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# SAE J1040 FEB86



# Performance Criteria for Rollover Protective Structures (ROPS) for Construction, Earthmoving, Forestry, and Mining Machines

**SAE Recommended Practice**
**Reaffirmed February 1986**



**Submitted for Recognition as an American National Standard**

SAE The Engineering Resource For Advancing Mobility®

400 COMMONWEALTH DRIVE, WARRENDALE, PA 15096

OFF-HIGHWAY MACHINERY PRACTICE

Submitted for recognition as an American National Standard

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# PERFORMANCE CRITERIA FOR ROLLOVER PROTECTIVE STRUCTURES (ROPS) FOR CONSTRUCTION, EARTHMOVING, FORESTRY, AND MINING MACHINES

1. OBJECTIVE: To establish a consistent, repeatable means of evaluating Force-Deflection and Vertical load carrying characteristics of Rollover Protective Structures under static loading and to prescribe performance requirements of a representative specimen under such loading. Rollover Protective Structures (ROPS) are structures whose primary purpose is to reduce the possibility of operators, who are wearing seat belts, being crushed if the machine they are operating should roll over.

2. SCOPE:

2.1 The following off-highway machines commonly used in earthmoving, construction, logging, and mining applications are included (pneumatic-tired agricultural machines and machines whose use is predominantly, or entirely, in manufacturing plants and/or warehouses are specifically excluded):

(a) Crawler tractors and crawler loaders of mass greater than 700 kg (1543 lb).

(b) Graders of mass greater than 700 kg (1543 lb).

(c) Wheel loaders, and wheel tractors, and their modifications used for rolling and compacting, and wheel log skidders of mass greater than 700 kg (1543 lb).

(d) The tractor portion of semi-mounted scrapers, dumpers, water wagons, bottom dump wagons, rear dump wagons and towed fifth wheel attachments of mass greater than 700 kg (1543 lb).

(e) Dumpers with full-mounted bodies of mass greater than 700 kg (1543 lb).

(f) Skid-steer loaders of mass greater than 700 kg (1543 lb).

2.1 (Continued):

(g) Wheel loaders and wheel tractors equipped with dozers of mass greater than 700 kg (1543 lb).

(h) Rollers and compactors of mass greater than 2700 kg (5952 lb).

2.2 The requirements are force resistance and energy absorption under horizontal loading, and vertical load carrying capability after removal of the horizontal load. (There are limitations on deflections under both horizontal and vertical loading.) Specific requirements derive from investigations on ROPS that have performed the intended function in a variety of actual rollovers, as well as analytical considerations based upon the compatibility of ROPS and the machine frame to which it attaches.

In addition to the loading requirements, there is a Temperature-Material requirement. This requires either making the static loadings with all structural members at, or below, a given temperature or making the loadings above the given temperature and constructing the ROPS of material that meets certain mechanical requirements.

It is intended that all portions of this Recommended Practice will be reviewed and revised as knowledge of ROPS performance, design, evaluation, and manufacture increases.

2.3 Because this Recommended Practice presents both procedure and criteria that are intended for consideration as worldwide standards for ROPS, the following points are explicitly stated to aid in understanding its underlying principles, intention, and application.

2.3.1 This evaluation procedure will not necessarily duplicate structural deformations due to a given actual roll.

2.3.2 This evaluation procedure is generally destructive of the ROPS-machine assembly, as permanent deformation is apt to be induced in either or both.

2.3.3 Although ROPS meeting these criteria may not give crush protection under all conceivable circumstances in which a machine could overturn, it is expected that crush protection will be assured under at least the following condition: An initial forward velocity of 0-16 km/h (0-10 mph) on a hard clay surface of 30 deg maximum slope, 360 deg of roll about the machine's longitudinal axis without losing contact with the slope.

2.3.4 The horizontal force requirement and limitation on deflection (deflection limiting volume (DLV), see SAE J397b) are intended to assure that the ROPS will penetrate unfrozen soil, thereby giving a braking action to a roll.

2.3.5 The energy requirement and limitations on deflection (DLV, see SAE J397b) under horizontal loading are intended to assure that the ROPS will deflect when it impacts a surface which will not significantly deform (frozen ground, concrete, rock), while retaining significant capability to withstand subsequent impacts in an overturn.

2.3.6 The vertical loading requirement is intended to assure that a deformed ROPS will be able to support the machine in an upside-down attitude.

2.3.7 The Temperature-Material requirement is intended to assure that the ROPS will have meaningful resistance to brittle fracture. The material requirement is the conventional Charpy V-notch evaluation; it is primarily a quality control check and the indicated temperature does not directly relate to operating conditions.

2.3.8 The specific force, energy, and vertical load carrying requirements, including the general requirement of paragraph 8.2, are to be met, or exceeded, in the testing of a representative specimen. The Force and Energy requirements do not need to be attainable simultaneously; accordingly, one may be significantly exceeded before the other is attained in the horizontal loading. The limitations on deflections (DLV, J397b) is absolute; it cannot be exceeded in attaining the Force-Energy-Vertical loading requirements.

2.3.9 Because, in an actual roll, loading will be dynamic (possibly impact), the use of "safety factors" which are based on elastic deformation, or ratio of the force attained to the force required, is not applicable. The "safety factor" of a ROPS is related more to energy absorption capability and details of weldment design and welding procedure than it is to either static force resistance or to avoiding permanent deformation. The static evaluation procedure of this Recommended Practice is itself a conservative element as it requires the representative specimen (ROPS, machine frame, and connecting members) to withstand a sustained loading that must be resisted by all components including those of the machine frame.

2.3.10 A representative specimen is one that is within the manufacturer's specifications.

2.3.11 The ROPS should be labeled in accordance with SAE J1164 (June, 1977).

3. FACILITIES AND INSTRUMENTS: Facilities to secure the ROPS machine frame assembly to the bedplate, as described below, and to apply the side and vertical loads are required. Typical, but not mandatory, installations are given for specific types of machines in accompanying illustrations.

Instrument systems used to measure mass, force, and deflection as follows:

| Means to Measure | Accuracy |
|---|---|
| Machine mass | ±5% of max mass |
| Deflection of ROPS | ±5% of max deflection |
| Force on ROPS | ±5% of max force |

The above percentages are nominal ratings of the accuracy of the instrumentation and should not be taken to indicate that compensating overtest is required.

4. MASS--WEIGHT:

4.1 In keeping with the directive to include SI units in SAE technical reports (SAE J916c (June, 1978)), the distinction between mass and weight is emphasized by use of the mass unit (kilograms) in SI equations. In the gravimetric equations, the units lbf (pounds-force) and lb (pounds) are used. As common usage of the word "weight" to denote "mass" is not likely to cease with formal adoption of SI units, it seems desirable to emphasize that mass (as pounds or as kilograms) will continue to be mistakenly called "weight" for the forseeable future. In fact, the greatest error possible in the weight-mass issue is 0.5%, which is small in relation to the ±5% allowable and any issue is one of semantics rather than engineering consequence.

