Vertical Natural Frequencies of Six Concrete Footbridges in Bangkok Measured with a Low-Cost Accelerometer

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Abstract

The vertical frequency of a footbridge matters when it is near walking pace. The author found no published measurements of Bangkok's concrete overpasses. Six concrete pedestrian overpasses on two Bangkok roads were measured using a low-cost MPU-6050 accelerometer and an Arduino Uno R3. Fifteen-minute ambient recordings, ground controls at the stair base and heel drops were taken. A peak counted only if it was at least 10 times stronger than at the ground (a rule fixed beforehand), and the prediction $f \approx 80/L$ (L = span) was sealed before the first recording. The frequencies of the six bridges ranged from 2.98 to 5.19 Hz, all inside the sealed ranges. Five bridges passed the ground check (32.0x to 113x), but bridge03 was unconfirmed (8.1x). The mean of $f \times L$ was 80.9, compared with 80 predicted, and the span fit gave a slope of −1.19 (95 % range −1.63 to −0.75), which is consistent with deck depth growing with span. No bridge was in the walking band (1.6 to 2.4 Hz); five were below 5 Hz, where a comfort check is required, and three were in the band of twice the walking pace (3.2 to 4.8 Hz). The damping ranged from 0.55 to 1.20 % where at least 5 drops were usable; these values are indicative only, because amplitude was not validated. A low-cost sensor with a ground rule fixed beforehand confirmed the first vertical frequency at five of the six bridges; the main limits were six bridges on two roads, paced spans and a noise floor of about 1 mg.

Keywords: footbridge, pedestrian overpass, natural frequency, ambient vibration, MEMS accelerometer, MPU-6050, damping ratio, concrete, low-cost sensing, a priori prediction, Bangkok

1 Introduction

Concrete pedestrian overpasses cross Bangkok's wide roads; the bridges in this study cross six lanes on Charoen Nakhon Road and eight lanes on Ratchadaphisek Road. The vertical frequency of a footbridge matters because walking pace is about 1.6–2.4 Hz (1); a bridge with a frequency near that range, or near twice it (3.2–4.8 Hz), can be made to vibrate by footsteps, which affects comfort. Published guides describe these ranges: the Sétra guide (1) gives risk ranges by frequency, and European guidance (EN 1990, Annex A2, as reported in (2)) requires a comfort check for vertical frequencies below 5 Hz.

In ambient testing, the vibration caused by traffic, wind and walkers is recorded, and the natural frequency is taken as the peak of its spectrum. Heel drops can also be used to make the bridge ring, and the rate at which the ringing dies away gives the damping. Wang et al. (3) found the same frequency (3.35 Hz) from heel drops and from ambient recordings. A study in Seoul (4) used phone-based jump tests on 30 steel footbridges; low-cost MEMS accelerometers, such as the MPU-6050, can also be read by an Arduino. A survey in Beijing (5) measured 37 footbridges and reported the results by frequency band.

The author found no published measurements of Bangkok's concrete overpasses; an unpublished study for the Bangkok Metropolitan Administration (BMA) was reported. This study set out to measure the first vertical frequency (and, as an indication only, the damping) of six overpasses with an MPU-6050 and an Arduino, and to test predictions made beforehand. The predictions were based on a simply supported beam with depth $h = L/20$, which gives $f \approx 80/L$. These predictions and three hypotheses (H1–H3) were written and committed on 14 October, six days before the first recording. All code and data are in a public repository (see Data availability).

2 Materials and Methods

2.1 Hardware

An MPU-6050 three-axis MEMS accelerometer (InvenSense, USA), mounted on a GY-521 breakout board (generic, purchased online via Lazada, Thailand), was used to measure the vibration; its headers were soldered on by hand. The board was connected to an Arduino® Uno R3 (Arduino, Italy) with four jumper wires (VCC to 5 V, GND to GND, SDA to A4, SCL to A5), and the I²C clock was set to 400 kHz. The GY-521 has its own 3.3 V regulator, so a 5 V supply is safe to use. The sensor was set to a ±2 g range (16 384 counts per g, about 61 µg per count). It recorded 200 samples per second and used its built-in low-pass filter at 21 Hz. This filter was used because it strongly reduces vibration faster than about 21 Hz, well below the 100 Hz limit for 200 samples per second (the Nyquist frequency), so fast vibration was unlikely to show up as a false slow peak (aliasing). Each sample was stamped in microseconds by the Arduino, and the gap between samples was kept by a timer rather than a fixed delay, so reading and printing time did not stretch it. The data were transmitted through a USB cable to a MacBook® (Apple, USA) at 115 200 baud; the same USB cable powered the Uno. A Python script then saved each recording as a CSV file (time plus three axes, in counts). To confirm that

the sensor was working in each run, the logger asked the chip for its ID (the WHO_AM_I register) at start-up, and every recording that contained data began with "WHO_AM_I ok (0x68)".

