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Mobile cranes — Experimental determination of crane performance —

Part 2: Structural competence under static loading

Grues mobiles — Détermination expérimentale des performances des grues —

Partie 2: Compétence structurale sous le chargement statique

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 96, *Cranes*, Subcommittee SC 6, *Mobile Cranes*.

ISO 11662 consists of the following parts, under the general title *Mobile cranes — Experimental determination of crane performance*:

— *Part 1: Tipping loads and radii*

— *Part 2: Structural competence under static loading*

Introduction

When design calculations are made for mobile cranes, they are based on an ideal model in which all members and components are perfectly straight and fabrication has been exact. For tension members and members subjected to bending, the difference between the real crane and the ideal model is usually not significant. But, for compression members subject to column buckling, an allowance for deviation in straightness and fabrication is necessary.

When mobile cranes are tested non-destructively by means of strain gauges, the stresses determined intrinsically include these effects of deviations in straightness and accuracy of fabrication.

This test method is intended to describe the approximate maximum loading conditions to which any component of the entire load-supporting structure of a crane is subjected (See Annex D). In some cases, a more severe loading condition(s) can be indicated by analysis. In these cases, the more severe condition(s) can be added to or substituted for the specified test loading condition(s). This test method also classifies stress areas as Types I (Uniform Stress Areas), II (Stress Concentration Areas), III (Column Buckling Areas), and IV (Local Plate Buckling Areas; see Clause 10), and defines limits for each class. Results can be used to correlate boom system calculation results for Class III stress areas as given by boom system calculations. Test results for Class I stress areas throughout the structure can be used to check any available calculations. This test method evaluates Class II stress areas for which calculations are seldom available. Class IV stress areas, where disproportionately high stress readings can occur, can be reviewed for better insight by calculation methods.

A production boom system that has been rated by the methods of this part of ISO 11662 can be used on another machine without re-testing by the methods specified herein, provided the same analytical procedure shows its stress levels will be less than or equal to the stress levels in the original application, and provided that the supporting structure is as rigid as the original mounting. Rigidity of the supporting structure is determined by the change in the slope of the jib foot axis as test loads are applied.

Mobile cranes — Experimental determination of crane performance —

Part 2:
Structural competence under static loading

1 Scope

This part of ISO 11662 applies to mobile construction-type lifting cranes utilizing

a) rope supported, lattice boom attachment or lattice boom, and fly jib attachment (see Annex E, Figure E.3),

b) rope supported, mast attachment and mast mounted boom, and fly jib attachment (see Annex E, Figures E.1 and E.2), or

c) telescoping boom attachment or telescopic boom and fly jib attachment (see Figure E.4).

Mobile crane manufacturers can use this part of ISO 11662 to verify their design for the mobile crane types illustrated in Figures E.1 through E.4.

This test method is to provide a systematic, non-destructive procedure for determining the stresses induced in crane structures under specified conditions of static loading through the use of resistance-type electric strain gauges, and to specify appropriate acceptance criteria for specified loading conditions.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9373:1989, *Cranes and related equipment — Accuracy requirements for measuring parameters during testing*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
strain
relative elongation or compression of material at any given point with respect to a specific plane passing through that point, expressed as change in length per unit length (m/m)

3.2
stress
S
internal force per unit area resulting from strain, expressed in pascals (Pa) or newtons/square meter

Note 1 to entry: For this document, megapascals (Mpa) will be used for brevity.

3.3
yield point
S_y
stress at which a disproportionate increase in strain occurs without a corresponding increase in stress

Note 1 to entry: For purposes of this code, yield point is to be considered as the minimum 0,2 % offset tensile yield point or yield strength specified by the appropriate standard for the material used.

3.4
critical buckling stress
S_{cr}
average stress which produces an incipient buckling condition in column-type members (See Annex C)

3.5
initial reference test condition
defined no-stress or zero-stress condition of the crane structure after the "break-in" as established by

a) supporting the structure on blocking to minimize the effects of gravity, or

b) the crane structure components in an unassembled state or any alternate method that will establish the zero-stress condition. Under this condition, the initial reference reading for each gauge is obtained, N_1

3.6
dead load stress condition
completely assembled crane structure on the test site and in the position or attitude, ready to apply the specified live load at the specified radius

Note 1 to entry: Under this condition, the second reading for each gauge is obtained, N_2.

Note 2 to entry: The hook, hook block, slings, etc. are considered part of the suspended load but may be supported by the crane when this reading is taken. For dead load purposes, the hook in the "home" position – suspended from the crane without lifting the test load. This position has to be repeated after placing the load back on the ground (see 9.4.4).

3.7
dead load stress
S_1
stress computed as defined in Clause 10 by using the difference in the readings obtained in 3.6 and 3.5 for each gauge ($N_2 - N_1$)

3.8
working load stress condition
completely assembled crane structure on the test site and in the specified position, supporting the specified rated load

Note 1 to entry: Under this condition, the third reading for each gauge is obtained, N_3.

3.9
working load stress
S_2
stress computed as defined in Clause 10 by using the difference in the readings obtained in 3.8 and 3.5 for each gauge ($N_3 - N_1$)

3.10
resultant stress
S_r
stress induced in the structure as a result of dead load stress (S_1) or the working load stress (S_2), whichever is greater in absolute magnitude

3.11
column average stress
S_{ra}
direct compression stress in a column or the average stress computed from several gauges located at the section (see Annex B)

3.12
column maximum stress
S_{rm}
maximum compression stress in a column computed from the plane of buckling as established from several gauges located at the section (see Annex B)

3.13
loadings
application of weights and/or forces of the magnitude specified under the condition specified

3.14
load radius
horizontal distance between the axis of rotation of the turntable of the crane and the vertical axis of the hoist line or load block when the crane is erected on a level site

4 Symbols and abbreviated terms

E	modulus of elasticity
K	effective length factor for a column
L	un-braced length of column
L_b	length of boom
L_j	length of fly jib
L_1	small arbitrary projected length of fly jib along x-axis
L_2	projected length of fly jib strut along y-axis
n	strength margin
n_1	strength margin, Class I area, ratio of yield strength to resultant or equivalent stress
n_2	strength margin, Class II area, ratio of yield strength to resultant or equivalent stress
n_3	strength margin, Class III area, derived from an interaction relationship
N_1	strain reading at initial reference test condition
N_2	strain reading at dead load stress condition
N_3	strain reading at working load stress condition
r	radius of gyration
RL	rated load as specified by manufacturer
"R"	plane (Figure 1) perpendicular to boom foot pin centreline (CL)
RR	rated radius as specified by manufacturer
S	stress

S_1	dead load stress
S_2	working load stress
S_{ra}	column average stress computed from several gauges at a cross section
S_{cr}	critical buckling stress for axially loaded columns
SL	side load, i.e. 0,02 × RL;
%SL	percentage of side load expressed as a percentage of rated load or %RL = Percentage of rated load
SLL	side load left
SLR	side load right
S_{rm}	maximum compression stress in a column
S_p	stress at the proportional limit
S_r	resultant stress
S_{RC}	maximum residual stress in compression
S_y	stress at the yield point
S'	equivalent uniaxial stress
t	horiz. distance from the load centre to the front pad reaction centre for each box jib section
σ_0	tensile yield stress
σ_x	maximum principal stress
σ_y	minimum principle stress
Z'	lattice boom tip slope (out of plane)
Z_b	lattice boom tip deflection from plane “R”
Z_j	fly jib tip deflection from plane “R”
Z_1	boom deflection at a point l_1 back from the boom tip
Z_2	fly jib strut deflection at its tip
α	imperfection factor
β	fly jib offset angle from centreline (CL) jib
ε	strain
ε_a	strain recorded from leg “a” of rosette
ε_b	strain recorded from leg “b” of rosette
ε_c	strain recorded from leg “c” of rosette
ε_d	strain recorded from leg “d” of rosette
ε_x	maximum principal strain

ε_y minimum principal strain

μ units of strain, 10^6

θ fly jib tip rotation about x-axis (radians)

π Pi = 3,1416

τ_0 shear yield stress

ν Poisson's ratio

X relative buckling stress (= S_{cr}/S_y)

$\bar{\lambda}_0$ initial relative slenderness

$\bar{\lambda}$ relative slenderness (= λ/λ_c)

λ slenderness ratio (= KL/r)

λ_c reference slenderness ratio $\left(=\pi\sqrt{E/S_y}\right)$

S_k allowable buckling stress

S_{ci} Euler's buckling stress

S_{ck} Jager's buckling stress

5 Limitations

5.1 This method applies to load-supporting structures as differentiated from power transmitting mechanisms. It is restricted to measuring stresses under static conditions and a general observation after overload conditions.

5.2 Personnel competent in the analysis of structures and the use of strain-measuring instruments are required to perform the tests.

6 Method of loading

6.1 Suspended load

The specified load suspended at the specified radius and held stationary a short distance above the ground. The weight of the hook, block, slings, etc., shall be included as part of the specified suspended load.

6.2 Side load (*SL*)

When the test specification requires side loading, the force displacing the suspended load should be horizontal and perpendicular to the plane containing the axis of upper structure rotation and the centreline of the undeflected boom. The side load shall be applied in each direction. Side loading is applied to simulate the various effects associated with machine operation including a 9 m/s wind loading that might be encountered.

6.2.1 Lattice boom attachment

For lattice boom attachments, the side load that is to be applied for the conditions listed in Table C2 is as follows. The side load shall be applied as 2 % (0,02 *RL*) of the rated load in each direction.

