SECTION 10: SERVICEABILITY REQUIREMENTS

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SECTION 10:

SERVICEABILITY REQUIREMENTS

10.1—SCOPE

This Section provides serviceability requirements for support structures.

10.2—DEFINITIONS

Camber—The condition of the horizontal support being arched.

Quadri-Chord Truss—A horizontal member composed of four longitudinal chords connected by bracing.

Rake—To slant or incline from the vertical.

Tri-Chord Truss—A horizontal member composed of three longitudinal chords connected by bracing.

10.3—NOTATION

d_{DL} = deflection at free end of horizontal support under dead load (mm, in.) (C10.5)
d_P = deflection at tip of vertical support under dead load from horizontal cantilevered support (mm, in.) (C10.5)
d_{PDL} = deflection at free end of horizontal support caused by slope at the tip of the vertical support (mm, in.) (C10.5)
d_{TOTAL} = total dead load deflection at free end of horizontal support (mm, in.) (C10.5)
E = modulus of elasticity (MPa, psi) (C10.5)
H = height of vertical support (mm, in.) (C10.5)
I = moment of inertia of vertical support (mm^4, in.^{4}) (C10.5)
L = distance between supports for an overhead bridge structure; distance from vertical support to free end for horizontal cantilevered support (mm, in.) (C10.5)
M = moment caused by dead loads applied to the vertical support at the connection of the horizontal support (N-mm, lb-in.) (C10.5)
r = radius of gyration (mm, in.) (10.4.3.1)
u = prefabricated camber (slope) in the horizontal cantilevered arm (mm/mm, in./in.) (C10.5)

10.4—DEFLECTION

Highway support structures of all materials should be designed to have adequate structural stiffness that will result in acceptable serviceability performance. Deflections for specific structure types shall be limited as provided in Articles 10.4.1 and 10.4.2. Permanent camber for specific structure types shall be provided per Article 10.5.

C10.4

The deflection limits that are set by these Specifications are to serve two purposes. The first purpose is to provide an aesthetically pleasing structure under dead load conditions. The second purpose is to provide adequate structural stiffness that will result in acceptable serviceability performance under applied loads.

10.4.1—Overhead Bridge Supports for Signs and Traffic Signals

For overhead bridge monotube and truss structures supporting sign and traffic signals, the maximum vertical deflection of the horizontal support resulting from Group I load combination with the addition of ice loads (i.e., dead load plus ice) shall be limited to $L/150$, where L is the span length. For those locations where ice loading is not applicable, only deflection resulting from Group I load combination shall be used.

C10.4.1

Research was sponsored by the Arizona Department of Transportation (Ehsani et al., 1984; Martin et al., 1985) to determine an appropriate deflection limitation for steel monotube bridge support structures. This research included field tests and analytical studies using computer modeling. The studies investigated the static and dynamic behavior of monotube bridge sign support structures. It determined a dead load deflection limit that should be specified for monotube bridge structures. The 1989 Interim Specification was revised to limit deflection to the span divided by 150 for dead and ice load applications based on this research, replacing the previous limit of $d^2/400$ in feet, where d was the depth of the sign panel in feet. A later study (Lundgren, 1989) indicated that because the deflection criterion was an aesthetic limitation, it could be increased to the span divided by 100; however, no additional work has been found to justify changing the deflection limit to a more liberal value. Although this study considered only steel members, the deflection limit has been generalized for other materials because aesthetics was the governing consideration.

Other types of overhead bridge sign supports (i.e., two-chord, tri-chord, and quadri-chord trusses) generally have higher stiffness than the monotube type. It is believed that this dead load deflection limit of the span divided by 150 (i.e., $L/150$) could be adopted as a conservative limit for those types of overhead bridge sign and traffic signal support structures made with two-chord, tri-chord, or quadri-chord trusses.

