Benchmark Buildings for an International HFBB Comparison

Introduction

The High Frequency Base Balance (HFBB) (also known as the High-Frequency *Force* Balance (HFFB)), has been widely used as a wind-tunnel tool for determining overall wind loading and dynamic response of tall buildings to wind for twenty-five years. The basic principles have been described by Tschanz (1982) and Boggs (1991).

However, although the same basic principles are applied, a variety of approaches have been used to deal with, for example:

- Treatment of mean and background response
- Calculation of resonant response
- Twist (torsional) modes of vibration
- Nonlinear mode shapes
- Coupled mode shapes
- Closely spaced frequencies
- Combined acceleration components

At a meeting held at the 12th International Conference on Wind Engineering (Cairns, Australia, July 2007), it was agreed that an International HFBB Comparison project should be initiated. Each participating laboratory will be responsible for its own building model fabrication and wind tunnel HFBB tests, and subsequently present results for comparison. Laboratories would not be explicitly named in any reporting of the study.

The following pages describe:

- An ‘advanced’ building specification for more experienced laboratories, denoted as **Building A**.
- A ‘basic’ test building intended primarily for as a benchmark for newer laboratories, denoted as **Building B**.

Although both buildings have a relatively simple geometry with rectangular cross-sections, the 'advanced' building has complex coupled modes, with twist components. The basic building has simple well-separated frequencies with linear mode shapes and uncoupled modes. Both buildings have been developed from previously defined benchmark buildings.

References

1. T. Tschanz. The base balance measurement technique and application to dynamic wind loading of structures. Ph. D. thesis, University of Western Ontario, 1982.
2. D.W. Boggs. Wind loading and response of tall structures using aerodynamic models. Ph.D. thesis, Colorado State University, 1991.

Simulated wind properties

Design full-scale mean wind speed at top of building (both cases): 20, 30 and 40 m/s (assumed uniform with wind direction)
Suburban terrain.
Mean velocity profile: Power law exponent = 0.25
(approximate roughness length z_0 : 0.2 mm)

Longitudinal turbulence intensity at rooftop of building A : 0.131 (±10%)
Longitudinal turbulence intensity at rooftop of building B : 0.143 (±10%)
Lateral and vertical intensities: not specified (but report if measured)
Integral turbulence length scale at rooftop height of building A : ~190 m (±20%)
Integral turbulence length scale at rooftop height of building B : ~175 m (±20%)

The mean wind speed profile should fall within ±10% of the target profile. The longitudinal wind speed power spectral densities at a number of heights should be smooth (without unusual peaks).

Recommended outputs for comparison

Scale of the building model and dimensions (i.e. height and width) of test section of wind tunnel in concern of the blockage ratio.

Boundary-layer profiles of mean wind speed and longitudinal turbulence intensity; test mean wind speed and spectrum of longitudinal turbulence at 200m equivalent height.

Mean, total standard deviation, and total peak base moments, M_x, M_y, M_z for full scale building as a function of wind direction (recommended 10^0 direction increments) at the geometric centre of the building where the base balance is installed.

Toal standard deviation non-dimensional coefficients of modal base moments C_{Mx1}, C_{My1}, C_{Mz1}, C_{Mx2}, C_{My2}, C_{Mz2}, C_{Mx3}, C_{My3}, C_{Mz3} for 10^0 direction increments.

Mean, total standard deviation, resonant and background components non-dimensional coefficients of base moments C_{Mx}, C_{My}, C_{Mz} for 10^0 direction increments. Please indicate explicitly the modal combination rules used to derive the total responses.

x-, y- and θ and combined accelerations at building rooftop level, centre of the building, and at the worst corner as a function of wind direction (22.5^0 direction increments).

Sample base moment spectra for the critical directions.

Report methods used for mode shape correction (function of azimuth if necessary); twist component correction, coupled mode determination etc.

Timeframe for the project

Analysis results from participating wind tunnels shall be submitted on or before 31 Dec 2010 and the summary of the results and comparisons will be presented in the 13th International Conference on Wind Engineering (Netherlands) in 2011.

