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WIND STUDY SUMMARY
ORIGINAL SFOBB EAST SPAN DEMOLITION
SPANS 504 FT AND 288 FT

for

T. Y. Lin International

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by

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A wind study was performed to determine the appropriate design wind pressure on the 504 ft. 288 ft. spans of the original San Francisco/Oakland Bay Bridge (SFOBB) East Span, during its demolition. During this demolition the spans will, and will not, be partially enclosed in bird netting.

The wind loads to use for the demolition process are to be computed using the ASCE 7-05 format. Specifically, the pressures on a designated surface are given by

$$P(psf) = 0.00256 K_Z G C_D V^2$$

where

- V 3-second gust wind speed, at an elevation of 10 m (33 ft), in an open exposure (Exposure C);
- K_Z exposure and elevation factor;
- G gust effect factor; and
- C_D drag coefficient.

The design wind speed, V, was obtained from the original wind study for the SFOBB self Anchored Suspension Bridge (SFOBB SAS) (Ref 2).

From the SAS report, one hour averaged design wind speeds, at an elevation of 50 m, were extrapolated from that shown in Table 1.4 (Table 1) here. Those one-hour-averaged wind speeds at an elevation of 50 m, in Exposure D were converted to one-hour-averaged wind speeds at an elevation of 10 m, in Exposure D, were converted to equivalent one-hour averaged wind speeds in Exposure C, at an elevation of 10 m and then converted to 3-second gust wind speeds at 10 m in Exposure C. The bridge is assumed to be in an Exposure D (open water). For Exposure D, z_0 = 0.005 m; and for Exposure C, z_0 = 0.03 m. A gust wind speed is assumed to be a one-hour mean wind speed plus 3-standard deviation wind speeds (1.52 times the one-hour averaged mean wind speed in Exposure C at an elevation of 10 m). The bridge deck for the SFOBB SAS is assumed to be at an elevation of 50 m.

MRI	EXP D U3600 (z = 50 m)	EXP D U3600 (z = 10 m)	EXP C U3600 (z = 10 m)	EXP C U3 (z = 10 m)
10	70	57.8	50.1	76.2
25	77	63.5	55.1	83.7
100	89	73.4	63.4	96.8

TABLE 1
3-SECOND EQUIVALENT REFERENCE WIND SPEEDS AS A FUNCTION OF MRI (mph)

In order to evaluate the gust effect factors, G, accurately for these flexible spans, a simplified buffeting analysis was performed for each span. Specifically, numerical simulations were performed in the time domain using an analytical model of the wind speed field, using published drag coefficients for truss members, using results from the previous wind tests for aerodynamic coefficients for the bird netting (Appendix A), and using the dynamic response characteristics provided by TYLI. Only properties of the fundamental lateral modes of vibration were used. Wind speed time histories were generated at 7 panel points for Span 504, and 9 panel points for Span 288.

Properties provided by TYLI (8/21/14) and used are shown in Table 2.

SPAN	ESTIMATED WEIGHT(k)	TRANSVERSE NATURAL FREQ (Hz)
504	11,600	0.425
288	5,900	0.478

TABLE 2 - DYNAMIC RESPONSE CHARACTERISTICS

For the numerical simulations performed, the mean hourly averaged wind speed, at mean bridge deck elevations, were determined to be 38 m/s for Span 504 and 36 m/s for Span 288 (these are wind speeds consistent with the 100 year design wind speed defined in following paragraphs). The purpose of the numerical simulations, again, was to determine precisely the gust effect factors, G, to use with the static equivalent pressures defined in the following paragraphs.

For each span, five 10-minute long simulations were performed. Results of those simulations are presented in Table 3 (the values are approximate lateral displacements at mid-span).

SPAN	AVE(m)	PMAX(m)	U3600(m/s)	U600(m/s)	U3(m/s)
504	0.135	0.242	38.00	39.49	50.45
288	0.089	0.206	36.00	37.52	48.67

TABLE 3 - NUMERICAL SIMULATION RESULTS

U3600	One-hour averaged wind speed (m/s)
U600	Ten-minute averaged wind speed (m/s)
U3	Three-second averaged wind speed (m/s)

The results presented are averages and extremes of the five simulations for each analysis.

