Performance Criteria for Rollover Protective Structures (ROPS) for Earthmoving, Construction, Logging and Industrial Vehicles — SAE J1040a

SAE RECOMMENDED PRACTICE

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PERFORMANCE CRITERIA FOR ROLLOVER PROTECTIVE STRUCTURES (ROPS) FOR EARTHMOVING, CONSTRUCTION, LOGGING AND INDUSTRIAL VEHICLES—SAE J1040a

SAE Recommended Practice

Report of Construction and Industrial Machinery Technical Committee approved April 1974 and last revised February 1975. (This document incorporates material formerly published as SAE J320, J395, J396, and J1011.)

1. OBJECTIVE—This SAE Recommended Practice is intended to establish a consistent, repeatable means of evaluating Force= Deflection characteristics of rollOver protective structures under static loading and to prescribe minimum performance requirements for these structures under such loading. RollOver protective structures (ROPS) are structures whose primary purpose is to reduce the possibility of an operator who is wearing a seat belt being crushed should his vehicle roll over.

2. SCOPE

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

(a) Track-type tractors of mass greater than 700 kg (1540 lb).

(b) Pneumatic-tired, self-propelled motor graders of mass greater than 700 kg (1540 lb).

(c) Pneumatic-tired front-end loaders and dozers of mass greater than 700 kg (1540 lb).

(d) Pneumatic-tired prime movers of mass greater than 700 kg (1540 lb).

(e) Pneumatic-tired, off-highway, nontrailed hauling units, with rear or side dump bodies, of mass greater than 700 kg (1540 lb).

(f) Four-wheel drive, skid steer, front-end loaders of mass greater than 700 kg (1540 lb).

(g) Industrial-type, wheeled front-end loaders and dozers of mass greater than 700 kg (1540 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 vehicle 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-vehicle 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 vehicle 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 vehicle'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 J397a) 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 J397a) 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 any 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 vehicle 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 force and energy requirements are minimum values. They do not need to be, and seldom are, attained simultaneously. Accordingly, either minimum is likely to be exceeded before the horizontal loading is completed. The limitation on deflection is a maximum. It is not to be exceeded during satisfaction of the force or energy minimums.

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 more related 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.

3. FACILITIES AND INSTRUMENTS—Facilities to secure the ROPS-vehicle 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 vehicles in accompanying illustrations.

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

Means to Measure	Accuracy
Vehicle 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 J916), 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 vehicle" values. Soil, mud, rocks, limbs, debris, etc., that commonly adhere to or lay on vehicles in actual use should not be considered in determining the maximum recommended values.

5. ROPS-VEHICLE ASSEMBLY AND ATTACHMENT TO BEDPLATE–The ROPS shall be attached to the vehicle frame as it would be on an operating vehicle. A complete vehicle is not required for the evaluation; however, the vehicle 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-vehicle 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-vehicle 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 vehicle 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-vehicle frame mounts must not be altered; at the start of the evaluations, they shall be as they would be on an operating vehicle.

For the vertical loading, there is no limitation on securing or supporting the ROPS-vehicle 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 vehicle 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 (Fig. 1). Any load distribution plate used must not impede rotation of the ROPS around a vertical axis during loading.