10.4.2—Cantilevered Supports for Signs, Luminaires, and Traffic Signals

10.4.2.1—Vertical Supports

The horizontal deflection limits for vertical supports, such as street lighting poles, traffic signal structures, and sign structures, shall be as follows:

- Under Group I load combination (dead load only), the deflection at the top of vertical supports with transverse load applications shall be limited to 2.5 percent of the structure height; and
- Under Group I load combination (dead load only), the slope at the top of vertical supports with moment load applications shall be limited to 30 mm/m (0.35 in./ft).

For luminaire support structures under Group II load combination (i.e., dead load and wind), deflection shall be limited to 15 percent of the structure height.

Deflections shall be computed by usual methods or equations for elastic deflections. For prestressed concrete members, the effects of cracking and reinforcement on member stiffness shall be considered.

C10.4.2.1

The dead load deflection and slope limitations were developed based on aesthetic considerations. The 2.5 percent deflection limit was developed for transverse load applications, such as strain pole applications, where a dead load caused by span-wire tension could cause unsightly deflection. The horizontal linear displacement at the top of the structure is measured in relation to a tangent to the centerline at the structure's base. The slope limitation of 30 mm/m (0.35 in./ft), which is equivalent to an angular rotation of 1 degree 40′, was initially developed for street lighting poles with a single mast arm, where the mast arm applied a concentrated dead load moment that could also cause unsightly deflections. It is measured by the angular rotation of the centerline at the top of the structure in relation to the centerline at its base. The concentrated moment loads result from the effect of eccentric loads of single or unbalanced multiple horizontally mounted arm members and their appurtenances.

The 15 percent deflection limitation for group II load combination is not a serviceability requirement, but it constitutes a safeguard against the design of highly flexible structures. It is intended mainly for high-level lighting poles. The deflections are calculated without the applied safety factor in Article 4.8.2, and second-order effects are normally considered in the analysis.

10.4.2.2—Horizontal Supports

Adequate stiffness shall be provided for the horizontal supports of cantilevered sign and traffic signal structures that will result in acceptable serviceability performance.

C10.4.2.2

No dead load deflection limit is prescribed for horizontal supports of cantilevered sign and traffic signal structures. Stiffness requirements are determined by the Designer. Structures are typically raked or the horizontal supports are

Galloping and truck gust-induced vibration deflections of cantilevered single-arm sign supports and traffic signal arms should not be excessive so as to result in a serviceability problem, as specified in Article 11.8.

cambered such that the deflection at the end of the arm is above a horizontal reference line for the unloaded configuration, which provides the appearance of a structure that is not overloaded. Camber requirements for cantilevered sign and traffic signal structures are provided in Article 10.5.

10.4.3—Vibration

Structural supports that are susceptible to damaging vibrations and not designed for fatigue in accordance with Section 11 should be equipped with appropriate damping or energy-absorbing devices. All aluminum overhead bridge sign and traffic signal support structures should be equipped with appropriate damping or energy-absorbing devices to prevent significant wind-induced vibration in the structure, both before and after installation of sign panels or traffic signals.

C10.4.3

A mitigation device is not always mandatory if the structure is designed for fatigue in accordance with Section 11. Should the structure exhibit vibrations in the field, a mitigation device may be considered.

Section 11, "Fatigue Design," contains provisions for designing various structural supports for fatigue using design loads that are a result of wind-induced vibrations and truck gust-induced vibrations.

Vibrations may be caused by wind-induced loads, such as galloping or vortex shedding. Moving traffic may induce gusts on nearby structures, such as a large truck passing under overhead sign structures. Vibrations may also be a result of support movement, such as those found on bridges and elevated roadways.

For street-lighting poles, reducing vibration that is caused by wind or traffic-induced vibration of elevated roadways is important to reduce the potential for fatigue damage and to increase lamp life (Van Dusen, 1965 and 1968). Mitigation by using a Stockbridge-type damper is suggested by Burt and LeBlanc (1974) and by Dusel and Bon (1986). Vibrations caused by wind have been controlled in street lighting poles with the impact damper (Minor, 1973).