The gust effect factor, G, is defined as the ratio PMAX/AVE, and is dependent upon the averaging time of the wind speed used. For the different wind speeds, the average response

is assumed to be a function of the wind speed squared. Therefore, the gust effect factors for wind speeds with different average times is given in Table 4.

SPAN	AVE3600	AVE600	AVE3	G3600	G600	G3
504	0.125	0.135	0.220	1.936	1.800	1.100
288	0.082	0.089	0.150	2.575	2.315	1.373

TABLE 4 - GUST EFFECT FACTORS

The gust effect factors with respect to three-second averaged wind speeds, G3, are to be used in determining the appropriate static equivalent pressures to use in the analysis of wind loads, with the bird netting, for Spans 504 and 288 (for wind speeds with MRI values of 100, 25, or 10 years).

The exposure/elevation factor K_Z is given in Table 5 (Ref. 3)

ELEV (ft.)	K_Z
< = 33	1.134
40	1.196
50	1.246
60	1.287
70	1.323
80	1.354
90	1.382
100	1.407
120	1.450
140	1.488
160	1.521
180	1.551
200	1.577
250	1.634
300	1.681

TABLE 5 - EXPOSURE AND ELEVATION FACTOR

For individual members that are wrapped in bird netting, or that have spikes, etc, treat them as if they were solid members. Ignore openings in any truss member, whether it is wrapped in bird netting or not. Treat all of the individual truss members as solid. For the individual truss members, use the following drag coefficients:

C_D = 2 (for all windward truss and barrier members on the existing bridge)

All of this is applied to the exposed gross area of the members, perpendicular to the axis of the bridge, for winds perpendicular to the axis of the bridge. Once you determine the total wind load on the existing windward truss and barriers, use half of that total to include wind loads on the existing leeward truss and barriers.

For the QuickDeck, assume the frontal area of the supporting truss is about 0.5 ft^2/ft, assume a $C_D = 2$ for it, then double the load to account for the cascade of 8 trusses downstream.

Where the bird netting is in front of a solid member, the bird netting will not add additional wind load to the structure. The bird netting on Span 504 is about 18 feet high; on Span 288, about 14 feet high. In both cases, it appears that there is no more than 6 feet total of bird netting with open air behind it. Assume there is about 6 ft^2/ft bird netting exposed to the wind. From the previous study of wind loading on a tower wrapped in bird netting (the same netting), use a $C_D = 1.0$ on the bird netting area. The tests were for bird netting wrapped around a tower (see Appendix A). Therefore, the value of $C_D = 1.00$ includes the wind load on the leeward bird netting as well as the windward bird netting. Do not add more load for the bird netting on the leeward side.

For longitudinal wind loads on the tower, below the deck level use a $C_D = 0.431$ times the overall, out-to-out width dimension of the tower for a given elevation. For this portion, do not use the exposed solid areas, but the gross area. Do not add additional load for bird netting wrapped around individual members.

For skew angles other than zero (the skew angle is measured from the perpendicular to the axis of the bridge), use the skew coefficients in Tables 6 and 7.

Use Table 6 to determine the longitudinal and lateral wind loads on the bridge superstructure (bridge deck and above) for skew angles other than 0 degrees. The longitudinal and lateral wind load components equal the coefficients times the LATERAL wind loads computed for winds that are perpendicular to the bridge.

SKEW ANGLE (DEGREES)	LATERAL COEF	LONG COEF
0	1.000	.000
15	.933	.160
30	.867	.373
45	.627	.547
60	.320	.667

TABLE 6 - SKEW COEFFICIENTS ON BRIDGE SUPERSTRUCTURE

Use Table 7 to determine the longitudinal and lateral loads on the lower towers for skew angles other than 0 degrees. The longitudinal and lateral wind load components equal the coefficients times the LONGITUDINAL wind loads computed for winds on the lower towers that are in the longitudinal to the bridge (skew angle of 90 degrees).

For skewed winds, the longitudinal and lateral loads shall be applied simultaneously.