4.2 In Section 8, the phrase "maximum recommended mass" is used. This refers to "clean machine" values. Soil, mud, rocks, limbs, debris, etc., that commonly adhere to or lay on machines in actual use should not be considered in determining the maximum recommended values.

5. ROPS-MACHINE ASSEMBLY AND ATTACHMENT TO BEDPLATE: The ROPS shall be attached to the machine frame as it would be on an operating machine. A complete machine is not required for the evaluation; however, the machine frame and ROPS mounting must represent an operating installation. All normally detachable windows, panels, doors, and other nonstructural elements shall be removed so they do not contribute to or detract from the structural evaluation. For horizontal loading, the ROPS-machine frame assembly shall be secured to the bedplate so that the members connecting the assembly and bedplate experience minimal deflection when the ROPS is side loaded. During side loading, the ROPS-machine frame assembly shall not receive any support from the bedplate, other than that due to the initial attachment.

The assembly shall be secured and/or modified so that any machine element that might be considered a suspension (rubber, gas, gas-oil, or mechanical spring) shall be effectively eliminated as an energy absorber. However, ROPS-to-machine frame mounts must not be altered; at the start of the evaluations, they shall be as they would be on an operating machine.

For the vertical loading, there is no limitation on securing or supporting the ROPS-machine frame assembly other than no repair or straightening of the assembly is permissible during or after side loading and during the vertical loading.

For editorial and printing convenience, specifics of attachment to bedplates are covered along with machine descriptions and ROPS requirements in Section 8.

6. LOADING PROCEDURE:

6.1 Side Loading:

6.1.1 Load distribution devices may be used to prevent localized penetration.

6.1.2 Load shall be applied to major, upper, and longitudinal members except when a one- or two-post structure without cantilevered overhead shield is used. For that type of structure, load shall be applied in line with the upper cross member.

6.1.3 Initial loading of a one- or two-post frame with an overhead shield shall be dictated by the total longitudinal distance between major, upper ROPS members (L) and the vertical projection of the front and rear planes of the DLV. The load point may not be within L/3 from the one- or two-post frame. Should the L/3 point be between the vertical projection of the DLV and the one- or two-post frame, the load point shall move away from the frame until it enters the vertical projection of the DLV. (See Fig. 1.) Any load distribution plate used must not impede rotation of the ROPS around a vertical axis during the loading and may not distribute the load over a distance greater than 80% of L. (See Fig. 1.)

6.1.4 For ROPS of more than two posts, loading shall not be distributed over more than 80% of the horizontal distance between the front and rear posts. Loading shall be within the 1000 mm (39.4 in) that is defined by vertical projections of planes 80 mm (3.2 in) outside of the front and rear planes of the DLV. (See Figs. 2-4.)

6.1.5 The initial direction of loading shall be horizontal and perpendicular to a vertical plane through the machine's longitudinal centerline. As loading continues, the ROPS machine frame deformations may cause the direction of loading to change; this is permissible.

6.1.6 Should the operator's seat be off of the machine's longitudinal centerline, the loading shall be against the outermost side nearest the seat. For on-centerline seats, if mounting of the ROPS is such that different force-deflection relations are obtained from loading from left or right sides, the side loaded shall be that which will place the most severe requirements on the ROPS-machine assembly.

6.1.7 The rate of application of deflection (load) shall be such that it can be considered static. At deflection increments no greater than 13 mm (0.5 in), at the point of application of the resultant load, force and deflection are to be recorded. This loading is to continue until the ROPS has achieved both the force and energy requirements. (See Fig. 5 for method of calculating energy.) The deflection(s) used in calculating energy is (are) to be that of the ROPS along the line(s) of action of the force(s). Any deflection of members used to support load application devices shall be deducted from total deflection.

6.2 Vertical Loading: After removal of the horizontal load, a vertical load shall be applied to the top of the ROPS. For one or two post structures with cantilevered overhead shields, the center of the vertical load shall not be applied any nearer to the posts than the horizontal load of paragraph 6.1.3 was. Any load distribution plate used must not impede rotation of the ROPS, about a horizontal axis, during loading. In no instance is there any further limitation on the manner of distributing this load on the ROPS unless specifically indicated in Section 8. Figs. 6-10 show typical vertical loading.

6.2 (Continued):

NOTE: Fig. 6 is loading by mass and the others are loading by force. As requirements are mass related, it is necessary to relate mass and force. The correct relation is N = 9.80665 x kg, 9.80665 $m/S^2$ being the gravitational acceleration at the standard conditions of sea level and 45 deg latitude (see SAE J916c (June, 1978)).

7. TEMPERATURE-MATERIAL REQUIREMENTS: These requirements shall be met by either performing the horizontal and vertical loadings with all ROPS and machine frame members at -18°C (0°F) or below, or performing the horizontal and vertical loadings at any higher temperature and meeting the following material requirements:

7.1 Bolts and nuts used to attach the ROPS to the machine frame and to connect structural parts of the ROPS shall be SAE Grade 5 or 8 (SAE J429 (July, 1977) and J995c (September, 1974)).

7.2 Structural members of the ROPS and the mounts which attach it to the machine frame shall be made of steels that have one of the Charpy V-notch impact strengths at -30°C (-20°F) shown in Table 1.

Specimens are to be "longitudinal" and taken from flat stock, tubular, or structural sections before forming or welding for use in the ROPS. Specimens from tubular or structural sections are to be taken from the middle of the side of greatest dimensions, not to include welds.

SAE Information Report J1119 (September, 1976) presents more data on specifics of CVN specimen size-test temperature interaction that meets the intent of the basic requirements of Table 1. SAE J1119 (September, 1976) also gives information on chemistries, manufacturing processes, and tensile properties of steel suitable for use in ROPS but only the CVN impact strengths of Table 1 of this document are the mandatory requirements for the ROPS material option.

TABLE 1 - MINIMUM CHARPY V-NOTCH IMPACT STRENGTHS

| Specimen Size, mm | J | ft-lbf |
|---|---|---|
| 10 x 10[a] | 11.0 | 8.0 |
| 10 x 9 | 10.0 | 7.5 |
| 10 x 8 | 9.5 | 7.0 |
| 10 x 7.5[a] | 9.5 | 7.0 |
| 10 x 7 | 9.0 | 6.5 |
| 10 x 6.7 | 8.5 | 6.5 |
| 10 x 6 | 8.0 | 6.0 |
| 10 x 5[a] | 7.5 | 5.5 |
| 10 x 4 | 7.0 | 5.0 |
| 10 x 3.3 | 6.0 | 4.5 |
| 10 x 3 | 6.0 | 4.5 |
| 10 x 2.5[a] | 5.5 | 4.0 |

[a]Indicates preferred size. Specimen size shall be no less than the largest preferred size that the material will permit.
(Reference: ASTM A370-68, Standard Methods and Definitions for Mechanical Testing of Steel Products.)