Advanced building specification (Building A)

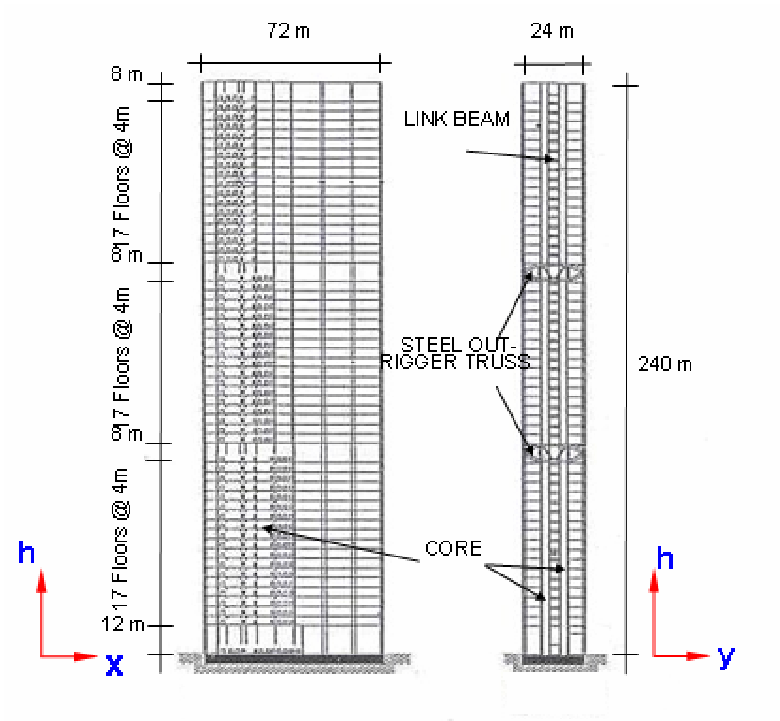


Figure 1. The proposed “advanced” (HFFB) benchmark building

Notes: This building has been modified from the Second Generation Structural Control Benchmark Building as follows: Additional coupling has been introduced to Mode 1 and 2.

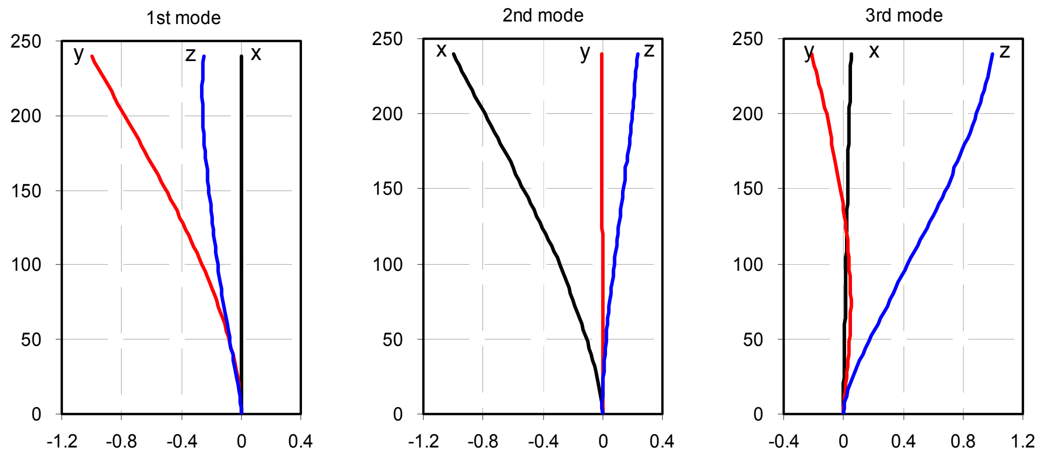
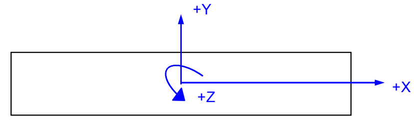