The Stockbridge-type vibration damper has been used to control vibration of aluminum overhead bridge sign structures (Lengel and Sharp 1969). For steel traffic signal structures with mast arms, research (McDonald et al., 1995) has suggested avoiding configurations that are susceptible to galloping, such as rigidly mounted traffic signals. Before these configurations (e.g., signals with an articulated connection to the arm) are used on a given structure, their acceptability from a traffic control perspective should be investigated. Permanent horizontal plane sign panels have been shown to reduce or eliminate galloping vibrations for some installations with rigidly mounted traffic signals, as discussed in Article 11.7.1.

Steel and aluminum overhead bridge sign and/or traffic signal support structures and cantilevered sign supports may be subject to damaging vibrations and oscillations when sign panels and/or traffic signals are not in place during erection or maintenance of the structure. To avoid these vibrations and oscillations, considerations should be given to providing temporary damping devices attached to the structure, such as blank sign panels.

10.4.3.1—Requirements for Individual Truss Members

The Specifications' limitations for L/r ratios should be adequate to prevent excessive vibration.

C10.4.3.1

Vibration in truss structures can occur in individual members. Slender tension members and redundant diagonals are particularly susceptible to vibration. Resistance to local vibrations can be provided by increasing member stiffness, thereby reducing flexural deflection and raising vibration response frequencies.

10.5—CAMBER

Permanent camber equal to $L/1000$, where L is the unsupported length of the horizontal support, shall be provided in addition to dead load camber for overhead sign and traffic signal structures.

C10.5

The camber requirement applies to overhead bridge sign and traffic signal supports and to sign and traffic signal supports with a horizontal cantilevered support. The permanent camber can aid in compensating for deflections resulting from foundation rotation. The permanent camber is in addition to the dead load camber, which compensates for dead load deflection.

Camber is the condition of the horizontal support being arched. Permanent camber is the condition of the horizontal support being arched upward after application of the dead loads. The horizontal support should be arched upward such that the vertical distance from the attachment point(s) to location of maximum deflection for the horizontal support is equal to $L/1000$. The permanent camber provides the visual effect of a low-pitched arch, which is more appealing than a horizontal support that is deflected downward.

Permanent camber can be provided by raking the vertical support and/or cambering the horizontal support. Raking the vertical support involves installing the vertical support with an initial deflection. The vertical support is raked during construction by adjusting the leveling nuts at the base of the structure. Raking the vertical support may result in the anchor bolts not being perpendicular to the support's base plate, and it can result in anchor bolt nuts not being properly tightened against the base plate. Cambering the horizontal support involves fabricating the support with an initial slope or curvature.

The following procedure may be used to calculate the camber required to compensate for dead load deflection in a cantilevered sign support structure with a monotube vertical support.

The cantilevered horizontal support should be cambered during fabrication, such that the permanent camber after application of dead load is a minimum of $L/1000$ above the horizontal plane, where L is the span of the horizontal support.

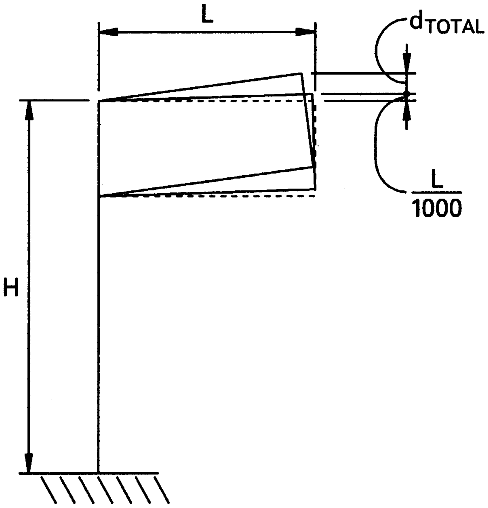

Figure C10.5-1—Camber of Cantilevered Sign Structure

The following procedure shown is for a nontapered vertical support with a constant stiffness.

