



SURFACE VEHICLE INFORMATION REPORT

J1078™

NOV2022

Issued 1974-07
Reaffirmed 2007-11
Revised 2022-11

Superseding J1078 JAN2020

(R) A Recommended Method of Analytically Determining
the Competence of Hydraulic Telescopic Cantilevered Crane Booms

RATIONALE

Revisions and updates to calculations defined in the standard.

1. SCOPE

This analysis applies to crane types as covered by ASME B30.5.

1.1 Purpose

This calculation method has been established to illustrate an analysis to determine the competence of hydraulic telescopic cantilevered crane booms.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 ASME Publications

Available from ASME, P.O. Box 2900, 22 Law Drive, Fairfield, NJ 07007-2900, Tel: 800-843-2763 (U.S./Canada), 001-800-843-2763 (Mexico), 973-882-1170 (outside North America), www.asme.org.

ASME B30.5 Mobile and Locomotive Cranes

2.1.2 AISI Publications

Available from American Iron and Steel Institute, 25 Massachusetts Avenue, NW, Suite 800, Washington, DC 20001, Tel: 202-452-7100, www.steel.org.

AISI, "Specification for the Design of Cold-Formed Steel Structural Members," 1968 edition. In addition, "Commentary on the 1968 Edition," by George Winter and Supplementary Information Part II.

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Documents

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2.1.3 Other Publications

AISC, "Specification for the Design, Fabrication and Erection of Structural Steel for Buildings," adopted February 12, 1969. In addition, Supplement Nos. 1, 2, 3, and Commentary with additions and revisions where applicable.

Column Research Council, "Guide to Design Criteria for Metal Compression Members," Second Printing, 1960.

"USS Steel Design Manual," by R. L. Brockenbrough and B. G. Johnston, November 1968 printing.

3. NOMENCLATURE

- a = Clear distance between transverse stiffeners on side plate; also the ratio of the material yield of the web to the material yield of the compression flange
- A = Actual area of section
- A_e = Total effective area of section used in calculating F_a (see Appendix E for illustration)
- A_f = Area of compression flange
- A_i = Area based on inside dimensions of section (see Appendix D for illustration)
- A_m = Area based on mean dimensions of section (see Appendix D for illustration)
- A_o = Area based on outside dimensions of section (see Appendix D for illustration)
- A_{st} = Cross-sectional area of stiffener or pair of stiffeners
- A_w = Area of both webs
- b = Actual width of stiffened and unstiffened compression elements whether flange or web (see Appendix F for illustration)
- b_e = Effective width of stiffened compression element (see Appendix D for illustration)
- b_f = Actual flange width (see Appendix E for illustration)
- b_m = Mean width of section or $b_w - t_w$ (see Appendix D for illustration)
- b_w = Overall width of section (see Appendix E for illustration)
- C_t = Distance from neutral axis to extreme tension fiber of box section (see Appendix D for illustration)
- C_c = Distance from neutral axis to compressive fiber of box section (see Appendix D for illustration)
- C_b = Bending coefficient dependent upon moment gradient; equal to (see Equation 1)

$$1.75 + 1.05 \left(\frac{M_{x \min}}{M_{x \max}} \right) + 0.3 \left(\frac{M_{x \min}}{M_{x \max}} \right)^2 \quad (\text{Eq. 1})$$

but not more than 1.3 (see Appendix C for illustration)

- C_c = Column slenderness ratio dividing elastic and inelastic buckling equal to (see Equation 2)

$$\sqrt{\pi^2 E / (F_y - \sigma_{rc})}$$

(Eq. 2)

C'_c = Effective column slenderness ratio dividing elastic and inelastic buckling equal to (see Equation 3)

$$\sqrt{\frac{\pi^2 E}{Q_s Q_a (F_y - \sigma_{re})}} \quad (\text{Eq. 3})$$

C_m = Coefficient applied to bending term in the interaction formula and dependent upon column curvature caused by applied moments; use 0.85

C_{mx} = 0.85

C_{my} = 0.85

C_v = Ratio of “critical” web stress, according to linear buckling theory, to the shear yield stress of web material

d = Overall depth of section (see Appendix E for illustration)

