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Superseding J987 APR1994

## Lattice Boom Cranes—Method of Test

**Foreword**—The SAE Technical Committee—Cranes and Lifting Devices has rewritten this document to include lattice boom luffing attachments. This document supersedes SAE J987 APR1994.

**1. Scope**—This SAE Standard applies to mobile construction-type lifting cranes utilizing rope-supported, conventional and luffing type lattice boom crane structures.

**1.1 Purpose**—The purpose of this test method is to provide a systematic nondestructive procedure for determining the stresses induced in crane structures under specified conditions of static loading through use of resistance-type electric strain gages, and to specify appropriate acceptance criteria for specified loading conditions.

## 2. References

**2.1 Applicable Publications**—The following publications form a part of the specification to the extent specified herein. Unless otherwise indicated, the latest revision of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J1028—Mobile Crane Working Area Definitions

SAE J1093—Latticed Crane Boom Systems—Analytical Procedure

2.1.2 ASTM PUBLICATION—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM E 251—Test Methods for Performance Characteristics of Bonded Resistance Strain Gages

2.1.3 COLUMN RESEARCH COUNCIL PUBLICATION—Available from Column Research Council, Cushing-Malloy, Inc., Ann Arbor, MI, 1960.

Guide to Design Criteria for Metal Compression Members

2.1.4 JOSEPH MARIN PUBLICATION—Available from Prentice-Hall, Inc., Englewood, NJ, 1962.

Mechanical Behavior of Engineering Materials

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**3. Definitions**—See Appendix A.

**3.1 Strain**—Deformation of material at any given point with respect to a specific plane passing through that point, expressed as change in length per unit length.

**3.2 Stress (S)**—The intensity of internal force accompanying strain, expressed in force per unit area. For purposes of this test method, stress is related to measured strain by the uniaxial stress equation (see Equation 1):

$$S = E \cdot \varepsilon \text{ (within proportional limits)} \quad (\text{Eq. 1})$$

where:

S = stress

E = modulus of elasticity, for the material involved

e = strain

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

**3.3 Yield Point (Sy)**—The stress at which a disproportionate increase in strain occurs without corresponding increase in stress. For purposes of this code, yield point is to be considered as the minimum 0.2% offset tensile yield point or yield (ASTM A 370) strength specified by the appropriate standard for the material used.

**3.4 Critical Buckling Stress (Scr)**—The average stress which produces an incipient buckling condition in column-type members (see Appendix C).

**3.5 Initial Reference Test Condition**—The defined no-stress or zero-stress condition of the crane structure after the “break-in” (see 7.3) 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 gage is obtained,  $N_1$ .

**3.6 Dead Load Stress Condition (DL)**—The 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. Under this condition, the second reading for each gage is obtained,  $N_2$ .

NOTE—Although the hook, block, slings, etc., are considered part of the suspended load, for purposes of safety and practicality they may be supported by the crane when this reading is taken.

**3.7 Dead Load Stress (S<sub>1</sub>)**—The stress computed as defined in 3.2 by using the difference in the readings obtained in 3.6 and 3.5 for each gage ( $N_2 - N_1$ ).

**3.8 Working Load Stress Condition**—The completely assembled crane structure on the test site and in the specified position, supporting the specified rated load. Under this condition, the third reading for each gage is obtained,  $N_3$ .

**3.9 Working Load Stress (S<sub>2</sub>)**—The stress computed as defined in 3.2 by using the difference in the readings obtained in 3.8 and 3.5 for each gage ( $N_3 - N_1$ ).

**3.10 Resultant Stress ( $S_r$ )**—The maximum 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.

3.10.1 COLUMN AVERAGE STRESS ( $S_{ra}$ )—The direct compression stress in a column or the average stress computed from the several gages located at the section (see Appendix C).

3.10.2 COLUMN MAXIMUM STRESS ( $S_{RM}$ )—The maximum compression stress in a column computed from the plane of buckling as established from the several gages located at the section (see Appendix C).

**3.11 Loadings**—The application of weights and/or forces of the magnitude specified under the condition specified.

**3.12 Specified**—The stated requirements of the manufacturer, the user, the testing agency, or any agreement between these parties.

#### 4. Applications

4.1 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. In some cases, a more severe loading condition(s) may be indicated by analysis. In these cases, the more severe condition(s) may be added to or substituted for the specified test loading condition(s). It also classifies stress area Types I, II, III, and IV (see 9.1), and defines limits for each class. Results may be used to correlate boom calculation results for Class III stress areas as given, e.g., by SAE J1093 boom calculation method. Test results for Class I stress areas throughout the structure may 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, may be reviewed for better insight by calculation methods.

4.2 This method applies to load-supporting structures as differentiated from power transmitting mechanisms. It is restricted to measuring strains under static conditions.

4.3 The procedures outlined are intended to supplement basic design analysis. One such method of analysis for crane boom systems is presented in SAE J1093. The relationship of this test method to calculations as presented in SAE J1093 is as follows:

4.3.1 A production boom system (serially produced) can be rated by the methods outlined in SAE J1093, but a prototype of this system should be subjected to the following test procedures as documentation of its capability.

4.3.2 A production boom system that has been rated by the methods of 4.3.1 may be used on another machine without retesting by the methods specified herein. This can be done only if the same analytical procedure shows its stress levels will be less than in the original application and provided 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 boom foot axis (see 8.5) as test loads are applied.

4.3.3 A specially designed boom system (not serially produced) similar to a known and tested design may be rated by the methods of SAE J1093. The applicable overload test conditions specified (see Tables 1 and 2) should also be applied as proof of competence.

TABLE 1—LUFFING ATTACHMENT TYPE CRANE—TEST CONDITIONS

| Test | Test Conditions First Select | Test Conditions Notes  | Test Conditions Working Load   | Test Conditions Then Apply Overload   | Test Purpose is to test:                                 | Tested Components and Strength Margins** Under-carriage | Tested Components and Strength Margins** Upper Structure | Tested Components and Strength Margins** Boom and Jib(s) | Tested Components and Strength Margins** Suspension (Except Ropes) |
|------|------------------------------|--|--|---|--|---|--|--|--|
| A    | 2                            | Max numerical rated load at its longest rated radius. Use longest luffing boom rated with this load                      | (Y) RL with upper structure in any position  | (Z) 1.25 RL or tipping load, whichever is less.   | Integrity luffing boom, luffing jib, and upper structure | —   | Y, Z   | Y, Z   | —  |
|      | 9                            |  |  |   |  |   |  |  |  |
|      | 16                           |  |  |   |  |   |  |  |  |
| B    | 3                            | Max (RR x RL) with largest rated load allowed at this load moment.   | (Y) RL and SL (0.02 x 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   |
|      | 6                            |  |  |   |  |   |  |  |  |
|      | 8                            |  |  |   |  |   |  |  |  |
|      | 12                           |  |  |   |  |   |  |  |  |
|      | 17                           |  |  |   |  |   |  |  |  |
| C    | 1                            | Max (RR x RL) over side, with largest rated load allowed at this load moment.  | (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  | —  | —  | —  |
|      | 3                            |  |  |   |  |   |  |  |  |
|      | 5                            |  |  |   |  |   |  |  |  |
|      | 6                            |  |  |   |  |   |  |  |  |
|      | 7                            |  |  |   |  |   |  |  |  |
|      | 8                            |  |  |   |  |   |  |  |  |
|      | 17                           |  |  |   |  |   |  |  |  |
| D    | 1                            | Max (RR x RL) over end, with largest rated load allowed at this load moment.   | (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  | —  | —  | —  |
|      | 3                            |  |  |   |  |   |  |  |  |
|      | 5                            |  |  |   |  |   |  |  |  |
|      | 6                            |  |  |   |  |   |  |  |  |
|      | 7                            |  |  |   |  |   |  |  |  |
|      | 8                            |  |  |   |  |   |  |  |  |
|      | 17                           |  |  |   |  |   |  |  |  |
| E    | 6                            | Rated radius which produces max (RR x RL). Use Luffing boom with longest luffing jib, which has a rating at this radius. | (Y) RL and SL (0.02 x 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 luffing boom, luffing jib, and suspension.  | —   | —  | Y, Z   | Y, Z   |
|      | 13                           |  |  |   |  |   |  |  |  |
|      | 14                           |  |  |   |  |   |  |  |  |
|      | 15                           |  |  |   |  |   |  |  |  |
|      | 17                           |  |  |   |  |   |  |  |  |
| F    | 4                            | Longest combination of luffing boom + luffing jib offered for each specified suspension.                                 | (X) Suspend luffing boom, luffing jib, just clear of ground.   | None  | Integrity of luffing boom, luffing jib, and suspension   | —   | —  | X  | X  |
|      | 16                           |  |  |   |  |   |  |  |  |
|      | 18                           |  |  |   |  |   |  |  |  |

