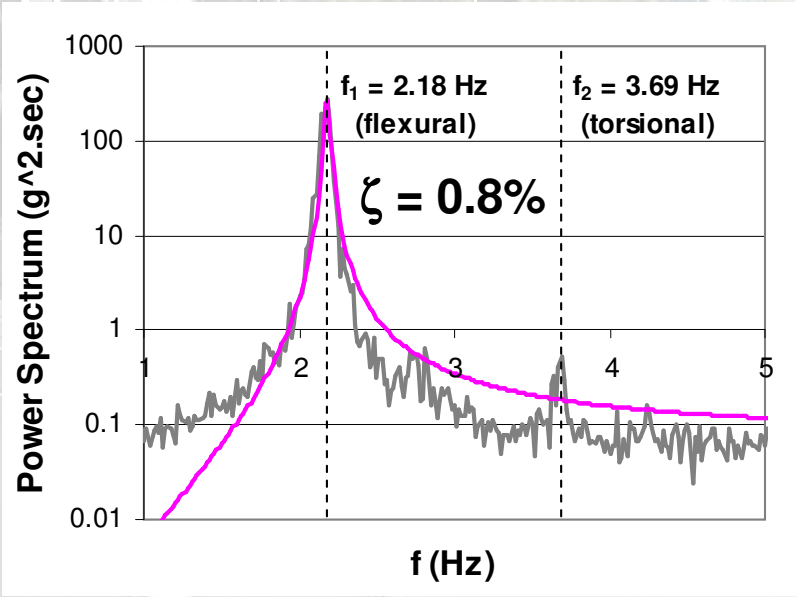
SparkFun Logomatic Datalogger

Instrumentation



Typical Data Capture – Bridge#1





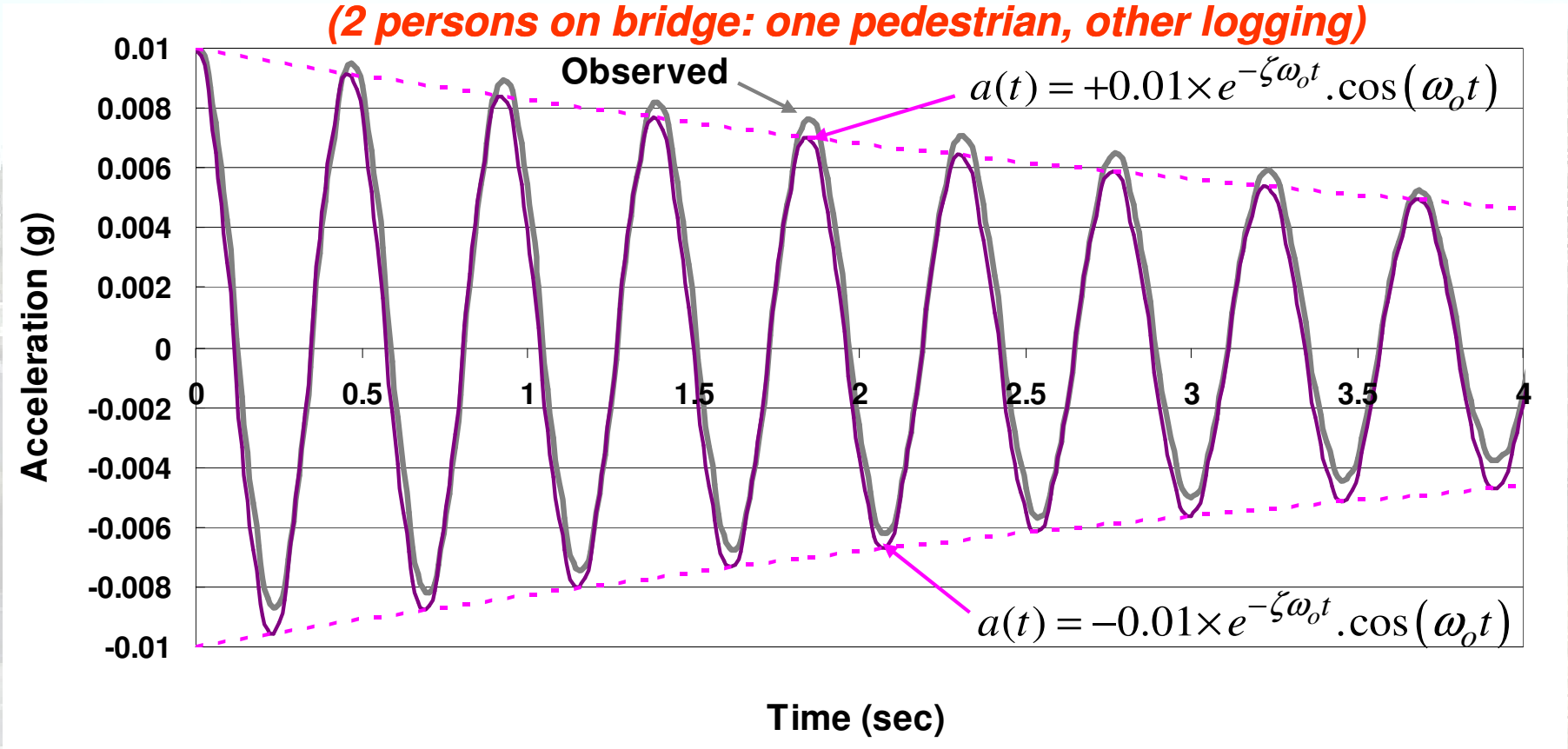
Spectral Fit of Inertance Function (“*white-noise input energy at resonance*” assumption)

