C10.4.2.2 *Slenderness ratio of a laced compression member*

The limit of $1.4(L_e/r)_c$ is to prevent the possibility of a main component failing between consecutive lacing points.

C10.4.2.3 *Lacing angle*

Studies have shown lacing angles to be the most effective for lacing members (Ref. 5).

C10.4.2.4 *Effective length of a lacing element*

The different effective length values reflect the difference in the restraint provided by single and double lacing systems.

C10.4.2.5 *Slenderness ratio limit of a lacing element*

A nominal value is provided to ensure a reasonable stiffness and capacity for the lacing.

C10.4.2.6 *Mutually opposed lacing*

The asymmetry of two single lacing systems opposed in direction on opposite sides of a main member results in torsional effects under axial compression.

Significant second-order effects can arise if additional lacing elements, except tie plates specified in Clause 10.4.2.7 of the Standard, are provided at 90° to the longitudinal axis of the member, and these effects cannot be neglected.

C10.4.2.7 *Tie plates*

Tie plates are used to anchor the lacing system at points where it is interrupted, such as at the member ends. They are designed as battens (see Clause 10.4.3 of the Standard).

C10.4.3 Battened compression members

The details in the Clause are based on past experience with modifications in line with Ref. 25.

C10.4.3.1 *Slenderness ratio of a main component*

The slenderness limit of 50 ensures that each main component is a relatively stocky member irrespective of the slenderness of the whole member. The slenderness limit of 0.6 times the slenderness ratio of the whole member not only ensures that each main component is less slender than the whole member, but also results in two intermediate battens being provided within the length of the member in addition to the end battens.

C10.4.3.2 *Slenderness ratio of battened compression members*

For a member with diagonal lacing with geometries and proportions in accordance with Clause 6.4.2 of the Standard, shear deformations are small and do not significantly reduce the strength below that for a similar member with a solid web; however, there are no webs or diagonals in battened columns to resist transverse shear and, hence, the main components and battens act together as a Vierendeel truss.

To account for the reduction in the strength of a battened member due to shear deformation, an increased slenderness ratio $(L_e/r)_{bn}$ is used which depends on the relative values of the slenderness of the member as a whole, assuming the main components act together as an integral member, and the slenderness of a single main component between consecutive points where battens are attached.

C10.4.3.3 *Effective length of a batten*

The reduction in effective length for an intermediate batten reflects the degree of restraint provided by the main components.

C10.4.3.4 *Maximum slenderness ratio of a batten*

A nominal value is provided to ensure a reasonable capacity and stiffness for the batten.

C10.4.3.5 *Width of a batten*

This width of batten is required so that it will be stiff and be able to provide adequate connection to the main components, so as to ensure adequate Vierendeel action.

C10.4.3.6 *Thickness of a batten*

Where plate slenderness could reduce capacity, provision is made for a stiffener.

C10.4.3.7 *Loads on battens*

The transverse shear force (V^*) in the main components results in a design longitudinal shear force (V_L^*) and a design bending moment (M^*), which should be resisted by the battens. V_l^* and M^* are determined from statics assuming points of inflection in the main components midway between the battens and at the midspan of each batten (Ref. 5).

C10.5 COMPRESSION MEMBERS BACK-TO-BACK

The details in the Clause are based on past experience, with modifications in line with Ref. 25.

C10.5.1 Components separated

C10.5.1.1 *Application*

The Clause is limited to double angles, channels or tees separated by no more than that required for end gusset connection in normal practice.

C10.5.1.2 *Configuration*

The arrangement should be symmetric.

C10.5.1.3 *Slenderness*

The member is treated as an equivalent battened member (see Clause 10.4.3.2 of the Standard).

C10.5.1.4 *Connection*

The member is treated as an equivalent battened member (see Clause 10.4.3 of the Standard). A minimum of two fasteners or the equivalent is required at the ends of each main component.

C10.5.1.5 *Design forces*

The design longitudinal shear force (V_L^*) is a close approximation to that which can be derived from statics assuming points of inflection in the main components midway between the connections and at the connections.