TABLE 1—LUFFING ATTACHMENT TYPE CRANE—TEST CONDITIONS

| Test | Test Conditions First Select   | Test Conditions Notes | Test Conditions Then Apply Working Load   | Test Conditions Then Apply Overload   | Purpose is to test:   | Tested   |   | Tested  |   | Tested |     |
|------|--|-----------------------|---|---|---|--|---|---|---|--------|-----|
|      |  |                       |   |   |   | Components and Strength Margins** Under-carriage | Components and Strength Margins** Upper Structure | Components and Strength Margins** Boom and Jib(s) | Components and Strength Margins** Suspension (Except Ropes) |        |     |
| G    | Longest combination of luffing boom + luffing jib offered for each specified suspension.   | 13                    | (Y) RL at minimum RR  | (Z) 1.25 RL or tipping load, whichever is less. Orient upper structure over a corner.   | Integrity of luffing boom, luffing jib, and suspension.                             | —  | —   | —   | Y,Z   | Y,Z    | Y,Z |
|      |  | 14                    | and SL (0.02 x RL) both left and right, upper structure over a corner.                  |   |   |  |   |   |   |        |     |
|      |  | 15                    |   |   |   |  |   |   |   |        |     |
|      |  | 16                    |   |   |   |  |   |   |   |        |     |
| H    | Max (luffing jib RL x L <sub>JL</sub> x sinβ). Use longest luffing jib where this condition exists. Then select longest luffing boom for the above conditions.                     | 11                    | (Y) RL at max RR and SL (0.02 x 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 luffing boom under condition of max torsion.                           | —  | —   | Y,Z   | —   | —      | —   |
|      |  | 13                    |   |   |   |  |   |   |   |        |     |
|      |  | 14                    |   |   |   |  |   |   |   |        |     |
|      |  | 15                    |   |   |   |  |   |   |   |        |     |
|      |  | 16                    |   |   |   |  |   |   |   |        |     |
|      |  | 18                    |   |   |   |  |   |   |   |        |     |
| I    | <b>Fixed Jib Test</b><br>Longest combination of luffing boom, luffing jib, and fixed jib(s) for each specified suspension with min. fixed jib offset.                              | 4                     | (X) Suspend boom and jib(s) just clear of ground.                                       | None  | Integrity of luffing boom, luffing jib, fixed jib, upper structure, and suspension. | —  | X   | —   | X   | —      | X   |
|      |  | 10                    |   |   |   |  |   |   |   |        |     |
|      |  | 11                    |   |   |   |  |   |   |   |        |     |
|      |  | 16                    |   |   |   |  |   |   |   |        |     |
| J    | <b>Fixed Jib Test</b><br>Longest combination of luffing boom, luffing jib, and fixed jib(s) for each specified suspension with min. fixed jib offset.                              | 10                    | (Y) RL at min RR and SL (0.02 x 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 luffing boom, luffing jib, and fixed jib.                              | —  | —   | Y,Z   | —   | —      | —   |
|      |  | 11                    |   |   |   |  |   |   |   |        |     |
|      |  | 13                    |   |   |   |  |   |   |   |        |     |
|      |  | 14                    |   |   |   |  |   |   |   |        |     |
|      |  | 15                    |   |   |   |  |   |   |   |        |     |
|      |  | 16                    |   |   |   |  |   |   |   |        |     |
| K    | <b>Fixed Jib Test</b><br>Max (fixed jib RL x F <sub>JL</sub> x sinβ). Use longest fixed jib where this condition exists. Then select longest luffing jib for the above conditions. | 11                    | (Y) RL at max RR and SL (0.02 x 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 luffing jib and fixed jib.   | —  | —   | Y,Z   | —   | —      | —   |
|      |  | 13                    |   |   |   |  |   |   |   |        |     |
|      |  | 14                    |   |   |   |  |   |   |   |        |     |
|      |  | 16                    |   |   |   |  |   |   |   |        |     |
| L    | <b>Midfall Test</b><br>Max numerical rated load at its longest rated radius. Use longest luffing jib rated with this load.   | 13                    | (Y) RL and SL (0.02 x 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 luffing jib, suspension, and midfall                                   | —  | —   | Y,Z   | —   | Y,Z    | Y,Z |
|      |  | 15                    |   |   |   |  |   |   |   |        |     |
|      |  | 16                    |   |   |   |  |   |   |   |        |     |

TABLE 1—LUFFING ATTACHMENT TYPE CRANE—TEST CONDITIONS

| Test | Test Conditions First Select   | Test Conditions Notes          | Test Conditions Then Apply Working Load  | Test Conditions Then Apply Overload   | Purpose is to test:                                | Tested   | Tested  | Tested  | Tested  |
|------|--|--------------------------------|--|---|--|--|---|---|---|
|      |  |                                |  |   |  | Components and Strength Margins** Under-carriage | Components and Strength Margins** Upper Structure | Components and Strength Margins** Boom and Jib(s) | Components and Strength Margins** Suspension (Except Ropes) |
| M    | <b>Midfall Test</b><br>Longest combination of luffing boom + luffing jib offered for each specified suspension.  | 2<br>9<br>12<br>13<br>15<br>16 | (Y) RL and SL (0.02 x 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 to any position.                 | Integrity of luffing jib, suspension, and midfall. | —  | —   | Y, Z  | Y, Z  |
| N    | <b>Midfall Test</b><br>Max (midfall RL x MFL x sinβ). Use longest fixed jib where this condition exists. Then select longest luffing jib for the above conditions. | 13<br>15<br>16                 | (Y) RL at max RR and SL (0.02 x 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 luffing jib, suspension, and midfall  | —  | —   | Y, Z  | Y, Z  |