8. MACHINE DESCRIPTION--ATTACHMENT TO BEDPLATE--FORCE/ENERGY/VERTICAL LOAD REQUIREMENTS:

8.1 Force-energy and vertical load requirements shall be met within the deflection(s) permitted by the Deflection Limiting Volume (DLV, SAE J397b) artifice. (M in the various equations denotes mass.)

8.2 In the horizontal loadings, if the force is attained before the energy, the force may decrease but must again attain the required level when the energy requirement is met or exceeded.

8.3 Track-Type Tractors, Without Sidebooms, Used Only for Bulldozing, Ripping, Pushloading, Front-End Loading, or Pulling a Drawbar Load: See SAE J727b (June, 1977) and J1057 (June, 1975) (paragraphs 3.1 and 7.1) for description and nomenclature.

8.3.1 Connection to the bedplate shall be through the main housing and/or track frames. (See Figs. 11 and 12.)

8.3.2 Requirements for machines whose mass is 59 499 kg (131 173 lb) or less are:

Force (side load):

$$F = 70\,000 \left[\frac{M}{10\,000}\right]^{1.20} \qquad \text{units: N and kg}$$

$$F = 6090 \left[\frac{M}{10\,000}\right]^{1.20} \qquad \text{units: lbf and lb}$$

8.3.3 Requirements for machines whose mass is from 59 499 kg (131 173 lb) to 120 000 kg (264 555 lb) are:

Force (side load):

$F = 10M$ units: N and kg
$F = 1.02M$ units: lbf and lb

8.3.4 For machines of maximum recommended mass less than 120 000 kg (264 555 lb).

Energy (side load):

$$U = 13\,000 \left[\frac{M}{10\,000}\right]^{1.25} \qquad \text{units: J and kg}$$

$$U = 42\,830 \left[\frac{M}{10\,000}\right]^{1.25} \qquad \text{units: in-lbf and lb}$$

8.3.5 Vertical: The ROPS-machine assembly shall support a vertical load after the side load is removed.

Force (vertical load):

$F = 19.6M$ units: N and kg
$F = 2.0M$ units: lbf and lb

8.3.6 M in the above equations is the machine manufacturer's maximum recommended mass of the machine and its attachments, excluding towed equipment such as scrapers and rollers.

8.4 Graders: See SAE J870 (April, 1977) and J1057a(6) (June, 1975) for description and nomenclature.

8.4.1 For non-articulated machines and articulated machines using both frames, connections to the bedplate shall be directly from the machine frame at or near the front axle support and the rear drive support. For articulated machines, the hinge shall be locked if both frames are used in the evaluation; if only that frame to which the ROPS is mounted is used, the connections shall be at or near the extreme ends of the frame. (See Figs. 13-16.)

8.4.2 Requirements for machines whose mass is 38 011 kg (83 800 lb) or less are:

Force (side load):

$$F = 70\,000 \left[\frac{M}{10\,000}\right]^{1.10} \qquad \text{units: N and kg}$$

$$F = 6600 \left[\frac{M}{10\,000}\right]^{1.10} \qquad \text{units: lbf and lb}$$

8.4.3 Requirements for machines whose mass is from 38 011 kg (83 800 lb) to 40 000 kg (88 185 lb) are:

Force (side load):

$F = 8M$ units: N and kg
$F = 0.82M$ units: lbf and lb

8.4.4 For machines of maximum recommended mass less than 40 000 kg (88 185 lb).

Energy (side load):

$$U = 15\,000 \left[\frac{M}{10\,000}\right]^{1.25} \qquad \text{units: J and kg}$$

$$U = 49\,410 \left[\frac{M}{10\,000}\right]^{1.25} \qquad \text{units: in-lbf and lb}$$

8.4.5 Vertical: The ROPS-machine assembly shall support a vertical load after the side load is removed.

Force (vertical load):

$F = 19.6M$ units: N and kg
$F = 2.0M$ units: lbf and lb

8.4.6 M in the above equations is the machine manufacturer's maximum recommended mass of the machine and its attachments excluding towed equipment.

8.5 Wheel Loaders and Wheel Tractors and Their Modifications Used for Rolling or Compacting, and Wheel Log Skidders: See SAE J1057a (paragraphs 3.2 and 7.2) (June, 1975) for description and nomenclature.

8.5.1 For non-articulated machines and articulated machines using both frames, connections to the bedplate shall be directly from the machine frame at or near the front axle support and the rear drive support. For articulated machines, the hinge shall be locked if both frames are used in the evaluation; if only that frame to which the ROPS is mounted is used, the connections shall be at or near the extreme ends of the frame. (See Figs. 13-16.)

8.5.2 Requirements for machines whose mass is 120 000 kg (264 555 lb) or less are:

Force (side load):

$$F = 60\,000 \left[\frac{M}{10\,000}\right]^{1.20} \qquad \text{units: N and kg}$$

$$F = 5220 \left[\frac{M}{10\,000}\right]^{1.20} \qquad \text{units: lbf and lb}$$

8.5.3 For machines of maximum recommended mass less than 120 000 kg (264 555 lb).

Energy (side load):

$$U = 12\,500 \left[\frac{M}{10\,000}\right]^{1.25} \qquad \text{units: J and kg}$$

$$U = 41\,180 \left[\frac{M}{10\,000}\right]^{1.25} \qquad \text{units: in-lbf and lb}$$

8.5.4 Vertical: The ROPS-machine assembly shall support a vertical load after the side load is removed.

Force (vertical load):

$F = 19.6M$ units: N and kg
$F = 2.0M$ units: lbf and lb

8.5.5 M in the above equation is the machine manufacturer's maximum recommended mass of the machine and its attachments, excluding towed equipment.

8.6 Tractor portion of semi-mounted scrapers, water wagons, bottom dump wagons, side dump wagons, rear dump wagons, and towed fifth-wheel attachments - See SAE J869a (April, 1977), J728a (April, 1977), and J1057a (paragraphs 4.1.1.4, 4.1.2.1, 4.2.1.1, 4.3.1.2, 4.3.1.3, 4.3.2.1, and 5) (June, 1975) for description and nomenclature.