6.2.2 Mast attachments

For mast attachments, the side load percentage that is to be applied in each direction at the load attachment point for the conditions listed in Table C1 is to be a minimum of 2 % (0,02 *RL*) of the rated load in each direction.

6.2.3 Telescoping boom attachment

For telescoping boom attachments, the side load that is to be applied for the conditions listed in Table C3 is as follows. The side load shall be applied as 3 % (0,03 *RL*) of the rated load in each direction with the boom over the end of the machine.

6.3 Deflection criteria

The usability of a latticed column [i.e. lattice boom and fly jib(s) combination] or a telescoping boom attachment is sometimes affected by the elastic stability of the overall column as well as of the individual members. Incipient out of plane elastic instability is indicated by excessive boom and/or fly jib tip deflection (sideways) as the attachment is side loaded when suspending a rated load. The following lateral deflection limits are therefore imposed.

6.3.1 Lattice boom attachments

The lateral deflection criteria for the rated load and side load of Table C2 are as follows. First, the deflection of the total boom and jib combination shall be less than or equal to 2 % of the total combination length. Furthermore, the deflection of each individual boom or fly jib member shall be less than or equal to 2 % of the length of that member. To satisfy these criteria, it should be noted that the deflection of an individual member does not include the deflection, rotation, or slope of the member to which it is mounted.

For a single fly jib mounted on a boom, the following relationship is given (Figure 1):

$$Z_j \le 0{,}02 L_j + Z_b + Z'\left(L_j \cos\beta\right) + \theta\left(L_j \sin\beta\right) \tag{1}$$

The following values are measured.

Z_j fly jib tip deflection

Z_b lattice boom tip deflection

Z_1 lattice boom deflection at a distance L_1 down from the boom tip

Z_2 fly jib strut deflection at the tip

The following values are calculated.

Slope:

$$Z' = \left(Z_b - Z_1\right) / L_1 \tag{2}$$

Rotation:

$$\theta = \left(Z_b - Z_2\right) L_2 \tag{3}$$

If slope (Z') and rotation (θ) are not measured, the last two terms of Formula (1) may be deleted.

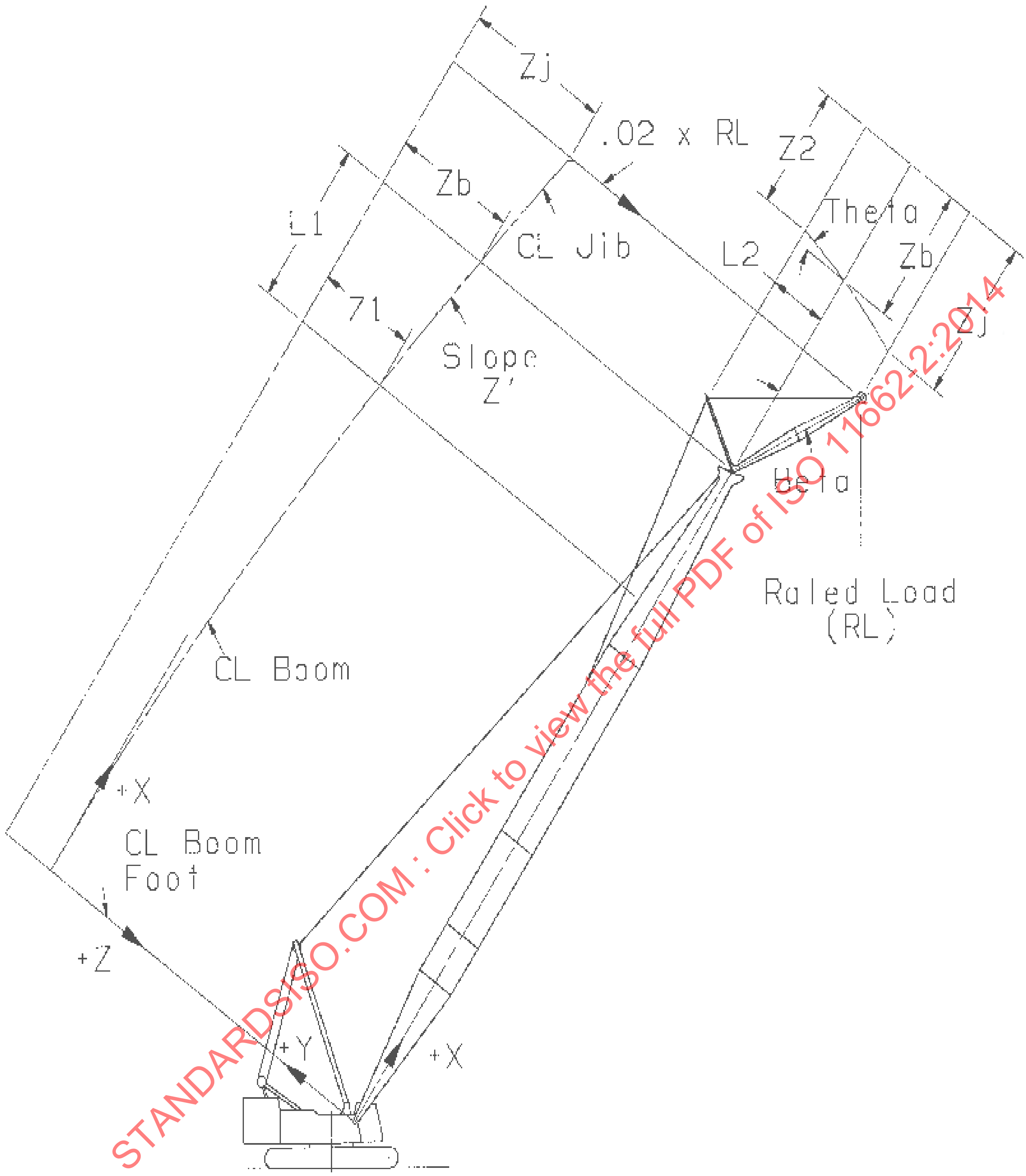


Figure 1 — Deflection measurement related terms — Lattice boom with fly jib

6.3.2 Telescoping boom attachments

For telescoping boom attachment crane structures, no tip deflection limitations have been established. Deflection of the mast attachment, the mast mounted boom, and fly jib shall be measured and recorded when the system is stable.

6.3.3 Mast attachments

For mast attachment crane structures, no tip deflection limitations have been established. The deflection of the telescopic boom attachment and fly jib shall be measured and recorded when the system is stable.

7 Facilities, apparatus, and material

7.1 A concrete or other firm supporting surface, sufficiently large to provide for unobstructed accomplishment of the tests required. Where tests are to be performed on crawler tracks, the machine shall be level within 0,25 % grade.

7.2 Means to measure levelness of the axis of the jib foot; accuracy 0,1 % of grade (see ISO 9373).

7.3 Means for determining the load radius to an accuracy of ±1 %, not to exceed 150 mm.

7.4 Means for producing traverse displacement of the suspended load and means for measuring the magnitude of the displacing force; accuracy ±3 % of measured force.

7.5 Temperature compensated strain gauges, cement, waterproofing compounds, and other necessary gauge installation equipment.

7.6 Strain recording system. It is the intent that commercially available, high quality, reliable instruments be used in the performance of this test. Accuracy of the recording system shall be determined to be ±2 % of the reading over the range of 500 μ m/m to 3 000 μ m/m strain (determined in suitable increments). Calibration can be accomplished by electrical shunts or by pre-calibrated strain bar.

7.7 Test weights and lifting apparatus of known weights accurate to within ±1 %.

7.8 Means for measuring side deflection of the boom and fly jib within 50 mm.

8 Preparation for test

8.1 An analysis of each structure sufficient to locate highly stressed areas shall be made. The strain gauge location and direction shall be determined from this analysis as well as from the use of other experimental techniques where necessary.

8.2 Perform a detailed inspection of the crane to ensure that all mechanical adjustments and condition of load supporting components conform to manufacturers' published recommendations. Check that the crane is equipped in compliance with the test specifications.

8.3 A previously un-worked crane should be given a "break-in" run at or near each anticipated test loading to mechanically relieve residual stresses that might have developed during manufacture and to minimize the possibility of "gauge zero shift" during the test.

8.4 Perform a thorough inspection after the "break-in" to reveal areas of high stress as evidenced by paint checking, scale flaking, or other indications of deformation.

8.5 Bond strain gauges at the points determined by prior analysis (see 8.1) and any areas selected as a result of the inspection conducted in 8.4. Only competent personnel using proven materials and practices can be employed to ensure that all gauges are of the correct type, properly oriented, and securely bonded to measure strains correctly.

8.6 Determine the minimum yield strength and the modulus of elasticity for the material at each gauge location by referring to the material certifications, if available, applicable standards, or Annex B. Determine the critical buckling stress when applicable (see Annex B).

9 Test procedure and records

9.1 Final test preparation

9.1.1 Locate the machine on the test course and lock travel brakes and latches. Level the machine to within 0,25 % grade in the unloaded condition by shimming or by jacking. Do not re-level after the load has been applied to the machine.

NOTE If the test is for operation on outriggers, jack the crane to a position where all the tires or tracks are unloaded, unless the manufacturer's rating chart requires some other conditions.

9.1.2 Connect strain measuring system and calibrate gauges and instruments. Correct any malfunctions.

9.2 Zero stress condition

If the assembled crane is to be used as the initial reference test condition, obtain these readings. If the unassembled components are to be used as the initial reference test condition, obtain these readings.