2.2 Bench checks

Before any bridge was recorded, five bench checks (B1–B5) were carried out on a table. Each had a pass rule written down before its result was seen, except that the rule for B5 was written after its first run, but before the second run was analysed. B1 tested whether the chip responded: it had to return its ID, 0x68. On 26 September the chip did not respond on the first two start-ups because two solder joints (VCC and GND) were poor; after these were re-soldered, B1 passed. It failed again on 12 October because the SDA solder joint had lifted; after re-soldering, it passed, and it was then confirmed before every recording through the logger's start-up message. B2 tested whether each axis read gravity correctly. The board was placed in six positions (each axis pointing up and down), and each reading was expected to be 1 g (16 384 ± 800 counts) or 0. B2 was done once, on 26 September, with the values read by eye. X and Y passed, but Z was offset by about −1 550 counts (about −95 mg), outside the manufacturer's ±80 mg limit (6), so Z failed. B2 was not repeated with recorded files. This failure did not affect the frequency results, because a constant offset does not change when the signal rises and falls: the average is removed before the spectrum is calculated, and the frequency comes from the timing. B3 measured how much noise the sensor had at rest. The board was kept still on the table for 60 s, and the standard deviation of each axis was found. On x (the axis used on the bridges) it was 16.8 counts on 26 September and 16.5 counts on 14 October (about 1.0 mg); on z it was 26.3 and 26.2 counts (about 1.6 mg). The pass rule was under 60 counts, so B3 passed on both days, and the noise level was repeatable. B4 checked whether the samples were taken at a steady rate, using the same recordings as B3. The median gap was 5 000.0 µs (5 000 µs expected), all gaps were within ±500 µs, the smallest and largest gaps were 4 992 and 5 008 µs, and no samples were dropped, so B4 passed on both 26 September and 14 October. B5 checked whether the sensor measured a known frequency correctly. The sensor was hung as a pendulum with L = 0.24 m, for which theory gives 1.018 Hz, and the pass rule was a measured frequency within ±0.05 Hz of this value. Five runs were done and all were kept. Runs 2–5 gave 1.163–1.170 Hz, repeatable to about 0.4 %, but 14–15 % above theory, so B5 did not pass. The failure was then investigated: ten swings were timed with a stopwatch six times, giving a mean of 8.51 s, or about 1.18 ± 0.02 Hz. This agrees with the sensor, not with theory, so the pendulum swung faster than simple theory predicts, possibly because of the wires and floss in the rig; this was not tested. B5 therefore still counts as not passed. All frequencies and check results are reported, including the B5 result. Amplitude was not validated, so the damping values are only indicative.

2.3 Sites and spans

Six concrete pedestrian overpasses in Bangkok were measured. Four were on Charoen Nakhon Road; these cross six lanes as a single span with no middle column (bridge03–06). Two were on Ratchadaphisek Road; these cross eight lanes and each has a middle column, giving two spans of about 17 m each (bridge01–02). The bridges were chosen on 13 October, before any recording.

They were selected for travel time (the main reason), an even 4 : 2 split between the two roads, and the absence of large signs, because signs add mass and their panels can sway and add a peak of their own. Because the two span groups were on different roads, the effect of span could not be separated from design differences between the roads; this was written down before any data were recorded. The sensor was placed at midspan; on the Ratchadaphisek bridges, it was placed at the middle of one of the two spans, not over the middle column. On 13 October, two methods were used to measure the spans: the iPhone Measure app and Apple Maps. However, both proved unreliable: the phone overheated and the app would not lock onto the surface, the maps gave only whole metres and could not show the column faces, and the readings for one bridge disagreed by 3 m. All of these readings were kept in the data file but were not used. The plan sealed beforehand was to measure each span the day before recording. However, because both methods failed, the spans were paced after all recordings instead. The final spans were therefore measured by pacing heel to toe, with a foot-plus-shoe length of 30 cm (checked repeatedly). Each bridge was paced three times, with the same count every time; bridge05 was paced on 3 November and the others on 10 November, after all recordings had been completed. The uncertainty of this method is about ±0.3 m. The span was defined as the distance from the inner face of one support column to the inner face of the other (the clear span), for all six bridges. This definition was written down on 10 November, before any span-based analysis, and was not changed afterwards. The outer-to-outer distance equals the inner span plus 0.6 m, taking all columns, on both roads, as 30 cm wide. The spans are listed in Table 1. They were paced, not surveyed, and no published lengths were found for these bridges (online search, 24 October), so they rest only on these measurements.