8.6.1 Connection to the bedplate shall be directly from the machine frame (or case) at or near the drive tire or axle connection. (For prime movers that are adaptations of another basic machine--that is, trucks, wheel tractors, etc.--the attachment shall be as specified under the ROPS criteria for the basic machine.) (See Figs. 17 and 18.)

8.6.2 Requirements for machines whose mass is 35 000 kg (77 162 lb) or less are:

Force (side load):

$$F = 95\ 000 \left[\frac{M}{10\ 000}\right]^{1.20} \qquad \text{units: N and kg}$$

$$F = 8270 \left[\frac{M}{10\ 000}\right]^{1.20} \qquad \text{units: lbf and lb}$$

8.6.3 For machines of maximum recommended mass of 35 000 kg (77 162 lb) or less.

Energy (side load):

$$U = 20\ 000 \left[\frac{M}{10\ 000}\right]^{1.25} \qquad \text{units: J and kg}$$

$$U = 65\ 880 \left[\frac{M}{10\ 000}\right]^{1.25} \qquad \text{units: in-lbf and lb}$$

8.6.4 Vertical: The ROPS-machine assembly shall support a vertical load afterthe side load is removed.

Force (vertical load):

$F = 19.6M$ units: N and kg
$F = 2.0M$ units: lbf and lb

8.6.5 M in the above equations is the machine manufacturer's maximum recommended mass of the prime mover only--kingpins, hitches, and articulated steering components that attach to hitches or towed units are excluded from the mass of the prime mover.

8.7 Dumpers with Full Mounted Bodies: See SAE J1057a (paragraphs 4.1.1.1, 4.1.1.2, 4.1.1.3, 4.1.1.5, and 4.3.1.1 (June, 1975) and J1016 (April, 1977) for description and nomenclature.

8.7.1 Connections to the bedplate shall be at, or near, the front and rear axle locations. (See Fig. 19.)

8.7.2 Requirements can be met by any of the following options: ROPS only, body only, combination of ROPS and body.

8.7.3 For a ROPS only, side load force-energy requirements as indicated by the equations of paragraph 8.7.7 shall be met. After meeting these requirements, the ROPS shall support a vertical load less the body tare mass.

Force (vertical load):

$F = 19.6M$ units: N and kg
$F = 2.0M$ units: lbf and lb

8.7.4 For a body only, side load force-energy requirements indicated by the equations of paragraph 8.7.8 shall be met. After meeting these requirements, the body canopy shall support a vertical load.

Force (vertical load):

$F = 19.6M$ units: N and kg
$F = 2.0M$ units: lbf and lb

8.7.5 When both ROPS and body are used, the side loading Force and Energy requirements for each shall be 60% of those indicated by the equations of paragraphs 8.7.7 and 8.7.8, respectively. The vertical load requirements for both ROPS and body shall be as specified in paragraphs 8.7.3 and 8.7.4, respectively.

8.7.6 Side or vertical loading of the ROPS and/or body need not be applied simultaneously to both members of a combination. The only limitation on the order of the four loadings is that the vertical loading of members shall be after their side loading. Side load and vertical load on the truck body shall be applied within the length bounded by the vertical projections of the front and rear planes of the DLV. (See Fig. 20.)

8.7.7(a) ROPS requirements for machines whose mass is 70 000 kg (154 324 lb) or less are:

Force (side load):

$$F = 55\,000 \left[\frac{M}{10\,000}\right]^{1.20} \quad \text{units: N and kg}$$

$$F = 4790 \left[\frac{M}{10\,000}\right]^{1.20} \quad \text{units: lbf and lb}$$

Energy (side load):

$$U = 9500 \left[\frac{M}{10\,000}\right]^{1.25} \quad \text{units: J and kg}$$

$$U = 31\,300 \left[\frac{M}{10\,000}\right]^{1.25} \quad \text{units: in-lbf and lb}$$

8.7.7(b) ROPS requirements for machines whose mass is greater than 70 000 kg (154 324 lb) are:

Force (side load):

$$F = 385\,000 \left[\frac{M}{10\,000}\right]^{0.20} \qquad \text{units: N and kg}$$

$$F = 73\,890 \left[\frac{M}{10\,000}\right]^{0.20} \qquad \text{units: lbf and lb}$$

Energy (side load):

$$U = 66\,500 \left[\frac{M}{10\,000}\right]^{0.25} \qquad \text{units: J and kg}$$

$$U = 482\,960 \left[\frac{M}{10\,000}\right]^{0.25} \qquad \text{units: in-lbf and lb}$$

8.7.8(a) Body (used as ROPS) requirements for machines whose mass is 70 000 kg (154 324 lb) or less, are:

Force (side load):

$$F = 60\,000 \left[\frac{M}{10\,000}\right]^{1.20} \qquad \text{units: N and kg}$$

$$F = 5220 \left[\frac{M}{10\,000}\right]^{1.20} \qquad \text{units: lbf and lb}$$

Energy (side load):

$$U = 6000 \left[\frac{M}{10\,000}\right]^{1.25} \qquad \text{units: J and kg}$$

$$U = 19\,770 \left[\frac{M}{10\,000}\right]^{1.25} \qquad \text{units: in-lbf and lb}$$

8.7.8(b) Body (used as ROPS) requirements for machines whose mass is greater than 70 000 kg (154 324 lb) are:

Force (side load):

$$F = 420\,000 \left[\frac{M}{10\,000}\right]^{0.20} \qquad \text{units: N and kg}$$

$$F = 80\,610 \left[\frac{M}{10\,000}\right]^{0.20} \qquad \text{units: lbf and lb}$$

Energy (side load):

$$U = 42\,000 \left[\frac{M}{10\,000}\right]^{0.25} \qquad \text{units: J and kg}$$

$$U = 305\,030 \left[\frac{M}{10\,000}\right]^{0.25} \qquad \text{units: in-lbf and lb}$$

8.7.9 M in the above equations is the machine manufacturer's maximum recommended mass, not including payload.

8.8 Skid Steer Loaders: Machines which include as a part of their propelling system the capability of driving, retarding, and reversing their driving wheels up to and including the limit of traction of their driving wheels within the control capability of the operator. The propulsion system serves the functions of propulsion, steering, retarding, stopping, and reversing. See SAE J1057a, paragraph 3.2.1.8 (June, 1975), for description.

8.8.1 Connection to the bedplate shall be directly from the machine frame at or near the drive tire or axle connection. (See Figs. 14 and 16.)