Determine horizontal deflection at tip of vertical support due to dead load (deflection of vertical support not shown in Figure C10.5-1):

$$d_P = \frac{MH^2}{2EI} \tag{C10.5-1}$$

Determine deflection of horizontal support due to slope at tip of vertical support:

$$d_{PDL} = \frac{2d_P}{H} L \tag{C10.5-2}$$

Determine deflection of horizontal support due to dead load acting on the horizontal support, d_{DL}.

Calculate total dead load deflection at the tip of the cantilevered arm:

$$d_{TOTAL} = d_{DL} + d_{PDL} \tag{C10.5-3}$$

Determine the slope u of the prefabricated camber in the horizontal support, such that:

$$u = \frac{1}{1000} + \frac{d_{DL}}{L} + \frac{d_{PDL}}{L} \tag{C10.5-4}$$

This slope will result in a final deflection at the end of the horizontal arm equal to $L/1000$ above the horizontal plane.

Provide fabrication details indicating the prefabricated camber (slope) u in horizontal support.

The above procedure does not consider the raking of the vertical support.

A slope for some cantilevered horizontal supports has been provided by tilting the arm by a small angle at its base connection.

When the total dead load deflection is very small, some vertical supports have been raked to compensate for the full deflection of the cantilevered horizontal support.

10.6—REFERENCES

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SECTION 11: FATIGUE DESIGN

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SECTION 11

FATIGUE DESIGN

11.1—SCOPE

This Section contains provisions for the fatigue design of cantilevered and noncantilevered steel and aluminum structural supports for highway signs, luminaires, and traffic signals.

C11.1

This Section focuses on fatigue, which is defined herein as the damage that may result in fracture after a sufficient number of stress fluctuations. It is based on NCHRP Report 412, *Fatigue Resistant Design of Cantilevered Signal, Sign and Light Supports* (Kaczinski et al., 1998); NCHRP Report 469, *Fatigue-Resistant Design of Cantilever Signal, Sign, and Light Supports* (Dexter and Ricker, 2002); NCHRP Report 494, *Structural Supports for Highway Signs, Luminaires, and Traffic Signals* (Fouad et al., 2003); NCHRP Web Only Document 176: *Cost-Effective Connection Details for Highway Sign, Luminaire and Traffic Signal Structures,* Final Report of NCHRP Project 10-70 (Roy et al., 2011); and NCHRP Project 10-74, *Development of Fatigue Loading and Design Methodology for High-Mast Lighting Towers* (Conner et al., 2012).

11.2—DEFINITIONS

Constant-Amplitude Fatigue Threshold (CAFT)—Nominal stress range below which a particular fatigue detail can withstand an infinite number of repetitions without fatigue failure.

Fatigue—Damage resulting in fracture caused by stress fluctuations.

High-Mast Lighting Tower (*HMLT*) —Another description for a pole-type high-level luminaire support. (See Article 1.2.)

In-Plane Bending—Bending in-plane for the main member (column). At the connection of an arm or arm's built-up box to a vertical column, the in-plane bending stress range in the column is a result of galloping or truck-induced gust loads on the arm, arm's attachments, or both.

Limit State Wind Load Effect—A specifically defined load criteria.

Load-Bearing Attachment—Attachment to main member where there is a transverse load range in the attachment itself in addition to any primary stress range in the main member.

Nonload-Bearing Attachment—Attachment to main member where the only significant stress range is the primary stress in the main member.

Out-of-Plane Bending—Bending out-of-plane for the main member (column). At the connection of an arm or arm's built-up box to a vertical column, the out-of-plane bending stress range in the column is a result of natural wind-gust loads on the arm and the arm's attachments.

Pressure Range—Pressure due to a limit state wind load effect that produces a stress range.

Stress Range—The algebraic difference between extreme stresses used in fatigue design.

Yearly Mean Wind Velocity—Long-term average of the wind speed for a given area.