Reassemble the crane and make all mechanical adjustments.

9.3 Dead load stress condition

9.3.1 Set the revolving upper structure to the specified position relative to the lower structure. Lock the swing brake or latch.

9.3.2 Set the attachment angles and lengths to develop the specified load radius.

9.3.3 Read all strain gauges for dead load stress condition (see 3.6). Compute the dead load stress (S_1) at each gauge (see 3.7) and record on the test data sheet (see Annex D).

NOTE A new dead load stress condition is established each time the position, attitude, or configuration is changed to suit the specified tests and operations: therefore, 9.3.1 to 9.3.3 shall be repeated for each new condition.

9.4 Working load stress

9.4.1 Prepare a test load which together with the hook, block, slings, etc., weighs within ±1 % of the specified load.

9.4.2 Suspend the test load (see 6.1) and apply side load (see 6.2) as required by specifications.

9.4.3 Read required strain gauges for working load stress condition. Compute the working load stresses (S_2) for each required gauge and record the test data. Measure and record tip side deflection due to suspended load and side load.

9.4.4 Release side load and lower suspended load, returning crane to dead load condition. Read required strain gauges and compare with reading taken under 9.3. If the deviation for any gauge exceeds ±0,03 S_y/E, determine cause, correct, and repeat all procedures until consistent readings are obtained.

NOTE Since temperature changes and the loading from even a moderate wind on long booms and fly jibs affects strain gauge readings, testing should be done under as favourable atmospheric conditions as possible. Position the machine so wind loading does not reduce the stress induced by side loading.

Compute resultant stress (S_r) per 3.10, for combined dead load and working load stresses and record.

Thoroughly examine the crane for any evidence which suggests a possibility of plastic deformation or other damage having occurred during the test.

9.5 Overload test condition

9.5.1 Repeat 9.1.1, if applicable.

9.5.2 Position the crane (upper structure, boom) in the specified test position.

9.5.3 Set attachment angles and lengths to develop the specified load radius and record dead load readings for Class IV gauges.

9.5.4 Prepare the test load (see 9.4.1).

9.5.5 Suspend the specified test load and adjust the boom angle(s; if necessary) to obtain the rated load radius.

9.5.6 Observe the performance of the structure and note any evidence of possible failure.

9.5.7 Release the suspended load and return the crane to the dead load stress condition. Record the dead load readings for Class IV gauges. (See 9.4.4)

At the completion of all applicable overload tests, the crane structures should be thoroughly examined by eye using straight edges and other references, where appropriate, to determine any evidence of buckling, permanent deformation, element out of line, etc. Scale flaking or paint checking can also be indicative of stresses beyond the yield point. Disassemble the boom structure to the state necessary to be ensured that all boom elements, extension cylinders, or elements, hoist mechanisms, suspension systems, and other load-carrying elements can be inspected.

Record all pertinent data regarding the test equipment, crane being tested, results, and observations. Suggested forms are presented in Annex D.

10 Stress evaluation

For purposes of this test method, stress is related to measured strain by the uniaxial stress equation (see Formula 4):

$$S = E \cdot \varepsilon \left(\text{within proportional limits}\right) \quad (4)$$

NOTE The simple uniaxial stress formula might not be sufficiently accurate for some areas of crane structures under biaxial stress, and special consideration should be given in such cases (see Annex A).

Stresses in different parts of crane structures are evaluated for acceptability on the basis of criteria appropriate to the area in question. These stress areas can be classed as follows (see Table 1 or 10.1 through 10.4 for minimum strength margins).

Table 1 — Minimum strength margins

	Class I (uniform stress area)	Class II (stress concentration area)	Class III (column buckling area)[a]			Class IV (local plate buckling area)
			Curves A, B, C, D	Curves a, b, c	Alternative	
X (erection loads)	$n_1 \geq 1,3$	$n_2 \geq 1,0$	$n_3 \geq 1,4$	$n_3 \geq 1,2$	$n_3 \geq 1,3$[b] and 2,2[c]	Gauges must return to ±0,03 S_y/E at dead load.
Y (rated loads)	$n_1 \geq 1,5$	$n_2 \geq 1,1$	$n_3 \geq 1,6$	$n_3 \geq 1,3$	$n_3 \geq 1,5$[a] and 2,5[b]	Gauges must return to ±0,03 S_y/E at dead load.
Z (over loads)	Observation only	Observation only	Observation only	Observation only	Observation only	Gauges must return to ±0,03 S_y/E at dead load.

a Refer to Annex B.

b Critical buckling stress S_{cr} is calculated by Jager's equation.

c Critical buckling stress S_{cr} is calculated by Euler's equation.

10.1 Class I — Uniform stress areas

Large areas of nearly uniform stress where exceeding the yield strength or yield point values will produce permanent deformation of the member as a whole. Strength margin:

— $n_1 = S_y/S_r$ *or* S_y/S' (refer to Annex A for S');

— $n_1 \geq 1,50$ for rated loads;

— $n_1 \geq 1,30$ for erection loadings.

10.2 Class II — Stress concentration areas

Small areas of high stress surrounded by larger areas of considerably lower stress where exceeding the yield strength or yield point values will not produce permanent deformation of the member as a whole. Examples are points of rapid section change such as sharp corners, holes, or weld fillets. Strength margins:

— $n_2 = S_y/S_r$ or S_y/S' (refer to Annex A for S');

— $n_2 \geq 1,10$ for rated loads;

— $n_2 \geq 1,00$ for erection loadings.

10.3 Class III — Column buckling stress areas

Areas in which failure can be considered to occur at some average stress value less than yield strength or yield point. Examples are individual unsupported compression elements such as, but not limited to, masts, struts, jib chords, or lattice, which require consideration as columns.

Strength margin (refer to Annex B).

If curves A, B, C, or D are chosen from Table 1:

— $n_3 \geq 1,60$ for rated loads;

— $n_3 \geq 1,40$ for erection loading.

For lattice structures, this criteria is intended to apply to lacing elements or chord elements between lacing points.

It is not intended for evaluation of the overall latticed compression member.

10.4 Class IV — Local plate buckling areas

Plates, when subjected to direct compression, bending, and/or shear in their plane, can buckle locally before the member as a whole becomes unstable. Local bucking is associated with wrinkling (initial buckling), which permits the member to redistribute the loading to stiffer edges.

As loading is further increased, the stress in Class IV areas (see Figure 2) does not necessarily increase in proportion to the load; however, considerable post buckling strength might remain. Requirements are that Class IV gauges return to the dead load readings for all test conditions, including overload.

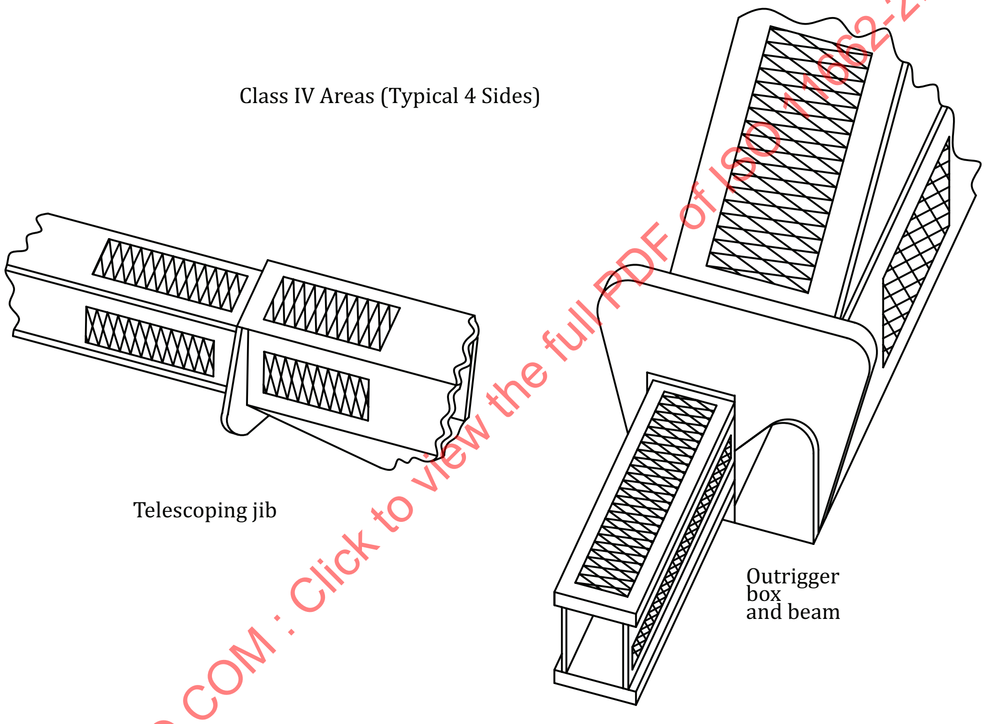


Figure 2 — Local plate buckling areas

Annex A
(normative)

Strength of materials

A.1 Biaxial stress fields

In biaxial stress fields, there might be some error if the uniaxial stress given by $S = E \cdot \varepsilon$ (see Clause 10) is compared to tensile yield point to determine the strength margin. The question arises when consideration is given to the theory of failure applicable to the material being tested.

A.2 Brittle materials

The use of $S = E\,\varepsilon_x$ (when ε_x is measured in the direction of maximum principal strain) presumes the applicability of the maximum strain theory of failure. This is the commonly accepted theory of failure for brittle materials, and results given are valid for materials of this type.

