DATABASE-ASSISTED DESIGN AND WIND DIRECTIONALITY EFFECTS

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Reprinted from the Bluff Body Aerodynamics and Applications, 4th International Colloquium. Volume of Abstracts. Proceedings. Organized by Ruhr-University Bochum. September 11-14, 2000, 213-216 pp, 2000.

Database-assisted design and wind directionality effects

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ABSTRACT: We present a simple methodology, developed for use in design assisted by electronic aerodynamic and climatological databases (for short, database-assisted design), that allows a realistic assessment of wind directionality effects. We apply the methodology to typical low-rise industrial steel frame buildings with a rectangular shape in plan, located in hurricane-prone areas. We compare our results with results obtained by the procedure specified in the ASCE 7-98 Standard, which consists, for buildings, of applying a blanket directionality reduction factor K_d=0.85 to wind effects obtained by disregarding directionality. The results show that in hurricane-prone areas, for significant numbers of buildings, the use of the ASCE procedure can result in the underestimation of wind effects corresponding to strength design, and that database-assisted design for wind offers the potential for significantly more risk-consistent, safe, and economical design of buildings with both known and unknown orientation.

1. INTRODUCTION

Wind directionality effects raise design and codification issues that have received increased attention in recent years. They are studied in this paper by using a methodology proposed for the development of electronic, database-assisted provisions for wind loads (Simiu et al., 1993, Whalen et al., 1998). We describe our approach and present results for a typical industrial building.

We show that database-assisted design can account for wind direction much more realistically than is the case for design based on conventional standards. For buildings whose orientation is known at the design stage, ASCE 7-98 Standard plots cannot be used to take advantage of building orientations that are favorable with respect to the directional wind climate. For buildings with unknown orientation, the ASCE 7-98 Standard does not take into account (1) the dependence of wind directionality reduction factors upon the mean recurrence interval of the wind load (Simiu and Heckert, 1998), (2) the structural properties of the specific type of building being designed, and (3) the directional wind climate at the location of interest. Database-assisted design for wind loads can account for each of these three factors.

We summarize typical results of calculations of bending moments at various cross-sections of frames of a common type of industrial building, first by disregarding and then by accounting for wind directionality effects. The results help to assess the adequacy of the directionality reduction factor K_d=0.85 specified for buildings by ASCE 7-98, for which there is, in our opinion, insufficient technical justification.

2. COMPUTATION METHODOLOGY

Our methodology makes use of records of measurements made on a 1/200 scale model of a typical rectangular building with overall dimensions 30.5 m x 61.0 m, 6.1 m eave height, and a two-slope roof with slopes 1/12. The measured data consist of time series of the fluctuating pressures sampled at 400 Hz for a duration of 60 seconds, corresponding to about 1 hour in the prototype and recorded at about 500 pressure taps distributed over the entire building envelope. Pressure records are available for each of 37 directions, i.e., 0° (coinciding with the direction of the long axis of the building), 5°, 10°, ..., 180° (Whalen et al., 1998).

In addition, the methodology makes use of (1) simulated largest 1-min hurricane wind speeds at 10 m above ground in open terrain near the coastline, for each of the 16 azimuths in each of 999 hurricanes, and (2) mean hurricane arrival rates estimated from historical records. This climatological database is recorded in NIST public electronic files for each of about 50 locations on the Gulf coast and Atlantic coast. To our knowledge, no other publicly accessible files of simulated hurricane wind speeds are available.

The wind-force resisting structure consists of steel frames hinged at the column bases and placed at 7.62 m intervals between centers. A plan view of the building and the locations of the frames are shown in Fig. 1. A schematic elevation of a typical frame is shown in Fig. 2. The frames were designed by G. Harris of CECO Building Systems (Whalen et al., 1998). The data are processed by a program currently under development and designed for routine office use. The program calculates peak moments as well as peak shear and axial forces at any desired number of cross-sections in any of the frames of buildings of the type just described.

2.1 *Calculations accounting for wind direction*

First, directional influence factors for internal forces are calculated using the aerodynamic database described earlier. The directional influence factors consist, for each frame, of internal forces at various cross-sections, induced by wind with a 1 m/s speed at 10 m above ground in open terrain, blowing from 0, 5, 10,…., 360 degrees. Next, internal forces induced by each of the 16 directional wind speeds are calculated for each of 999 simulated hurricanes. For each hurricane and for each of these 16 directions, these internal forces are equal to the respective largest directional influence factor in the half-octant corresponding to the direction of interest, times the square of the wind speed blowing in that hurricane from that direction. For each hurricane, one of the 16 directional speeds produces the maximum internal force at the cross-section being considered. In this manner 999 largest internal forces at each cross-section and for each frame are obtained. The rate of arrival of hurricanes at the building location being □/year, it follows that the m-th highest of the 999 calculated internal forces is an estimator of the internal force with a [999/(m□)]-year mean recurrence interval. Calculations were performed for each of 16 distinct building orientations, i.e., for the cases where the long building axis is in the N, NNE, .., NNW direction.