Figure 2 The first 3 mode shapes of the advanced benchmark building

Table 1. Building Dimensions and Dynamic Properties

Number of storeys	60
Cross-section	uniform rectangular (72 x 24 metres)
Building dimensions	240 x 72 x 24 metres
Aspect ratio	10:3:1 (H x W x D)
Structural form	concrete core-frame system + steel out-rigger trusses
Natural frequency, n	0.231, 0.429, 0.536 Hertz
Damping ratio, z	1% and 2.5% of critical for all modes



sign convention

Table 2. Building Mass Properties

storey	storey level [m]	storey mass [kg]	storey mass moment of inertia [kgm^2]	centre of mass (x) from origin [m]	centre of mass (y) from origin [m]
60	240	1231000	5.116E+08	-0.550	0.000
59	236	1231000	5.116E+08	-0.550	0.000
58	232	1231000	5.116E+08	-0.550	0.000
57	228	1231000	5.116E+08	-0.550	0.000
56	224	1231000	5.116E+08	-0.550	0.000
55	220	1231000	5.116E+08	-0.550	0.000
54	216	1231000	5.116E+08	-0.550	0.000
53	212	1231000	5.116E+08	-0.550	0.000
52	208	1231000	5.116E+08	-0.550	0.000
51	204	1231000	5.116E+08	-0.550	0.000
50	200	1231000	5.116E+08	-0.550	0.000
49	196	1231000	5.116E+08	-0.550	0.000
48	192	1231000	5.116E+08	-0.550	0.000
47	188	1231000	5.116E+08	-0.550	0.000
46	184	1231000	5.116E+08	-0.550	0.000
45	180	1231000	5.116E+08	-0.550	0.000
44	176	1231000	5.116E+08	-0.550	0.000
43	172	1231000	5.116E+08	-0.550	0.000
42	168	1231000	5.116E+08	-0.550	0.000
41	164	1231000	5.116E+08	-0.550	0.000
40	160	1231000	5.116E+08	-1.460	0.000
39	156	1231000	5.116E+08	-1.460	0.000
38	152	1231000	5.116E+08	-1.460	0.000
37	148	1231000	5.116E+08	-1.460	0.000
36	144	1231000	5.116E+08	-1.460	0.000
35	140	1231000	5.116E+08	-1.460	0.000
34	136	1231000	5.116E+08	-1.460	0.000
33	132	1231000	5.116E+08	-1.460	0.000
32	128	1231000	5.116E+08	-1.460	0.000
31	124	1231000	5.116E+08	-1.460	0.000
30	120	1231000	5.116E+08	-1.460	0.000
29	116	1231000	5.116E+08	-1.460	0.000
28	112	1231000	5.116E+08	-1.460	0.000
27	108	1231000	5.116E+08	-1.460	0.000
26	104	1231000	5.116E+08	-1.460	0.000
25	100	1231000	5.116E+08	-1.460	0.000
24	96	1231000	5.116E+08	-1.460	0.000
23	92	1231000	5.116E+08	-1.460	0.000
22	88	1231000	5.116E+08	-1.460	0.000
21	84	1231000	5.116E+08	-2.140	0.000
20	80	1231000	5.116E+08	-2.140	0.000
19	76	1231000	5.116E+08	-2.140	0.000
18	72	1231000	5.116E+08	-2.140	0.000
17	68	1231000	5.116E+08	-2.140	0.000
16	64	1231000	5.116E+08	-2.140	0.000
15	60	1231000	5.116E+08	-2.140	0.000
14	56	1231000	5.116E+08	-2.140	0.000
13	52	1231000	5.116E+08	-2.140	0.000
12	48	1231000	5.116E+08	-2.140	0.000
11	44	1231000	5.116E+08	-2.140	0.000
10	40	1231000	5.116E+08	-2.140	0.000
9	36	1231000	5.116E+08	-2.140	0.000
8	32	1231000	5.116E+08	-2.140	0.000
7	28	1231000	5.116E+08	-2.140	0.000
6	24	1231000	5.116E+08	-2.140	0.000
5	20	1231000	5.116E+08	-2.140	0.000
4	16	1231000	5.116E+08	-2.140	0.000
3	12	1231000	5.116E+08	-2.140	0.000
2	8	1231000	5.116E+08	-2.650	0.000
1	4	1231000	5.116E+08	-2.650	0.000