2.4 Field procedure

Four recordings were taken at each bridge, in this order: an orientation check (10 s), an ambient recording (900 s, or 15 min), a decay recording with heel drops (300 s) and a ground control (300 s). Field days ran from 20 October to 1 November 2026, and some bridges took more than one session. The sensor was taped to the deck at midspan, standing on its edge because there was no flat surface, with one strip of double-sided tape laid flat underneath. Since the board kept coming unstuck, from 25 October onwards the cable was also taped to the deck behind the board with double-sided tape, so that its weight did not pull on the sensor. From 30 October, at bridge06, green Scotch® Strong Outdoor mounting tape (3M, USA), an acrylic foam tape, was used instead; it held the board without unsticking, so the cable was no longer taped. The sensor was kept in shade where possible (with an umbrella on Ratchadaphisek Road), but most recordings were made in the early morning, before the hottest part of the day. The 10 s orientation file read $x \approx -16\,600$ counts (about −1.01 g, meaning that gravity acted along x), which confirmed that x was the vertical axis. This was the same at every bridge, so x was analysed everywhere. The ambient recording lasted 15 minutes with no deliberate excitation; traffic below, wind and passing pedestrians shook the bridge. The laptop was kept awake for the whole recording with the macOS caffeinate command. The decay recording lasted 5 minutes and contained 5 or 6 heel drops (rising onto the toes and dropping onto the heels), made no more than 1 m from the sensor and about 40 s apart. The drops were scheduled about every 40 s, and for most recordings the

number of drops and any pauses were noted. Only detections that fitted this record were counted. The ground control used the same sensor and orientation (x vertical), placed on the base of the stairs at ground level, for 300 s. This position was chosen because every bridge has one. The stair base is still attached to the structure, so any bridge vibration reaching it makes the 10x ground test harder to pass, not easier. On Charoen Nakhon Road, recordings were made mostly in the early morning, at about 06:20–08:10, to avoid heat and crowds, although one decay recording (bridge04, 1 November) was made at 09:24. On Ratchadaphisek Road, recordings were made in the afternoon of 20 October, at about 14:35–16:40. Weather, wind, people on the bridge and traffic were noted for each session. When the board came loose or moved, or a recording was stopped early, the file was kept, not renamed or deleted, and the reason was logged. Repeat recordings and the reasons for them were also logged.

2.5 Analysis

Part A: frequency and ground check

The analysis used Python 3.14 with NumPy 2.5.4, SciPy 1.18.1 and Matplotlib 3.11.2. The official runs were made by the author on his own computer on 10 November 2026 (and on 20 November for the second bridge05 decay), and all code is available in the public repository. To prepare each recording, the x axis was converted from counts to g (÷ 16 384) and its average was removed. The true sample rate was measured from the timestamps instead of being assumed to be 200 Hz. The spectrum was calculated with Welch's method (7): the recording was cut into pieces of 4 096 samples (about 20.5 s each), each overlapping the next by half and smoothed at its ends with a Hann window, and their power spectra were then averaged. Averaging smooths out random noise, while a steady vibration remains as a peak. The frequency resolution was about 0.049 Hz. The natural frequency was taken as the tallest peak between 1 and 20 Hz, refined between the 0.049 Hz steps by fitting a parabola through the top three points. Its uncertainty was found by bootstrap resampling: the pieces were resampled 1 000 times with replacement, and the peak was found again each time. The middle 95 % of those 1 000 values (the 2.5th to 97.5th percentiles) is reported as the 95 % range. A fixed random seed was used, so the same file always gives the same range. A limitation of this range is that the pieces overlap, so they are not fully independent, and the range may be slightly too narrow. The spectrum of the control recording was computed in the same way. The ratio was calculated as the bridge power divided by the ground power, both taken within ±1 frequency step of the bridge's peak. A peak counted as the bridge's own only if this ratio was at least 10. This rule was fixed on 14 October, before the first bridge recording, and a bridge below 10 is reported as "unconfirmed", not dropped. The written rule named the pavement as the ground reference; the base of the stairs was used instead, which makes the test stricter, because the stair base is attached to the bridge. Where a bridge had more than one ambient recording (bridge06), the ambient from the same mounting and session as the control was used; this rule was written on 29 October, during fieldwork but before the control result for bridge06 was seen. Bridge03 had only one ambient recording (21 October), which was compared with each of its four controls; the fourth (30 October) was the last, under a stop rule written before it was recorded. The 4 096-sample piece length, the ±1-step