Results from Pilot Test Series (Spectral fitting approach)

Bridge (#)	f_o (Hz)	ζ (% crit.)	Acc. limits (% g)
1	2.18	0.8	4
2	1.95	1.4	2
3	2.84	0.6	5
4	3.05	1.0	2.5
5	2.73*	1.5	3
6	2.75	0.6	3

** later identified to be torsional mode*

Results from "Follow-on"Test Series (RanDec fitting approach)



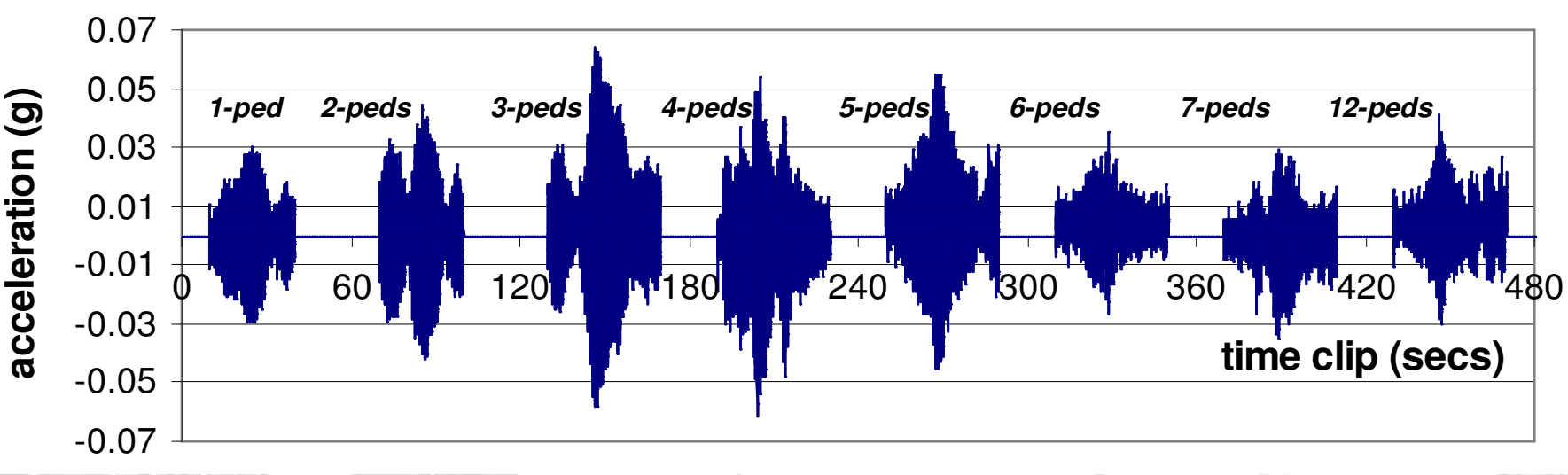
$f_o = 2.17$ Hz; $\zeta = 1.4\%$

Results from "Follow-on" Test Series
(Comparisons: Spectral/RanDec fits)

Bridge (#)	f_o (Hz)	ζ (% crit.)	Acc. limits (% g)
1	2.18, 2.18 (2.17)	0.8 (1.4)	4.5
2	1.94, 1.94 (1.94)	1.2 (1.9)	3
4	3.03, 3.05 (unreliable)	1.3 (unreliable)	2
5	4.02, 4.02 (4.00)	0.6 (0.7)	2