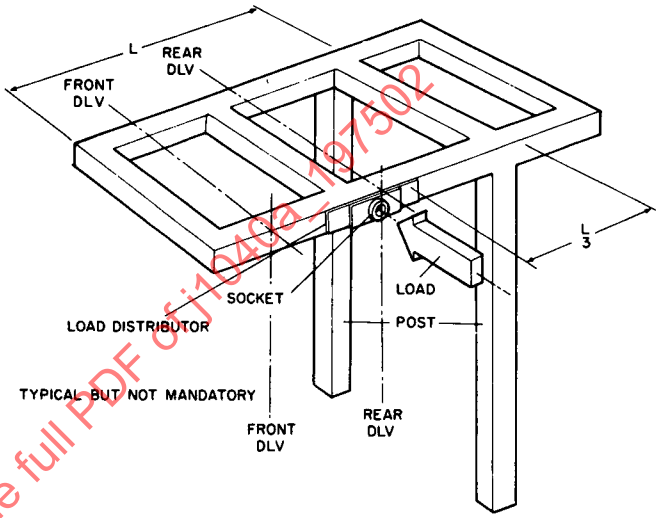
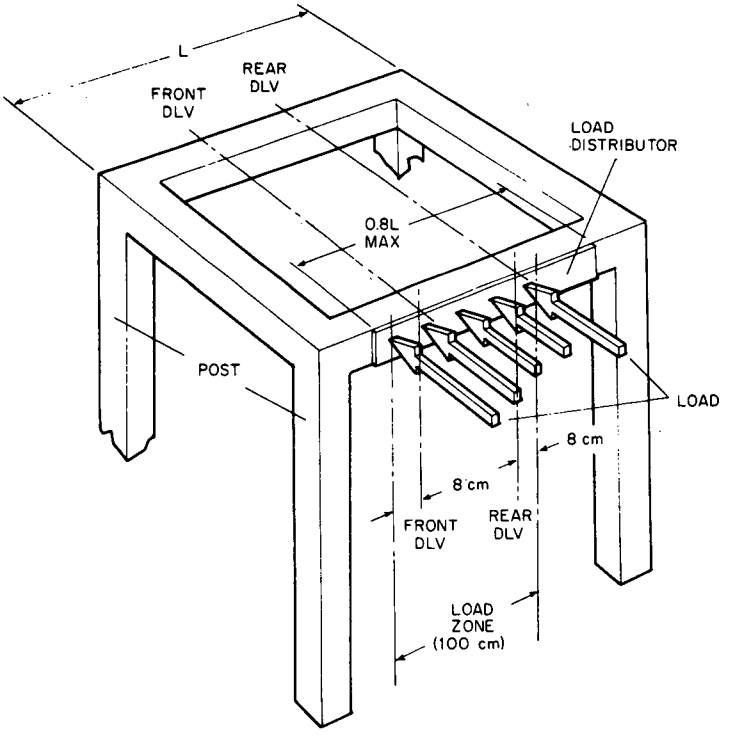


FIG. 1 - LOAD DISTRIBUTOR AND SOCKET ARE TO PREVENT LOCAL PENETRATION AND TO HOLD END OF LOAD GENERATING DEVICE



TYPICAL BUT NOT MANDATORY

FIG. 2

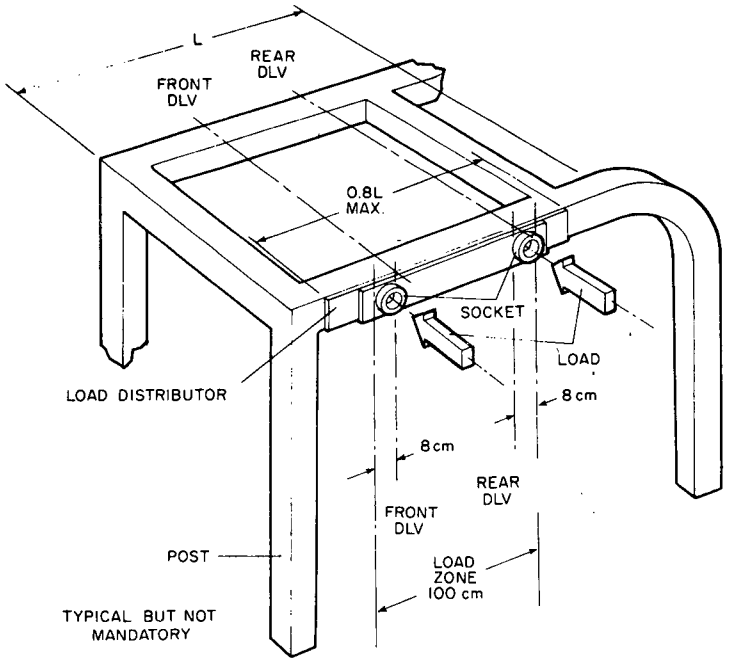


FIG. 3 - LOAD DISTRIBUTOR AND SOCKET ARE TO PREVENT LOCAL PENETRATION AND TO HOLD END OF LOAD GENERATING DEVICE

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 (Figs. 2-4).