- Position of the upper as defined by SAE J1028 or manufacturer's specification.
- Where this rated load is offered with the upperstructure counterweight in variable positions, testing shall be performed with this counterweight at the maximum specified distance to the centerline of rotation.
- Where this rated load is offered with the upperstructure counterweight in variable positions, testing shall be performed with this counterweight at the minimum specified distance to the centerline of rotation.
- Hook block, overhaul ball, or load line attachments resting on the ground.
- For carriers utilizing various boom configurations, only the configuration that produces the maximum moment conditions should be tested.
- For upperstructure utilizing various boom configurations, only the configuration that produces the maximum moment conditions should be tested.
- Use heaviest specified carrier auxiliary counterweight.
- If a choice of counterweights exists for the maximum moment condition, use the lightest specified counterweight for this condition.
- Use the heaviest specified upperstructure counterweight.
- Where more than one allowable boom and jib combination result in the same longest numerical value (i.e., 100 ft boom + 60 ft jib = 160 ft, also 120 ft boom + 40 ft jib = 160 ft), use the combination that includes the longest boom (i.e., 120 ft boom + 40 ft jib in this example).
- When two or more jibs are attached simultaneously to extend the length of the boom, each system should be tested as a separate rigging. (Apply SAE J987 to luffing boom + jib(A) and then apply SAE J987 to luffing boom + jib(B).
- For upperstructures utilizing various boom configurations, only the configuration that produces the maximum load condition should be tested.
- In no instance shall the wind be utilized to favorably influence the outcome of the test.
- Note the direction of tip deflection due to suspending the load directly over an end. Swing the upperstructure in the same direction to the nearest corner for testing.
- Use manufacturer's specified reeving with minimum specified parts of load hoist line and with hoist line leaving the drum from an arbitrary position.
- Where several booms with significant structural or geometrical differences are utilized on the same upperstructure, each boom shall be tested.
- Tests C and D can be eliminated if machine has been tested to a greater RR x RL with another attachment and has also been tested to a greater thrust with another attachment.
- When the luffing jib point cannot be lifted from the ground with the luffing boom point just clear of the ground, two positions are required for testing.
  - Luffing boom just clear of the ground - luffing jib point on the ground.
  - Luffing boom point at the minimum boom angle that will allow erection of the luffing jib - luffing jib point just clear of the ground.

\*\* X = Erection Loads, Y = Rated Loads, Z = Over Loads

TABLE 2—CONVENTIONAL TYPE CRANE-TEST CONDITIONS

| Test | Test Conditions First Select   | Test Conditions Notes | Test Conditions Then Apply Working Load   | Test Conditions Then Apply Overload  | Purpose is to Test                                     | Tested Components and Strength Margins** |                 | Tested Components and Strength Margins** |              | Tested Components Strength Margins** Suspension (Except Ropes) |  |   |   |  |  |     |   |   |   |
|------|--|-----------------------|---|--|--|--|-----------------|--|--------------|--|--|---|---|--|--|-----|---|---|---|
|      |  |                       |   |  |  | Under-Carriage                           | Upper-Structure | Boom and Jib                             | Boom and Jib |  |  |   |   |  |  |     |   |   |   |
| A    | Max numerical rated load at its longest rated radius. Use longest boom rated with this load.   | 2                     | (Y) RL with upperstructure in any position.   | (Z) 1.25 RL or tipping load, whichever is less.  | Integrity of boom and upperstructure                   | —  | Y,Z             | Y,Z                                      | —            |  |  |   |   |  |  |     |   |   |   |
|      |  |                       |   |  |  |  |                 |  |              | 9  |  |   |   |  |  |     |   |   |   |
|      |  |                       |   |  |  |  |                 |  |              | 16   |  |   |   |  |  |     |   |   |   |
| B    | Max (RR x RL) with largest rated load allowed at this load moment.                             | 3                     | (Y) RL and SL (0.02 x RL) both left and right. Orient upperstructure to any position.                   | (Z) 1.25 RL or tipping load, whichever is less. Orient upperstructure to any position. | Upperstructure and suspension for maximum load moment. | —  | Y,Z             | —  | Y,Z          |  |  |   |   |  |  |     |   |   |   |
|      |  |                       |   |  |  |  |                 |  |              | 6  |  |   |   |  |  |     |   |   |   |
|      |  |                       |   |  |  |  |                 |  |              | 8  |  |   |   |  |  |     |   |   |   |
|      |  |                       |   |  |  |  |                 |  |              | 12   |  |   |   |  |  |     |   |   |   |
|      |  |                       |   |  |  |  |                 |  |              | 17   |  |   |   |  |  |     |   |   |   |
| C    | Max (RR x RL) over side, with largest rated load allowed at this load moment.                  | 1                     | (Y) RL and position upperstructure in allowed rotation range to obtain maximum strain in member tested. | (Z) 1.25 RL or tipping load, whichever is less. Orient upperstructure to any position. | Undercarriage for maximum load moment.                 | Y,Z                                      | —               | —  | —            |  |  |   |   |  |  |     |   |   |   |
|      |  |                       |   |  |  |  |                 |  |              | 3  |  |   |   |  |  |     |   |   |   |
|      |  |                       |   |  |  |  |                 |  |              | 5  |  |   |   |  |  |     |   |   |   |
|      |  |                       |   |  |  |  |                 |  |              | 6  |  |   |   |  |  |     |   |   |   |
|      |  |                       |   |  |  |  |                 |  |              | 7  |  |   |   |  |  |     |   |   |   |
|      |  |                       |   |  |  |  |                 |  |              | 8  |  |   |   |  |  |     |   |   |   |
|      |  |                       |   |  |  |  |                 |  |              | 12   |  |   |   |  |  |     |   |   |   |
|      |  |                       |   |  |  |  |                 |  |              | 17   |  |   |   |  |  |     |   |   |   |
|      |  |                       |   |  |  |  |                 |  |              | D  | Max (RR x RL) over end, with largest rated load allowed at this load moment. | 1 | (Y) RL and position upperstructure in allowed rotation range to obtain maximum strain in member tested. | (Z) 1.25 RL or tipping load, whichever is less. Orient upperstructure to any position. | Undercarriage for maximum load moment. | Y,Z | — | — | — |
|      |  |                       |   |  |  |  |                 |  |              |  |  |   |   |  |  |     |   |   |   |
| 5    |  |                       |   |  |  |  |                 |  |              |  |  |   |   |  |  |     |   |   |   |
| 6    |  |                       |   |  |  |  |                 |  |              |  |  |   |   |  |  |     |   |   |   |
| 7    |  |                       |   |  |  |  |                 |  |              |  |  |   |   |  |  |     |   |   |   |
| 8    |  |                       |   |  |  |  |                 |  |              |  |  |   |   |  |  |     |   |   |   |
| 12   |  |                       |   |  |  |  |                 |  |              |  |  |   |   |  |  |     |   |   |   |
| 17   |  |                       |   |  |  |  |                 |  |              |  |  |   |   |  |  |     |   |   |   |
| E    | Rated radius which produces max (RR x RL). Use longest boom which has a rating at this radius. | 6                     | (Y) RL and SL (0.02 x RL) both left and right, upperstructure over a corner.                            | (Z) 1.25 RL or tipping load, whichever is less. Orient upperstructure over a corner.   | Integrity of boom and suspension.                      | —  | —               | Y,Z                                      | Y,Z          |  |  |   |   |  |  |     |   |   |   |
|      |  |                       |   |  |  |  |                 |  |              | 13   |  |   |   |  |  |     |   |   |   |
|      |  |                       |   |  |  |  |                 |  |              | 14   |  |   |   |  |  |     |   |   |   |
|      |  |                       |   |  |  |  |                 |  |              | 15   |  |   |   |  |  |     |   |   |   |
|      |  |                       |   |  |  |  |                 |  |              | 16   |  |   |   |  |  |     |   |   |   |
|      |  |                       |   |  |  |  |                 |  |              | 17   |  |   |   |  |  |     |   |   |   |
|      |  |                       |   |  |  |  |                 |  |              | 4  |  |   |   |  |  |     |   |   |   |
| F    | Longest boom offered for each specified suspension.  | 4                     | (X) Suspend boom just clear of ground.  | None   | Integrity of boom and suspension.                      | —  | —               | X  | X            |  |  |   |   |  |  |     |   |   |   |
|      |  |                       |   |  |  |  |                 |  |              | 16   |  |   |   |  |  |     |   |   |   |