A.3 Ductile materials

The distortion energy theory of failure generally is accepted as the performance criterion of ductile materials subjected to biaxial stresses. This assumes that yield failure occurs when the distortion energy under biaxial stress is equal to the distortion energy at yield stress in pure tension. An equivalent uniaxial stress (S') developing the same distortion energy as the actual biaxial stress is determined for comparison to the yield point (S_y) to establish the strength margin against failure. The equivalent uniaxial stress is shown in Formula A.1:

$$S' = \sqrt{\sigma_x^2 - \sigma_x \sigma_y + \sigma_y^2} \qquad \text{(A.1)}$$

Principal stresses are obtained from strain gauge readings by Formulae (A.2) and (A.3):

$$\sigma_x = E\left(\varepsilon_x + v\varepsilon_y\right) / \left(1 - v^2\right) \qquad \text{(A.2)}$$

$$\sigma_y = E\left(\varepsilon_x + v\varepsilon_y\right) / \left(1 - v^2\right) \qquad \text{(A.3)}$$

Principal strains are obtained by interpreting rosette gauge readings on Mohr's circle or other convenient means. Equivalent stress S' can also be calculated from principal strains shown in Formula (A.4):

$$S' = \frac{E\sqrt{(1-v)^2(\varepsilon_x - \varepsilon_y)^2 + (\varepsilon_x + v\varepsilon_y)(\varepsilon_y + v\varepsilon_x)}}{(1-v^2)} \qquad \text{(A.4)}$$

When three and four gauge rosettes are used (Figure A.1), the following equations can be used directly to obtain the equivalent stress based on the readings of each of the legs.

Rectangular Rosette (Figure A.1):

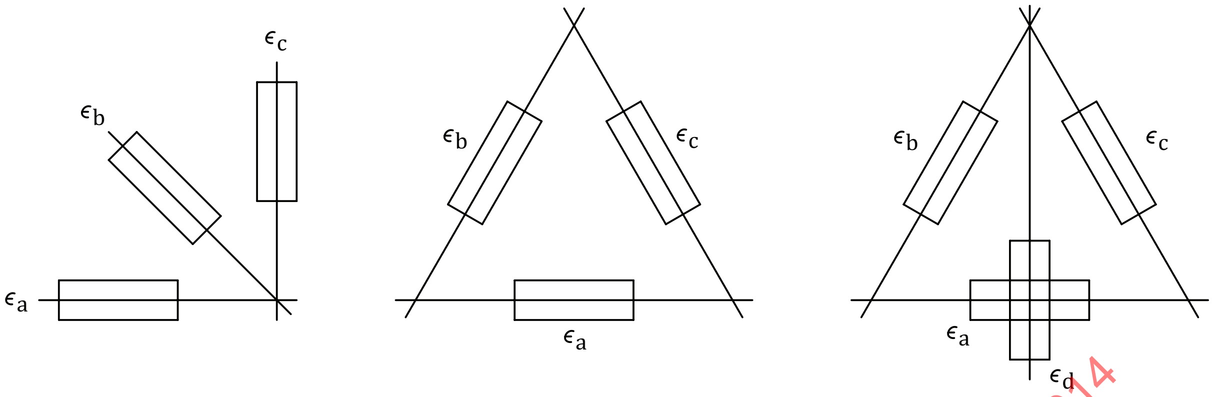


Figure A.1 — Rectangular, delta, and T-delta rosettes

A.4 Ductile material approximate method

In most ductile material biaxial fields, the assumption that the equivalent uniaxial stress S' equals $E\,\varepsilon_x$ will be accurate within 10 %. The main factors affecting the accuracy are

a) The ratio of minimum to maximum principal stress, σ_y/σ_x, and

b) The ratio of shear yield to tensile yield, τ_o/σ_o.

— σ_o = Tensile yield stress

— σ_x = Maximum principal stress

— σ_y = Minimum principal stress

Figure A.2 shows the magnitude of accuracy variance with respect to these two ratios, using Poisson's ratio ν = 0,285. The plot shows that as the condition approaches biaxial tension or compression error can be 25 % to 30 %, as the condition approaches pure shear error can be 0 to 30 % depending on the ratio τ_o/σ_o.

The solid curve line in Figure A.2 is based on the distortion energy theory of failure as compared to $S = E\,\varepsilon_x$. Distortion Energy Theory, while most generally correct, will check with the torsion yield test (pure shear) only if τ_o/σ_o = 0,577. For materials in which τ_o/σ_o does not equal 0,577, the dashed curve lines (which do not correspond to any theory of failure, but only the tensile and torsion yield tests) give some idea of the probable error. If a single gauge and $S = E\,\varepsilon_x$ is to be applied instead of rosettes and more complicated formulation, principal direction must be determined by some other means, such as paint checking or (better) brittle lacquer.

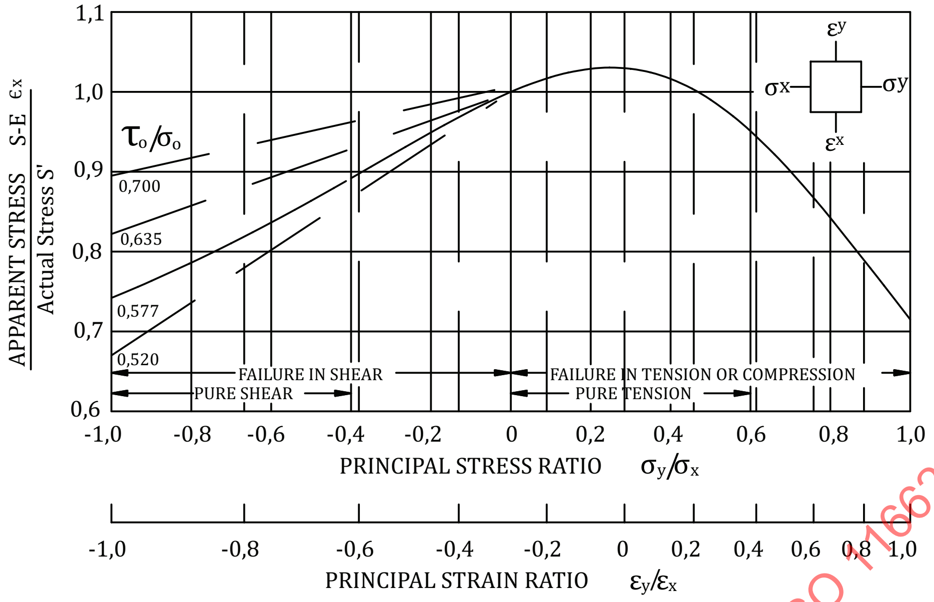


Figure A.2 — Ratio of apparent stress to actual stress versus biaxial stress ratio

Recommended values to be used in calculating stress from measured strain are listed in Table A.1.

Table A.1 — Elastic properties of materials

	Modulus of elasticity (E) (Young's; 10^3 Mpa)	**Modulus of rigidity** (G; Shear)[a] (10^3 Mpa)	**Poisson's ratio**
Steel			
Carbon and alloy structural	206,7	79,2	0,285
Cast	206,7	77,2	0,265
Stainless	137,8/192,9		0,305
Aluminium, structural	72,3	27,6	0,333
Magnesium, structural	44,8		
Titanium, structural	89,6/110,2		

[a] The modulus of elasticity generally is quoted as a range; the figures listed are towards the high and of the range for conservatism. The modulus of elasticity of some materials varies widely with chemistry, heat treatment, or stress level. In such cases a range is listed, and the proper value must be selected for the particular conditions in each case.

Annex B
(normative)

Column buckling stress

B.1 General comments

In deriving buckling curves or numerical tables for use in practical design, one has to be aware of some inevitable imperfections of the member being considered, such as non-homogeneity of the material, deviation from the assumed geometric form (initial crookedness), unintentional eccentricities of axial load due to the unavoidable imperfection of shop and erection work. Each of these imperfections varies over a wide range and combines with the others in each individual case in a particular manner. In order to compensate all uncertainties encountered in practice, proper factors of safety or load factors should be utilized.

Each compression member in a structure represents an individual case that must be designed according to its particular loading and end restraint conditions.

B.2 Critical buckling curves related to residual stress

Various column buckling curves are shown in Figure B.2. Curves A, B, C, and D are the curves that are related to residual stress and are used with the allowable stress method of calculation. A safety factor must be applied to the critical buckling strength obtained from Figure B.2. Table B.1 lists the Yield Strength, S_y, the Proportional Limit, S_p, and the Residual Stress, S_{RC} for each of the four material types (A, B, C, and D).

The shape of these curves can be defined by three parameters: the modulus of elasticity E, the proportional limit S_p and the material yield strength S_y. Axially loaded members can buckle elastically or inelastically, depending on the stress levels. At stress levels below the proportional limit S_p, axially loaded members buckle elastically. Inelastic buckling of the axially loaded members occurs at stress levels above the proportional limit S_p. For inelastic buckling, relative buckling stress (ratio of buckling stress to yield strength) is a function of the ratio of residual stress to yield strength as shown in Formula (B.5).

The residual stress is included directly in the buckling formulae. No factor of the uncertainties such as out-of-straightness. is incorporated in the formulae. The buckling curves are indeed for “specially straightened material”. Nevertheless, a strength margin of 1,6 (see Table 1) must be applied to the critical buckling curves. This strength margin overcomes such uncertainties that would affect the buckling strength of the members.