D = Factor depending upon type of transverse stiffeners

E = Modulus of elasticity, 29500 ksi (203400 MPa)

f = Computed axial and bending compression stress on appropriate flange or web

f_a = Computed axial stress based on total section area

f_b = Computed bending stress about the appropriate axis

f_c = Sum of the computed axial and side bending compressive stresses

f_{bx} = Computed bending stress about the x-x axis

f_{by} = Computed bending stress about the y-y axis

f_s = Sum of the computed torsional and vertical shear stress

f_v = Computed average web or flange shear stress

f_{vs} = Total shear transfer of stiffener(s), kips per inch of length (Pa/m)

F_a = Allowable axial stress permitted in the absence of a bending moment

F_b = Allowable bending stress for the appropriate axis

F_{bx} = Allowable bending stress about the x-x axis if this bending moment alone existed

F'_{bx} = Allowable bending stress in compression flange of box sections as reduced for hybrid sections or because of large web depth-to-thickness ratio

F_{by} = Allowable bending stress about the y-y axis if this bending moment alone existed

F'_e = Euler stress divided by factor of safety; equal to (see Equation 4)

$$\frac{12 \pi^2 E}{23 (Kl/r)^2} \quad (\text{Eq. 4})$$

- F'_{ex} = Same as F'_e about the x-x axis
- F'_{ey} = Same as F'_e about the y-y axis
- F_v = Allowable web shear stress
- F_y = Specified minimum yield stress of material being used, based on “yield stress” or yield strength, whichever is applicable
- g = Wind load, lb/in², $g = 0.004 \text{ (mph)}^2/144$
- G = Shear modulus of elasticity 11300 ksi
- h = Clear distance between flanges (see Appendix D for illustration)
- h_m = Mean height of section $d - (t_c + t_t)/2$ (see Appendix E for illustration)
- h_v = Vertical height of horizontal stiffener
- H_o = Height to boom foot pin from ground
- H_p = Height to center of pressure on boom
- H_r = Reference height at which wind velocity is measured (20 feet in U.S.)
- I_x = Area moment of inertia about the x-x axis
- I_y = Area moment of inertia about the y-y axis
- I_{st} = Moment of inertia of a pair of intermediate stiffeners, or a single intermediate stiffener, with reference to an axis in the plane of the web
- I_{xe} = Effective moment of inertia about the x-x axis
- I_{ye} = Effective moment of inertia about the y-y axis
- J = Torsional constant; equal to (see Appendix D for other equations) (see Equation 5)

$$\frac{4(b_m)^2(h_m)^2}{\frac{2h_m}{t_w} + \frac{b_m}{t_c} + \frac{b_m}{t_t}} \quad (\text{Eq. 5})$$

- k = Coefficient relating linear buckling strength of a plate to its dimensions and conditions of edge support
- K = Effective length factor for cantilevered sections; use the value 2 unless a smaller one can be justified
- K_t = Torsional length factor for cantilevered sections; use the value 4/3
- ℓ = Dimensional lengths of boom
- L = Distance from tip to section in question
- L_b = Actual unbraced length of section in the plane of bending

M	Bending moment about the appropriate axis
M_1	Constant moment load about the x-x axis resulting from eccentric loading on the head
M_2	Constant moment load about the y-y axis resulting from the side loading on the head
$M_{x\min}$	Smaller moment at end of unbraced length of beam-column at tip
$M_{x\max}$	Larger moment at end of unbraced length of beam-column at section in question
M_x	Bending moment about the x-x axis
M_y	Bending moment about the y-y axis
N	Number of parts of line
p	Wind velocity exponent
P	Externally applied load at the tip
P_a	Axial load applied to section
P_x	Lateral loading component (side load)
P_y	Vertical loading component
P_z	Axial loading component
Q_a	Ratio of effective profile area of an axially loaded member to its total profile area of A_e/A
Q_s	Axial stress reduction factor for unstiffened elements of a section (see Appendix F)
r	Radius of gyration for appropriate axis
r_b	Radius of gyration about the axis of concurrent bending, computed on the basis of actual cross-sectional area
R	Load radius from centerline of rotation to centerline of load
R_h	Hoist cylinder reaction
R_x	Reaction loads in the lateral direction
R_y	Reaction loads in the vertical direction
R_z	Reaction loads in the axial direction
S_x	Strong axis section modulus with c taken to the compressive side
S_y	Weak axis section modulus with c taken to the compressive side
S_{xe}	Effective strong axis section modulus with c taken to the compressive side
S_{ye}	Effective weak axis section modulus with c taken to the compressive side
t	Thickness of flange or web in compression (see Appendix D for illustration)