SKEW ANGLE	LONG COEF	LATERAL COEF
90	1.000	.000
67.5	1.074	.089
45	.835	.588
22.5	.434	.906
0	.000	.784

TABLE 7 - SKEW COEFFICIENTS ON LOWER TOWER

APPENDIX A
WIND LOADS ON FREE-STANDING TOWER WITH AND WITHOUT BIRD NETTING

In order to determine the aerodynamic effect of the bird netting wrapped around the lower portion of the towers (below the deck level), wind tunnel tests were performed to determine static longitudinal and lateral pressure coefficients, with and without the bird netting. For this study a 1:75 scale model was constructed of hardwood, and placed on a balance that measured overturning moments. The model was tested in smooth, uniform flow. Therefore, the average pressure over the lower tower could be computed from the measured overturning moments. The actual bird netting that is used on the towers was used to wrap the model. It would have been incorrect to use a 1:75 scale model of the netting, because flow through the 1/75th size hole in the netting would have introduced significant Reynolds Number errors. It is standard experimental testing procedure to use full-scale netting, or screens, in the model. All pressure coefficients were taken as the average of at least five samples (ten for the critical directions). See the photographs of the model in the wind tunnel (Figure A.1).

For the basic wind loads on the bridge, for a 100-year wind speed, for your use with a load factor of 1.4, use the following (NB - For this study, loads were based on a design wind speed with a MRI = 100 years. The drag coefficients apply for any wind speed).

$p(psf) = 0.00256\ K_Z\ G\ C_D\ V^2$

where

V = 91 mph (a 3-second gust wind speed at an elevation of 33 ft. in an open exposure, C, with a MRI = 100 years). This was taken from ASCE 7-05.

G = 0.85 (because the loaded area is large and the bridge isn't too flexible like a cable-stayed bridge)

K_Z (from Table A.1, for an Exposure D - open water exposure)

ELEV (ft.)	K_Z
< = 33	1.134
40	1.196
50	1.246
60	1.287
70	1.323
80	1.354
90	1.382
100	1.407
120	1.450
140	1.488
160	1.521
180	1.551
200	1.577
250	1.634
300	1.681

TABLE A.1 - EXPOSURE AND ELEVATION FACTOR

C_D = 2 (for windward truss members)

= 1 (for leeward truss members)

All of this is applied to the exposed, solid area of members, perpendicular to the direction of the wind.

For longitudinal wind loads on the tower, below the deck level, for the uncovered, existing tower, use a C_D = 0.431 times the overall, out-to-out width dimension of the tower (about 97.5 feet at the bottom and about 75.5 feet just under the deck), for a given elevation. For this portion, do not use the exposed solid areas, but the gross area. With the tower wrapped all around with the "bird netting", use a C_D = 0.935, again times the overall, out-to-out width dimension of the tower.

For skew angles other than zero (the skew angle is measured from the perpendicular to the axis of the bridge), use the skew coefficients in Tables A.2, A.3, and A.4.

Use Table A.2 to determine the longitudinal and lateral wind loads on the bridge superstructure (bridge deck and above) for skew angles other than 0 degrees. The longitudinal and lateral wind load components equal the coefficients times the LATERAL wind loads computed for winds that are perpendicular to the bridge.

SKEW ANGLE (DEGREES)	LATERAL COEF	LONG COEF
0	1.000	.000
15	.933	.160
30	.867	.373
45	.627	.547
60	.320	.667

TABLE A.2
SKEW COEFFICIENTS ON BRIDGE SUPERSTRUCTURE

Use Tables A.3 and A.4 (without and with the bird netting) to determine the longitudinal and lateral loads on the lower towers for skew angles other than 0 degrees. The longitudinal and lateral wind load components equal the coefficients times the LONGITUDINAL wind loads computed for winds on the lower towers that are in the longitudinal to the bridge (skew angle of 90 degrees). The coefficients in Table A.3 modify the wind load on the lower tower without the bird netting. The coefficients in Table A.4 modify the wind load on the lower tower with the bird netting.

For skewed winds, the longitudinal and lateral loads shall be applied simultaneously.