Applicable formulae for the elastic buckling of columns ($S_{cr} \le S_p$):

$$S_{cr} = \frac{\pi^2 E}{(KL/r)^2} \tag{B.1}$$

or

$$X = \frac{1}{\bar{\lambda}^2} \tag{B.2}$$

Applicable formulae for the inelastic buckling of columns ($S_{cr} \ge S_p$):

$$S_{cr} = S_y - \frac{S_p(S_y - S_p)}{\pi^2 E}(KL/r)^2 \tag{B.3}$$

$$S_p = S_y - S_{RC} \tag{B.4}$$

or

$$X = 1 - (1 - \frac{S_{RC}}{S_y})\frac{S_{RC}}{S_y}\bar{\lambda}^2 \tag{B.5}$$

As shown in Table C.1, a value of S_{RC} = 103 Mpa can be assumed in lieu of specific residual stress information on the following steel materials:

a) hot finished shapes in the as-rolled condition;

b) quenched and tempered shapes with stress relief heat treatment;

c) cold-drawn shapes with stress relief heat treatment;

d) fabricated welded shapes with stress relief heat treatment.

On other materials, a value of S_{RC} = 0,5 × S_y can be assumed in lieu of specific residual stress information.

Table B.1 — Residual stress assumption

Residual stress assumption	**Curve**[a]	S_y **Yield stress** (Mpa)	S_p **Proportional lLimit** (Mpa)
S_{RC} = 103 Mpa (lowresidualstress)	A	690	586
	B	483	379
	C	345	241
	D	248	145
S_{RC} = 0,5 S_y (highresidualstress)	D	690	345
	D	483	241
	D	345	172
	D	248	124

[a] Refer to Figure B.2, Critical buckling curves. Steels other than those listed can be used, provided it can be shown they are suitable for the application intended.

The following values can be used for the end restraint factor *K*.

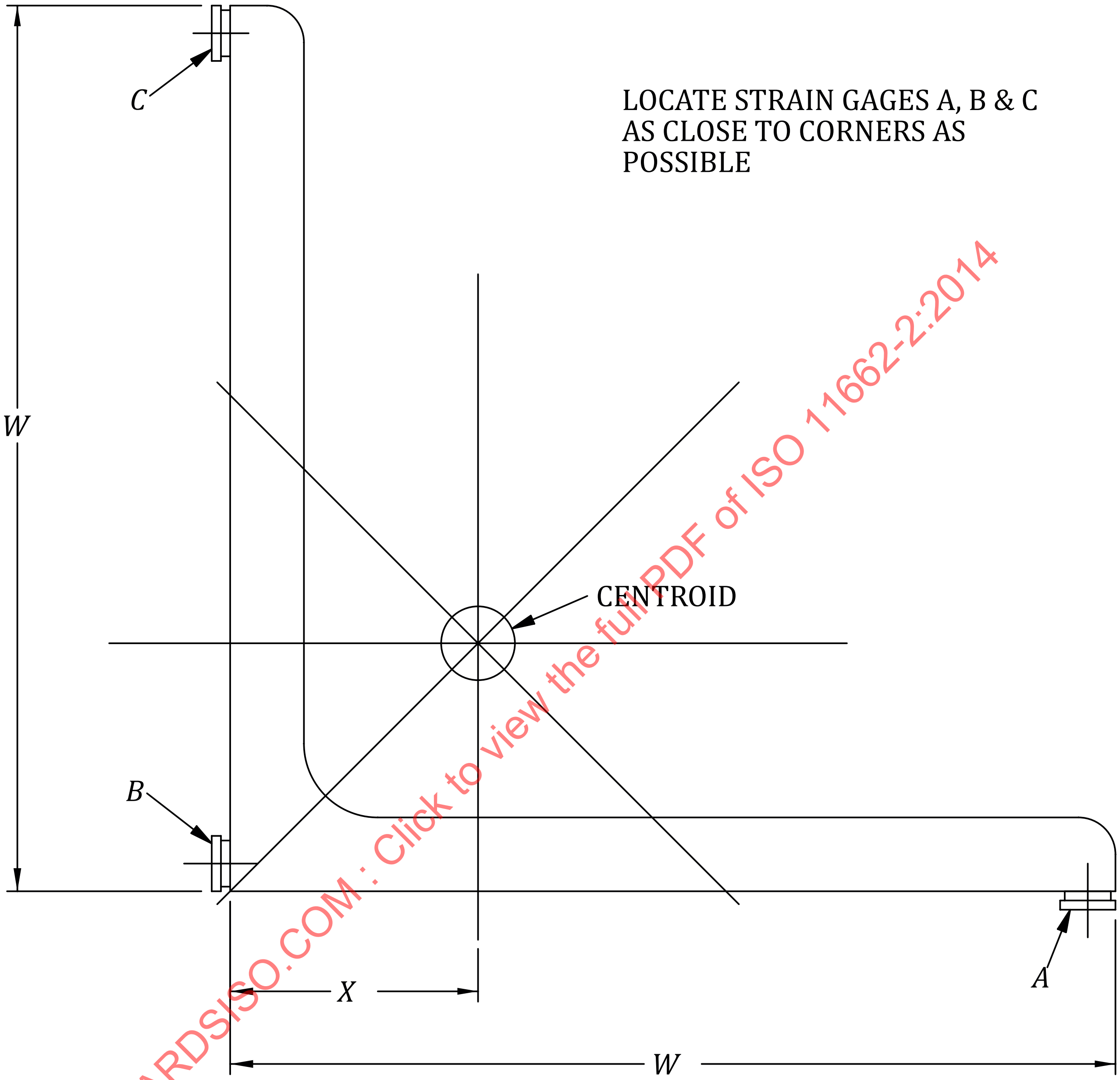
a) For chord members, *K* = 1,00.

b) For lacing members with full section connection to tubular chords, *K* = 0,75.

c) For lacing members with full section connection to angle or tee chords, *K* = 0,90.

d) For lacing members with reduced section connection to chord, *K* = 1,00.

In testing compression members, strain gauges should be located at the midspan or expected buckling point. When gauges are placed at the logical points of highest buckling stress, the highest observed reading can be used for S_{rm} in lieu of computation of the stress plane. When gauge locations are asymmetrical with respect to the centroid, the average of the test values cannot be used for S_{ra}. In this case, the test values must be weighted so that S_{ra} represents the value of the stress plane at the centroid. Figure B.1 demonstrates a method of weighting test values for an angle section with equal legs. Compression members which are asymmetrical with respect to the centroid, such as structural angles, have different values of radius of gyration (*r*) in different planes. For evaluation of data obtained from gauges in these areas, the determination of S_{cr} must be based on the largest value of *KL/r* occurring at the chosen area. For lattice chord members the largest value of *KL/r* must be utilized, whether lacings are staggered or concentric.



$$S_{ra} = \frac{x}{W}(S_a) + \frac{W-2x}{W}(S_b) + \frac{x}{W}(S_c)$$

Figure B.1 — Weighting test data for average stress

B.3 Critical buckling curves related to imperfection factor

The critical buckling stress can be obtained by the buckling curves a, b, and c as shown in Figure B.2. These three buckling curves are the results of a test program involving tests of columns of various cross sections.

The appropriate buckling curves should be chosen from Table B.2 for members with different cross sections. For the cross sections not shown in Table B.2, curve c can be used.

Formulae (B.6) and (B.7) can be used in lieu of curves a, b, and c with a satisfactory accuracy.

$$X = \frac{1}{B + (B^2 - \bar{\lambda}^2)^{0,5}} \quad \text{(B.6)}$$

where

$$B = 0,5\left(1 + \alpha(\bar{\lambda} - \bar{\lambda}_0) + \bar{\lambda}^2\right) \quad \text{(B.7)}$$

The factor α in Formula (B.7) is the imperfection factor introduced to account for the imperfections such as initial out-of-straightness, load eccentricity and residual stresses.

$\bar{\lambda}_0$ represents the relative slenderness, below which no instability will occur due to strain hardening effects.

The imperfection factor α and $\bar{\lambda}_0$ corresponding to the appropriate buckling curve shall be obtained as follows:

— Curve a*:* $\alpha = 0,21$; $\bar{\lambda}_0 = 0,2$

— Curve b: $\alpha = 0,34$; $\bar{\lambda}_0 = 0,2$

— Curve c: $\alpha = 0,49$; $\bar{\lambda}_0 = 0,2$

Other values for the imperfection factor α and $\bar{\lambda}_0$ can be used in Formula (B.7) in accordance with ISO 10721-1.

B.4 Allowable buckling stress associated with two factors of safety

In the practical applications of the critical buckling stress, allowable buckling stress can be established by different methods. One of the methods to establish the allowable buckling stress is to utilize two factors of safety: 2,5 for Euler's critical buckling stress S_{ci} (elastic buckling) and 1,5 for Jager's critical buckling stresses S_{ck}. The allowable buckling stress S_K for each individual member can then be obtained as follows:

$$S_K = \mathrm{Min}\{S_{ci} / 2,5, S_{ck} / 1,5\} \quad \text{(B.8)}$$

Curves b and c in Figure B.2 represent Jager's critical buckling stress S_{ck}. Curve b is for pipe section members and curve c is for general sections. Euler's critical buckling stress S_{ci} is determined by Formula (B.1) or Formula (B.2) and is shown by the dotted line in Figure B.2.