window for the ratio and the 10x threshold were chosen for this study and were not taken from a published standard.

Part B: damping

Damping was measured from the decay recording (x axis, in g, average removed), using the natural frequency f of each bridge from its ambient spectrum (Part A). To separate the bridge's own ringing, a band-pass filter from 0.7f to 1.3f (4th-order Butterworth) was applied. It was run forwards and then backwards, so that it added no time shift. The filter kept the bridge's bounce and reduced footsteps, traffic rumble and sensor noise. A heel drop was detected as a burst in the filtered signal more than 8 times its typical level, with bursts at least 10 s apart. The first version of this rule looked for bursts in the unfiltered signal, where walking, traffic and board drift hid most drops: it found only 0–1 of about 6 drops on the recordings made up to 26 October at bridges 01, 03, 04 and 05. On 26 October, after the data had been seen, the rule was changed to use the filtered signal. The factor 8 and every other setting stayed the same, the change was applied to all bridges, and the count from the old rule is reported alongside. To avoid false detections, a detection counted only if it fitted the drop record from the field (Section 2.4). Each drop was measured from 0.5 s after the burst (after the drop itself), using the successive positive peaks of the ringing until they fell below 3 times the background level or the next drop began. A drop with fewer than 5 such peaks was not analysed. A straight line was then fitted to ln(peak height) against peak number; its slope is −δ, where δ is the logarithmic decrement. The damping ratio ζ was calculated from δ with equation (eq1):

$$\zeta = \frac{\delta}{\sqrt{4\pi^2 + \delta^2}} \approx \frac{\delta}{2\pi} \qquad \text{(eq1)}$$

where ζ is the damping ratio and δ is the logarithmic decrement.

Every usable drop is reported with its fit quality (R^2), with no R^2 cut (decided on 26 October), and the mean and standard deviation are given for each decay recording. A bridge with only one usable drop is reported as "single drop, unreliable", and the factor 8 was not lowered to find more drops. Because amplitude was not validated (B5 not passed), the damping values are indicative only. The settings (the 0.7f–1.3f band, the factor 8, the 10 s gap, the 0.5 s skip, the 3x floor and the 5-peak minimum) were chosen for this study and were not taken from a standard.

2.6 Prediction made before recording

The predictions were written by the author on the morning of 14 October and worked by hand on a calculator, before any bridge recording. They were first committed to the repository on 14 October at 10:44 (commit d556ca3), six days before the first bridge recording (20 October, 14:35), and were never changed afterwards. Each span was treated as a simply supported beam, using equation (eq2):

$$f = \frac{\pi}{2L^2}\sqrt{\frac{EI}{m}} \tag{eq2}$$

where L is the span, E is the elastic modulus, I is the second moment of area of the section and m is the mass per unit length. The model assumed a solid rectangular concrete section with depth h = L/20, E = 30 GPa and a density of 2 400 kg/m³. With these values, the formula simplifies to f ≈ 1 600 h/L², and putting in h = L/20 gives f ≈ 80/L, as in equation (eq3):