8.8.2 The side load force shall be as required by the following equation:

$$F = 60\,000 \left[\frac{M}{10\,000}\right]^{1.20} \qquad \text{units: N and kg}$$

$$F = 5220 \left[\frac{M}{10\,000}\right]^{1.20} \qquad \text{units: lbf and lb}$$

8.8.3 The energy absorbed during side loading shall be as required by the following equation:

$$U = 12\,500 \left[\frac{M}{10\,000}\right]^{1.25} \qquad \text{units: J and kg}$$

$$U = 41\,180 \left[\frac{M}{10\,000}\right]^{1.25} \qquad \text{units: in-lbf and lb}$$

8.8.4 Vertical: The ROPS-machine assembly shall support a vertical load after removal of the side load.

Force (vertical load):

$F = 19.6M$ units: N and kg
$F = 2.0M$ units: lbf and lb

8.8.5 M in the above equations is the machine manufacturer's maximum recommended mass of the machine and its attachments, excluding towed equipment.

8.9 Wheel Industrial Front End Loaders and Wheel Tractors Equipped with Dozers: See SAE J1092 (June, 1977) and J1057a paragraph (3.2) (June, 1975) for description and nomenclature.

8.9.1 Connection to the bedplate shall be directly from the machine frame at or near the front axle support and the rear drive support. (See Figs. 13, 15, and 19.)

8.9.2 The side load force shall be as required by the following equation:

$$F = 60\,000 \left[\frac{M}{10\,000}\right]^{1.20} \quad \text{units: N and kg}$$

$$F = 5220 \left[\frac{M}{10\,000}\right]^{1.20} \quad \text{units: lbf and lb}$$

The energy absorbed during side loading shall be as required by the following equation:

$$U = 12\,500 \left[\frac{M}{10\,000}\right]^{1.25} \quad \text{units: J and kg}$$

$$U = 41\,180 \left[\frac{M}{10\,000}\right]^{1.25} \quad \text{units: in-lbf and lb}$$

8.9.3 After removal of the side load, the rear load shall be applied to front engine, rear wheel drive machines without backhoes to cover the possibility of a rear upset.

A horizontal load (rear to front) shall be applied one-quarter of the width of the ROPS from either rear post and shall be parallel to the machine's centerline. Should the operator's seat be off the machine's longitudinal centerline, the resultant loading shall be one-quarter of the ROPS width from the rear post nearest the seat. The rear posts may be spanned to permit application of the load.

8.9.4 The rear load force shall be as required by the following equations:

$$F = 60\,000 \left[\frac{M}{10\,000}\right]^{1.20} \qquad \text{units: N and kg}$$

$$F = 5220 \left[\frac{M}{10\,000}\right]^{1.20} \qquad \text{units: lbf and lb}$$

Energy abosrbed during the rear loading shall be as required by the following equations:

$U = 1.40M$ units: J and kg
$U = 5.62M$ units: in-lbf and lb

8.9.5 Vertical: After removal of the side load (or rear load, if applicable) the ROPS machine assembly shall support a vertical load.

Force (vertical load):

$F = 19.6M$ units: N and kg
$F = 2.0M$ units: lbf and lb

8.9.6 M in the above equations is the machine manufacturer's maximum recommended mass of the machine and its attachments, excluding backhoes and towed equipment.

8.10 Rollers and Compactors: (See SAE J1017 (April, 1977) for description and nomenclature) with the following exceptions:

(a) Smooth steel wheel rollers with the operator standing at the extreme rear of the machine.

(b) Pneumatic Tired Prime Movers which push or pull attached rollers or compactors (as covered by the contents of paragraph 8.6).

(c) Adaptations of wheel loaders and dozers used for rolling or compacting (as covered by the contents of paragraph 8.5).

8.10.1 Connections to the bedplate shall be directly from the machine frame at or near the front axle support and the rear drive support. If both frames of articulated machines are used the hinge shall be locked; if only that frame to which the ROPS is mounted is used the connections shall be at or near the extreme ends of the frame. (See Figs. 13-16.)

8.10.2 Requirements for machines whose mass is 25 000 kg (55 116 lb) or less are:

Force (side load):

$$F = 50\,000 \left[\frac{M}{10\,000}\right]^{1.20} \qquad \text{units: N and kg}$$

$$F = 4350 \left[\frac{M}{10\,000}\right]^{1.20} \qquad \text{units: lbf and lb}$$

8.10.3 Energy (side load):

$$U = 9500 \left[\frac{M}{10\,000}\right]^{1.25} \qquad \text{units: J and kg}$$

$$U = 31\,300 \left[\frac{M}{10\,000}\right]^{1.25} \qquad \text{units: in-lbf and lb}$$

8.10.4 Vertical: The ROPS-machine assembly shall support a vertical load after the side load is removed.

Force (vertical load):

$F = 19.6M$ units: N and kg
$F = 2.0M$ units: lbf and lb

8.10.5 Requirements for machines whose mass is greater than 25 000 kg (55 116 lb) are:

Force (side load):

$$F = 125\,000 \left[\frac{M}{10\,000}\right]^{0.20} \qquad \text{units: N and kg}$$

$$F = 23\,990 \left[\frac{M}{10\,000}\right]^{0.20} \qquad \text{units: lbf and lb}$$

8.10.6 Energy (side load):

$$U = 23\,750 \left[\frac{M}{10\,000}\right]^{0.25} \qquad \text{units: J and kg}$$

$$U = 172\,490 \left[\frac{M}{10\,000}\right]^{0.25} \qquad \text{units: in-lbf and lb}$$

8.10.7 Vertical: The ROPS-machine assembly shall support a vertical load after the side load is removed.

Force (vertical load):

| | |
|---|---|
| F = 19.6M | units: N and kg |
| F = 2.0M | units: lbf and lb |

8.10.8 M in the above equations is the machine manufacturer's Maximum Recommended Mass of the machine and its attachments, excluding towed equipment.