Table B.2 — Relation between cross section and appropriate buckling curve

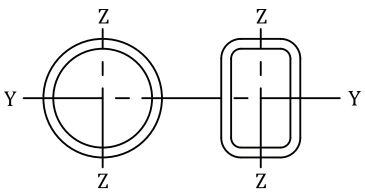
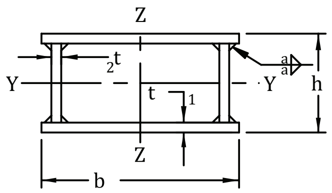
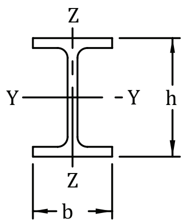
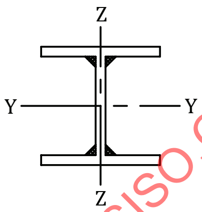
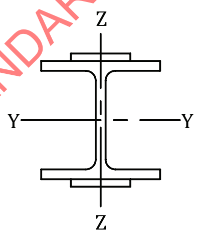
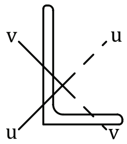
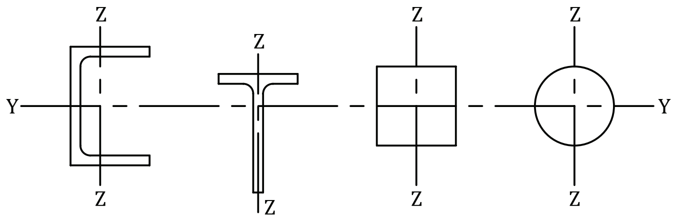
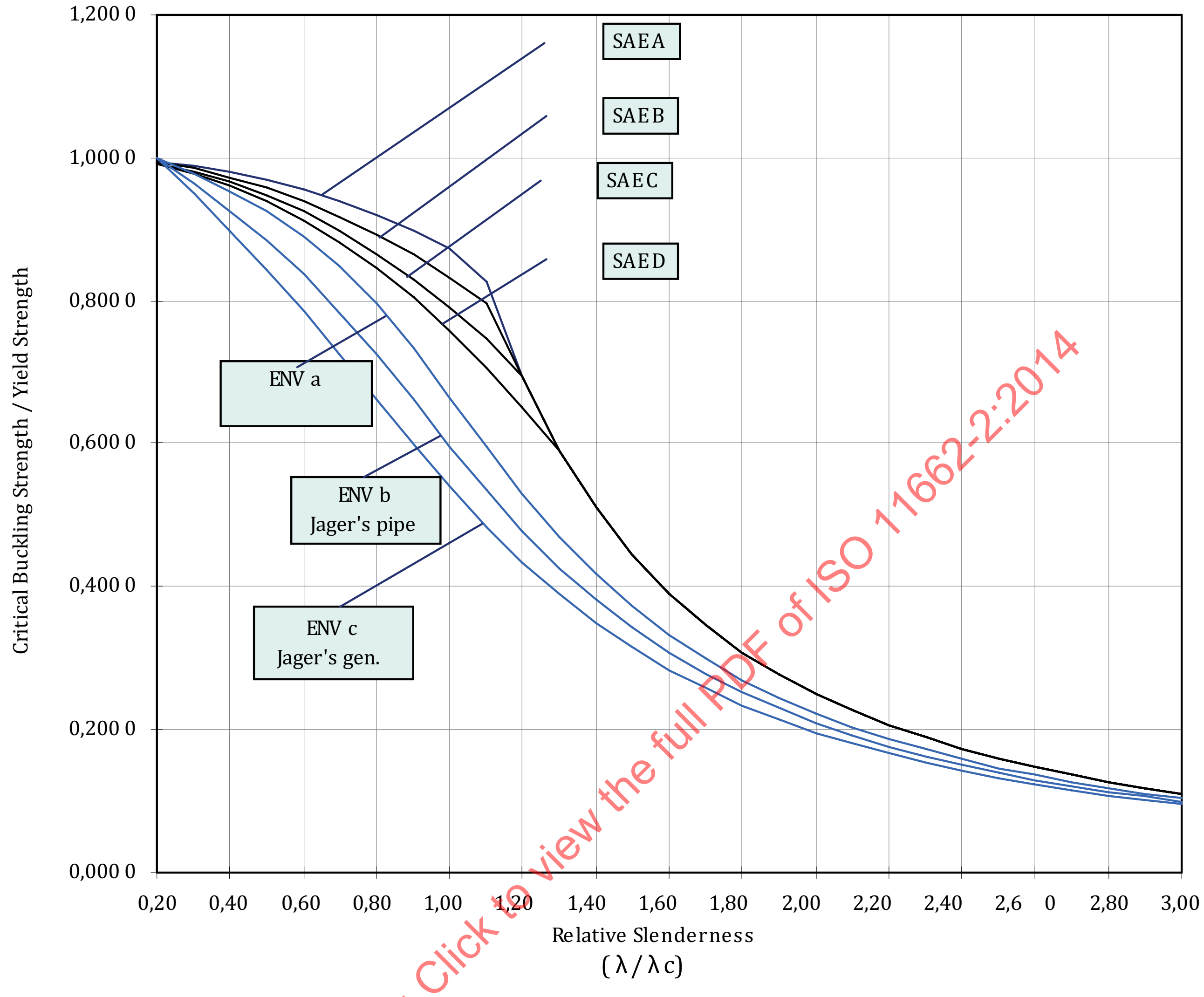
Cross section	Condition requirement		Buckling perpendicular to the axis	Buckling curve
Hollow sections 	Hot formed, or cold formed and stress relieved		Y-Y or Z-Z	a
	Cold formed (fy based on stub column testing)		Y-Y or Z-Z	b
Welded box sections 	Stress relieved		Y-Y or Z-Z	a
	As welded (except as below)		Y-Y or Z-Z	b
	Thick welds $(a >) \frac{t}{2}$	$\frac{b}{t} < 30$	Y-Y	c
		$\frac{h}{t} < 30$	Z-Z	
Rolled I-sections 	$\frac{h}{b} \leq 1,2$		Y-Y	a
			Z-Z	b
	$\frac{h}{b} \leq 1,2$		Y-Y	b
			Z-Z	c
Welded I-sections 	Stress relieved		Y-Y	a
			Z-Z	b
	Flame cut flanges		Y-Y or Z-Z	b
	Rolled flanges		Y-Y	b
			Z-Z	c
Re-enforced I-section 	Rolled I-sections with welded flange plates		Y-Y	b
			Z-Z	a

Table B.2 *(continued)*

Cross section	Condition requirement	Buckling perpendicular to the axis	Buckling curve
L-sections: 	Generally		c
	Hot-dip galvanized	u-u or v-v	b
U-, T-, and solid sections 		Y-Y or Z-Z	c



Curves A, B, C, and D are for residual stress = 103 Mpa
Curve A: Yield Strength = 690 MPa
Curve B: Yield Strength = 483 Mpa
Curve C: Yield Strength = 345 MPa
Curve D: Yield Strength = 248 MPa
Buckling stress is dependant upon the ratio of residual stress to yield stress.
ENV a: Imperfection Factor α = 0,21
ENV b: Imperfection Factor α = 0,34
ENV c: Imperfection Factor α = 0,49
The imperfection Factor accounts for:
1. out of straightness
2. load eccentricity
3. residual stress

Figure B.2 — Critical buckling curves

Annex C
(normative)

Test conditions and strength margins

The following test conditions (Tables C.1, C.2, and C.3) are intended for testing cranes as defined in the scope of this document. The method of test can be applicable to other types, but the test conditions and strength margins suggested here should be reviewed and perhaps modified to suit the application.

The standard test loading conditions for the principle structural components of cranes are listed in Tables C.1, C.2, and C.3.

Suggested minimum allowable strength margins for these loadings are shown in Table 1. These tables cover lifting crane hook work for which the number of stress cycles during the expected life of the crane does not require consideration of fatigue endurance limits. This is as opposed to cyclic type services such as bucket, magnet, or grapple work. With the exception of overloads, the conditions listed closely approximate the typical maximum loading imposed on cranes when operating within the range of manufacturer's published ratings.

Table C.1 — Mast and mast mounted boom attachment — Test conditions

Test	Test conditions				Purpose is to test:	Tested components and strength margins**			
	First select	Notes	Then apply			Under-carriage	Upper structure	Attachment	Suspension (except ropes)
			Working load	Overload					
A	Maximum numerical rated load at its longest rated radius. Use longest mast rated with this load.	2 9 16 17	(Y) *RL* with upper structure in any position.	(Z) 1,25 *RL* or tipping load, whichever is less.	Integrity of the attachment and upper structure.	—	Y,Z	Y,Z	—
B	Maximum *(RR* × *RL)* with largest rated load allowed at this load moment.	3 6 8 12 17	(Y) *RL* and *SL* (0,02 × *RL*) both left and right. Orient upper structure to any position.	(Z) 1,25 *RL* or tipping load, whichever is less. Orient upper structure to any position.	Upper structure and suspension for maximum load moment	—	Y,Z	—	Y,Z
C	Maximum *(RR* × *RL)* over side, with largest rated load allowed at this load moment.	1 3 5 6 7 8 12 17	(Y) *RL* and position upper structure in allowed rotation range to obtain maximum strain in member tested.	(Z) 1,25 *RL* or tipping load, whichever is less. Orient upper structure to any position.	Undercarriage for maximum load moment.	Y,Z	—	—	—
D	Maximum *(RR* × *RL)* over end, with largest rated load allowed at this load moment.	1 3 5 6 7 8 12 17	(Y) *RL* and position upper structure in allowed rotation range to obtain maximum strain in member tested.	(Z) 1,25 *RL* or tipping load, whichever is less. Orient upper structure to any position.	Undercarriage for maximum load moment.	Y,Z	—	—	—
E	Rated radius which produces maximum *(RR* × *RL)*. Use the mast with the longest mast mounted boom that has a rating at this radius.	6 13 14 15 16 17	(Y) *RL* and *SL* (0,02 × *RL*) both left and right, upper structure over a corner.	(Z) 1,25 *RL* or tipping load, whichever is less. Orient upper structure over a corner.	Integrity of the attachment and upper structure.	—	—	Y,Z	Y,Z
F	Longest combination of mast + mast mounted boom offered for each specified suspension.	4 16 18	(X) Suspend mast and mast mounted boom just clear of ground.	None	Integrity of the attachment and suspension.	—	—	X	X
G	Longest combination of mast + mast mounted boom offered for each specified suspension.	13 14 15 16	(Y) *RL* at minimum *RR* and *SL* (0,02 × *RL*) both left and right, upper structure over a corner.	(Z) 1,25 *RL* or tipping load, whichever is less. Orient upper structure over a corner.	Integrity of the attachment and suspension.	—	—	Y,Z	Y,Z