"(..)" – obtained from RanDec Method

Multiple Pedestrians on Bridge#1

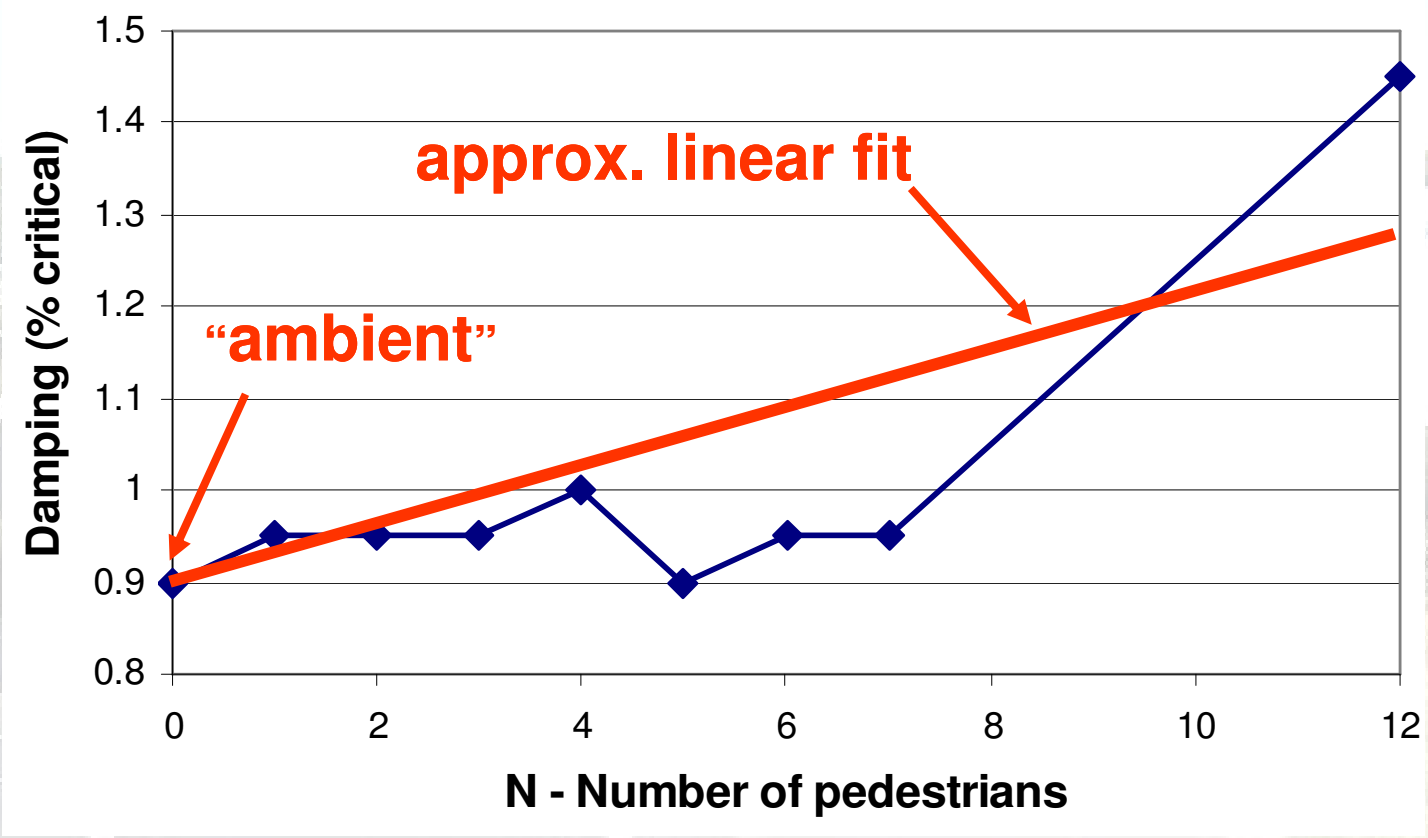


Why the "drop" in response level ?