C10.5.2 Components in contact

C10.5.2.1 *Application*

The Clause directs the design engineer to Clauses 10.5.2.2 to 10.5.2.5 of the Standard.

C10.5.2.2 *Configuration*

The arrangement should be symmetric.

C10.5.2.3 *Slenderness*

The member is treated as an equivalent battened member (see Clause 10.4.3.2 of the Standard).

C10.5.2.4 *Connection*

The member is treated as an equivalent battened member. A minimum of two fasteners or the equivalent is required at the ends of each main component.

C10.5.2.5 *Design forces*

The Clause directs the design engineer to Clause 10.5.1.5 of the Standard.

C10.6 COMPOSITE COMPRESSION MEMBERS

C10.6.1 General

The Clause is based on Eurocode 4 (Ref. 26). Design engineers may refer to that Standard, which also covers concrete encased compression members. Although Eurocode 4 (Ref. 26) has been written for buildings rather than bridges, the fact that dynamic effects in bridge columns are much less than those that occur in superstructures, makes the use of these provisions appropriate.

C10.6.1.1 *Scope*

(See Clause C10.6.1.)

C10.6.1.2 *Materials*

(See Clause C10.6.1.)

C10.6.1.3 *Shear connection*

(See Clause C10.6.1.)

C10.6.1.4 *Steel contribution factor*

(See Clause C10.6.1.)

C10.6.1.5 *Local buckling*

(See Clause C10.6.1.)

C10.6.2 Ultimate section capacity

The design rules of the Clause are based on Eurocode 4 (Ref. 26), reformatted to match the layout of the Standard. The Clause allows the benefits of confinement of concrete for both rectangular and circular sections in that the nominal concrete compressive strength does not have to be factored by 0.85, and Clause 4.4.2 of the Standard permits reduced creep to be assumed in the concrete (as a result of the fact that no water loss can occur during the concrete's curing and later life). For circular composite columns, the increase in the concrete's ultimate strength caused by the restraint of the steel tube is permitted for in Clause 10.6.2.2 of the Standard.

C10.6.2.1 *Rectangular members*

(See Clause C10.6.2.)

C10.6.2.2 *Circular members*

(See Clause C10.6.2.)

C10.6.2.3 *Effective flexural stiffness*

(See Clause C10.6.2.)

C10.6.2.4 *Relative slenderness*

(See Clause C10.6.2.)

C10.6.3 Ultimate member capacity

The design rules of the Clause are based on the provisions of Eurocode 4 (Ref. 26), rewritten so that it can be used in the same way as Clause 10.3 of the Standard.

C10.6.3.1 *Definitions*

(See Clause C10.6.3.)

C10.6.3.2 *Effective length*

(See Clause C10.6.3.)

C10.6.3.3 *Nominal capacity of composite members of constant cross-section*

(See Clause C10.6.3.)

C10.6.3.4 *Nominal capacity of composite members of varying cross-section*

(See Clause C10.6.3.)

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SECTION C11 MEMBERS SUBJECT TO COMBINED ACTIONS

INTRODUCTION

The strength design of members subject to combined axial and bending actions is governed by Clauses 11.1 to 11.4 of the Standard. Further information is given in Refs 1 to 3. The behaviour on which these clauses are based is described in textbooks such as Ref. 4. This Commentary should be read in conjunction with such a textbook. Worked examples are given in Refs 5 and 6, while computer programs are described in Refs 7 and 8.

Clause 11.2 defines the member actions that are to be designed for. Clause 11.3 of the Standard defines the section capacity, which is governed either by yielding or local buckling, and which may control the design of highly restrained members. Clause 11.4 of the Standard defines the member capacity, which often controls the design of members without full restraint.

The members of steel structures are often subjected to secondary torsional actions, in addition to the primary axial and bending actions. In the past, these actions were usually ignored, but design engineers who use three-dimensional analysis programs are becoming more aware of them. Because the Standard provides no guidance on designing against torsion, and neither do many other steel design Standards around the world, there are no provisions for designing against combined torsion, axial and bending actions. This subject is discussed further in Refs 4, 9, 10, 11 and 12.