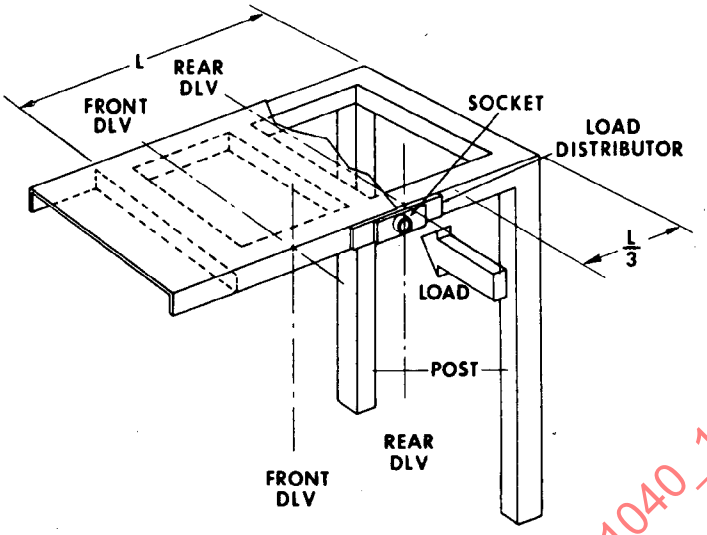
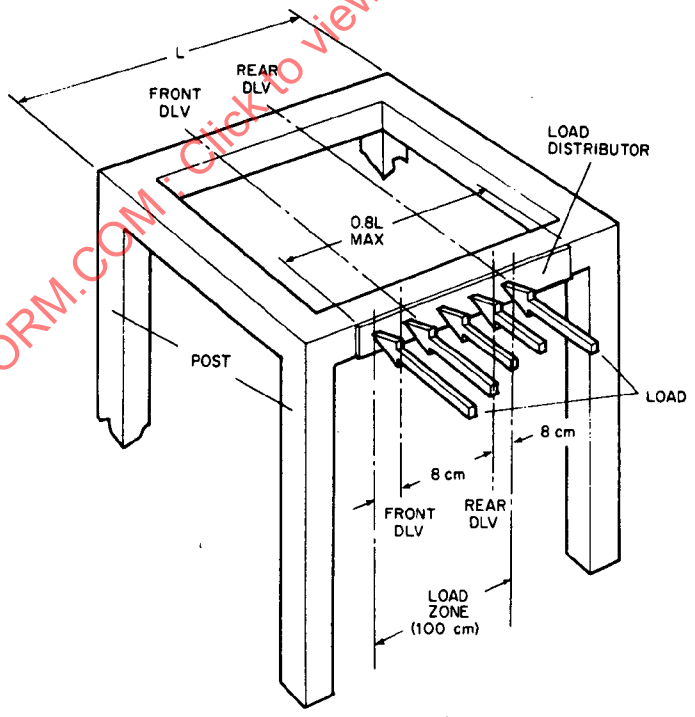



FIG. 1 - LOAD DISTRIBUTOR AND SOCKET ARE TO PREVENT LOCAL PENETRATION AND TO HOLD END OF LOAD GENERATING DEVICE






TYPICAL BUT NOT MANDATORY

FIG. 2

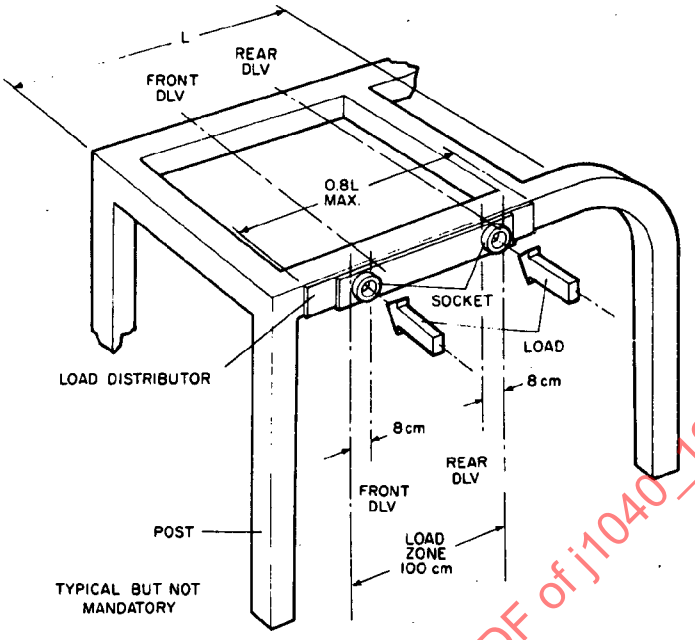



FIG. 3 - LOAD DISTRIBUTOR AND SOCKET ARE TO PREVENT LOCAL PENETRATION AND TO HOLD END OF LOAD GENERATING DEVICE

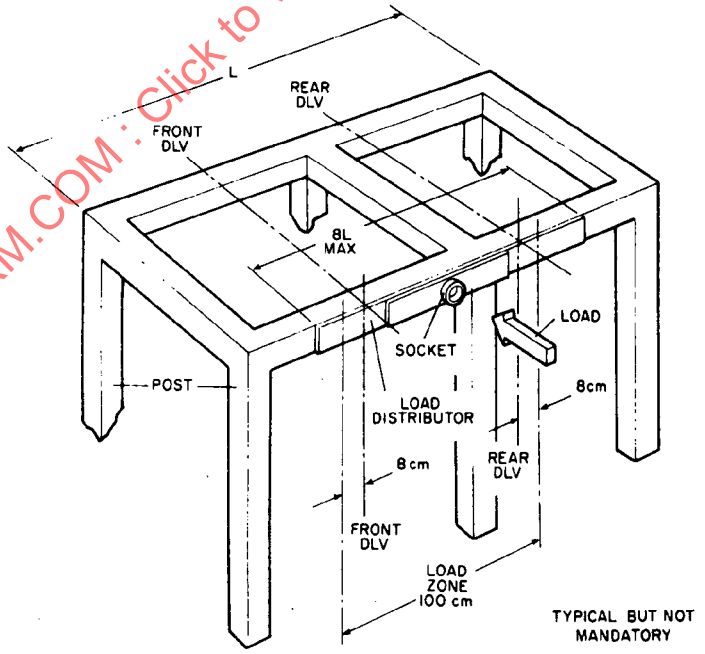
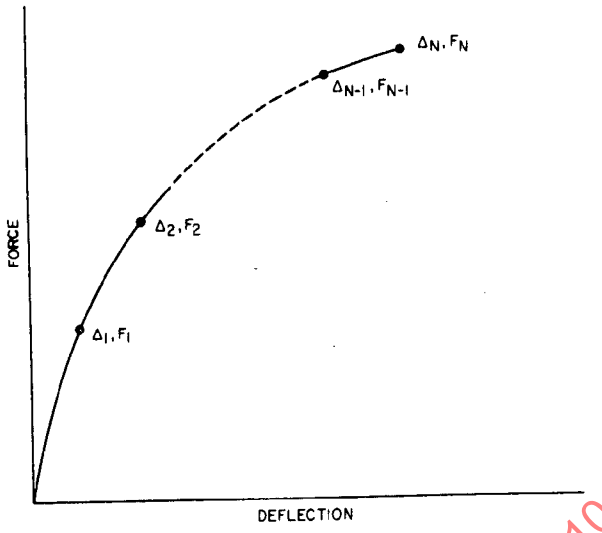



