GUIDE FOR THE DESIGN OF CRANE-SUPPORTING STEEL STRUCTURES

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From Rowswell (1987), the probable amplification of stress that may occur is given by the following magnification factor:

$$Magnification\ Factor = \frac{1}{1 - \left[\dfrac{forcing\ \ frequency}{natural\ \ frequency}\right]^2}$$

2.4 Load Combinations Specific to Crane-Supporting Structures

The structure must also be designed for load combinations without cranes, in accordance with the NBCC 2005. Load combinations comprising fewer loads than those shown below may govern.

Where multiple cranes or multiple aisles are involved, only load combinations that have a significant possibility of occurring need to be considered. Load combinations as will be given in the NBCC 2010, but including crane loads, are presented here.[1]

Crane load combinations C_1 to C_7 shown in Table 2.2 are combinations of the crane loads given in Section 2.2 that are used in the industry. For more information see AISE (2003), Fisher (2004), and MBMA (2002).

For load combinations involving column-mounted jib cranes, see Fisher and Thomas (2002).

Table 2.2
Crane Load Combinations

C_1	$C_{vs} + 0.5\,C_{ss}$	Fatigue
C_2	$C_{vs} + C_{is} + C_{ss} + C_{ls}$	Single crane in a single aisle.
C_3	$C_{vm} + C_{ss} + C_{ls}$	Any number of cranes in single or multiple aisles.
C_4	$C_{vm} + 0.5\,C_{sm} + 0.9\,C_{lm}$	Two cranes in tandem in one aisle only. No more than two need be considered except in extraordinary circumstances.
C_5	$C_{vm} + 0.5\,C_{sm} + C_{im} + 0.5\,C_{lm}$	One crane in each adjacent aisle.
C_6	$C_{vm} + 0.5\,C_{sm}$	Maximum of two cranes in each adjacent aisle, side thrust from two cranes in one aisle only. No more than two need be considered except in extraordinary circumstances.
C_7	$C_{vs} + C_{is} + C_{bs}$	Bumper impact

[1] *The load combinations given in this section represent the best available information at the time of printing. The reader should consult the online version of this Design Guide on the CISC website (www.cisc-icca.ca) once the NBCC 2010 is available.*

2.4.1 Fatigue

The calculated fatigue stress range at the detail under consideration, to meet the requirements of Clause 26 of S16-01 and as described in Chapter 3 of this document, will be taken as that due to C_1.

Note: *Dead load is a steady state and does not contribute to the stress range. However, the dead load stress may cause the stress range to be entirely in compression and therefore favourable or wholly or partly in tension and therefore unfavourable.*

2.4.2 Ultimate Limit States of Strength and Stability

In each of the following inequalities, for load combinations with crane loads, the factored resistance, ϕR, and the effect of factored loads such as $0.9D$, are expressed in consistent units of axial force, shear force or moment acting on the member or element of concern. The most unfavourable combination governs.

	Case	Principal Loads	Companion Loads	
1.	$\phi R \geq$	$1.4D$		
2.	$\phi R \geq$	$(1.25D \text{ or } 0.9D) + (1.5C + 1.0L)$	$1.0S$ or $0.4W$	
3.	$\phi R \geq$	$(1.25D \text{ or } 0.9D) + (1.5L + 1.0C)$	$0.5S$ or $0.4W$	
4.	$\phi R \geq$	$(1.25D \text{ or } 0.9D) + 1.5S$	$(1.0C + 0.5L)$	
5.	$\phi R \geq$	$(1.25D \text{ or } 0.9D) + 1.4W$	$(1.0C + 0.5L)$	See Note 8.
6.	$\phi R \geq$	$(1.25D \text{ or } 0.9D) + 1.0C_7$		
7.	$\phi R \geq$	$1.0D + 1.0E$	$1.0C_d + 0.5L + 0.25S$	Previous load combination 7 deleted
8.	$\phi R \geq$	$1.0D + C_1$		

where C is any one of the crane load combinations C_2 to C_6 from Table 2.2.

Loads D, L, S, W and E are loads defined in the National Building Code of Canada (NBCC) issued by the Canadian Commission on Building and Fire Codes with the exception that the load L is all the live loads excluding loads due to cranes. Notes (1) through (9) of table 4.1.3.2.B of the 2010 NBCC shall apply to the factored load combinations.