C11.1 GENERAL

The Clause directs the design engineer to subsequent clauses.

C11.2 DESIGN ACTIONS

The Clause first defines the member design actions N^*, M_x^*, M_y^*. For checking the section capacity, these are the values at the section under consideration. All sections in the member should satisfy the requirements of Clause 11.3 of the Standard, but usually the most heavily loaded sections are obvious and only these need be considered.

For checking the member capacities, the design actions are the maximum values in the member. Each of the appropriate in-plane, out-of-plane and biaxial bending member capacity requirements of the Section should be satisfied for the member as a whole.

The Clause then reminds the design engineer that the actions should include the second-order components arising from the axial forces and the changes in geometry of the structure and its members under load, when these are significant.

The Clause then lists the methods of structural analysis of Section 4 of the Standard, one of which should be used to determine the member design bending moments M_x^*, M_y^*.

Design engineers should note that plastic design methods are not permitted for bridges.

C11.3 SECTION CAPACITY

C11.3.1 General

The Clause directs the design engineer to the appropriate subsequent clause, depending on whether the bending actions are confined to one of the principal planes (uniaxial bending), or whether they cause biaxial bending about both principal axes. It again points out that all sections along the member should satisfy the section capacity requirements. The Clause then defines the section capacities that are used in later clauses.

C11.3.2 Uniaxial bending about the major principal *x*-axis

The nominal section capacity of a member subjected to bending alone is reduced by the presence of axial force. Axial compression and tension both reduce the yield capacity of the section, while axial compression also reduces the local buckling capacity.

A simple straight line approximation is given for the reduction in the section moment capacity caused by axial force, which can be applied to any type of member cross-section. Substituting the approximation into the design inequality leads to the equivalent formulation—

$$\frac{M_x^*}{\phi M_{sx}} + \frac{N^*}{\phi N_c} \leq 1.0 \qquad \text{. . . C11.3.2}$$

The approximation is conservative for tension members and compact compression members of doubly-symmetric I section or rectangular and square hollow section to AS 1163 (Ref. 13) and so more accurate alternatives are provided.

C11.3.3 Uniaxial bending about the minor principal *y*-axis

The Clause is similar to the previous one for bending about the *x*-axis, in that a simple straight line approximation for the reduction in the section moment capacity is given for general use, and also more accurate and economical alternatives for compact doubly-symmetric I sections and rectangular and square hollow sections to AS 1163 (Ref. 13).

C11.3.4 Biaxial bending

The Clause gives a simple linear approximation for the section capacity of members subjected to biaxial bending about both principal axes, which reduces to the earlier linear approximations for uniaxial bending.

This is often very conservative, and so a more accurate and economical power law approximation is permitted for compact doubly-symmetric I sections and rectangular and square hollow sections to AS 1163 (Ref. 13). This power law approximation will be overridden by the corresponding power law approximations for the member capacity given in Clauses 11.4.4.1 and 11.4.4.2 of the Standard, except when there is a significant local reduction in section geometry at a heavily loaded cross-section.

C11.4 MEMBER CAPACITY

C11.4.1 General

The Clause directs the design engineer to the appropriate subsequent clauses for design against failure in a principal plane of bending, against lateral buckling failure out of a principal plane of bending, or against biaxial bending failure.

C11.4.2 In-plane capacity

The Clause governs the in-plane capacity of members that are bent in one principal plane, and that fail in that plane. Members that are bent about the major principal *x*-axis and that do not have sufficient lateral restraint to prevent buckling out of the plane of bending should also be checked for their out-of-plane member capacity using Clause 11.4.3 of the Standard.

The Clause permits the application of subsequent clauses to members analysed elastically, or to statically determinate members.

C11.4.2.1 *Compression members*

The destabilizing effects of axial compression reduce the member in-plane moment capacity. The Clause gives a simple linear approximation for the reduced member capacity.

This approximation is often conservative, and so a more accurate approximation is permitted for compact doubly-symmetric I section and rectangular and square hollow section (to AS 1163) members. The economy produced by the use of this more accurate approximation instead of the linear approximation is most marked for members with high moment gradient (high values of β_m).