TABLE 2—CONVENTIONAL TYPE CRANE-TEST CONDITIONS (CONTINUED)

| Test | Test Conditions First Select   | Test Conditions Notes | Test Conditions Then Apply Working Load  | Test Conditions Then Apply Overload  | Purpose is to Test                                      | Tested   |   |  | Tested Components Strength Margins** Suspension (Except Ropes) |
|------|--|-----------------------|--|--|---|--|---|--|--|
|      |  |                       |  |  |   | Components and Strength Margins** Under-Carriage | Components and Strength Margins** Upper-Structure | Components and Strength Margins** Boom and Jib |  |
| G    | Longest boom offered for each specified suspension.  | 13                    | (Y) RL at minimum RR and SL (0.02 x RL) both left and right, upperstructure over a corner. | (Z) 1.25 RL or tipping load, whichever is less. Orient upperstructure over a corner. | Integrity of boom and suspension.                       | —  | —   | Y,Z  | Y,Z  |
|      | Longest allowable combination of boom and jib(s) for each specified suspension with min. jib offset. | 4                     | (X) Suspend boom and jib(s) just clear of ground.  | None   | Integrity of boom, jib, upperstructure, and suspension. | —  | X   | —  | X  |
|      |  | 10                    | (Y) RL at min RR and SL (0.02 x RL) both left and right, upperstructure over a corner.     | (Z) 1.25 RL or tipping load, whichever is less. Orient upperstructure over a corner. | Integrity of boom and jib.                              | —  | —   | —  | —  |
|      |  | 11                    | (Y) RL at max RR and SL (0.02 x RL) both left and right, upperstructure over a corner.     | (Z) 1.25 RL or tipping load, whichever is less. Orient upperstructure over a corner. | Integrity of boom and jib.                              | —  | —   | Y,Z  | —  |
| I    | Longest allowable combination of boom and jib(s) for each specified suspension with min. jib offset. | 10                    | (Y) RL at min RR and SL (0.02 x RL) both left and right, upperstructure over a corner.     | (Z) 1.25 RL or tipping load, whichever is less. Orient upperstructure over a corner. | Integrity of boom and jib.                              | —  | —   | —  | —  |
|      | Longest allowable combination of boom and jib(s) for each specified suspension with min. jib offset. | 11                    | (Y) RL at min RR and SL (0.02 x RL) both left and right, upperstructure over a corner.     | (Z) 1.25 RL or tipping load, whichever is less. Orient upperstructure over a corner. | Integrity of boom and jib.                              | —  | —   | —  | —  |
|      |  | 13                    | (Y) RL at max RR and SL (0.02 x RL) both left and right, upperstructure over a corner.     | (Z) 1.25 RL or tipping load, whichever is less. Orient upperstructure over a corner. | Integrity of boom and jib.                              | —  | —   | —  | —  |
|      |  | 14                    | (Y) RL at max RR and SL (0.02 x RL) both left and right, upperstructure over a corner.     | (Z) 1.25 RL or tipping load, whichever is less. Orient upperstructure over a corner. | Integrity of boom and jib.                              | —  | —   | Y,Z  | —  |
| J    | Max (jib RL x JL x sin $\beta$ ).  | 11                    | (Y) RL at min RR and SL (0.02 x RL) both left and right, upperstructure over a corner.     | (Z) 1.25 RL or tipping load, whichever is less. Orient upperstructure over a corner. | Integrity of boom and jib.                              | —  | —   | —  | —  |
|      | Use longest jib where this condition exists.   | 13                    | (Y) RL at max RR and SL (0.02 x RL) both left and right, upperstructure over a corner.     | (Z) 1.25 RL or tipping load, whichever is less. Orient upperstructure over a corner. | Integrity of boom and jib.                              | —  | —   | —  | —  |
|      | Then select longest boom for the above conditions.   | 15                    | (Y) RL at max RR and SL (0.02 x RL) both left and right, upperstructure over a corner.     | (Z) 1.25 RL or tipping load, whichever is less. Orient upperstructure over a corner. | Integrity of boom and jib.                              | —  | —   | —  | —  |

SAE J987 - 200306

TABLE 2—CONVENTIONAL TYPE CRANE-TEST CONDITIONS (CONTINUED)

| Test | Test Conditions First Select   | Test Conditions Notes | Test Conditions Then Apply Working Load | Test Conditions Then Apply Overload | Purpose is to Test | Tested   | Tested  | Tested   | Tested  |
|------|--|-----------------------|---|-------------------------------------|--------------------|--|---|--|---|
|      |  |                       |   |                                     |                    | Components and Strength Margins** Under-Carriage | Components and Strength Margins** Upper-Structure | Components and Strength Margins** Boom and Jib | Components and Strength Margins** Suspension (Except Ropes) |
| 1.   | Position of the upper as defined by SAE J1028 or manufacturer's specification.   |                       |   |                                     |                    |  |   |  |   |
| 2.   | Where this rated load is offered with the upperstructure counterweight in variable positions, testing shall be performed with this counterweight at the maximum specified distance to the centerline of rotation.  |                       |   |                                     |                    |  |   |  |   |
| 3.   | Where this rated load is offered with the upperstructure counterweight in variable positions, testing shall be performed with this counterweight at the minimum specified distance to the centerline of rotation.  |                       |   |                                     |                    |  |   |  |   |
| 4.   | Hook block, overhaul ball, or load line attachments resting on the ground.   |                       |   |                                     |                    |  |   |  |   |
| 5.   | For carriers utilizing various boom and/or upperstructure configurations, only the configuration that produces the maximum moment condition should be tested.  |                       |   |                                     |                    |  |   |  |   |
| 6.   | For upperstructure utilizing various boom configurations, only the configuration that produces the maximum moment conditions should be tested.   |                       |   |                                     |                    |  |   |  |   |
| 7.   | Use heaviest specified carrier auxiliary counterweight.  |                       |   |                                     |                    |  |   |  |   |
| 8.   | If a choice of counterweights exists for the maximum moment condition, use the lightest specified counterweight for this condition.  |                       |   |                                     |                    |  |   |  |   |
| 9.   | Use the heaviest specified upperstructure counterweight.   |                       |   |                                     |                    |  |   |  |   |
| 10.  | Where more than one allowable boom and jib combination result in the same longest numerical value (i.e., 100 ft boom + 60 ft jib = 160 ft, and also 120 ft boom + 40 ft jib = 160 ft), use the combination that includes the longest boom (i.e., 120 ft boom + 40 ft jib in this example.) |                       |   |                                     |                    |  |   |  |   |
| 11.  | When two or more jibs are attached simultaneously to extend the length of the boom, each system should be tested as a separate rigging. (Apply SAE J987 to boom + jib(A) and then apply SAE J987 to boom + jib(A) + jib(B).)   |                       |   |                                     |                    |  |   |  |   |
| 12.  | For upper structures utilizing various boom configurations, only the configuration that produces the maximum load condition should be tested.  |                       |   |                                     |                    |  |   |  |   |
| 13.  | In no instance shall the wind be utilized to favorably influence the outcome of the test.  |                       |   |                                     |                    |  |   |  |   |
| 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.   |                       |   |                                     |                    |  |   |  |   |
| 15.  | Use manufacturer's specified reeving the minimum specified parts of load hoist line and with hoist line leaving the drum from an arbitrary position.   |                       |   |                                     |                    |  |   |  |   |
| 16.  | Where several booms with significant structural or geometrical differences are utilized on the same upperstructure, each boom shall be tested.   |                       |   |                                     |                    |  |   |  |   |
| 17.  | Tests C and D can be eliminated if machine has been tested to a greater RR x RL with another attachment and has also been tested to a greater thrust with another attachment.  |                       |   |                                     |                    |  |   |  |   |

