Combined Ice and Wind Load Case 2

D (dead load)	$D_{SW} = 500\,\text{lb/phase}$ $D_{bus} = 45\,\text{lb/phase}$ $D_{structure}$
I (ice load)	$I_{bus} = 57\,\text{lb/ft}^3\ ((\Pi(5.50^2 - 3.50^2)/4)\ \text{in.}^2 \times 30\,\text{in.}/2/(12\,\text{in./ft})^2)$ $= 84\,\text{lb/phase}$ $I_{structure} = 0$
F (wind load in combination with ice)	$F_{SW} = 3.07\,\text{lb/ft}^2 \times 10\,\text{ft}^2 = 31\,\text{lb/phase}$ $F_{bus} = 3.41\,\text{lb/ft}^2 \times (5.50\,\text{in.} \times 30\,\text{ft}/2/(12\,\text{in./ft}))$ $= 23\,\text{lb/phase}$ $F_{structure} = 6.82\,\text{lb/ft}^2 \times A_{structure}$
Short-circuit load	$SC_{bus} = 8.1\,\text{lb/ft} \times 30\,\text{ft}/2 = 122\,\text{lb}$

Ice importance factor: $I_{FI} = 1.0$.
T_w (wire tension): T_w = N/A.
Wind with ice importance factor: $I_{FWI} = 1.0$ (per ASCE 7 2005).
Load combination/Factors: 1.1 D + 1.2 I_W I_{FI} + 1.2 W_I I_{FIW} + 0.75 SC.

Earthquake Load Case 3

D_3 (dead load)	$D_{SW} = 500\,\text{lb/phase}$ $D_{bus} = 45\,\text{lb/phase}$ $D_{structure}$
F_E (earthquake load)	$F_{ESW} = 0.33 \times 500\,\text{lb} = 165\,\text{lb/phase}$ $F_{Ebus} = 0.33 \times 45\,\text{lb} = 15\,\text{lb/phase}$ $F_{ESTR} = 0.33\,W$ lb
Short-circuit load	$SC_{bus} = 8.1\,\text{lb/ft} \times 30\,\text{ft}/2 = 122\,\text{lb}$

T_w (wire tension): T_w = N/A.
Load combination/Factors: 1.1 D + 1.25 E (or E_{FS}) I_{FE} + 0.75 SC.

Short-Circuit Load Case 4

Load combination/Factors: 1.1 D + 1.00 SC_{bus} + 1.1 T_w.

The designer would apply these load combinations to the structure. Then, using the appropriate analysis method, the member stresses are checked. The deflection load cases would be developed, and the deflection limits of Chapter 4 would be checked.

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CHAPTER 4
DEFLECTION CRITERIA

Deflection and rotation of substation structures and members can affect the mechanical operation of supported electrical equipment, reduce electrical clearances, and cause unpredicted stress in structures, insulators, connectors, and rigid bus conductors. For these reasons, structural deflections should be limited to magnitudes that are not detrimental to the mechanical and electrical operation of the substation.

The sensitivity of equipment to deflection of supporting structures varies considerably. Disconnect switches, with complex mechanical operating mechanisms, are highly susceptible to binding if the structure distorts from the installed geometry. Conversely, structures supporting only stranded bus conductors or overhead line dead-ends can withstand structure deflections without any effect on operation. Therefore, structures are classified for the purpose of applying deflection limitations that reflect the sensitivity of supported equipment.

Loading criteria for deflection limitations are recommended in Section 3.1.11 in Chapter 3.

4.1 STRUCTURE CLASSIFICATIONS AND DEFLECTION LIMITATIONS

4.1.1 Deflection Analysis and Criteria

4.1.1.1 Horizontal Members. For determination of maximum deflections, the span of a horizontal member is the clear distance between connections to vertical supporting members, or for cantilever members, the distance from the point of investigation to the vertical supporting member (Fig. 4-1).

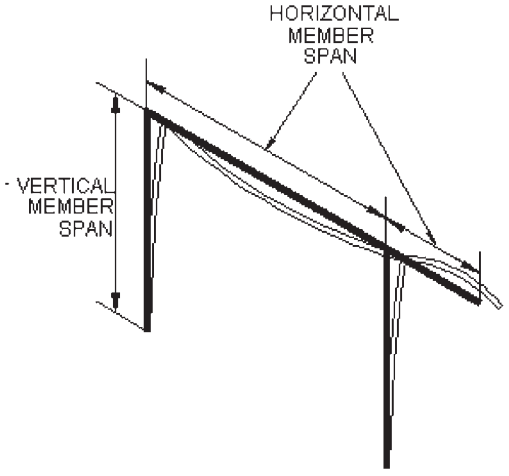

FIGURE 4-1. Span Definitions.

For horizontal members, the deflection is the maximum net displacement, horizontal or vertical, of the member relative to the member connection points. Deflection analysis typically does not include the foundation displacement or rotation.

4.1.1.2 Vertical Members. For determination of maximum deflections, the span of a vertical member is the vertical distance from the foundation support to the point of investigation on the structure. The deflection to be limited is the gross horizontal displacement of the member relative to the foundation support.