6.1.5 The initial direction of loading shall be horizontal and perpendicular to a vertical plane through the vehicle's longitudinal centerline. As loading continues, the ROPS vehicle 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 vehicle'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-vehicle 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)

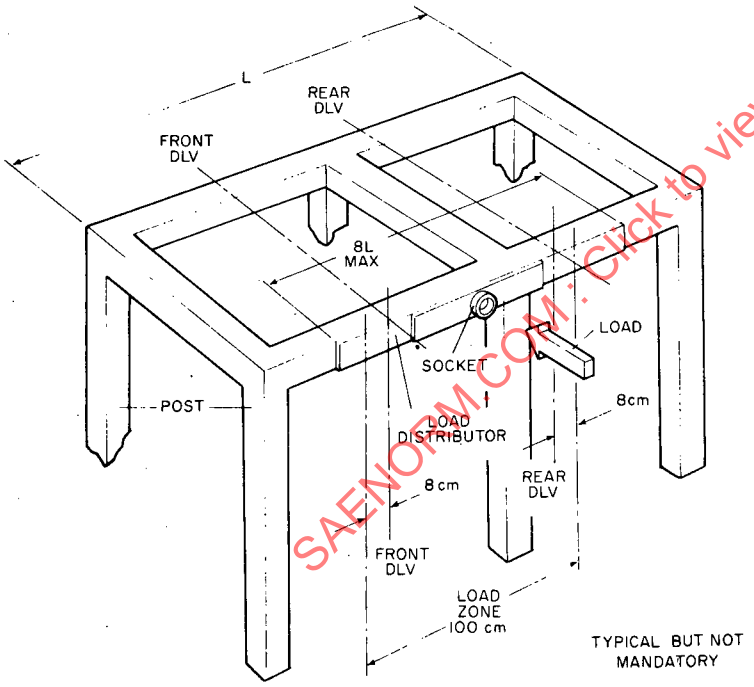
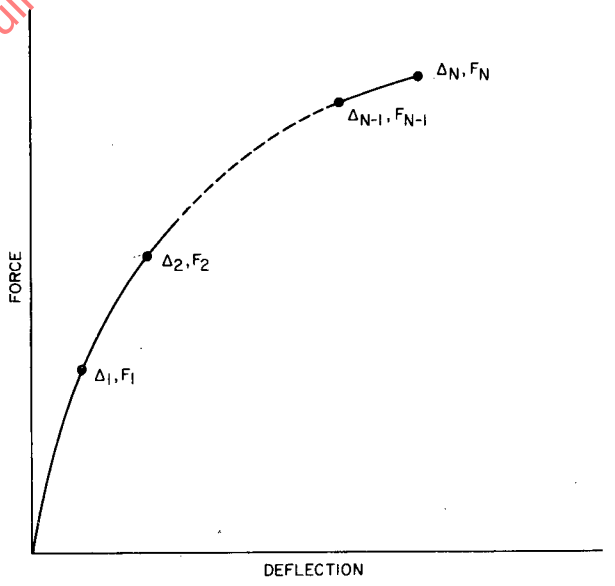
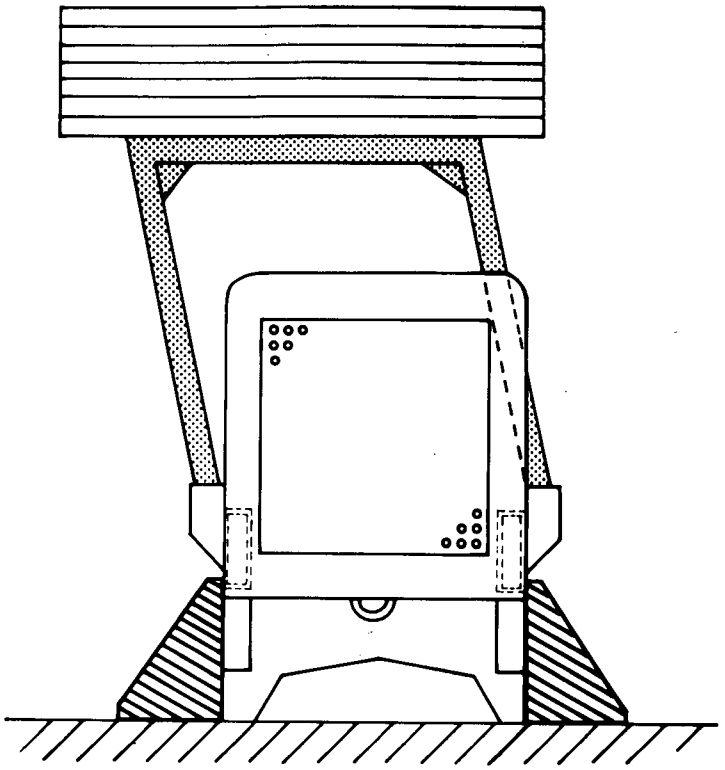