\*\* X = Erection Loads, Y = Rated Loads, Z = Over Loads

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

5. **Method of Testing**

5.1 **Suspended Load**—The specified load suspended at the specified radius and held stationary a short distance off the ground.

NOTE—The weight of the hook, block, slings, etc., shall be included as part of the specified suspended load.

5.1.1 RATED LOAD (RL)—The rated load is any load rating as specified by the manufacturer's applicable capacity chart.

5.1.2 RATED RADIUS (RR)—The rated radius is any radius as specified by the manufacturer's applicable capacity chart.

5.2 **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 upperstructure rotation and the centerline of the undeflected boom. The side load shall be in each direction.

NOTE— Side loading is applied to simulate the various effects associated with machine operation including a 20 mph wind loading that may be encountered.

5.3 **Deadman Load**—Deadman loading may be used, but caution must be exercised to assure accurate simulation of live load testing. as Positioning with this system is difficult, deadman loading is not acceptable for Tests from Tables 1 and 2 which require side load.

6. **Facilities, Apparatus, and Material**

6.1 A concrete or other firm supporting surface, sufficiently large to provide for unobstructed accomplishment of the tests required.

6.2 Means to measure levelness of the axis of the boom foot; accuracy 0.1% of grade.

6.3 Means for determining the load radius to an accuracy of  $\pm 1\%$ , not to exceed 0.15 m (6 in).

6.4 Means for producing transverse displacement of the suspended load and means for measuring the magnitude of the displacing force; accuracy  $\pm 3\%$  of measured force.

6.5 Temperature compensated strain gages, cement, waterproofing compounds, and other necessary gage installment equipment. Gages must conform with ASTM E 251-67.

6.6 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  $\pm 2\%$  of the reading over the range of 500 to 3000  $\mu\text{m/m}$  strain (determined in suitable increments). Calibration may be accomplished by electrical shunts or by precalibrated strain bar.

6.7 Test weights and lifting apparatus of known weights accurate to within  $\pm 1\%$ .

6.8 Means for measuring side deflection of the boom and jib within 0.05 m (2 in).

**7. Preparations for Test**

- 7.1 An analysis of each structure sufficient to locate highly stressed areas shall be made. The strain gage location and direction shall be determined from this analysis as well as from the use of other experimental techniques where necessary.
- 7.2 Perform a detailed inspection of crane to insure 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.
- 7.3 A previously unworked crane should be given a "break-in" run at or near each anticipated test loading to mechanically relieve residual stresses that may have developed during manufacture and to minimize the possibility of "gage zero shift" during the test.
- 7.4 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.
- 7.5 Bond strain gages at the points determined by prior analysis (see 7.1) and any areas selected as a result of the inspection conducted in 7.4. Only competent personnel using proven materials and practices may be employed to insure that all gages are of the correct type, properly oriented, and securely bonded to measure strains correctly.
- 7.6 Determine minimum yield strength and the modulus of elasticity for the material at each gage location by referring to the material certifications, if available, applicable standards, or Appendix B. Determine critical buckling stress when applicable (see Appendix C).

**8. Test Procedure and Records**

- 8.1 Service and adjust the crane to assure specified conditions of lubrication; fuel supply, coolant supply, tire inflation; track tension; bolts, pins, rope fittings, and other load-bearing components; clutches, brakes, and other power-transmission components. At all times during testing, the crane shall be set up and operated in conformance with the manufacturers' specifications.
- 8.2 Locate the machine on the test course.
- 8.3 Connect strain measuring system and calibrate gages and instruments (see 6.6). Correct any malfunctions.
- 8.4 If the assembled crane is to be used as the initial reference test condition (see 3.5, item a), obtain these readings. If the unassembled components are to be used as the initial reference test condition (see 3.5, item b), obtain these readings. Reassemble the crane and make all mechanical adjustments.
- 8.5 Level the crane so that the boom foot axis is within 0.25% of grade in the unloaded condition. This shall be done directly over an end and over a side of the lower structure. Do not relevel during any specific test condition.
- 8.6 Set the revolving upperstructure to the specified position relative to the lower structure. Lock swing brake or latch.
- 8.7 Prepare a test load that together with the hook, block, slings, etc., weighs within  $\pm 1\%$  of the specified load.
- 8.8 Lift the specified load and set boom angle to develop specified radius. As the test load is lifted from the ground, the overall operation should be observed for any indications of problems before proceeding.

**8.9** Set the load on the ground. Do not change the boom angle. Read required strain gages for dead load stress condition (see 3.6). Compute the dead load stress ( $S_1$ ) for each required gage (see 3.7) and record data. At this time, zero the means for measuring side deflection of the boom and/or jib(s) tip(s).

NOTE—A new dead load stress condition is established each time the position, attitude, or configuration is changed to suit specified tests and operations; therefore, 8.5 through 8.9 must be repeated for each new condition.

**8.10** Suspend the test load (see 5.1) and apply side load (see 5.2) as required by specifications.

**8.11** Read required strain gages for working load stress condition (see 3.8). Compute the working load stresses ( $S_2$ ) for each required gage (see 3.9) and record the test data. Measure and record tip side deflection due to suspended load and side load.

**8.12** Release side load and lower suspended load, returning crane to dead load condition (see 8.9). Read required strain gages and compare with reading taken under 8.9. If the deviation for any gage exceeds  $\pm 0.03 S_y/E$ , determine cause, correct and repeat all procedures until consistent readings are obtained.

**8.13** Compute resultant stress ( $S_r$ ) per 3.10, for combined dead load (see 3.6) and working load stresses (see 3.9) and record.

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

**8.15** Record all pertinent data regarding the test equipment, crane being tested, results, and observations. Suggested forms are presented in Appendix E.

**9. Stress and Deflection Criteria**

**9.1 Stress Criteria**—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 may be classed as follows (see Table 3 or 9.1.1, 9.1.2, and 9.1.3 for minimum strength margins).

