APPENDIX H:
HMLT FATIGUE LIFE EVALUATION

(Proposed Specification Appendix)

APPENDIX D: FATIGUE LIFE EVALUATION OF HIGH-MAST LIGHTING TOWERS

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APPENDIX D:

FATIGUE LIFE EVALUATION OF HIGH-MAST LIGHTING TOWERS

D1—SCOPE

The intention of previous fatigue provisions was to provide for infinite life. However, recent failures and subsequent research into the behavior of high-mast lighting towers (HMLTs) shows that deficiencies exist which limit fatigue life. An HMLT originally designed for infinite life may actually be subject to a limited (finite) life for main two reasons: the original design used an unconservative fatigue load, or the original design assumed a better fatigue detail than actually used. This appendix serves as a guide for owners who wish to make a quantitative assessment of fatigue life for HMLT structures in their inventory. Fatigue loads and number of daily stress range cycles are presented for evaluation purposes along with sample calculations showing how the data may be used to calculate expected or remaining fatigue life.

D2—DEFINITIONS

Constant-amplitude effective static pressure range—the fatigue load effect equivalent to all variable-amplitude loads in the wind load spectrum and used for finite life evaluation.

Fatigue-limit-state static pressure range—the fatigue load effect associated with the maximum load in the wind load spectrum and used for infinite life evaluation.

D3—NOTATION

Δf_{eff} = constant-amplitude effective stress range (ksi)
Δf_{fls} = fatigue-limit-state stress range (ksi)
P_{eff} = constant-amplitude effective static pressure range (psf)
P_{fls} = fatigue-limit-state static pressure range (psf)
N_{life} = expected number of cycles in structure lifetime
n = frequency of cyclic loading in number of stress cycles per day

D4—FATIGUE LOADS FOR EVALUATION

The fatigue-limit-state static pressure range to be used for infinite life evaluation of HMLTs and the constant-amplitude effective static pressure range to be used for limited (finite) life evaluation of HMLTs are listed in Table D-1.

Table D-1—Fatigue Loads for Evaluation

Fatigue load effect	Pressure Range
Infinite life, P_{fls}	280 Pa (5.8 psf)
Limited (finite) life, P_{eff}	70 Pa (1.3 psf)

D5—STRESS RANGE CYCLES FOR EVALUATION

The accumulation of damaging fatigue cycles for HMLTs is known to vary with wind speed. The proposed evaluation method takes advantage of this variation and allows evaluating engineers to choose an appropriate cycle frequency based on mean wind speed. Mean wind speeds and effective cycle counts are listed in Table D-2.

Table D-2—Stress Range Cycles for Evaluation

Mean Wind Speed, V_{mean} (mph)	n (cycles/day)
≤ 9	9,500
$9 < V_{mean} \leq 11$	15,000
> 11	23,000

Note:
HMLTs with mitigation devices installed to prevent excessive wind-induced oscillations are subject to considerably less damaging stress range cycles. A value of 7,000 may be used in such cases.

D6—METHOD

The method for evaluating the fatigue life of HMLT structures is based on traditional methods for highway bridges. It is an application of data obtained from recent research of the behavior of HMLTs. Those familiar with fatigue design will find the method similar with the exception that greater importance is placed on determining the fatigue-limit-state stress range.

D6.1—Fatigue Life

The procedure for evaluating fatigue life is broken down in two parts: (1) determine whether the HMLT is subject to finite life, and if so, (2) calculation of a finite lilfetime. Certain criteria have been identified which may alert an owner that finite life is likely for an existing HMLT. An owner may wish to consider finite fatigue life for any of the following reasons:

1. A fillet-welded socket type tube to baseplate connection
2. Baseplate thickness less than 3”
3. A history of loose anchor nuts
4. Less than 6 anchor rods
5. Tube wall less than or equal to 5/16”
6. Excessive corrosion of tube wall

HMLTs with just one of the factors listed above have been shown through experience, i.e. observed cracking, to have less than the intended fatigue life. If this is the case, an evaluator may skip step one and proceed directly to step two below.

A conceptual evaluation for an HMLT structure is provided. The structure is located in Kansas, where the yearly mean wind velocity is expected to exceed 11 mph, and has the following properties:

Pole Height:	100 ft	Tube thickness at base:	0.188 in
Number of sides:	12	EPA of Luminaire:	9.9 ft^2
Diameter at top:	5.6 in	Center of pressure of pole:	45 ft
Diameter at base:	18”	Critical fatigue detail:	E

The procedure is as follows:

1. Check if the HMLT qualifies for infinite life by comparing the fatigue limit-state-load with the constant-amplitude fatigue limit (CAFL) for detail category E.

   a. The fatigue-limit-state load for evaluation, P_{fls}, equals 5.8 psf from Table D-1. The applied loads are:

      pole: $P_W = P_{fls} C_d I_F \quad \rightarrow \quad 5.8(1.2)(1) = 7.0 \ psf$

      luminaire: $P_W = 5.8(1)(1) = 5.8 \ psf$

   b. Next, calculate the bending moment at the base of the pole.