Table C.1 *(continued)*

Test	Test conditions				Purpose is to test:	Tested components and strength margins**			
	First select	Notes	Then apply			Under-carriage	Upper structure	Attachment	Suspension (except ropes)
			Working load	Overload					
H	Maximum (*RL* × Jib Length × sinβ). Use longest mast mounted boom where this condition exists. Then select longest mast for the above conditions.	11 13 14 15 16	(Y) *RL* at max. *RR* and *SL* (0,02 × *RL*) both left and right, upper structure over a corner.	(Z) 1,25 *RL* or tipping load, whichever is less. Orient upper structure over a corner.	Integrity of the attachment under the condition of maximum torsion.	—	—	Y,Z	—
I	Fly jib test Longest combination of mast, mast mounted boom, and fly jib(s) for each specified suspension with minimum fly jib offset.	4 10 11 16 18	(X) Suspend mast mounted boom and fly jib(s) just clear of ground.	None	Integrity of the attachment, upper structure, and suspension.	—	X	X	X
J	Fly jib test Longest combination of mast, mast mounted boom, and fly jib(s) for each specified suspension with minimum fly jib offset.	10 11 13 14 15 16	(Y) *RL* at min *RR* and *SL* (0,02 × *RL*) both left and right, upper structure over a corner.	(Z) 1,25 *RL* or tipping load, whichever is less. Orient upper structure over a corner.	Integrity of the attachment.	—	—	Y,Z	—
K	Fly jib test Maximum (fly jib *RL* × Fly Jib Length × sinβ). Use longest fly jib where this condition exists. Then select longest mast mounted boom for the above conditions.	11 13 14 15 16	Y) *RL* at min *RR* and *SL* (0,02 × *RL*) both left and right, upper structure over a corner.	(Z) 1,25 *RL* or tipping load, whichever is less. Orient upper structure over a corner.	Integrity of the attachment.	—	—	Y,Z	—
L	Midfall test Maximum numerical rated load at its longest rated radius. Use longest mast mounted boom rated with this load.	13 15 16	(Y) *RL* and *SL* (0,02 × *RL*) both left and right. Orient upper structure to any position.	(Z) 1,25 *RL* or tipping load, whichever is less. Orient upper structure to any position.	Integrity of the attachment, suspension, and midfall	—	—	Y,Z	Y,Z
M	Midfall test Longest combination of mast + mast mounted boom offered for each specified suspension.	2 9 12 13 15 16	(Y) *RL* and *SL* (0,02 × *RL*) both left and right @ both max. and min radius. Orient upper structure to any position.	(Z) 1,25 *RL* or tipping load, whichever is less. Orient upper structure to any position.	Integrity of the attachment, suspension, and midfall	—	—	Y,Z	Y,Z

Table C.1 *(continued)*

Test	Test conditions				Purpose is to test:	Tested components and strength margins**			
	First select	Notes	Then apply			Under-car-riage	Upper struc-ture	Attachment	Suspension (except ropes)
			Working load	Overload					
N	Midfall test Maximum (mid-fall RL × Midfall Length × sinβ). Use long-est mast mounted boom where this condition exists. Then select longest mast for the above condi-tions.	13 15 16	(Y) *RL* at max. *RR* and *SL* (0,02 × *RL*). Orient upper structure to any position.	(Z) 1,25 *RL* or tipping load, whichever is less. Orient upper structure to any position.	Integrity of the attachment, suspen-sion, and midfall	—	—	Y,Z	Y,Z

**X Erection loads, Y Rated loads, Z Over loads.

NOTE 1 Position the upper as defined in manufacturer’s specification.

NOTE 2 Where this rated load is offered with the upper structure counterweight in variable positions, testing shall be performed with this counterweight at the maximum specified distance to the centreline of rotation.

NOTE 3 Where this rated load is offered with the upper structure counterweight in variable positions, testing shall be performed with this counterweight at the minimum specified distance to the centreline of rotation.

NOTE 4 Hook block, overhaul ball, or load line attachments resting on the ground.

NOTE 5 For carriers utilizing various mast and/or upper structure configurations, only the configuration which produces the maximum moment condition should be tested.

NOTE 6 For upper structure utilizing various mast configurations, only the configuration which produces the maximum moment conditions should be tested.

NOTE 7 Use heaviest specified carrier auxiliary counterweight.

NOTE 8 If a choice of counterweights exists for the maximum moment condition, use the lightest specified counterweight for this condition.

NOTE 9 Use the heaviest specified upper structure counterweight.

NOTE 10 Where more than one allowable mast mounted boom and fly jib combination result in the same longest numerical value (i.e. 100’ mast mounted boom + 60’ fly jib = 160’, and also 120’ mast mounted boom + 40’ fly jib = 160’), use the combination which includes the longest jib (i.e. 120’ mast mounted boom + 40’ fly jib in this example).

NOTE 11 When two or more mast mounted booms are attached simultaneously to extend the length of the attachment, each system should be tested as a separate rigging. (Apply ISO 11662-2 to mast + mast mounted boom(A) and then apply ISO 11662-2 to mast + mast mounted boom(A) + fly jib(B).

NOTE 12 For upper structures utilizing various mast configurations, only the configuration which produces the maximum load condition should be tested.

NOTE 13 In no instance shall the wind be utilized to favourably influence the outcome of the test.

NOTE 14 Note the direction of tip deflection due to suspending the load directly over an end. Swing the upper structure in the same direction to the nearest corner for testing.

NOTE 15 Use manufacturer’s specified reeving with minimum specified parts of load hoist line and with hoist line leaving the drum from an arbitrary position.

NOTE 16 Where several masts with significant structural or geometrical differences are utilized on the same upper structure, each mast shall be tested.

NOTE 17 Tests C and D can be eliminated if machine has been tested to a greater RR × RL with another attachment and has also been tested to a greater thrust with another attachment.

NOTE 18 When the mast mounted boom point cannot be lifted from the ground with the mast point just clear of the ground, two positions are required for testing.

- Mast just clear of the ground - mast mounted point on the ground.
- Mast point at the minimum angle that will allow erection of the mast mounted boom - boom point just clear of the ground.

Table C.2 — Lattice boom attachment — Test conditions

Test	Test conditions				Purpose is to test:	Tested components and strength margins**			
	First select	Notes	Then apply			Under-carriage	Upper structure	Attachment	Suspension (except ropes)
			Working load	Overload					
A	Maximum numerical rated load at its longest rated radius. Use longest boom rated with this load.	2 9 16 17	(Y) *RL* with upper structure in any position.	(Z) 1,25 *RL* or tipping load, which-ever is less.	Integrity of the attachment and upper structure.	—	Y,Z	Y,Z	—
B	Maximum (*RR* × *RL*) with largest rated load allowed at this load moment.	3 6 8 12 17	(Y) *RL* and *SL* (0,02 × *RL*) both left and right. Orient upper structure to any position.	(Z) 1,25 *RL* or tipping load, which-ever is less. Orient upper structure to any position.	Upper structure and suspension for maximum load moment	—	Y,Z	—	Y,Z
C	Maximum (*RR* × *RL*) over side, with largest rated load allowed at this load moment.	1 3 5 6 7 8 12 17	(Y) *RL* and position upper structure in allowed rotation range to obtain maximum strain in member tested.	(Z) 1,25 *RL* or tipping load, which-ever is less. Orient upper structure to any position.	Undercarriage for maximum load moment.	Y,Z	—	—	—
D	Maximum (*RR* × *RL*) over end, with largest rated load allowed at this load moment.	1 3 5 6 7 8 12 17	(Y) *RL* and position upper structure in allowed rotation range to obtain maximum strain in member tested.	(Z) 1,25 *RL* or tipping load, which-ever is less. Orient upper structure to any position.	Undercarriage for maximum load moment.	Y,Z	—	—	—
E	Rated radius which produces maximum (*RR* × *RL*). Use longest boom that has a rating at this radius.	6 13 14 15 16 17	(Y) *RL* and *SL* (0,02 × *RL*) both left and right, upper structure over a corner.	(Z) 1,25 *RL* or tipping load, which-ever is less. Orient upper structure over a corner.	Integrity of the attachment and upper structure.	—	—	Y,Z	Y,Z
F	Longest boom offered for each specified sus-pension.	4 16	(X) Suspend boom and fly jib just clear of ground.	None	Integrity of the attachment and suspension.	—	—	X	X
G	Longest boom offered for each specified sus-pension.	13 14 15 16	(Y) *RL* at minimum RR and *SL* (0,02 × *RL*) both left and right, upper structure over a corner.	(Z) 1,25 *RL* or tipping load, which-ever is less. Orient upper structure over a corner.	Integrity of the attachment and suspension.	—		Y,Z	Y,Z