**TABLE 3—MINIMUM STRENGTH MARGINS**

|                      | Class I          | Class II         | Class III        | Class IV       |
|----------------------|------------------|------------------|------------------|----------------|
| X (erection loading) | 1.30             | 1.00             | 1.40             | Refer to 9.1.4 |
| Y (rated loads)      | 1.50             | 1.10             | 1.60             | Refer to 9.1.4 |
| Z (overloads)        | Observation Only | Observation Only | Observation Only | Refer to 9.1.4 |

**9.1.1 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:

$$n_1 = S_y/S_r \text{ or } S_y/S' \text{ (refer to Appendix B for } S') \tag{Eq. 2}$$

$$n_1 \geq 1.50 \text{ (for rated loads)}$$

$$n_1 \geq 1.30 \text{ for erection loadings}$$

- 9.1.2 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:

$$n_2 = S_y/S_r \text{ or } S_y/(S') \text{ (refer to Appendix B for } S') \quad (\text{Eq. 3})$$

$$n_2 \geq 1.10 \text{ for rated loads}$$

$$n_2 \geq 1.00 \text{ for erection loadings}$$

- 9.1.3 CLASS III—COLUMN BUCKLING STRESS AREAS—Areas in which failure may 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, boom chords, or lattice, which require consideration as columns. Strength margin:

$$n_3 = \frac{1}{\frac{S_{ra}}{S_{cr}} + \frac{S_{rm} - S_{ra}}{S_y}} \text{ (Refer to Appendix C)} \quad (\text{Eq. 4})$$

$$n_3 \geq 1.60$$

$$n_3 \geq 1.40 \text{ for erection loadings}$$

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.

- 9.1.4 CLASS IV—LOCAL PLATE BUCKLING AREAS—Plates, when subjected to direct compression, bending, and/or shear in their plane, may buckle locally before the member as a whole becomes unstable. Local buckling is associated with wrinkling (initial buckling), which permits the member to redistribute loadings to stiffer edges. As loading is further increased, the stress in Class IV areas (see Figure 1) does not necessarily increase in proportion to the load; however, considerable post buckling strength may remain. Requirements are that Class IV gages return to the dead load readings (see 8.12) for all test conditions, including overload.

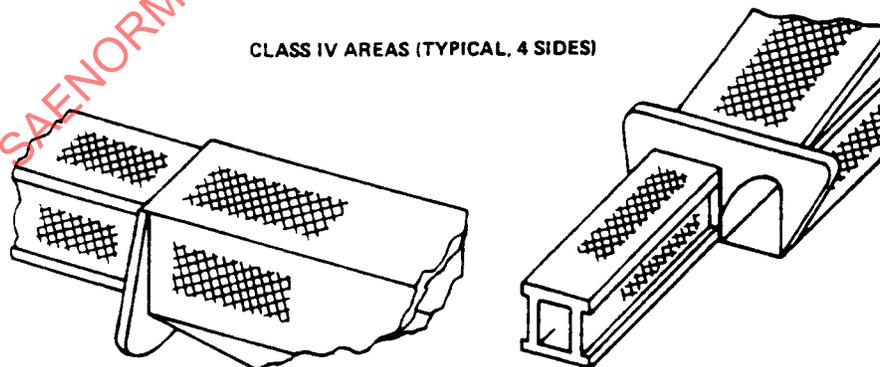


FIGURE 1—LOCAL PLATE BUCKLING AREAS

**9.2 Side Load and Deflection Criteria**—The usability of a latticed column (i.e., crane boom or boom and jib(s) combination) is sometimes affected by the elastic stability of the overall column as well as the individual members. Incipient out of plane elastic instability is indicated by excessive boom and/or jib point deflection (sideways) as the boom or jib(s) is side loaded when suspending rated load. The following lateral deflection limits are therefore imposed.

9.2.1 For conventional boom and jib combinations, the side load percentage that is to be applied in each direction at the load attachment point is to be a minimum of 2% of the rated load.

9.2.2 For conventional boom and jib combinations, the lateral deflection criteria for rated load and side load of Table 1 are as follows:

First, the deflection of the total boom combination shall be less than or equal to 2% of the total combination length.

Furthermore, the deflection of each individual boom or 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 jib mounted on a boom, the following relationship is given (see Figure 2):

$$Z_j \leq 0.02 L_j + Z_b + Z'(L_j \cos \beta) + \theta(L_j \sin \beta) \quad (\text{Eq. 5})$$

The following values are measured.

$Z_j$  = Jib Point Deflection

$Z_b$  = Boom Point Deflection

$Z_1$  = Boom Deflection at a Distance  $L_1$  Down From the Boom Point

$Z_2$  = Jib Strut Deflection at the Tip

The following values are calculated:

a. Slope:

$$Z' = (Z_b - Z_1)/(L_1) \quad (\text{Eq. 6})$$

b. Rotation:

$$\text{Theta} = (Z_b - Z_2)/(L_2) \quad (\text{Eq. 7})$$

If slope ( $Z'$ ) and torsion ( $\theta$ ) are not measured, the last two terms of Equation 7 may be deleted. Both of the previous criteria correspond to those set forth in the boom calculation practice SAE J1093.

9.2.3 For luffing attachment combinations, the side load percentage that is to be applied in each direction at the load attachment point is to be a minimum of 2% of the rated load.

9.2.4 For luffing attachment combinations, no deflection limitations have been established.

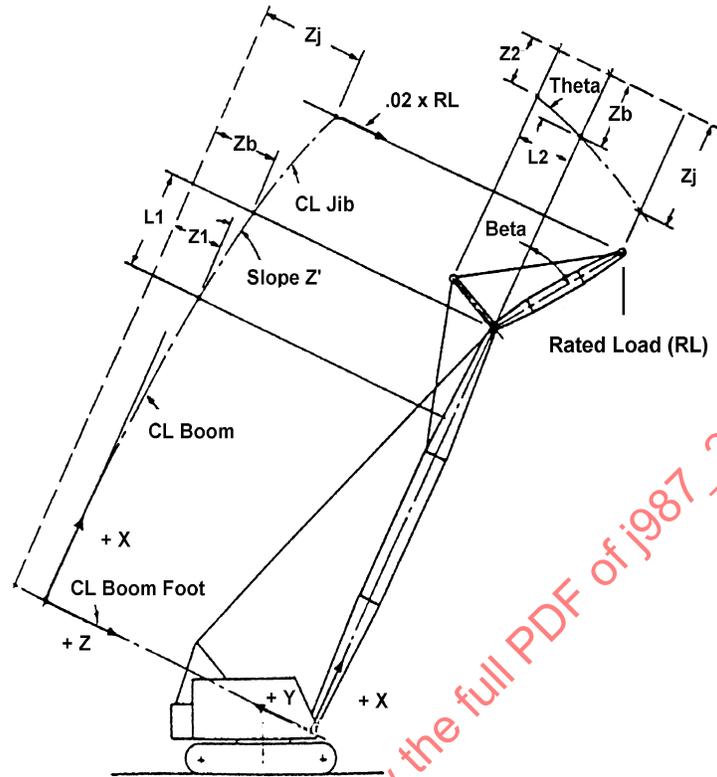


FIGURE 2—DEFLECTION MEASUREMENT RELATED TERMS LATTICE BOOM WITH JIB

10. Notes

10.1 **Marginal Indicia**—The change bar (l) located in the left margin is for the convenience of the user in locating areas where revisions have been made to the previous issue of the report. An (R) symbol to the left of the document title indicates a complete revision of the report.