4.1.2 Class A Structures

Class A structures support equipment with mechanical mechanisms where structure deflection could impair or prevent proper operation. Examples are group-operated switches, vertical reach switches, ground switches, circuit-breaker supports, and circuit-interrupting devices. Equipment manufacturers should be consulted to determine if any specific structure deflection limits are required for their equipment.

4.1.2.1 Deflection Limitations of Horizontal Members in Class A Structures. Vertical deflection of horizontal members (Fig. 4-2) should not exceed 1/200 of the member span. Horizontal deflection of horizontal members should also not exceed 1/200 of the member span.

4.1.2.2 Deflection Limitations of Vertical Members in Class A Structures. Horizontal deflection of vertical members should not exceed 1/100 of the height of the point of investigation above the foundation.

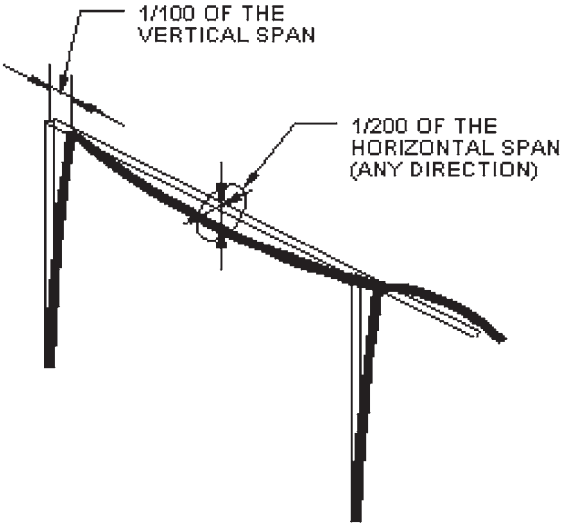

FIGURE 4-2. Deflection Limits for Class A Structures.

4.1.3 Class B Structures

Class B structures support equipment without mechanical mechanisms, but where excessive deflection could result in compromised phase-to-phase or phase-to-ground clearances or unpredicted stresses in equipment, fittings, or bus conductors. Examples are support structures for rigid bus conductors, surge arresters, metering devices (such as CTs, PTs, and CCVTs), station power transformers, hookstick switches or fuses, and wave traps. Equipment manufacturers should be consulted to determine if any specific structure deflection limits are required for their equipment.

4.1.3.1 Deflection Limitations of Horizontal Members in Class B Structures. Vertical deflection of horizontal members (Fig. 4-3) should not exceed 1/200 of the member span. Horizontal deflection of horizontal members should not exceed 1/100 of the member span.

4.1.3.2 Deflection Limitations of Vertical Members in Class B Structures. Horizontal deflection of vertical members should not exceed 1/100 of the height of the point of investigation above the foundation.

4.1.4 Class C Structures

Class C structures support equipment relatively insensitive to deflection or are stand-alone structures that do not support any equipment. Examples are support structures for flexible (stranded conductor) buses, masts for

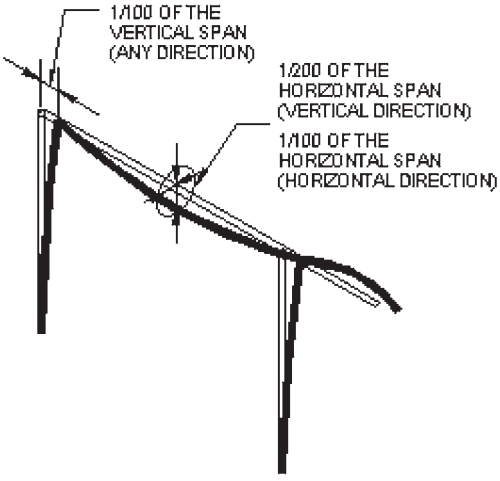

FIGURE 4-3. Deflection Limits for Class B Structures.

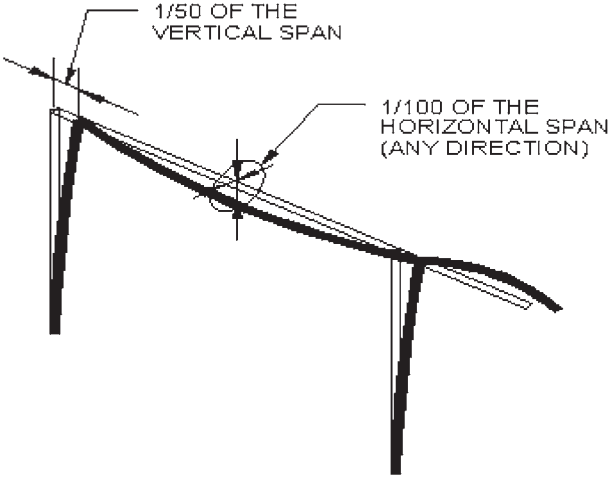

FIGURE 4-4. Deflection Limits for Class C Structures.

lightning shielding, and dead-end structures for incoming transmission lines. Deflection limitations for these structures are intended to limit P-delta stresses, wind-induced vibrations, and visual impact.