- t_c = Thickness of compression flange (see Appendix D for illustration)
- t_t = Thickness of tension flange (see Appendix D for illustration)
- t_w = Thickness of web (see Appendix D for illustration)
- T = Torsional moment
- V_p = Wind velocity (mph) at center of pressure height H_p
- V_r = Wind velocity (mph) at reference height H_r
- V_x = Statical shear load on section in the lateral direction
- V_y = Statical shear load on section in the vertical direction
- w = Component weight, lb/in
- W = Total component weight
- x = Subscript relating symbol to strong axis bending
- Y = Ratio of yield stress of web steel to that of yield stress of stiffener steel
- y = Subscript relating symbol to weak axis bending
- z = Subscript relating symbol to axial loading
- α = Boom centerline elevation angle relative to a horizontal plane, or the ratio of web yield stress to flange yield stress
- θ = Angle between a line perpendicular to the boom axis and the hoist cylinder axis
- σ_{rc} = Residual compressive stress; equal to $0.5 F_y$ in lieu of specific information on steel used
- u = Poisson's ratio; equal to 0.3

4. CRITERIA

Calculations shall include the dead weight loads, rated load, and a minimum side load of 2% of the rated load at the rated load radius. The side load provides for "normal" conditions of machine operation. In addition, the effect of the wind on the boom should be considered, as is provided for in the calculations.

- 4.1 The factors of safety used herein are the recommended factors of the AISC "Specification for the Design, Fabrication and Erection of Structural Steel for Buildings," adopted February 12, 1969.
- 4.2 The boom shall be deemed competent when the solution of the interaction equations provided herein yield a value equal to or less than one.

5. LOADS AND FORCES

- 5.1 The 2% side load provides for "normal" conditions of boom motion. No allowances have been made for dynamic loads, duty cycle operation, effects of the wind on the load lifted, or operations other than lifting crane service.
- 5.2 All forces and loads are expressed in pounds (kg). Dimensions are in inches (m). Stresses both allowable and calculated are in units of ksi (MPa). Also, the modulus of elasticity is expressed in units of ksi (MPa).

6. ANALYTICAL DETERMINATION OF STRESSES AND CRITICAL LOADS

6.1 Applicability

This analysis is applicable to multi-sectioned “box” type booms, which are totally enclosed and cantilevered beyond the base section.

6.2 Basis for Analysis

The equations presented in this analysis are based on laterally unsupported beam column formulas, the solution of which are combined in interaction equations. In determining the section properties, the effective width of the plates in compression are used. The areas covered in this analysis consist of axial and torsional loading, bidirectional bending, and panel buckling. Of primary importance in the analysis are the compressive stress calculations.

The work of this committee is not intended to cover all design concepts, but rather a basic system. However, other design configurations may use alternative calculation methods when substantiated with suitable test data.

6.3 Summary

Where strain gage results are available, they should be used to supplement the analytical data.