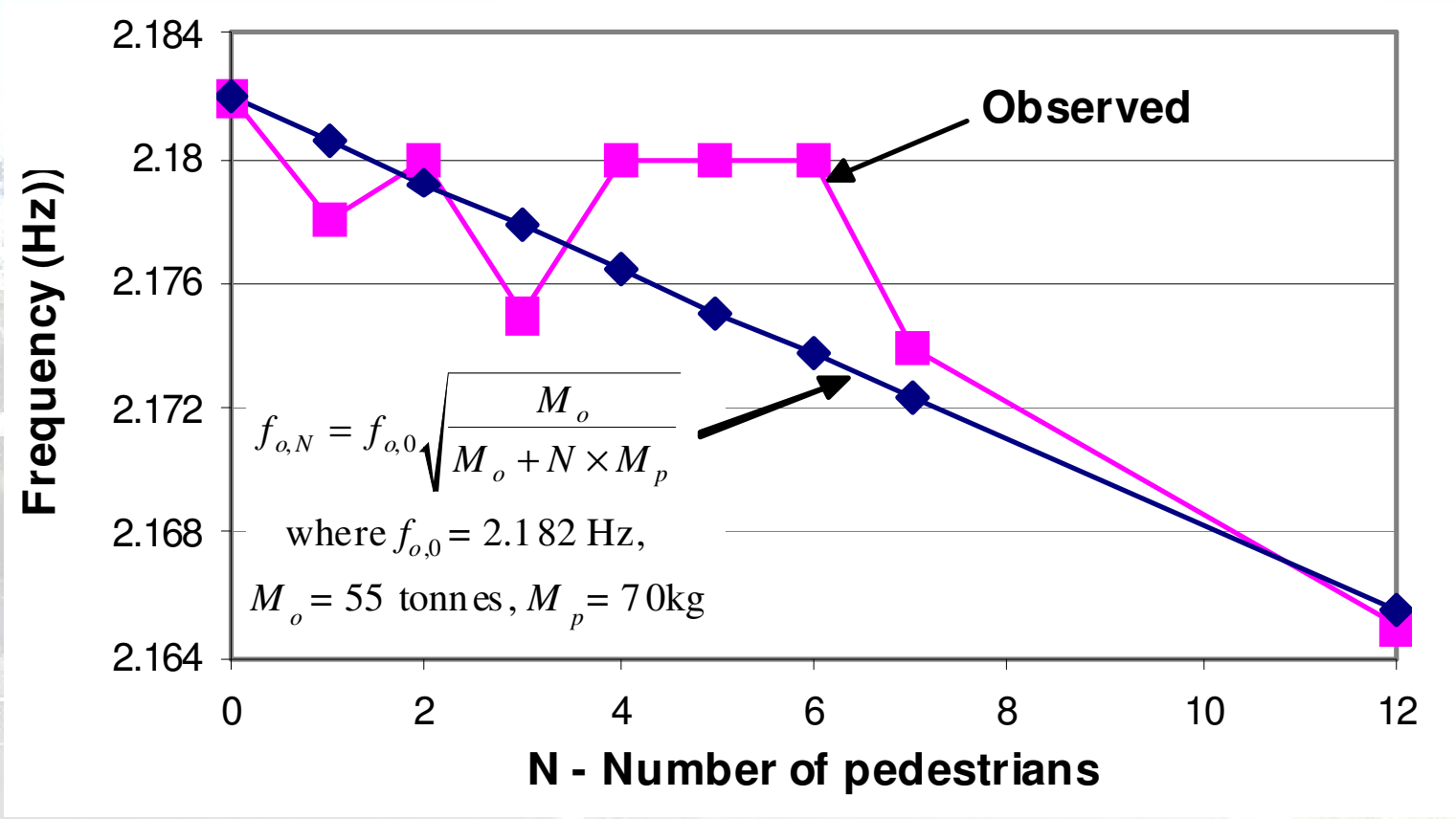
- *spreading over span of pedestrians as number increases*
- *the inability to synchronise pacing over the bridge*
- *increase in overall damping level of the bridge due to the pedestrians themselves, amongst others*

(not able to be captured by a simple factor on the single pedestrian response as implied by Matsumoto Eq (4)).

Multiple Pedestrians on Bridge#1
(damping due to pedestrians)



Multiple Pedestrians on Bridge#1
(frequency due to pedestrians)



Concluding Remarks

Field testing of all 6 pedestrian bridges over Melbourne's Eastern Freeway:

- *fundamental mode frequencies generally in the so-called "troublesome" range (1.5 - 3.5 Hz),*
- *observed peak response accelerations < 5%g threshold limit (despite generally relatively low damping levels of < 1% critical)*
- *response characteristics of bridge#1 under multiple pedestrian excursions were found to be rather complex and did not follow theoretical response factor of Eq. (4).*
- *Chart in AS5100.2 needs to be revisited in terms of applicability to seviceability limits*

Acknowledgements

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