$$f \approx \frac{1600\,h}{L^2} = \frac{80}{L} \tag{eq3}$$

Each prediction was given a range from 0.8 to 1.25 times its value, because the true frequency could be lower or higher. It could be lower because railings, roofs and finishes add mass but little stiffness, and higher because real beams may be T-shaped or hollow, which makes them stiffer for their weight. Using the spans planned before measurement, the predictions were 3.2 Hz (2.56–4.0 Hz) for the 25 m Charoen Nakhon bridges and 4.71 Hz (3.76–5.875 Hz) for the 17 m Ratchadaphisek bridges. Three hypotheses were stated, each with a condition that would prove it wrong. H1: every bridge would be between 2 and 6 Hz (wrong if any bridge fell outside this range). H2: some bridges would be below 5 Hz, where a comfort check is needed, but none would be inside the 1.6–2.4 Hz walking band (wrong if all six were above 5 Hz, or if any was inside 1.6–2.4 Hz). H3: the 17 m bridges would be faster, with f(17 m)/f(25 m) ≈ 1.46 as written in the sealed file, though the exact ratio of the two predicted values is 1.47 (wrong if the 17 m spans were not faster). The span fit was a least-squares straight line through $\log_{10} f$ against $\log_{10} L$ for all six bridges, using the measured spans. The slope is reported with a 95 % range from the t-distribution (4 degrees of freedom) on its standard error, together with R². The slope implied by the prediction is about −1, because f ≈ 80/L; for comparison, a beam of fixed depth would give −2. The sealed test of span was H3, the ratio. The fitted slope was already in the analysis code before any bridge data (committed on 9 October), and it is compared with the slope of −1 implied by the prediction.

3 Results

Each of the six ambient recordings used ran for 15 min at a measured 200.000 Hz, with no dropped samples (179 864–179 881 samples each). The frequencies are listed in Table 1 and range from 2.977 Hz (bridge06) to 5.187 Hz (bridge01); each 95 % range is at most 0.04 Hz wide. Figure 1 shows a typical spectrum (bridge05, bridge compared with ground). The frequencies of all six bridges fell inside their sealed predicted ranges (Table 1). H1 (all bridges between 2 and 6 Hz) and H2 (some below 5 Hz, none in 1.6–2.4 Hz) were not contradicted; only bridge01 was above 5 Hz. Five of the six bridges passed the ground check, with ratios from 32.0x to 113x. Bridge03 gave 8.1x, which is below 10, so its peak is unconfirmed. Bridge03 had four full controls, with ratios of 1.4–1.6x (people stepping on the base), 6.6x (board creeping), 0.7x (board came loose once) and 8.1x (clean, board steady); the stop rule then applied, and no more controls were recorded. For H3, the mean frequency of the 17 m group (4.964 Hz) divided by that of the 25 m group (3.197 Hz) gave a ratio of 1.55, compared with the predicted 1.46. The

17 m bridges were faster, so H3 was not contradicted; without bridge03, the ratio was 1.58. The span fit gave a slope of −1.19 (95 % range −1.63 to −0.75) with $R^2 = 0.93$ (Figure 2). Without bridge03, as decided before the official run, the slope was −1.21 (−1.80 to −0.62). The product f × L ranged from 75.6 to 91.7, with a mean of 80.9 (bridge01 91.7, bridge02 79.6, bridge03 81.0, bridge04 81.3, bridge05 75.6, bridge06 76.1), compared with 80 predicted. The damping results are listed in Table 2. Bridge02 had the highest damping, 1.20 ± 0.12 %. Where at least 5 drops were usable, the other bridges ranged from 0.55 to 0.80 %. Bridge04 had single drops only (0.46 and 0.54 %, reported as unreliable), and damping could not be measured at bridge06. The damping value for bridge03 is meaningful only if its peak is the bridge's own. The old detection rule found 0–1 drops on most recordings; the two rules agreed only at bridge02 (6 and 6) and on the second bridge05 recording of 31 October (5 and 5). The 31 October file was named bridge04 in error; the author identified it as recorded at bridge05, and its ringing frequency (3.31 Hz) matched bridge05 and not bridge04 (3.16 Hz). The recording of 24 October (about 3.28 Hz) came from a bridge that could not be identified, so it was excluded. All failed attempts are kept in the repository.

Table 1. The six bridges, with their roads, clear spans, measured vertical frequencies and 95 % ranges, periods, ground ratios and sealed predicted ranges.