4.1.4.1 Deflection Limitations of Horizontal Members in Class C Structures. Vertical deflection of horizontal members (Fig. 4-4) should not exceed 1/100 of the member span. Horizontal deflection of horizontal members should not exceed 1/100 of the member span.

4.1.4.2 Deflection Limitations of Vertical Members in Class C Structures. Horizontal deflection of vertical members should not exceed 1/50 of the height of the point of investigation above the foundation.

4.2 SPECIAL CONSIDERATIONS FOR DEFLECTION ANALYSIS

4.2.1 Multiple-Use Structures

Structures can be designed to support several pieces of equipment that require different structure classifications. When investigating deflection of a multiple-use structure, the deflection limits applicable to any point on the structure are determined by the classification of the structure from that location upward. If there is Class A equipment at or above the location being analyzed, then the analysis of that location is governed by Class A limits. If there is only Class B and C equipment at or above the location being analyzed, then the analysis of that location is governed by Class B limits. If there is only Class C equipment at or above the location being analyzed, then the analysis of that location is governed by Class C limits. As an example, Fig. 4-5 shows a line dead-end structure (Class C) that also supports a switch (Class A) at a lower elevation. The switch platform and the vertical members from the foundation to the switch platform should meet Class A deflection criteria. Members associated with the line

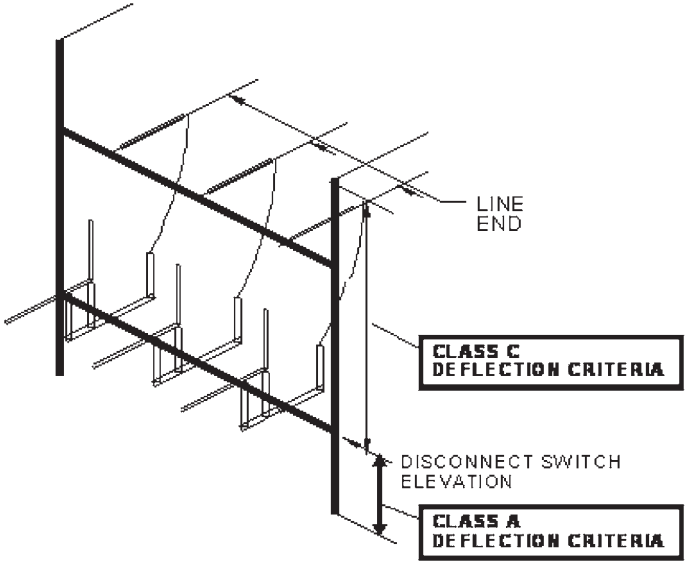

FIGURE 4-5. Multiple-Use Structures.

dead-end and vertical members from the switch elevation to the line dead-end should meet Class C criteria.

4.2.2 Rotational Limitation

Some equipment and rigid bus designs may be sensitive to rotation of supporting members in addition to the deflection of the member. Equipment manufacturers should be consulted as to any rotational limits that may be necessary to ensure reliable operation. Where an analysis is performed of the rigid bus and support system, the sensitivity of the system to support rotation should be investigated and limits determined if necessary.

4.2.3 Lightning Masts and Other Tall, Slender Structures

In certain cases, the structure type, design loads, and lower deflection limits for Class C structures can result in a flexible (low stiffness) structure. These structures can be subject to potentially damaging wind-induced oscillations. Such structures can be susceptible to fatigue cracking and failure. In addition to the specified static deflection limits, consideration should be given to the use of dampening devices or other techniques to minimize potential for damage. Methods include the use of internal cables or covered chains, external spoilers, or other means of interrupting the oscillations. Additional information on structural member vibrations is discussed in Sections 6.9.10 and 6.10.2 in Chapter 6.

TABLE 4-1. Summary of Structure Deflection Limitations

Maximum Structure Deflection as a Ratio of Span Length[a]				
		Structure Class		
Member Type	Deflection Direction	Class A	Class B	Class C
Horizontal[b]	Vertical	1/200	1/200	1/100
Horizontal[b]	Horizontal	1/200	1/100	1/100
Vertical[c]	Horizontal	1/100	1/100	1/50

[a]For loading criteria for deflection limitations, see Section 3.1.11 in Chapter 3.
[b]Spans for horizontal members should be the clear span between vertical supports, or for cantilever members, the distance to the nearest vertical support. Deflection should be the net displacement, horizontal or vertical, relative to the member support points.
[c]Spans for vertical members should be the vertical distance from the foundation connection to the point of investigation. Deflection should be the gross, horizontal displacement relative to the foundation support.

4.2.4 Rigid Bus Conductor Deflection Criteria

To obtain an acceptable appearance, it is recommended that the vertical deflection of rigid bus conductors (aluminum or copper tubing or shapes) be limited to 1/200 of the bus span. This criterion should be applied with the deadweight of the rigid bus, with dampers, and with no ice or wind. Vertical deflection of rigid bus conductors is measured from the attachment point of the bus conductor at the insulators to the midspan point.

4.3 SUMMARY

Table 4-1 summarizes the structure classes and associated deflection limits.

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