SKEW ANGLE	LONG COEF	LATERAL COEF
90	1.000	.000
67.5	1.074	.089
45	.835	.588
22.5	.434	.906
0	.000	.784

TABLE A.3
SKEW COEFFICIENTS ON LOWER TOWER
WITHOUT BIRD NETTING

SKEW ANGLE	LONG COEF	LATERAL COEF
90	1.000	.000
67.5	.930	.078
45	.735	.269
22.5	.375	.343
0	.000	.256

TABLE A. 4
SKEW COEFFICIENTS ON LOWER TOWER
WITH BIRD NETTING

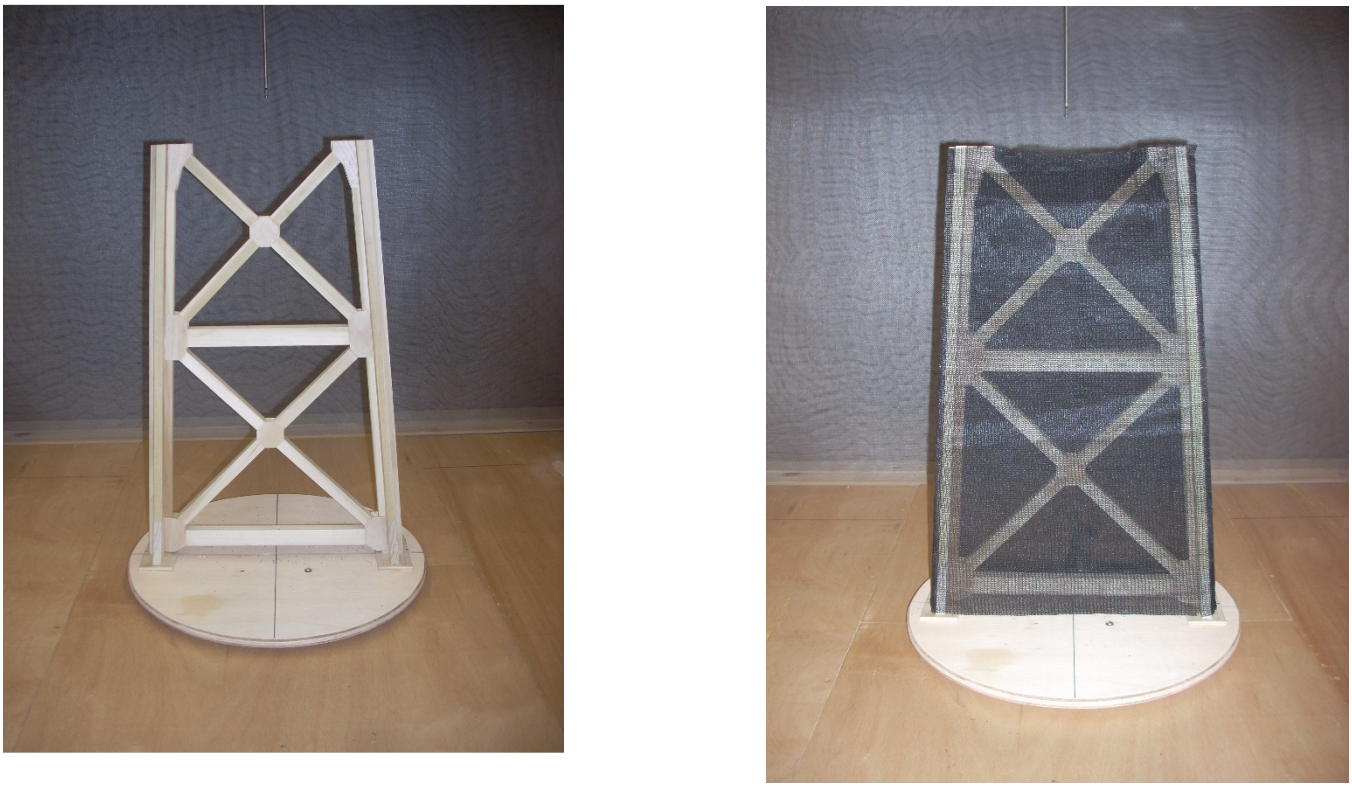

FIGURE A.1
MODELS (WITH AND WITHOUT BIRD NETTING) IN WIND TUNNEL

REFERENCES

1. Simiu, E., and Scanlan, R. H. *Wind Effects on Structures,* Third Edition, John Wiley & Sons, New York, 1996.

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3. ____, *ASCE Standard, American Society of Civil Engineers, Minimum Design Loads for Buildings and Other Structures, ASCE* 7-05, American Society of Civil Engineers, New York 2005.