      Moment due to luminaire: $100\,ft(9.9\,ft^2)(5.8\,psf) = 5740\,lb \cdot ft$

      Moment due to pole: $45\,ft\left[\frac{1}{2}\left(\frac{5.6"+18"}{12}\right)(100\,ft)\right](7.0\,psf) = 30980\,lb \cdot ft$

      Total bending moment: $M_{fls} = 5740 + 30980 = 36700\,lb \cdot ft$

   c. Calculate the section modulus of the pole using equations provided in Appendix B, $S = 3.29R^2t$.

      Radius to center of tube: $R = (18" - 0.188")/2 = 8.91"$

      Section modulus: $S = 3.29(8.91")^2(0.188") = 49.1\,in^3$

   d. Then calculate the stress range at the base and compare with the CAFL.

      Stress range at base: $\Delta f_{fls} = \frac{36700 lb \cdot ft(12 in)}{49.1 in^3 (1000 lb/k)} = 8.92\ ksi$

      The stress range is greater than what is allowed for category E (4.5 ksi). Therefore, finite life must be used.

   e. If the fatigue-limit-state stress range, Δf_{fls}, is less than the CAFL, then infinite life may be assumed and no further calculation is necessary.

2. After establishing the HMLT is subject to limited life, the evaluation should proceed using the constant-amplitude effective fatigue load to calculate the effective stress-range, S_{Reff}. Then, the number of lifetime cycles can be found from the appropriate stress-life (S-N) curve. Since it has already been shown that S_{Rfls} exceeds the CAFL, the CAFL should not be considered on the S-N curve. This may be a source of confusion – only the sloping portion of the S-N curve should be considered.

   a. The constant-amplitude effective pressure range, Peff, equals 1.3 from Table D-1. The applied loads are:

      pole: $P_W = 1.3\,psf\,(1.2)(1) = 1.56 \ psf$

      luminaire: $P_W = 1.3\,psf\,(1)(1) = 1.3 \ psf$

   b. Next, calculate the bending moment at the base of the pole.

      Moment due to luminaire: $100\,ft(9.9\,ft^2)(1.3\,psf) = 1287\,lb \cdot ft$

      Moment due to pole: $45\,ft\left[\frac{1}{2}\left(\frac{5.6"+18"}{12}\right)(100\,ft)\right](1.56\,psf) = 6903\,lb \cdot ft$

      Total bending moment: $M_{eff} = 1287 + 6903 = 8190\,lb \cdot ft$

c. Next, calculate the stress range at the detail.

Stress range at base: $$\Delta f_{eff} = \frac{8190 lb \cdot ft(12in)}{49.1in^3(1000lb/k)} = 2.00\ ksi$$

d. Then determine the lifetime cycle count from the S-N curve. From the AASHTO bridge specification,

$$N_{life} = {}^{A}\!/_{(\Delta f_{eff})^3},$$ where $A = 11x10^8$ ksi for category E.

$$N_{life} = \frac{11.0\times10^8 ksi^3}{(2.00ksi)^3} = 1.38\times10^8\ cycles$$

e. Lastly, calculate the life in years using the appropriate value for n from Table D-2.

Evaluation cycles per day: $n = 23000\ cycles/day$

Estimated fatigue life: $$\frac{1.38\times10^8 cycles}{23000 cycles/day} = 6000\ days \rightarrow 16.5 years$$

D6.2—Mitigation

Fatigue life may be improved significantly by installation of a vibration mitigating device such as a strake, shroud, or mechanical damper that reduces wind-induced oscillations. Consider the HMLT used in the example above. After 9 years, the remaining life is estimated to be 7.5 years. If a mitigation device is installed, the estimated remaining life may be increased. Using the linear cumulative damage or Miner's rule:

$$\sum \frac{n_i}{N_{life}} = 1 \quad \rightarrow \quad \frac{n_1 + n_2}{N_{life}} = 1$$

where $n_1 = 9\ years(365\ days)(23{,}000\ cyc/day) = 7.6\times10^7 cycles$.

Solving for n_2: $$n_2 = 1.38\times10^8 - 7.6\times10^7 = 6.2\times10^7 cycles$$

The remaining life using a mitigation device, where n = 8,000 cycles per day from Table D-2, becomes:

$$6.2\times10^7 cyc \big/ 7{,}000 cyc/day = 8900 cycles \quad \rightarrow \quad 24 years$$

an increase of 16.5 years.