7. LOAD MOMENT DIAGRAMS AND EQUATIONS

7.1 Assumptions Used on Load Moment Equations

- 7.1.1 Wind force is negligible on head (should include effects if jib used).
- 7.1.2 Torque is created by the side load P on the head (would also be applicable for a jib).
- 7.1.3 Equations are still applicable if jib used but dimensions, weights, and center of gravity to be adjusted accordingly.
- 7.1.4 $P_y = P \cos \alpha$; $P_z = P \sin \alpha$.
- 7.1.5 Winch rope fleet angle and angle relative to boom is negligible.
- 7.1.6 Wind force is uniformly distributed along the exposed length of the side of the section with its reaction at the center (is a valid assumption since each section considered individually).
- 7.1.7 That the dimensions are to the reaction points and that the tips of each section beyond these points are small in length and will not affect the validity of the equations.
- 7.1.8 That the axial stresses produced by the friction forces due to the section reaction points from one to the next are small in comparison to the other stresses, that the section support cylinders carry the axial loads.
- 7.1.9 That equations and formulations appearing in the foregoing analysis are for the boom in the extended position—Figures 1, 2, 3, 4, 5, 6, and 7. Partially retracted positions will require reformulation of some equations; as an example, in Figure 4 when l_{11} is zero or negative, the cylinder no longer takes the axial load at the section being considered. The moment equations would then appear as those written for reference Figure 3. Similar changes would appear in the axial load, reactions, and shear force equations.