Notes:

1) *The combinations above cover the whole steel structure. For design of the crane runway beams in an enclosed structure for instance, S and W would not normally apply.*
2) *Crane runway columns and occasionally crane runway beams support other areas with live loads.*
3) *The effects of factored imposed deformation, 1.25T, lateral earth pressure, 1.5H, factored pre-stress, 1.0P, shall be considered where they affect structural safety.*
4) *The earthquake load, E, includes earthquake-induced horizontal earth pressures.*
5) *Crane wheel loads are positioned for the maximum effect on the element of the structure being considered.*
6) *The basic NBCC load factors shown above are in accordance with information available at the time of publication of this document. The designer should check for updates.*
7) *Note that the NBCC requires that for storage areas the companion load factor must be increased to 1.0.*
8) *Side thrust due to cranes need not be combined with full wind load.*

5.4 Methods of Analysis

At the very least second-order elastic methods of analysis should be used for structures covered by this design guide in keeping with the philosophy of S16-01. Plastic design methods are not recommended except perhaps for rehabilitation studies where aspects such as deflection and fatigue may not control.

Use of computerized structural modelling with proven software to account for sway effects, P-Δ, instead of the more approximate methods of Clause 8.7.1 of S16-01 are recommended. Commonly used computer software is easily capable of not only doing second-order elastic analysis, but by adding joints along the length of compression members subject to bending; the P-δ effects (Clause 13.8.4 of S16-01) are generated along with the P-Δ effects. Consideration of these effects can be simplified by judicious structural modelling. The experienced designer should be able to isolate critical load combinations and thus reduce the number of load combinations that require a second-order analysis.

5.5 Notional Loads

One sentence deleted

S16-01 requires use of "notional loads" to assess stability effects (Clause 8.7.2). This approach is somewhat different from AISE and AISC ASD, WSD and LRFD methods where effective lengths using the well known but approximate elastic factor "K" are used. Their use avoids weak beams. Notional loads are fictitious or pseudo-lateral loads, taken in S16-01 as a small percentage (0.5%) of the factored gravity loads at each "storey" of the structure. The translational load effects thus generated (otherwise there might be no lateral load) transform the sway buckling or bifurcation problem to an in-plane strength problem. There is no need to consider "effective" length factors greater than one.

The use of notional loads applied to a crane-supporting structure requires considerations beyond those usually encountered in residential or commercial construction because lateral loads are applied at the crane runway beam level. The definition of a "storey" for an industrial building may be open to interpretation and the concepts of "effective" and "equivalent" lengths as applied to stepped columns requires steps in the analysis and design that are not well covered in commonly used design aids.

MacCrimmon and Kennedy (1997) provide more detailed information and a worked example is presented. See also Section 5.6.

5.6 Segmented Columns

Segmented columns may be of constant or varying (stepped) cross section. Several different column configurations can be used for crane-carrying structures (see Fisher 2004 and Galambos 1998). If a member has a constant cross section with axial loads applied between in-plane lateral supports or frame connections, or if the member cross section changes between in-plane lateral supports or frame connections, it it considered to be segmented. Where segmented columns are used and where the components of built-up sections are connected so that they act integrally, the concept of "equivalent lengths" of the column segments may be applied and a buckling analysis may be required. Galambos (1998) and MacCrimmon and Kennedy (1997) provide the designer with information on limit states analysis and design methods. Fisher (2004) and AISE (2003) contain design aids.

Section 5.5 refers to aspects of notional loads that require consideration. Schmidt (2001) provides an alternative method of analysis of stepped columns using notional loads, but with cautions that further research is required.

5.7 Building Longitudinal Bracing

For lighter crane duty service, a properly designed single plane of vertical bracing at the columns should provide satisfactory service. A decision whether to add another plane of vertical bracing, under the runway beams, should be taken considering the magnitude of the longitudinal forces and the effects of eccentricity in plan. Refer to reference 9 for more information. It is suggested that when the magnitude of longitudinal forces due to traction or end stop collision exceed a (specified) load of 100 kN, that a second plane of bracing should be introduced. For large forces, and for Crane Service Classifications C and up, bracing also in the plane of the crane runway beams similar to that shown in Figure 9 is recommended.

Compared to ordinary industrial buildings, it is even more important in crane-carrying structures subjected to repeated loads that the longitudinal bracing be located as close as possible to the mid point between expansion joints or ends of the building.