Bridge	Road	Span (m)	f (Hz)	95 % range (Hz)	Period (s)	Ground ratio	Predicted range (Hz)
01	Ratchadaphisek	17.68	5.187	5.178–5.201	0.193	113	3.76–5.875
02	Ratchadaphisek	16.80	4.741	4.724–4.761	0.211	33.2	3.76–5.875
03	Charoen Nakhon	24.25	3.339	3.334–3.350	0.300	8.1 (unconfirmed)	2.56–4.0
04	Charoen Nakhon	25.73	3.158	3.154–3.162	0.317	32.0	2.56–4.0
05	Charoen Nakhon	22.80	3.315	3.306–3.328	0.302	46.3	2.56–4.0
06	Charoen Nakhon	25.55	2.977	2.973–2.987	0.336	39.7	2.56–4.0

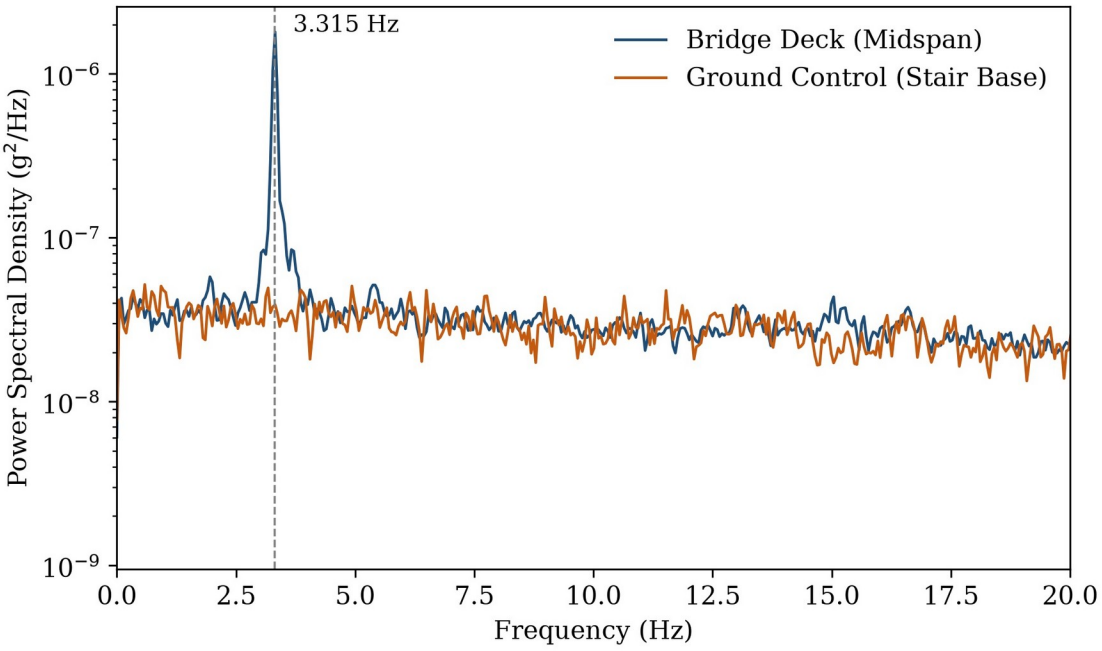

Figure 1 shows the power spectral density of the vertical (x) axis at bridge05: the fifteen-minute ambient recording at midspan (26 October, 06:44) and the ground control at the stair base (26 October, 07:18). The peak at 3.315 Hz (dashed line) was 46.3 times stronger on the bridge than at the ground. The spectra were calculated with Welch's method, using 4 096-sample pieces with a Hann window and half overlap; the vertical axis is logarithmic.