* origin is set at the geometric centre

Table 3. First 3 mode shape values about origin (electronic copy can be found from an EXCEL file available on request)

storey	storey level [m]	ϕx1 [m]	ϕy1 [m]	ϕz1 [rad]	ϕx2 [m]	ϕy2 [m]	ϕz2 [rad]	ϕx3 [m]	ϕy3 [m]	ϕz3 [rad]
60	240	4.104E-04	-1.424E-01	-1.629E-03	-8.501E-02	-6.251E-04	9.027E-04	2.543E-02	-1.097E-01	2.326E-02
59	236	4.060E-04	-1.393E-01	-1.656E-03	-8.326E-02	-6.208E-04	8.888E-04	2.493E-02	-1.047E-01	2.303E-02
58	232	4.009E-04	-1.362E-01	-1.666E-03	-8.153E-02	-6.007E-04	8.772E-04	2.441E-02	-9.902E-02	2.282E-02
57	228	3.962E-04	-1.331E-01	-1.677E-03	-7.979E-02	-5.846E-04	8.653E-04	2.391E-02	-9.360E-02	2.261E-02
56	224	3.906E-04	-1.300E-01	-1.685E-03	-7.802E-02	-5.646E-04	8.533E-04	2.337E-02	-8.820E-02	2.238E-02
55	220	3.856E-04	-1.268E-01	-1.695E-03	-7.624E-02	-5.459E-04	8.404E-04	2.283E-02	-8.275E-02	2.215E-02
54	216	3.806E-04	-1.237E-01	-1.698E-03	-7.446E-02	-5.230E-04	8.281E-04	2.229E-02	-7.753E-02	2.190E-02
53	212	3.757E-04	-1.205E-01	-1.691E-03	-7.264E-02	-4.984E-04	8.158E-04	2.176E-02	-7.261E-02	2.163E-02
52	208	3.697E-04	-1.172E-01	-1.686E-03	-7.083E-02	-4.749E-04	8.025E-04	2.122E-02	-6.793E-02	2.133E-02
51	204	3.645E-04	-1.142E-01	-1.683E-03	-6.899E-02	-4.459E-04	7.891E-04	2.065E-02	-6.304E-02	2.104E-02
50	200	3.594E-04	-1.109E-01	-1.668E-03	-6.717E-02	-4.169E-04	7.757E-04	2.009E-02	-5.831E-02	2.073E-02
49	196	3.555E-04	-1.077E-01	-1.656E-03	-6.533E-02	-3.981E-04	7.601E-04	1.954E-02	-5.426E-02	2.039E-02
48	192	3.508E-04	-1.045E-01	-1.647E-03	-6.349E-02	-3.801E-04	7.432E-04	1.898E-02	-5.020E-02	2.003E-02
47	188	3.476E-04	-1.013E-01	-1.637E-03	-6.165E-02	-3.591E-04	7.268E-04	1.843E-02	-4.606E-02	1.968E-02
46	184	3.420E-04	-9.807E-02	-1.618E-03	-5.981E-02	-3.390E-04	7.099E-04	1.786E-02	-4.224E-02	1.931E-02
45	180	3.375E-04	-9.481E-02	-1.595E-03	-5.798E-02	-3.236E-04	6.918E-04	1.733E-02	-3.877E-02	1.892E-02
44	176	3.328E-04	-9.165E-02	-1.572E-03	-5.616E-02	-3.111E-04	6.718E-04	1.679E-02	-3.547E-02	1.852E-02
43	172	3.281E-04	-8.844E-02	-1.549E-03	-5.435E-02	-2.907E-04	6.527E-04	1.627E-02	-3.185E-02	1.812E-02
42	168	3.213E-04	-8.525E-02	-1.511E-03	-5.257E-02	-2.944E-04	6.297E-04	1.580E-02	-2.828E-02	1.770E-02
41	164	3.056E-04	-8.205E-02	-1.464E-03	-5.078E-02	-3.631E-04	5.934E-04	1.550E-02	-2.413E-02	1.725E-02
40	160	3.086E-04	-7.888E-02	-1.454E-03	-4.930E-02	-3.959E-04	5.909E-04	1.501E-02	-2.060E-02	1.695E-02
39	156	3.084E-04	-7.602E-02	-1.446E-03	-4.780E-02	-3.266E-04	5.841E-04	1.450E-02	-1.655E-02	1.665E-02
38	152	2.940E-04	-7.307E-02	-1.417E-03	-4.606E-02	-3.635E-04	5.468E-04	1.429E-02	-1.311E-02	1.622E-02
37	148	2.849E-04	-7.014E-02	-1.387E-03	-4.432E-02	-3.423E-04	5.258E-04	1.388E-02	-9.221E-03	1.578E-02
36	144	2.768E-04	-6.719E-02	-1.358E-03	-4.261E-02	-3.085E-04	5.084E-04	1.344E-02	-5.930E-03	1.534E-02
35	140	2.694E-04	-6.426E-02	-1.332E-03	-4.089E-02	-2.771E-04	4.894E-04	1.297E-02	-2.359E-03	1.489E-02
34	136	2.615E-04	-6.135E-02	-1.304E-03	-3.916E-02	-2.517E-04	4.707E-04	1.250E-02	6.758E-04	1.443E-02
33	132	2.537E-04	-5.850E-02	-1.274E-03	-3.746E-02	-2.212E-04	4.522E-04	1.204E-02	3.448E-03	1.395E-02
32	128	2.462E-04	-5.568E-02	-1.248E-03	-3.573E-02	-1.962E-04	4.336E-04	1.156E-02	6.121E-03	1.347E-02