2.2 *Calculations not accounting for wind direction*

In this case, instead of multiplying, for each hurricane, the 16 directional influence factors by the squares of the respective directional speeds, the *largest* of the 16 directional influence factors is multiplied by the square of the *largest* wind speed in that hurricane, regardless of that speed's direction. Thus 999 internal forces are obtained. The m-th highest internal force is an estimator of the internal force with a nominal (rather than actual, directionality-based) [999/(m□)]-year mean recurrence interval.

3. RESULTS

Detailed typical results are shown in Table 1. They correspond to a coastline site at milepost 1100, that is, at a distance measured along the coastline of about 275 km (150 nautical miles) west of Miami, Florida.

The results consist of wind-induced moments with 50-year and 500-year mean recurrence intervals estimated by taking wind directionality effects into account for buildings whose axis parallel to the long dimension is oriented in the N, NE, NE,…., NW, and N direction (cols. 1-16), moments with nominal 50-year and 500-year mean recurrence intervals estimated by disregarding wind directionality effects (col. 17), and ratios K between the maximum moment of cols. 1-16 and the moment of col. 17.

Except for small moments that do not control the design, the results show that moments with a 50-year mean recurrence estimated by accounting for directionality do not exceed about 85% of the corresponding moment estimated by disregarding wind directionality. Therefore, the K_d=0.85 directionality reduction factor reflects in a reasonable manner the wind directionality effect for 50-year mean recurrence intervals.

However, for a number of frames and frame cross-sections, it was found that for about 3 out of a total of 16 building orientations the estimated 500-year moments calculated by accounting for wind directionality are equal to about 0.95 times the moments calculated by disregarding directional effects. The use of the 0.85 factor specified by ASCE 7-98 to obtain the value corresponding to strength design would thus lead to the underestimation by about 10% of 500-yr wind effects on, typically, almost 20% of the total number of buildings at a typical site.

The ASCE 7-98 Standard is purported to provide *minimum* design loads. Therefore, in our opinion, the 0.85 wind directionality reduction factor specified in that standard in effect violates the intent of the standard; that is, a significant number of buildings – buildings that are unfavorably oriented -- are susceptible to experiencing loads that are larger than the loads specified by the standard. This would be acceptable if the load factor specified by the standard would make allowance for this excess loading. To our knowledge, however, this is not the case. Rather, to avoid specifying envelopes for wind loads that would cover adequately all buildings but would be uneconomical, about 10 to 20% of the total number of buildings are exposed to loads they might not be able to sustain in the event of a strong hurricane occurrence. Increased damage levels for buildings may therefore be expected for buildings with the "wrong" orientation.

Finally, we note that our results confirm the finding, obtained by a different method and explained by Simiu and Heckert (1998), that wind directionality reduction factors depend upon mean recurrence interval. This dependence is not accounted for in ASCE 7-98.

CONCLUSIONS

Database-assisted design makes it possible to account for wind direction in a manner that yields more risk-consistent and economical designs than can be achieved by using conventional standard provisions for wind loads. This is the case for buildings with orientation that is unknown at the design stage, and to an even greater extent for buildings with known orientation. Data-base assisted design allows more economical and risk-consistent designs within any one frame, as well as the option of differentiated designs of various frames within a building.

For as many as 20% of buildings designed in accordance with the standard, the use of the blanket reduction factor $K_d = 0.85$ -- specified for buildings in the ASCE 7-98 Standard and implicit in earlier versions of the Standard -- may result in the underestimation by about 10% of wind effects corresponding to strength design.

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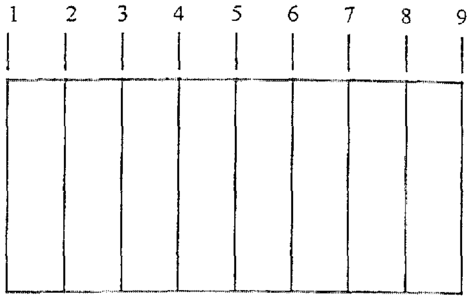

Figure 1. Plan view of building with numbered frames.

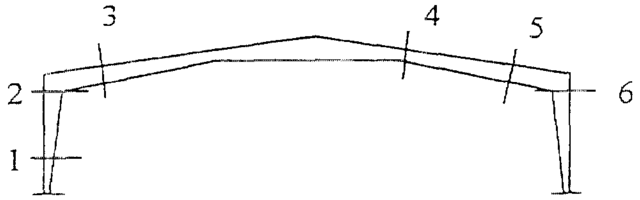

Figure 2. View of frame with designation of cross-sections.