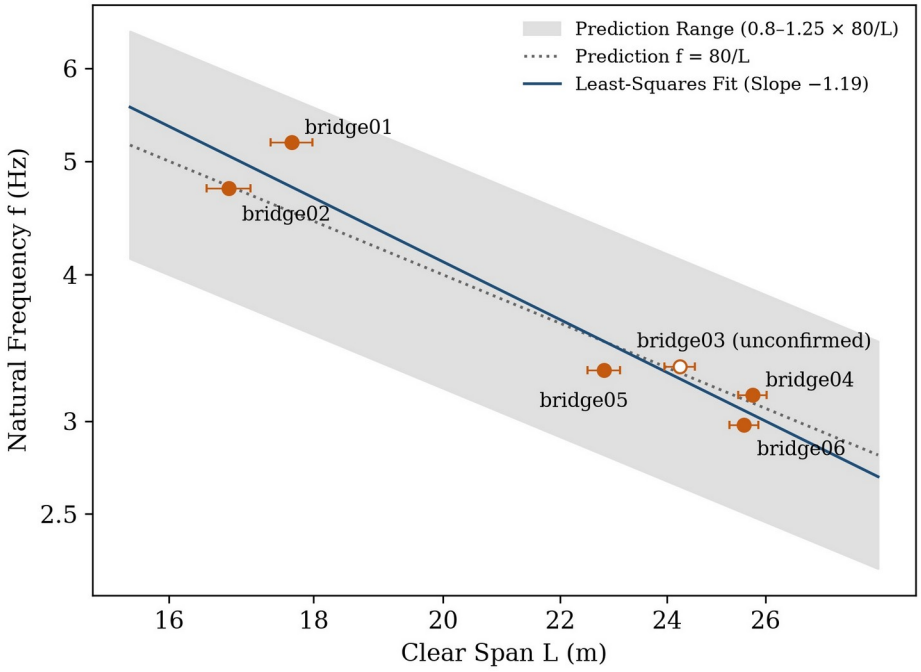

Figure 2 shows the natural frequency against the clear span for the six bridges, on log–log axes. The filled circles are confirmed peaks, and the open circle (bridge03) is unconfirmed (8.1x). The

horizontal bars show the ±0.3 m span uncertainty from pacing. The solid line is the least-squares fit, with a slope of −1.19 (95 % range −1.63 to −0.75) and $R^2 = 0.93$. The dotted line is the prediction f = 80/L, and the grey band is the prediction range (0.8–1.25 × 80/L), drawn at the measured spans; the sealed ranges in Table 1 used the planned spans (25 m and 17 m).

Table 2. The damping of each analysed decay recording, with the drops found by the new and old rules, the usable drops matched to the drop record, the ζ mean ± SD, the ζ range and the R^2 range.

Bridge	Recording	Found (new rule)	Found (old rule)	Usable, matched to drop record	ζ mean ± SD (%)	ζ range (%)	R^2 range
01	20 Oct 15:02	6	1	5	0.55 ± 0.15	0.30–0.68	0.38–0.95
01	20 Oct 15:10	8	1	5	0.60 ± 0.20	0.25–0.71	0.52–0.97
02	20 Oct 16:19	6	6	6	1.20 ± 0.12	1.04–1.35	0.93–0.99
03	21 Oct 07:07	6	0	6	0.80 ± 0.22	0.58–1.12	0.46–0.91
04	25 Oct 06:41	1	0	1	0.46 (single drop, unreliable)	–	0.92
04	1 Nov 09:24	1	0	1	0.54 (single drop, unreliable)	–	0.90
05	26 Oct 07:00	5	1	5	0.66 ± 0.13	0.52–0.85	0.84–0.97
05	31 Oct 07:40 (file named bridge04; recorded at bridge05)	5	5	5	0.73 ± 0.20	0.55–1.08	0.82–0.95
06	30 Oct 07:28	1	0	0	not measurable	–	–

4 Discussion

The author measured six concrete pedestrian overpasses in Bangkok, and their frequencies ranged from 2.98 to 5.19 Hz. All six frequencies were inside the predicted ranges, which were sealed before any recording took place (written and committed on 14 October). H1, H2 and H3 were not contradicted. The mean of f × L was 80.9, compared with 80 in the sealed prediction, and the values ranged from 75.6 to 91.7 (bridge01 was the highest). The span fit gave a slope of −1.19, with a 95 % range of −1.63 to −0.75. This result is consistent with deck depth growing with span (h proportional to L), not with a fixed depth.

The slope should be treated with care. Because the two span groups were on two different roads, the effect of span is mixed with design differences. This was noted before any data were recorded. The four 22.8–25.7 m bridges on Charoen Nakhon Road alone gave a slope of −0.70; their span range is too narrow for this value to mean much. Even between similar bridges, bridge01 was longer than bridge02 (17.68 vs 16.80 m) but 9 % faster (5.187 vs 4.741 Hz). Similarly, bridge03 and bridge05 had almost equal frequencies (3.339 vs 3.315 Hz), although their spans were 1.45 m apart (24.25 vs 22.80 m). The ±0.3 m pacing error cannot explain either case; differences in mass, supports or construction details might, but these were not tested.

The Sétra guide (1) gives the following risk ranges for vertical frequency: 1.7–2.1 Hz, maximum risk; 1.0–1.7 and 2.1–2.6 Hz, medium risk; 2.6–5.0 Hz, low risk; and above 5 Hz, negligible risk. Based on the measured frequencies, bridges 02–06 were in the low-risk range, and bridge01 was in the negligible range. European guidance (2) requires a comfort check below 5 Hz, so it would apply to bridges 02–06. No bridge was in the walking band (1.6–2.4 Hz); however, bridges 02, 03 and 05 were in the band of twice the walking pace (3.2–4.8 Hz). No comfort verdict can be given, because amplitude was not validated (B5 was not passed).