31	124	2.386E-04	-5.290E-02	-1.218E-03	-3.406E-02	-1.723E-04	4.149E-04	1.110E-02	8.663E-03	1.299E-02
30	120	2.306E-04	-5.014E-02	-1.183E-03	-3.240E-02	-1.474E-04	3.964E-04	1.062E-02	1.092E-02	1.250E-02
29	116	2.228E-04	-4.743E-02	-1.153E-03	-3.075E-02	-1.244E-04	3.778E-04	1.016E-02	1.292E-02	1.200E-02
28	112	2.150E-04	-4.477E-02	-1.122E-03	-2.915E-02	-1.033E-04	3.594E-04	9.701E-03	1.478E-02	1.150E-02
27	108	2.066E-04	-4.216E-02	-1.088E-03	-2.756E-02	-8.378E-05	3.401E-04	9.240E-03	1.669E-02	1.100E-02
26	104	1.975E-04	-3.958E-02	-1.051E-03	-2.603E-02	-6.571E-05	3.220E-04	8.805E-03	1.817E-02	1.050E-02
25	100	1.869E-04	-3.710E-02	-1.018E-03	-2.453E-02	-4.770E-05	3.029E-04	8.385E-03	1.954E-02	9.987E-03
24	96	1.760E-04	-3.468E-02	-9.846E-04	-2.309E-02	-3.141E-05	2.848E-04	7.980E-03	2.056E-02	9.487E-03
23	92	1.601E-04	-3.228E-02	-9.315E-04	-2.172E-02	-1.883E-05	2.666E-04	7.619E-03	2.215E-02	9.009E-03
22	88	1.381E-04	-2.997E-02	-8.849E-04	-2.039E-02	-3.237E-05	2.427E-04	7.336E-03	2.292E-02	8.522E-03
21	84	1.100E-04	-2.774E-02	-8.630E-04	-1.928E-02	-6.241E-05	2.223E-04	7.111E-03	2.406E-02	8.122E-03
20	80	8.822E-05	-2.567E-02	-8.395E-04	-1.815E-02	-5.091E-05	2.053E-04	6.834E-03	2.448E-02	7.721E-03
19	76	7.379E-05	-2.360E-02	-8.021E-04	-1.689E-02	-4.567E-05	1.859E-04	6.523E-03	2.492E-02	7.258E-03
18	72	6.232E-05	-2.155E-02	-7.588E-04	-1.564E-02	-3.669E-05	1.695E-04	6.151E-03	2.495E-02	6.783E-03
17	68	5.371E-05	-1.957E-02	-7.129E-04	-1.441E-02	-2.758E-05	1.536E-04	5.743E-03	2.473E-02	6.301E-03
16	64	4.698E-05	-1.765E-02	-6.675E-04	-1.318E-02	-1.800E-05	1.390E-04	5.310E-03	2.430E-02	5.818E-03
15	60	4.114E-05	-1.581E-02	-6.182E-04	-1.199E-02	-1.095E-05	1.241E-04	4.866E-03	2.366E-02	5.342E-03
14	56	3.598E-05	-1.402E-02	-5.683E-04	-1.081E-02	-3.224E-06	1.103E-04	4.428E-03	2.281E-02	4.865E-03
13	52	3.146E-05	-1.234E-02	-5.200E-04	-9.675E-03	3.114E-06	9.692E-05	3.992E-03	2.170E-02	4.388E-03
12	48	2.742E-05	-1.073E-02	-4.718E-04	-8.573E-03	8.087E-06	8.402E-05	3.567E-03	2.041E-02	3.922E-03
11	44	2.326E-05	-9.191E-03	-4.196E-04	-7.509E-03	1.193E-05	7.147E-05	3.142E-03	1.896E-02	3.461E-03
10	40	1.938E-05	-7.754E-03	-3.669E-04	-6.489E-03	1.434E-05	5.952E-05	2.734E-03	1.727E-02	3.010E-03
9	36	1.616E-05	-6.429E-03	-3.193E-04	-5.519E-03	1.658E-05	4.840E-05	2.347E-03	1.552E-02	2.575E-03
8	32	1.317E-05	-5.214E-03	-2.736E-04	-4.599E-03	1.748E-05	3.793E-05	1.967E-03	1.368E-02	2.160E-03
7	28	1.018E-05	-4.089E-03	-2.236E-04	-3.734E-03	1.668E-05	2.772E-05	1.611E-03	1.166E-02	1.758E-03
6	24	7.323E-06	-3.081E-03	-1.748E-04	-2.930E-03	1.446E-05	1.841E-05	1.278E-03	9.531E-03	1.379E-03
5	20	5.381E-06	-2.222E-03	-1.361E-04	-2.192E-03	1.289E-05	1.027E-05	9.610E-04	7.625E-03	1.042E-03
4	16	3.853E-06	-1.496E-03	-1.015E-04	-1.530E-03	1.026E-05	3.068E-06	6.730E-04	5.771E-03	7.395E-04
3	12	1.753E-06	-8.714E-04	-6.071E-05	-9.568E-04	5.686E-06	-3.595E-06	4.292E-04	3.661E-03	4.556E-04
2	8	-1.078E-07	-3.892E-04	-2.465E-05	-4.894E-04	1.934E-07	-9.147E-06	2.306E-04	1.592E-03	2.180E-04
1	4	-5.783E-07	-1.087E-04	-7.891E-06	-1.529E-04	-2.483E-06	-1.269E-05	7.457E-05	5.451E-04	6.970E-05
G/F	0	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