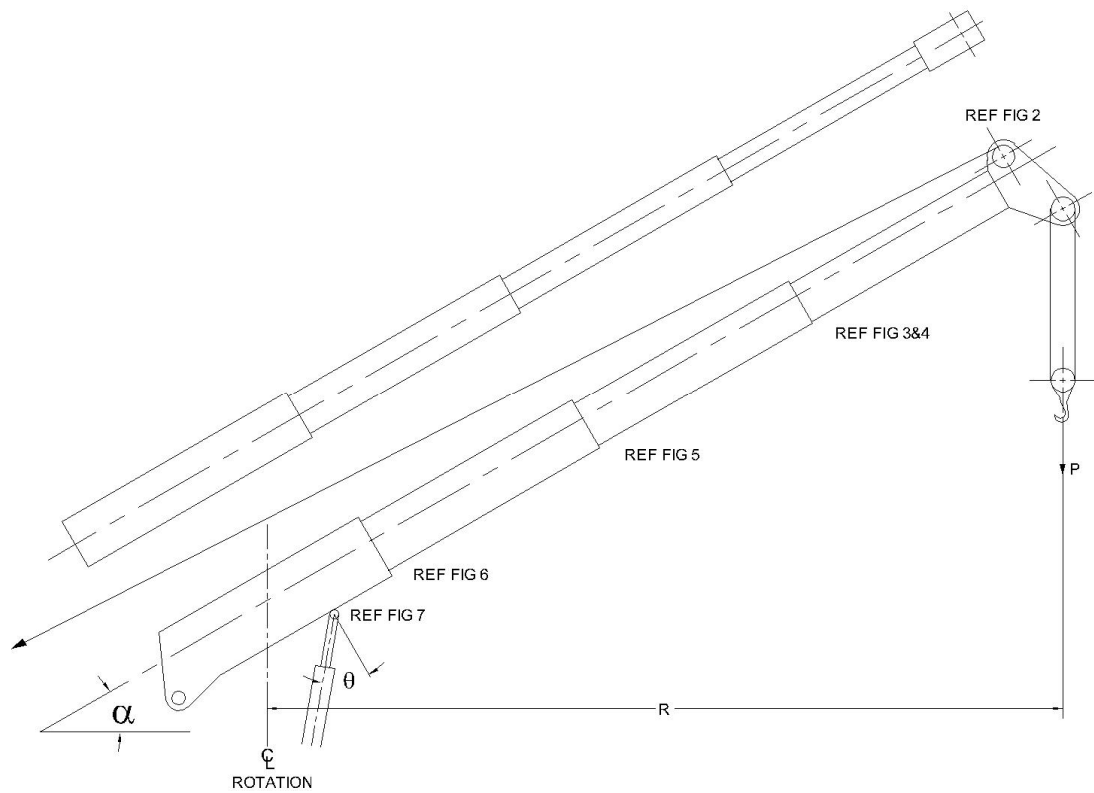


Figure 1 - Loading diagram - boom assembly

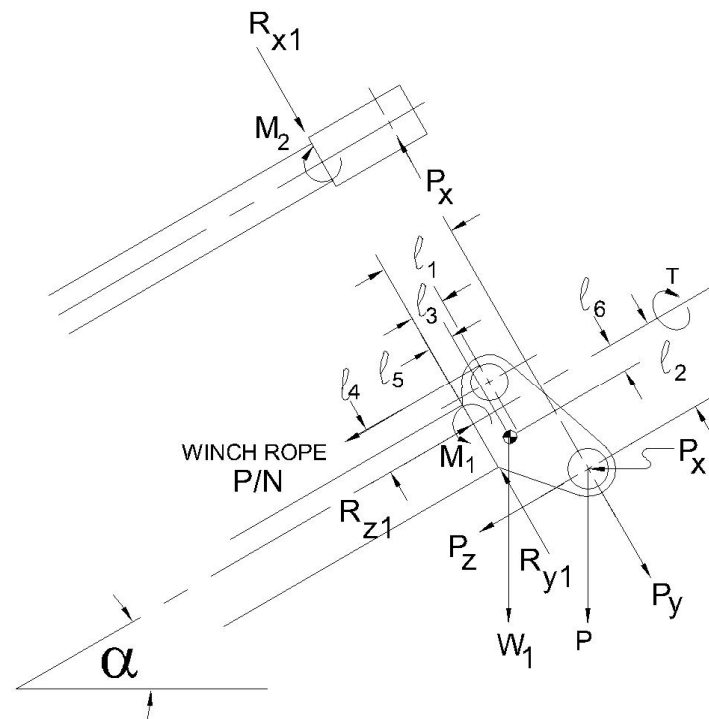


Figure 2 - Load moment diagram - head section

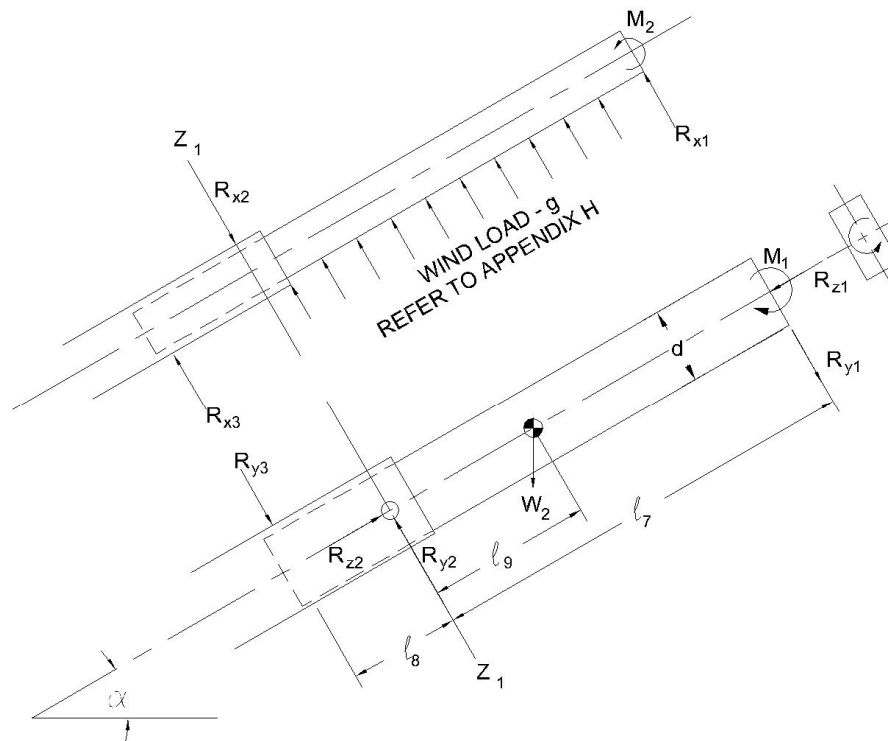


Figure 3 - Load moment diagram - tip section

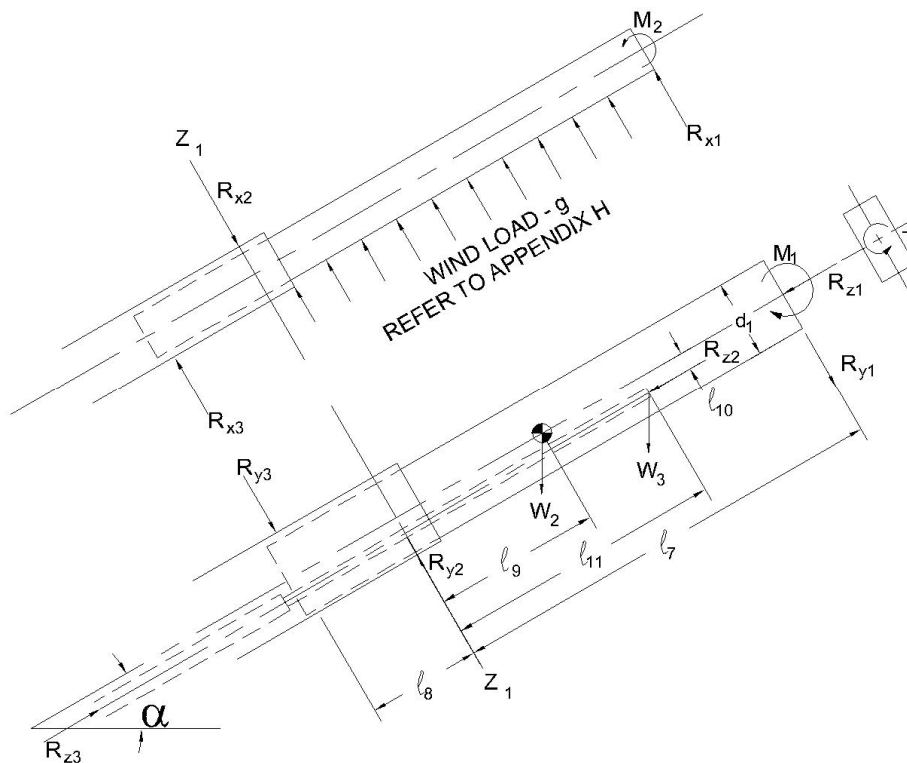


Figure 4 - Load moment diagram - alternate tip section

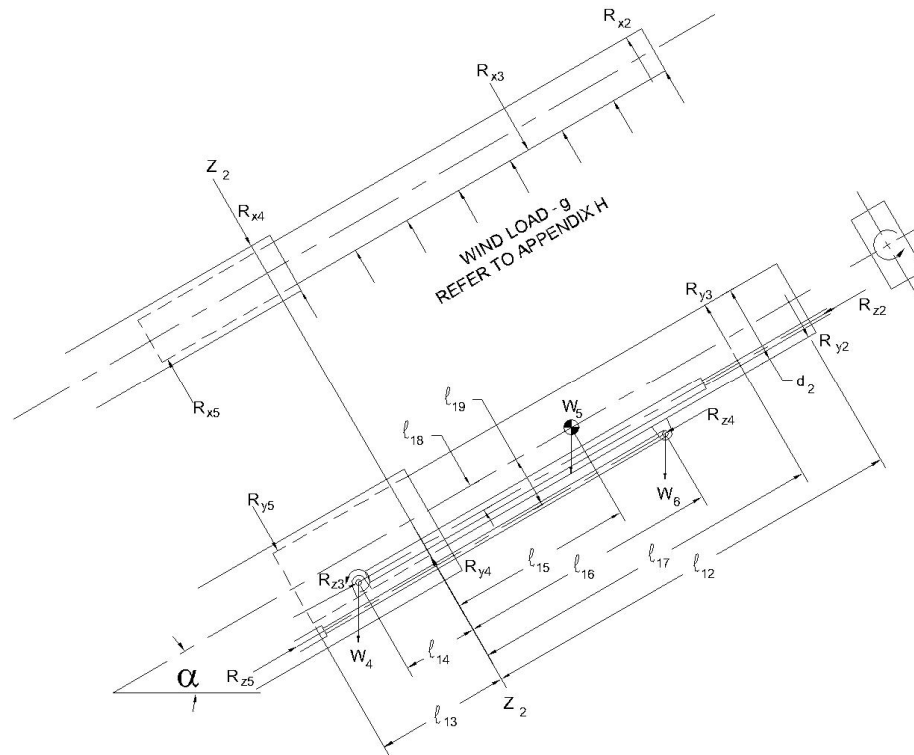


Figure 5 - Load moment diagram - intermediate section

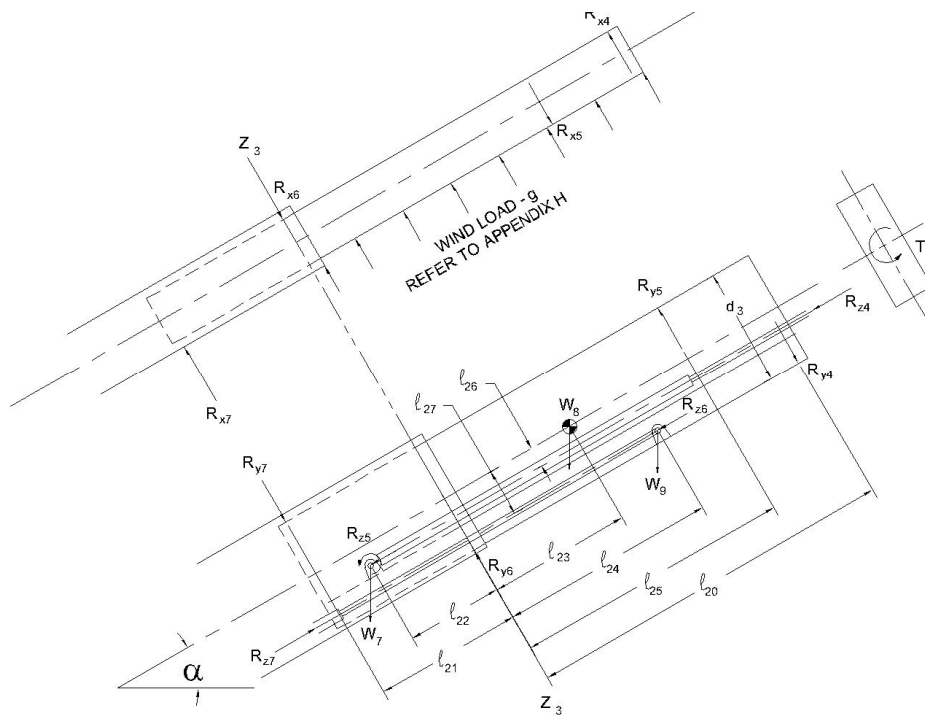


Figure 6 - Load moment diagram - intermediate section

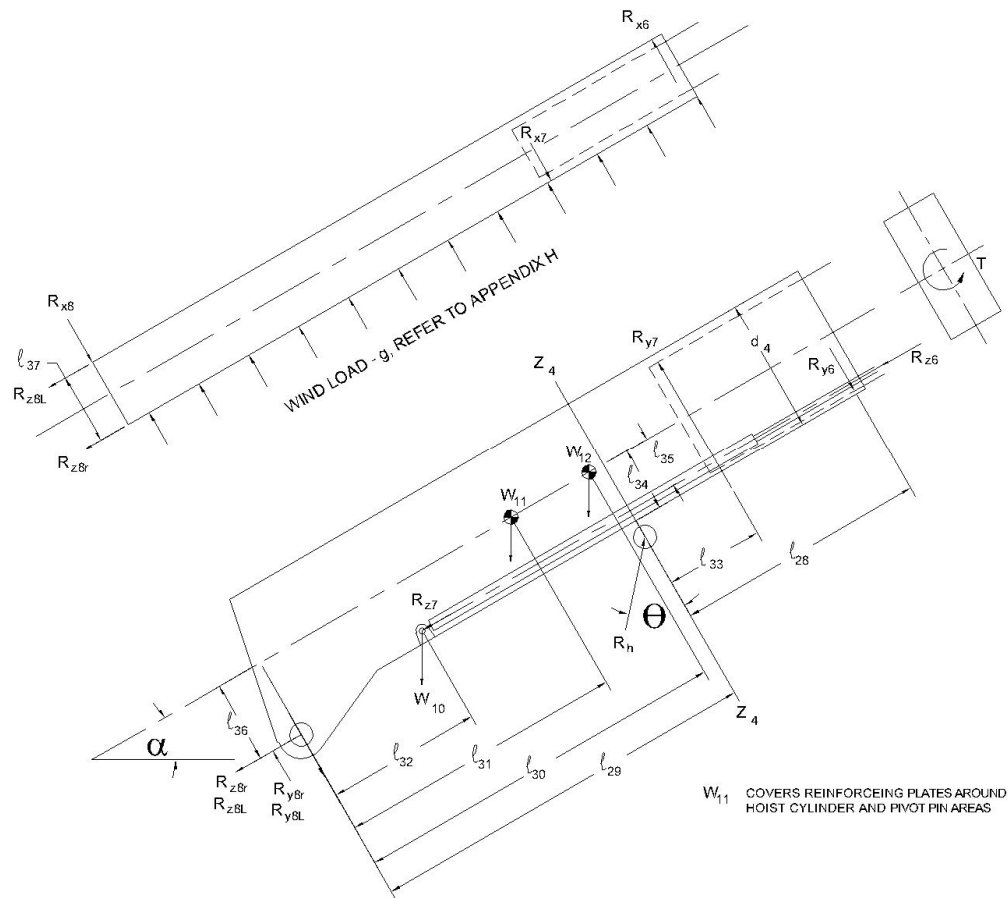