Design guidance (8) gives damping values for reinforced-concrete footbridges of 0.8 % (minimum) and 1.3 % (average). The measured damping was 0.55–0.80 % for the bridges with at least 5 usable drops (01, 03 and 05) and 1.20 % for bridge02. Assuming that the decks are reinforced, not prestressed, concrete, most bridges were therefore at or below the design minimum, although these values are indicative only.

A study in Seoul (4) measured 30 steel footbridges using phone-based jump tests. A similar study in Beijing (5) measured 37 footbridges. It found that bridges under 3 Hz failed serviceability checks, those at 3–5 Hz generally passed, and those over 5 Hz passed easily. In the present study, bridge06 (2.977 Hz) was the only bridge under 3 Hz. Wang et al. (3) used heel drops and ambient recordings, as in this study, and both methods gave 3.35 Hz. In this study, the decays also rang at the ambient frequencies (mean over the usable drops): 3.31 vs 3.315 Hz at bridge05 and 4.76 vs 4.741 Hz at bridge02. No published measurements from Bangkok were found; an unpublished study for the BMA was reported, but no results from it were available for comparison.

The ground rule flagged bridge03 (8.1x, below the threshold of 10); the rule was not changed, and its peak is reported as unconfirmed. A limitation of a low-cost sensor for the ground rule is its noise floor, which was about 1 mg (B3: 16.5–16.8 counts on x), so weak peaks are hard to confirm.

4.1 Limitations

Amplitude was not validated: B5 was not passed, so the damping values are indicative only, and the frequency readout was not confirmed against a known frequency, although the measured sample rate (B4) and the stopwatch check concur with it. The axes were checked in B2 only once, by eye; Z failed (offset about −95 mg), and the check was not repeated. This does not affect the frequencies. The spans were paced, not surveyed, so their uncertainty is about ±0.3 m. The sample was small (six bridges in two groups on two roads), so the results cannot be generalised. The drop-detection rule was changed on 26 October, after the data had been seen; the change was applied to all bridges, and the counts from the old rule are still reported. Too few drops were usable at bridges 04 and 06: one per recording at bridge04 and none at bridge06. The peak of bridge03 is unconfirmed (8.1x). Only one sensor was used, at midspan, and only its vertical axis was analysed, so only the first vertical mode was measured; mode shapes and lateral motion were not. The control was recorded at the stair base instead of the pavement named in the written rule; this made the test stricter, not easier. Commit dates and times are recorded by the

author's own computer, and the repository was private until 19 November, so these dates are not independently verified. The deck section was unknown, and the prediction assumed a solid rectangle; whether the decks are reinforced or prestressed concrete is also unknown.

5 Conclusion

Six concrete pedestrian overpasses in Bangkok were measured with a low-cost MPU-6050 and an Arduino Uno R3, using 15-min ambient recordings, ground controls and heel drops. The first vertical frequencies were 2.98 to 5.19 Hz, all inside ranges sealed before recording. The simple rule $f \approx 80/L$ held on average (mean $f \times L$ of 80.9), and the slope of the span fit (−1.19) is consistent with depth growing with span, although the two span groups on two roads limit this. No bridge was in the walking band; however, five were below 5 Hz and would need a comfort check, and three were in the band of twice the walking pace. No comfort verdict can be given without validated amplitude. The damping was 0.55 to 1.20 % where at least 5 drops were usable, and it is indicative only. Most bridges were at or below the reinforced-concrete design minimum. A low-cost sensor with a ground rule fixed beforehand can find the first vertical frequency, although the noise floor (about 1 mg) left one peak (bridge03) unconfirmed. Validated amplitude (by passing B5), surveyed spans, a larger sample and more than one sensor would all improve the study, as listed in the limitations.

Data Availability

All data and code are available in a public GitHub repository (https://github.com/rydvanaliscratch/bangkok-footbridge-vibration). It includes the raw accelerometer recordings, span measurements, field notes (in the build log), results tables, analysis code and firmware, the sealed predictions, the build log and the AI-use log. The code is released under the MIT licence and the data under CC BY 4.0. The README explains how to rerun the analysis.

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