Table C.2 *(continued)*

Test	Test conditions				Purpose is to test:	Tested components and strength margins**			
	First select	Notes	Then apply			Under-carriage	Upper structure	Attachment	Suspension (except ropes)
			Working load	Overload					
H	Longest allowable combination of boom and fly jib(s) for each specified suspension wiht minimum jib offset.	4 10 11 16	(Y) *RL* at max. *RR* and *SL* (0,02 × *RL*) both left and right, upper structure over a corner.	(Z) 1,25 *RL* or tipping load, whichever is less. Orient upper structure over a corner.	Integrity of the attachment under the condition of max. torsion.	—	—	Y,Z	—
I	Longest allowable combination of boom and fly jib(s) for each specified suspension with minimum fly jib offset.	11 13 14 15 16	(X) Suspend boom and fly jib(s) just clear of ground.	None	Integrity of the attachment, upper structure, and suspension.	—	X	X	X
J	Maximum (fly jib *RL* × fly jib length × sin β) Use longest fly jib where this condition exists. Then select longest boom for the above conditions.	11 13 14 15 16	(Y) *RL* at min RR and *SL* (0,02 × *RL*) both left and right, upper structure over a corner.	(Z) 1,25 *RL* or tipping load, whichever is less. Orient upper structure over a corner.	Integrity of the attachment.	—	—	Y,Z	—

Table C.2 *(continued)*

Test	Test conditions				Purpose is to test:	Tested components and strength margins**			
	First select	Notes	Then apply			Under-carriage	Upper structure	Attachment	Suspension (except ropes)
			Working load	Overload					
**X Erection loads, Y Rated loads, Z Over loads.									
NOTE 1 Position the upper as defined manufacturer's specification.									
NOTE 2 Where this rated load is offered with the upper structure counterweight in variable positions, testing shall be performed with this counterweight at the maximum specified distance to the centreline of rotation.									
NOTE 3 Where this rated load is offered with the upper structure counterweight in variable positions, testing shall be performed with this counterweight at the minimum specified distance to the centreline of rotation.									
NOTE 4 Hook block, overhaul ball, or load line attachments resting on the ground.									
NOTE 5 For carriers utilizing various boom and/or upper structure configurations, only the configuration which produces the maximum moment condition should be tested.									
NOTE 6 For upper structure utilizing various boom configurations, only the configuration which produces the maximum moment conditions should be tested.									
NOTE 7 Use heaviest specified carrier auxiliary counterweight.									
NOTE 8 If a choice of counterweights exists for the maximum moment condition, use the lightest specified counterweight for this condition.									
NOTE 9 Use the heaviest specified upper structure counterweight.									
NOTE 10 Where more than one allowable boom and fly jib combination result in the same longest numerical value (i.e. 100’ boom + 60’ fly jib 160’, and also 120’ boom + 40’ fly jib = 160’), use the combination which includes the longest boom (i.e. 120’ boom + 40’ fly jib in this example).									
NOTE 11 When two or more booms are attached simultaneously to extend the length of the attachment, each system should be tested as a separate rigging. (Apply ISO 11662-2 to boom + fly jib(A) and then apply ISO 11662-2 to boom + fly jib(A) + fly jib(B).									
NOTE 12 For upper structures utilizing various boom configurations, only the configuration which produces the maximum load condition should be tested.									
NOTE 13 In no instance shall the wind be utilized to favourably influence the outcome of the test.									
NOTE 14 Note the direction of tip deflection due to suspending the load directly over an end. Swing the upper structure in the same direction to the nearest corner for testing.									
NOTE 15 Use manufacturer’s specified reeving with minimum specified parts of load hoist line and with hoist line leaving the drum from an arbitrary position.									
NOTE 16 Where several booms with significant structural or geometrical differences are utilized on the same upper structure, each boom shall be tested.									
NOTE 17 Tests C and D can be eliminated if machine has been tested to a greater $RR \times RL$ with another attachment and has also been tested to a greater thrust with another attachment.									

Table C.3 — Telescoping boom attachment — Test conditions

Test	Test conditions			Purpose is to test:	Tested components and strength margins**			
	First select	Notes	Then apply		Under carriage	Upper structure	Attachment	Suspension (except ropes)
1	Max. (*RR* × *RL*) with largest rated load allowed at this load moment. a. over end b. over side	1 2 3 4 9	*RL* and position superstructure in allowed rotation range to obtain maximum strain in member tested.	Outrigger and carrier frame for maximum live load moment.	Y Y	Y —	— —	— —
2	Max. (*RR* × *RL*) with longest telescoping boom at this load moment.	4	a. Rated load and side load (0,03 × *RL*). b. 1,25 *RL* or tipping load, whichever is less. Orient upper structure over end.	a. Telescoping boom overlap effects, hoist or suspension system, super structure and turntable bearing system. b. Telescoping boom buckling, hoist cylinder, or suspension system.	— —	Y Z	Y Z	Y Z
3	Max. telescoping boom length, then max. (*RR* × *RL*)	8	a. Rated load and side load. b. 1,25 *RL* or tipping load, whichever is less. Orient upper structure over end.	a. Telescoping boom overlap effect. b. Telescoping boom buckling and side bending effects.	— —	— Z	Y Z	Y —
4	Max. telescoping boom length then minimum attainable *RR*	8	a. Rated load and side load (0,03 × *RL*). b. 1,25 *RL* or tipping load, whichever is less. Orient upper structure over end.	a. Side bending of telescoping boom, side load effect on super structure. b. Extension cylinder buckling, telescoping boom bending effect, hoist cylinder buckling, or suspension system.	— —	Y Z	Y Z	Y Z
5	Max. numerical load, then shortest telescoping boom and minimum *RR*	1 6	a. *RL* and position super structure in allowed rotation range to obtain maximum strain in member tested. b. 1,25 *RL* or tipping, whichever is less.	a. Telescoping boom point integrity, foot pin force, outrigger and carrier frame. Turntable bearing system. b. Suspension system	Y Z	Y Z	Y Z	— Z
6	Max. (fly jib *RL* × fly jib length × cos(α-β)), then longest telescoping boom and fly jib specified	5	a. Rated load and side load (0,03 × *RL*). b. 1,25 RL or tipping load, whichever is less. Orient upper structure over end.	Integrity of fly jib, telescoping boom point, and telescoping boom top section.	— —	— —	Y Z	Y Z

Table C.3 *(continued)*

Test	Test conditions			Purpose is to test:	Tested components and strength margins**			
	First select	Notes	Then apply		Under carriage	Upper structure	Attachment	Suspension (except ropes)
7	Max. (fly jib *RL* × fly jib length × sin(β)), then longest telescoping boom specified	5	a. Rated load and side load (0,03 × *RL*). b. 1,25 *RL* or tipping load, whichever is less. Orient upper structure over end.	Torsional effects of fly jib offset on telescoping boom and fly jib	— —	— —	Y Z	Y Z
8	Max. telescoping boom angle, max. telescoping boom length, max. specified fly jib at minimum offset	5 7	a. Rated load and side load (0,03 × *RL*). b. 1,25 *RL* or tipping load, whichever is less. Orient upper structure over end.	Integrity and stability of fly jib and telescoping boom.	— —	— —	Y Z	Y Z
9	Max. allowable *RL* with telescoping boom extended 1 to 3 inches (25 to 76 mm) at minimum *RR*	8	1,25 *RL* or tipping load, whichever is less. Orient upper structure over end.	Telescoping boom extension cylinder attachments.	—	—	Z	Z
10	Max. (*RL* × t) for each section. With the largest rated load allowed at this load moment.	8	a. Rated load and side load (0,03 × *RL*). b. 1,25 *RL* or tipping load, whichever is less. Orient upper structure over end.	Bending effects on manual and powered sections at random telescoping boom angles and section extension.	— —	— —	Y Z	— —
11	Max. auxiliary outrigger load		a. Rated load. b. 1,25 *RL* or tipping	Auxiliary outrigger and carrier frame integrity.	Y Z	— —	— —	— —

*X Erection loads, Y Rated loads, Z Over loads

NOTE 1 Position the upper as defined by manufacturer's specification.

NOTE 2 For carriers utilizing various boom and/or upperstructure configurations, only the configuration which produces the maximum moment condition should be tested.

NOTE 3 Use heaviest specified carrier auxiliary counterweight.

NOTE 4 If a choice of counterweights exists for the maximum moment condition, use the lightest specified counterweight for this condition.

NOTE 5 When two or more fly jibs are attached simultaneously to extend the length of the telescopic boom attachment, each system should be tested as a separate rigging. (Apply ISO 11662-2 to telescopic boom + fly jib(A) and then apply ISO 11662-2 to telescopic boom + fly jib(A) + fly jib(B).

NOTE 6 For upperstructures utilizing various telescopic boom configurations, only the configuration which produces the maximum load condition should be tested.

NOTE 7 In no instance shall the wind be utilized to favourably influence the outcome of the test.

NOTE 8 Where several telescopic booms with significant structural or geometrical differences are utilized on the same upperstructure, each boom shall be tested.

NOTE 9 Test can be eliminated if machine has been tested to a greater RR × RL with another attachment and has also been tested to a greater thrust with another attachment.