Basic building specification (Building B)

- Dimensions : height : 180 metres
- Horizontal dimensions: 45 metres × 30 metres (rectangular cross-section).
- Reinforced concrete construction.
- Sway frequencies, n_y = 0.20 Hertz., n_x = 0.23 Hertz
  (pure sway and twist – no coupling).
- Twist frequency, n_θ = 0.40 Hertz
- Mode shapes are linear (exponent, k = 1.0).
- Average building density: 160 Kg/m^3.
- Structural damping : 1.0 and 2.5 % of critical for all modes.

Note: This building has been modified from the original CAARC aeroelastic benchmark test model as follows:

a) Dimensions have been converted to metric units and rounded

b) Sway frequencies have been separated

c) Third (twist) mode has been introduced.

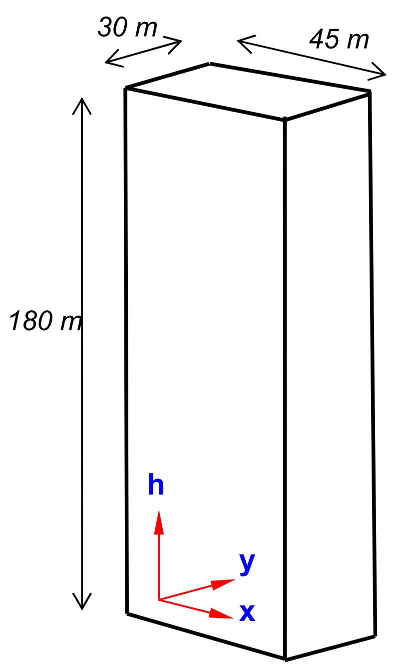


Figure 3. The proposed "basic" (HFFB) benchmark building