FIG. 4 - LOAD DISTRIBUTOR AND SOCKET ARE TO PREVENT LOCAL PENETRATION AND TO HOLD END OF LOAD GENERATING DEVICE




$$\text{AREA} = \frac{\Delta_1 F_1}{2} + (\Delta_2 - \Delta_1)\left[\frac{F_1 + F_2}{2}\right] + \cdots + (\Delta_N - \Delta_{N-1})\left[\frac{F_{N-1} + F_N}{2}\right]$$

FIG. 5

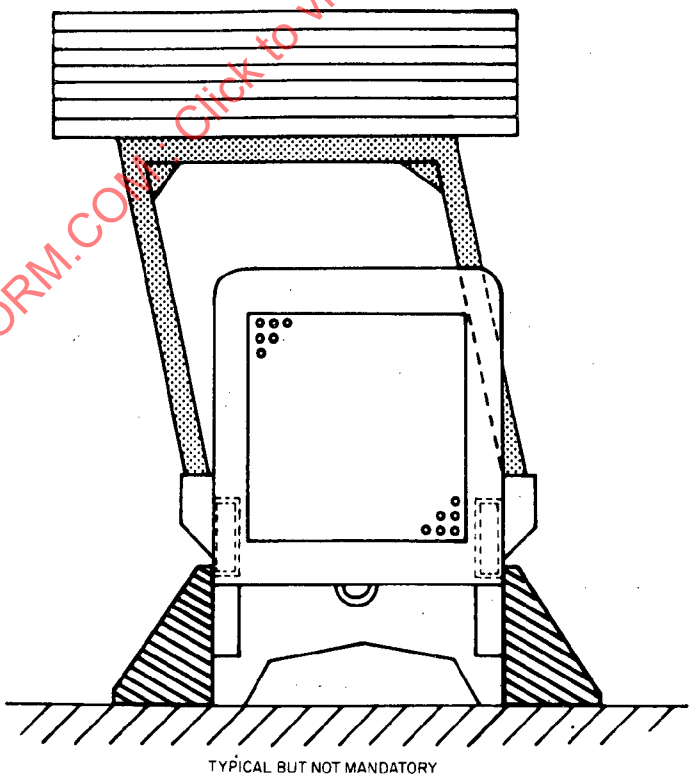



FIG. 6

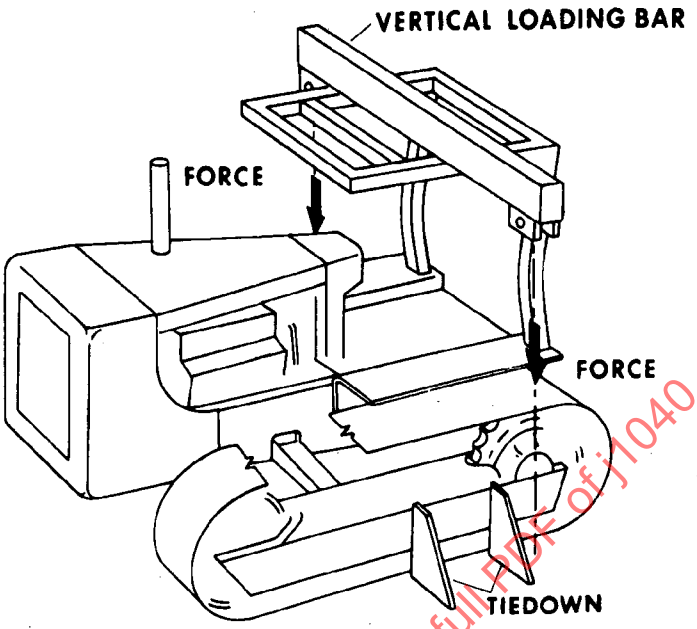
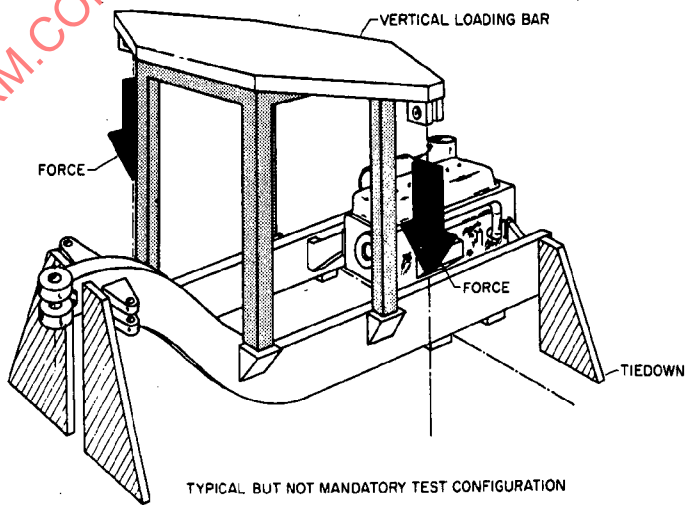