TABLE 1. Moments at cross-sections 1 through 6 for frames 1, 2, and 5, milestone 1,100,

in kN-m. and ratio *K* of maximum directional moment to non-directional moment

	Frame 1																Non Direct	K
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]	[18]
Sect. 1	N-NE	NE	E-NE	E	E-SE	SE	S-SE	S	S-SW	SW	W-SW	W	W-NW	NW	N-NW	N		
50 yr Max	53	57	55	62	68	70	68	70	73	70	66	60	56	51	58	62	94	0.78
500 yr Max	95	97	94	108	110	107	111	113	123	133	134	111	107	91	126	111	141	0.95
Sect. 2	N-NE	NE	E-NE	E	E-SE	SE	S-SE	S	S-SW	SW	W-SW	W	W-NW	NW	N-NW	N		
50 yr Max	150	152	149	156	175	188	190	183	175	169	162	149	140	136	157	175	222	0.86
500 yr Max	253	261	257	257	284	284	304	304	291	316	318	298	266	242	318	305	333	0.95
Sect. 3	N-NE	NE	E-NE	E	E-SE	SE	S-SE	S	S-SW	SW	W-SW	W	W-NW	NW	N-NW	N		
50 yr Max	40	42	39	41	48	52	50	46	48	45	44	37	33	34	41	47	61	0.86
500 yr Max	68	73	68	70	78	77	87	85	80	86	87	74	70	60	80	77	91	0.95
Sec. 4	N-NE	NE	E-NE	E	E-SE	SE	S-SE	S	S-SW	SW	W-SW	W	W-NW	NW	N-NW	N		
50 yr Max	3	3	3	3	4	4	3	2	1	1	1	1	1	2	3	3	5	0.75
500 yr Max	6	6	5	6	7	7	7	6	6	5	4	4	4	5	7	6	8	0.95
Sec. 5	N-NE	NE	E-NE	E	E-SE	SE	S-SE	S	S-SW	SW	W-SW	W	W-NW	NW	N-NW	N		
50 yr Max	36	40	42	41	43	47	53	50	47	46	44	42	38	34	37	43	61	0.88
500 yr Max	65	70	77	70	72	75	80	89	87	82	84	85	71	74	87	82	91	0.98
Sec. 6	N-NE	NE	E-NE	E	E-SE	SE	S-SE	S	S-SW	SW	W-SW	W	W-NW	NW	N-NW	N		
50 yr Max	137	143	154	157	168	178	194	187	176	172	164	153	144	134	148	152	222	0.87
500 yr Max	257	257	280	251	264	279	305	326	317	298	294	297	272	260	313	311	333	0.98

	Frame 2																Non Direct	K
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]	[18]
Sect. 1	N-NE	NE	E-NE	E	E-SE	SE	S-SE	S	S-SW	SW	W-SW	W	W-NW	NW	N-NW	N		
50 yr Max	60	61	67	75	72	70	77	86	82	71	63	57	58	60	66	66	110	0.78
500 yr Max	115	111	127	121	126	131	128	144	157	157	131	126	102	117	125	138	166	0.95
Sect. 2	N-NE	NE	E-NE	E	E-SE	SE	S-SE	S	S-SW	SW	W-SW	W	W-NW	NW	N-NW	N		
50 yr Max	161	163	176	196	197	202	207	215	210	194	174	150	146	150	177	186	277	0.78
500 yr Max	288	292	318	324	324	346	347	363	394	395	328	318	265	293	365	351	416	0.95
Sect. 3	N-NE	NE	E-NE	E	E-SE	SE	S-SE	S	S-SW	SW	W-SW	W	W-NW	NW	N-NW	N		
50 yr Max	50	46	49	53	58	64	63	60	54	52	44	37	37	40	52	57	80	0.80
500 yr Max	88	92	92	92	104	108	106	113	114	100	94	84	85	79	116	109	120	0.97
Sec. 4	N-NE	NE	E-NE	E	E-SE	SE	S-SE	S	S-SW	SW	W-SW	W	W-NW	NW	N-NW	N		
50 yr Max	3	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	0.95
500 yr Max	5	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5	0.97
Sec. 5	N-NE	NE	E-NE	E	E-SE	SE	S-SE	S	S-SW	SW	W-SW	W	W-NW	NW	N-NW	N		
50 yr Max	37	43	50	53	51	50	55	63	64	63	56	51	48	41	44	44	80	0.80
500 yr Max	78	83	84	92	93	92	99	109	105	113	114	106	99	83	119	96	120	0.99
Sec. 6	N-NE	NE	E-NE	E	E-SE	SE	S-SE	S	S-SW	SW	W-SW	W	W-NW	NW	N-NW	N		
50 yr Max	150	163	181	188	184	182	207	224	219	195	185	172	155	154	173	174	277	0.81
500 yr Max	288	279	318	319	318	329	376	363	394	395	350	323	286	293	325	334	416	0.95