11.3—NOTATION

A = finite life constant (MPa^3, ksi^3) (11.9.3)

C_{BC} = bolt circle ratio, $\dfrac{D_{BC}}{D_T}$ (11.9.3.1)

C_d = appropriate drag coefficient from Section 3, "Loads," for given attachment or member (11.7.2)

C_{OP} = opening ratio, $\frac{D_{OP}}{D_T}$ (11.9.3.1)

D_{BC} = diameter of circle through the fasteners in the transverse plate (mm, in.) (11.9.3.1)

D_{OP} = diameter of concentric opening in the transverse plate (mm, in.) (11.9.3.1)

D_T = external diameter of a round tube or outer flat-to-flat distance of a multi-side tube at top of transverse plate (mm, in.) (11.9.3.1)

H = effective weld throat (mm, in.) (note c in Table 11.9.3.1-1)

h_{ST} = height of longitudinal attachment (stiffener) (mm, in.) (11.9.3.1)

I_F = fatigue importance factors applied to limit state wind load effects to adjust for the desired level of structural reliability (11.7.1.2)

K_F = finite life fatigue stress concentration factor (Table 11.9.3.1-3)

K_I = infinite life fatigue stress concentration factor (11.9.3.1)

L = length of the pole (mm, in.) (11.7.2)

L = slip-splice overlap length (mm, in.) (example of Detail 1.2 in Table 11.9.3.1-1)

L = length of longitudinal attachment (mm, in.) (example of Detail 6.1 in Table 11.9.3.1-1)

N = number of wind-load-induced stress cycles expected during the lifetime of the structure (11.9.3)

N_{ST} = number of longitudinal attachment (stiffener) (11.9.3.1)

P_{CW} = combined wind pressure range for fatigue design of HMLTs (Pa, psf) (11.7.2)

P_{FLS} = fatigue limit state wind pressure range for fatigue design of HMLTs (Pa, psf) (11.7.2)

P_G = galloping-induced vertical shear pressure range (Pa, psf) (11.7.1.1)

P_{NW} = natural wind gust pressure range (Pa, psf) (11.7.1.1)

P_{TG} = truck-induced gust pressure range (Pa, psf) (11.7.1.3)

r = radius of chord or column (mm, in.) (note a in Table 11.9.3.1-1)

r_b = inside bend radius of plate (mm, in.) (11.9.3.1)

S_R = nominal stress range of the main member or branching member (MPa, ksi) (note b of Table 11.9.3.1-1)

t = thickness (mm, in.) (note a in Table 11.9.3.1-1)

t_b = wall thickness of branching member (mm, in.) (note b of Table 11.9.3.1-1)

t_c = wall thickness of main member (column) (mm, in.) (note b of Table 11.9.3.1-1)

t_p = plate thickness of attachment (mm, in.) (note c of Table 11.9.3.1-1)

t_{ST} = thickness of longitudinal attachment (stiffener) plate (mm, in.) (11.9.3.1)

t_T = thickness of tube (mm, in.) (11.9.3.1)

t_{TP} = thickness of transverse plate (mm, in.) (11.9.3.1)

V_{mean} = yearly mean wind velocity for a given area (m/s, mph) (11.7.1.2)

V_T = truck speed for truck-induced wind gusts (m/s, mph) (11.7.1.3)

α = ovalizing parameter for bending in the main member (note b of Table 11.9.3.1-1)

ΔF = fatigue resistance stress range (MPa, ksi) (11.5)

$(\Delta F)_{TH}$ = constant amplitude fatigue threshold (MPa, ksi) (11.9.3)

$(\Delta F)_n$ = nominal fatigue resistance (MPa, ksi) (11.5.1) (11.9.3)

Δf = wind-load-induced stress range (MPa, ksi) (11.5)

$(\Delta f)_n$ = nominal wind-load-induced stress range (MPa, ksi) (11.5.1) (11.9.2)

$\Delta\sigma$ = indication of stress range in member (Table 11.9.3.1-1)