PREPARED BY THE SAE OFF-ROAD MACHINERY TECHNICAL COMMITTEE SC31—  
CRANES AND LIFTING DEVICES

## APPENDIX A

## NOMENCLATURE

|            |   |   |
|------------|---|---|
| E          | = | Modulus of elasticity (3.2)   |
| G          | = | Modulus of shear (Appendix B)   |
| K          | = | Effective length factor for a column (Appendix C)                     |
| L          | = | Un-braced length of column (Appendix C)                               |
| $L_b$      | = | Length of boom (9.2 Figure A1)  |
| $L_j$      | = | Length of jib (9.2; Figure A1)  |
| $l_1$      | = | Small arbitrary projected length of boom along x-axis                 |
| $l_2$      | = | Projected length of jib strut along y-axis                            |
| n          | = | Strength margin (9.1.1, 9.1.2, and 9.1.3)                             |
| $N_1$      | = | Strain reading at initial reference test condition (4.5)              |
| $N_2$      | = | Strain reading at dead load stress condition (4.6)                    |
| $N_3$      | = | Strain reading at working load stress condition (4.8)                 |
| r          | = | Radius of gyration (Appendix C)                                       |
| $R_L$      | = | Rated load as specified by manufacturer (5.1.1)                       |
| "R"        | = | Plane perpendicular to boom foot pin $C_L$ (9.2; Figure A1)           |
| RR         | = | Rated radius as specified by manufacturer (5.1.2)                     |
| S          | = | Stress (4.2)  |
| $S_1$      | = | Dead load stress  |
| $S_2$      | = | Working load stress (4.9)   |
| $S_{ra}$   | = | Average stress at a cross section (4.10.1; Appendix C)                |
| $S_{cr}$   | = | Critical buckling stress for axially loaded columns (4.4; Appendix C) |
| $S_L$      | = | Side load, i.e., $0.02 \times RL$ (5.2 and 8.10)                      |
| $S_{rm}$   | = | Maximum compression stress in a column (4.10.2; Appendix C)           |
| $S_p$      | = | Stress at the proportional limit (Appendix C)                         |
| $S_r$      | = | Resultant Stress (4.10)   |
| $S_{re}$   | = | Maximum compressive residual stress (Appendix C)                      |
| $S_y$      | = | Stress at the yield point (4.3)                                       |
| $S'$       | = | Equivalent uniaxial stress (9.1.1 and 9.1.2; Appendix B)              |
| $Z'$       | = | Boom tip slope (out of plane) (9.2; Figure A1)                        |
| $Z_b$      | = | Boom point deflection from plane "R" (9.2; Figure A1)                 |
| $Z_j$      | = | Jib point deflection from plane "R" (9.2; Figure A1)                  |
| $Z_1$      | = | Boom deflection at a point $l_1$ back from the boom tip               |
| $Z_2$      | = | Jib strut deflection at its tip                                       |
| $\beta$    | = | Jib offset angle from $C_L$ boom (9.2; Figure A1)                     |
| $\epsilon$ | = | Strain (4.2)  |
| $\epsilon$ | = | Maximum principal strain (Appendix B)                                 |
| $\epsilon$ | = | Minimum principal strain (Appendix B)                                 |
| $\sigma_0$ | = | Tensile yield stress (Appendix B)                                     |
| $\sigma_x$ | = | Maximum principal stress (Appendix B)                                 |
| $\sigma_y$ | = | Minimum principal stress (Appendix B)                                 |
| $\theta$   | = | Boom point rotation about x axis (radians) (9.2; Figure A1)           |
| $\pi$      | = | Pi = 3.1416 (Appendix B)  |
| $\tau_0$   | = | Shear yield stress (Appendix B)                                       |
| $\nu$      | = | Poisson's ratio (Appendix B)  |

## APPENDIX B

## STRENGTH OF MATERIALS

**B.1** In biaxial stress fields, there may be some error if the uniaxial stress given by  $S = E \cdot \epsilon$  3.2 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.

Triaxial stresses are not considered here because the third direction cannot be measured with a strain gage.

**B.2 Brittle Materials**—The use of  $S = E \cdot \epsilon_x$  (when  $\epsilon_x$  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.

**B.3 Ductile Materials**—The distortion energy theory of failure (see 2.1.4) 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 ( $S_y$ , see 3.3) to establish the strength margin against failure. The equivalent stress is shown in Equation B1:

$$S' = \sqrt{\sigma_x^2 - \sigma_x \sigma_y + \sigma_y^2} \quad (\text{Eq. B1})$$

where:

$\sigma_x$  = maximum principal stress

$\sigma_y$  = minimum principal stress

Principal stresses are obtained from strain gage readings by Equations B2 and B3:

$$\sigma_x = E(\epsilon_x + \nu \epsilon_y) / (1 - \nu^2) \quad (\text{Eq. B2})$$

$$\sigma_y = E(\epsilon_y + \nu \epsilon_x) / (1 - \nu^2) \quad (\text{Eq. B3})$$

where:

$E$  = modulus of elasticity

$\epsilon_x$  = maximum principal strain

$\epsilon_y$  = minimum principal strain

$\nu$  = Poisson's ratio

Principal strains are obtained by interpreting rosette gage readings on Mohr's circle or other convenient means. Equivalent stress  $S'$  may also be calculated from principal strains shown in Equation B4:

$$S' = E \sqrt{(1 - \nu)^2 (\epsilon_x - \epsilon_y)^2 + (\epsilon_x + \nu \epsilon_y)(\epsilon_y + \nu \epsilon_x) / (1 - \nu^2)} \quad (\text{Eq. B4})$$

**B.4 Ductile Material Approximate Method**—In most ductile material biaxial fields, the assumption that the equivalent stress  $S'$  equals  $E \epsilon_x$  will be accurate within 10%. The main factors affecting the accuracy are:

- a. The ratio of minimum to maximum principal stress,  $\sigma_y / \sigma_x$
- b. The ratio of shear yield to tensile yield,  $\tau_o / \sigma_o$

Figure B1 shows the magnitude of accuracy variance with respect to these two ratios, using Poisson's ratio  $\nu = 0.285$ . 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 may be 0 to 30% depending on the ratio  $\tau_o / \sigma_o$ .

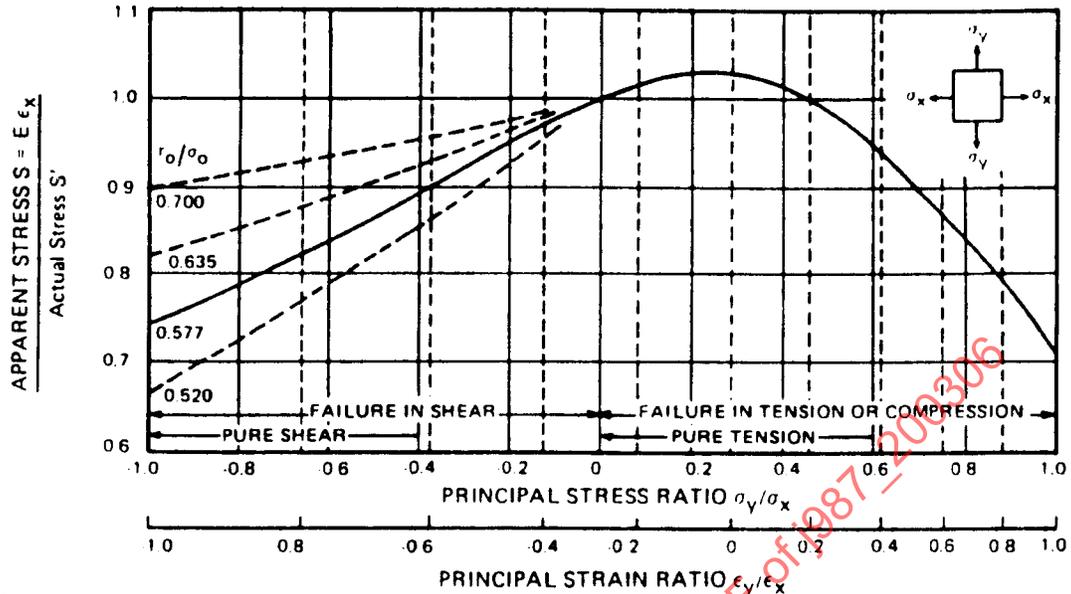


FIGURE B1—RATIO OF APPARENT STRESS TO ACTUAL STRESS VERSUS BIAxIAL STRESS RATIO

The solid curve line in Figure B1 is based on the distortion energy theory of failure as compared to  $S = E \cdot \epsilon_x$ . Distortion energy theory, while most generally correct, will check with the torsion yield test (pure shear) only if  $\tau_o/\sigma_o = 0.577$ . For materials in which  $\tau_o/\sigma_o$  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 gage and  $S = E \cdot \epsilon_x$  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.