Figure 7 - Load moment diagram - base section

7.2 Figure 2

Load moment equations for reaction of head forces on tip section (see Equations 6, 7, 8, and 9).

Moment (Equation 6):

$$\begin{aligned} M_1 &= P_y l_1 + P_z l_2 - P/N l_4 + W_1 [l_5 \cos \alpha + l_6 \sin \alpha] \\ M_2 &= P_x l_1 \\ T &= P_x l_2 \end{aligned} \quad (\text{Eq. 6})$$

Axial load (Equation 7):

$$R_{Z1} = P/N + P_z + W_1 \sin \alpha \quad (\text{Eq. 7})$$

Shear loads (Equation 8):

$$\begin{aligned} V_x &= -R_{x1} = P_x \\ V_y &= -R_{y1} = W_1 \cos \alpha + P_y \end{aligned} \quad (\text{Eq. 8})$$

Side load (Equation 9):

$$P_x = 0.02 P \quad (\text{Eq. 9})$$

7.3 Figure 3

Load moment equations for tip section at Section Z₁ - Z₁ (see Equations 10, 11, 12, 13, 14, 15, and 16).

Moments (Equation 10):

$$\begin{aligned} M_x &= M_1 + R_{y1} l_7 + \frac{0.5 W_2 \cos \alpha l_7^2}{l_7 + l_8} \\ M_y &= M_2 + R_{x1} l_7 + 0.5 g d_1 l_7^2 \\ T &= P_x l_2 \end{aligned} \quad (\text{Eq. 10})$$

Axial load on pin (Equation 11):

$$R_{z2} = R_{z1} + W_2 \sin \alpha \quad (\text{Eq. 11})$$

Axial load on section (Equation 12):

$$P_{ar} = R_{z1} + W_2 \sin \alpha \frac{l_7}{l_7 + l_8}; P_{aL} = W_2 \sin \alpha \frac{l_8}{l_7 + l_8} \quad (\text{Eq. 12})$$

Vertical reactions (Equation 13):

$$R_{y3} = \frac{M_x}{l_8} - 0.5 W_2 \cos \alpha \frac{l_8}{l_7 + l_8}; R_{y2} = R_{y1} + R_{y3} + W_2 \cos \alpha \quad (\text{Eq. 13})$$

Lateral reactions (Equation 14):

$$R_{x3} = \frac{M_y}{l_8}; R_{x2} = R_{x1} + R_{x3} + g d_1 l_7 \quad (\text{Eq. 14})$$

Vertical shear forces (Equation 15):

$$V_{yr} = R_{y1} + W_2 \cos \alpha \frac{l_7}{l_7 + l_8}; V_{yL} = R_{y3} + W_2 \cos \alpha \frac{l_8}{l_7 + l_8} \quad (\text{Eq. 15})$$

Lateral shear forces (Equation 16):

$$V_{xr} = R_{x1} + g d_1 l_7; V_{xL} = R_{x3} \quad (\text{Eq. 16})$$

NOTE: Subscripts r and L refer to right and left of Section Z₁ - Z₁.