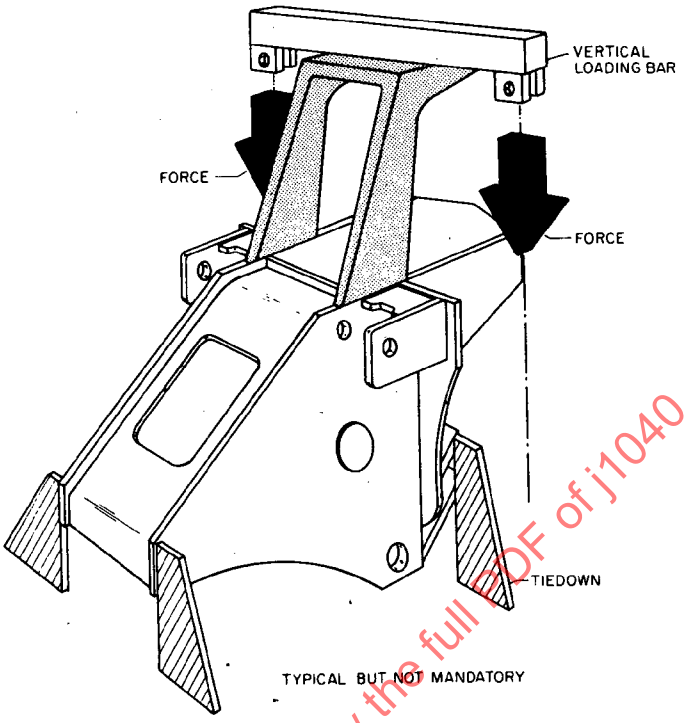

FIG. 7





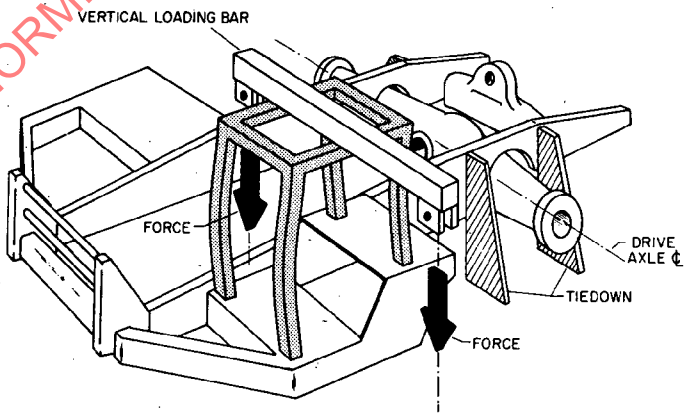

TYPICAL BUT NOT MANDATORY TEST CONFIGURATION

FIG. 8



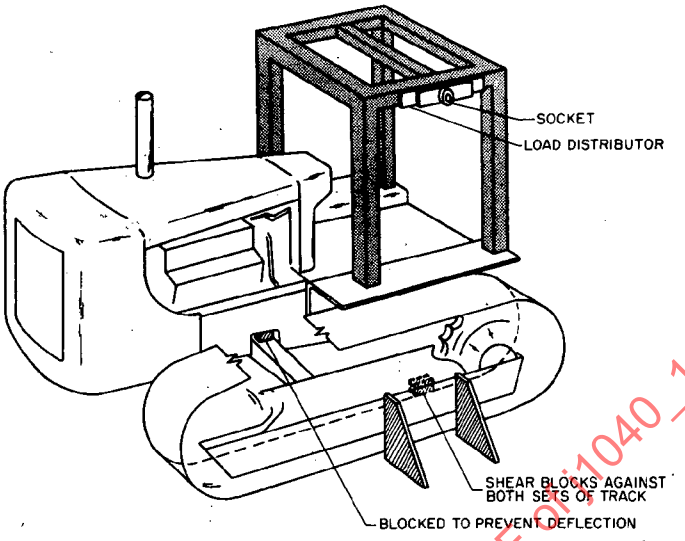

TYPICAL BUT NOT MANDATORY

FIG. 9



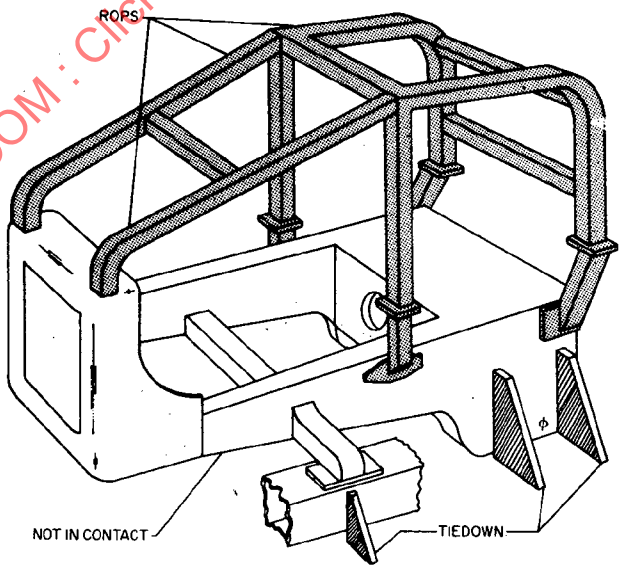

TYPICAL BUT NOT MANDATORY TEST CONFIGURATION

FIG. 10




TYPICAL BUT NOT MANDATORY TEST CONFIGURATION

FIG. 11




TYPICAL BUT NOT MANDATORY CONFIGURATION

FIG. 12

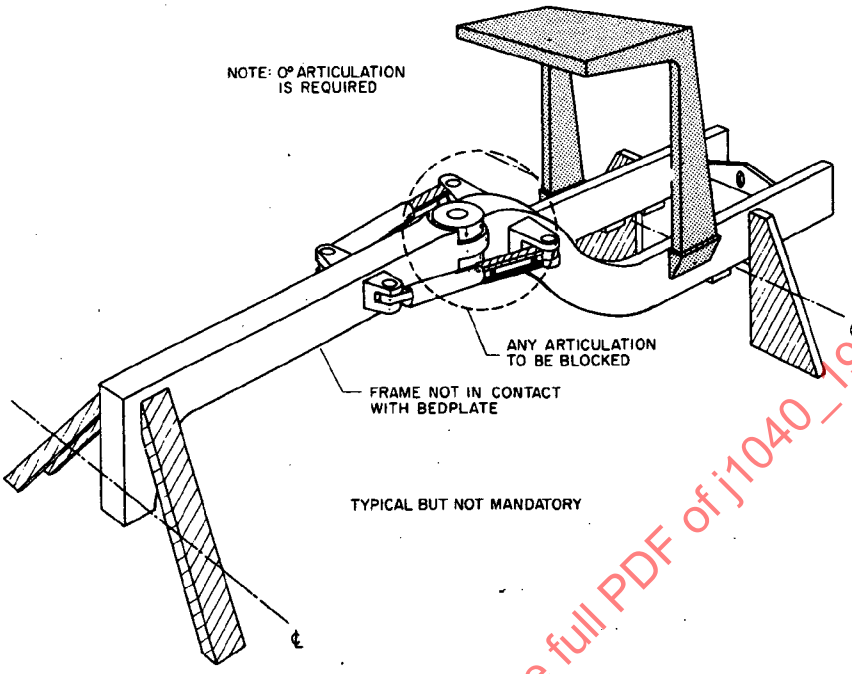
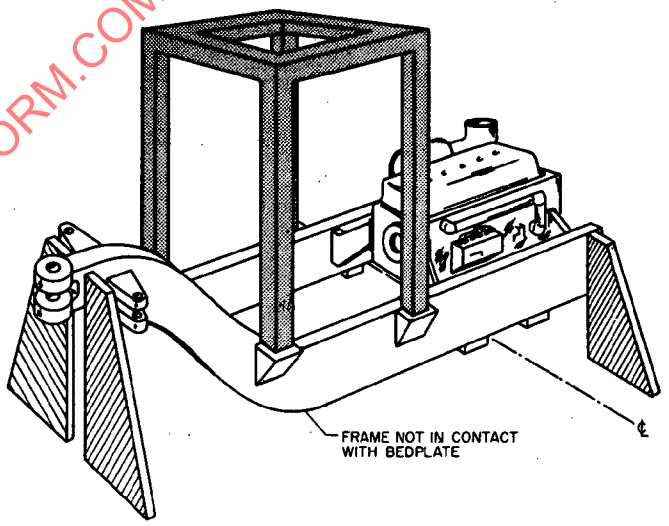



FIG. 13




TYPICAL BUT NOT MANDATORY TEST CONFIGURATION

FIG. 14