Recommended values to be used in calculating stress from measured strain are listed in Table B1.

TABLE B1—ELASTIC PROPERTIES OF MATERIAL

|                             | Modulus of Elasticity (E)<br>(Young's) <sup>(1)</sup><br>(10 <sup>6</sup> psi) | Modulus of Rigidity<br>(G) (Shear) <sup>(1)</sup><br>(10 <sup>6</sup> psi) | Poisson's Ratio |
|-----------------------------|--|--|-----------------|
| Steel                       |  |  |                 |
| Carbon and alloy structural | 30   | 11.5   | 0.285           |
| Cast                        | 30   | 11.2   | 0.265           |
| Stainless                   | 20/28  |  | 0.305           |
| Gray Iron                   |  |  |                 |
| Class 20                    | 9.6/14.0   |  |                 |
| Class 60                    | 20.4/23.5  |  |                 |
| Malleable Iron              | 25   | 11   | 0.271           |
| Nodular Iron                | 24   | 10   |                 |
| Aluminum, structural        | 10.5   | 4  | 0.333           |
| Magnesium, structural       | 6.5  |  |                 |
| Titanium, structural        | 13/16  |  |                 |

1. The modulus of elasticity generally is quoted as a range; the figures listed are towards the high end of the range for conservatism. The modulus of elasticity of some materials varies widely 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.

## APPENDIX C

## COLUMN BUCKLING STRESS

**C.1** At stress levels below the proportional limit, axially loaded columns buckle elastically. (See Equation C1):

$$S_p \geq S_{cr} = \frac{\pi^2 E}{(KL/r)^2} \quad (\text{Eq. C1})$$

At stress levels above the proportional limit, axially loaded columns buckle inelastically (See Equation C2):

$$S_p < S_{cr} = S_y - \frac{S_p(S_y - S_p)(KL/r)^2}{\pi^2 E} \quad (\text{Eq. C2})$$

The proportional limit is defined by Equation C3:

$$S_p = S_y - S_{RC} \quad (\text{Eq. C3})$$

where:

SRC = maximum residual stress in compression

A value of  $S_{RC} = 15\,000$  psi may be assumed in lieu of specific residual stress information on the following steel materials:

- Hot finished shapes in the as-rolled condition
- Quenched and tempered shapes with stress relief heat treatment
- Cold-drawn shapes with stress relief heat treatment
- Fabricated welded shapes with stress relief heat treatment

On other steel materials a value of  $S_{RC} = 0.5 S_y$  may be assumed in lieu of specific residual stress information. Equations C1 and C2 are plotted in Figure C1 for four grades of steel with  $S_{RC} = 15\,000$  psi and also with  $S_{RC} = 0.5 S_y$ . The end restraint factor, K, can be calculated by methods outlined in another report, article 2.6 (see 2.1.3).

The following values may be used in lieu of calculation:

- For chord members—K = 1.00
- For lacing members with full section connection to tubular chords—K = 0.75
- For lacing members with full section connection to angle or tee chords—K = 0.90
- For lacing members with reduced section connection to chord—K = 1.00

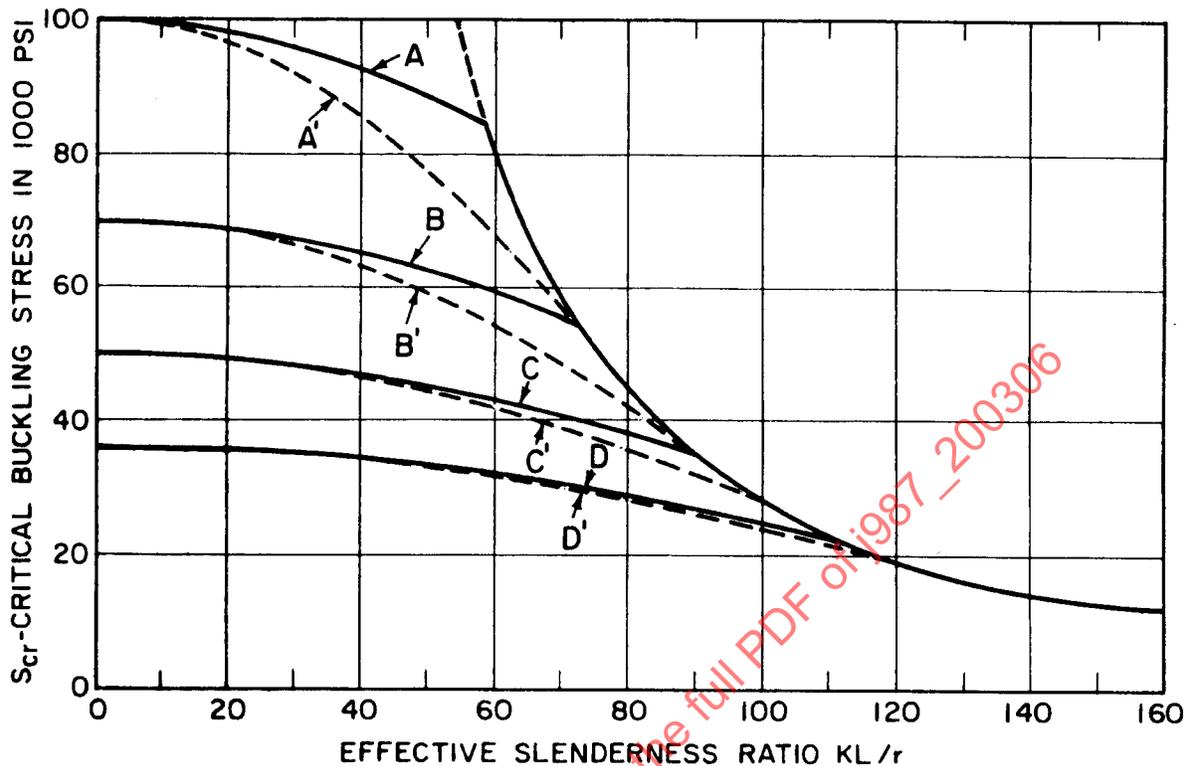


FIGURE C1—CRITICAL BUCKLING STRESS,  $S_{cr}$  (TO BE USED WITH EQUATION 4)

In testing compression members, strain gages should be located at the midspan or expected buckling point. When gages are placed at the logical points of highest buckling stress, the highest observed reading may be used for  $S_{rm}$  in lieu of computation of the stress plane. When gage 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 C2 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 gages in these areas, the determination of  $S_{cr}$  must be based on the largest value of  $KL/r$  occurring at the chosen area. For boom chord members the largest value of  $KL/r$  must be utilized, whether lacings are staggered or concentric.