β_x, C_w and J can be calculated using information from the Technical Resources at the CISC website for calculating torsional sectional properties. Refer also to Design Example 1, step 12.

$$M_i = F_L S_{xc} \text{ or } F_y S_{xt}, \text{ whichever is less}$$

$$L_p = 1.76\, r_{yc} \sqrt{\frac{E}{F_y}}$$

L_i can not be calculated directly and must be solved by a trial and error iteration until the unbraced length used in the formula for M_u produces a moment $M_u = M_i$. That length is then L_i.

The symbols from the reference documents are not necessarily covered by S16-01. Symbols different from or in addition to those in S16-01, for these calculations only, are as follows:

C_b	=	Coefficient to account for increased moment resistance of a laterally unsupported beam segment when subject to a moment gradient, usually taken as 1.0
F_L	=	$F_y - F_r$
F_r	=	Compressive residual stress in the flange
	=	69 MPa for rolled shapes
	=	114 MPa for (continuously) welded shapes
K	=	Effective length factor
L_i	=	Limiting laterally unbraced length for inelastic lateral-torsional buckling
L_p	=	Limiting laterally unbraced length for full plastic bending capacity, uniform moment case
r_{yc}	=	Radius of gyration of the compression flange about the beam axis of symmetry
S_{xc}	=	Section modulus referred to the compression flange
S_{xt}	=	Section modulus referred to the tension flange

5.10 Biaxial Bending

Crane runway beams subject to biaxial bending are proportioned in accordance with Clause 13.8.3 of S16-01, which when the axial compression is zero, gives

$$\left[M_{fx}/M_{rx}\right] + \left[M_{fy}/M_{ry}\right] \leq 1.0$$

The capacity of the member is examined for

(a) overall member strength, and

(b) lateral-torsional buckling strength.

It is noted that this formulation requires lateral-torsional buckling about the strong axis to be considered as appropriate and allows inelastic action to be considered provided that the width-thickness ratios of the elements are sufficiently stocky.

See Appendix A, Design Examples 1 and 2.

CHAPTER 6 - REHABILITATION AND UPGRADING OF EXISTING CRANE-CARRYING STEEL STRUCTURES

6.1 General

Designers may be asked to assess and report on the condition of a crane-carrying steel structure for different reasons such as:

- concern about the condition of the structure,
- due diligence brought on by a change in ownership,
- to extend the useful life under the same operating conditions,
- to increase production by adding cranes or other equipment, and
- to modify processes and add new and possibly heavier cranes or other equipment.

The structure may be several decades old, materials of construction are not clear, drawings and calculations are nonexistent, and past crane duty cycles unknown. The local building code authority may be unprepared to accept measures which might be interpreted as contrary to the provisions of the local building code.

Little guidance is available that is directly related to crane-carrying structures in Canada. AISE (2003) and Millman (1991) provide guidance and are the basis of several of the recommendations contained herein. AISE (2003) provides an appendix that addresses recommended practices for inspecting and upgrading of existing mill building structures. Note that the NBCC Commentary contains relevant information.

6.2 Inspections, Condition Surveys, Reporting

An inspection plan should be prepared that is based on the following as a minimum:

- site visits,
- review of existing drawings, specifications, calculations, site reports, photographs,
- available records of modifications to the structure and equipment,
- interviews with plant personnel, to gain insight into the operation, past and present, and
- review of the applicable codes and standards.

The field inspection may involve use of a professional inspection and testing agency and may include the following:

- visual inspection noting defects such as corrosion, cracks, missing components, reduction of area, detrimental effects of welding, and physical damage,
- visual inspection of crane rails and their connections,
- visual inspection of connections,
- recording of field alterations not noted on available drawings,
- comments on misalignments and settlement, including need for an alignment survey, and
- special investigations such as identifying older steel, weldability, nondestructive testing, measurements of actual crane wheel loads, strain gauging, impact measurements, deflection under live load measurements, and thermal loads.

A common problem when evaluating older structures is to identify older steel. S16-01 covers this in Clause 5.2.

The report of the field inspection should be tailored to the ultimate purpose of the inspection. Suggested contents, as a minimum, are as follows:

- background, including purpose of the inspection,
- scope,
- available records, records of discussions,

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