The effective length factor (k_e) used in the Clause to determine the in-plane compression member capacity (N_c) is taken as unity for a sway member, because the effects of end restraints that influence member buckling have already been taken into account, either in amplifying the first order moment distribution, or in carrying out a second order analysis; however, this procedure may be unsafe for some unbraced compression members which have small bending moments. For this reason, the design axial compression alone should satisfy Clause 10.1 of the Standard when a greater effective length factor (k_e), determined using Clause 4.3.2 of the Standard, is used to determine the compression capacity.

C11.4.2.2 *Tension members*

Axial tension does not reduce the member in-plane moment capacity, and so the design of these members will be governed by their section capacities, determined using Clause 11.3 of the Standard.

C11.4.3 Out-of-plane capacity

The Clause governs the design of members that are bent about the major principal x-axis and fail by buckling laterally out of the plane of bending. The in-plane capacity of these members should also be checked using Clause 11.4.2 of the Standard. Members that are bent about the minor principal y-axis do not normally fail by buckling out of the plane of bending unless there are transverse loads acting far above the critical flange, and their design is rarely governed by Clause 11.4.4 of the Standard.

C11.4.3.1 *Compression members*

The destabilizing effects of axial compression reduce the member lateral buckling moment capacity (M_{bx}). Clause 11.4.4.1 of the Standard gives a simple linear approximation for the reduced member capacity, which uses the out-of-plane compression member capacity (N_{cy}).

This approximation is often conservative, and so a more accurate approximation is permitted for compact doubly-symmetric I section members without transverse loads. The economy produced by the use of this instead of the linear approximation is most marked for members with high moment gradient (high values of β_m).

C11.4.3.2 *Tension members*

Axial tension increases the member lateral buckling moment capacity (M_{bx}). Clause 11.4.4.2 of the Standard gives a simple linear approximation for the increased moment capacity which is conservative for small to moderate axial tensions. The design of members with high axial tensions will be governed by the section capacity requirements of Clause 11.3.2 of the Standard.

C11.4.4 Biaxial bending capacity

The Clause governs the biaxial capacities of members that are bent about both principal axes.

C11.4.4.1 *Compression members*

The Clause gives a power law approximation for the biaxial bending capacities of members with axial compression. For the term M_{cx} associated with bending about the major principal x-axis, the lesser of the in-plane member capacity (M_{ix}) and the out-of-plane member capacity (M_{ox}) is used, while for the term associated with bending about the minor principal y-axis, the in-plane capacity (M_{iy}) is used.

The power law inequality can be approximated conservatively by a linear relationship obtained by setting the index $\gamma = 1.0$, but often at the expense of significant economy.

C11.4.4.2 *Tension members*

The Clause gives a power law approximation for the biaxial bending capacities of members with axial tension, which is similar to that of the previous clause for members with axial compression, except that the term (M_{tx}) associated with bending about the major principal x-axis is taken as the lower of the in-plane reduced section capacity (M_{rx}) and the out-of-plane member capacity (M_{ox}).

The power law inequality can again be approximated conservatively by a linear relationship obtained by setting the index γ equal to 1.0, but often at the expense of significant economy.

C11.5 CAPACITY OF COMPOSITE COMPRESSION MEMBERS

The Clause is complementary to Clause 10.6 of the Standard, and is based on Eurocode 4 (Ref. 14) to which reference may be made. Some of the content of Eurocode 4, together with some of the content of Annex C of Eurocode 4 (Ref. 14) have been summarized in Appendix F of the Standard. Eurocode 4 (Ref. 14) covers the use of other types of composite columns, and reference may be made to those provisions when required.

C11.5.1 General

(No Commentary.)

C11.5.2 Uniaxial bending

(No Commentary.)

C11.5.3 Biaxial bending

The procedure provided in the Clause is derived from Eurocode 4 (Ref. 14), adjusted to be compatible with the provisions of Clause 11.4.4 of the Standard for steel compression members.

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