FIG. 4 - LOAD DISTRIBUTOR AND SOCKET ARE TO PREVENT LOCAL PENETRATION AND TO HOLD END OF LOAD GENERATING DEVICE



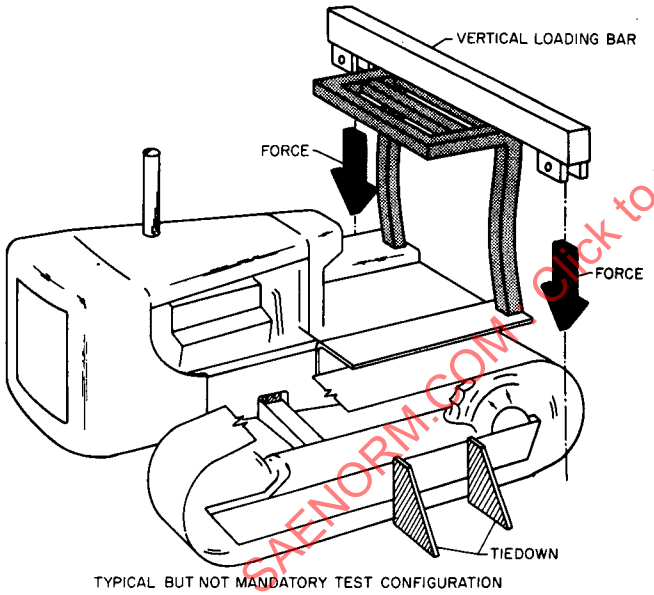
$$\text{AREA} = \frac{\Delta_1 F_1}{2} + (\Delta_2 - \Delta_1)\left[\frac{F_1 + F_2}{2}\right] + \cdots + (\Delta_N - \Delta_{N-1})\left[\frac{F_{N-1} + F_N}{2}\right]$$

FIG. 5



TYPICAL BUT NOT MANDATORY

FIG. 6

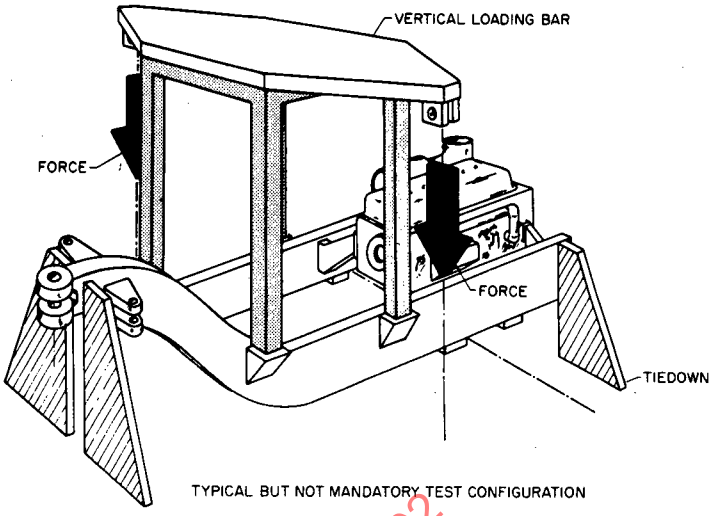


TYPICAL BUT NOT MANDATORY TEST CONFIGURATION

FIG. 7

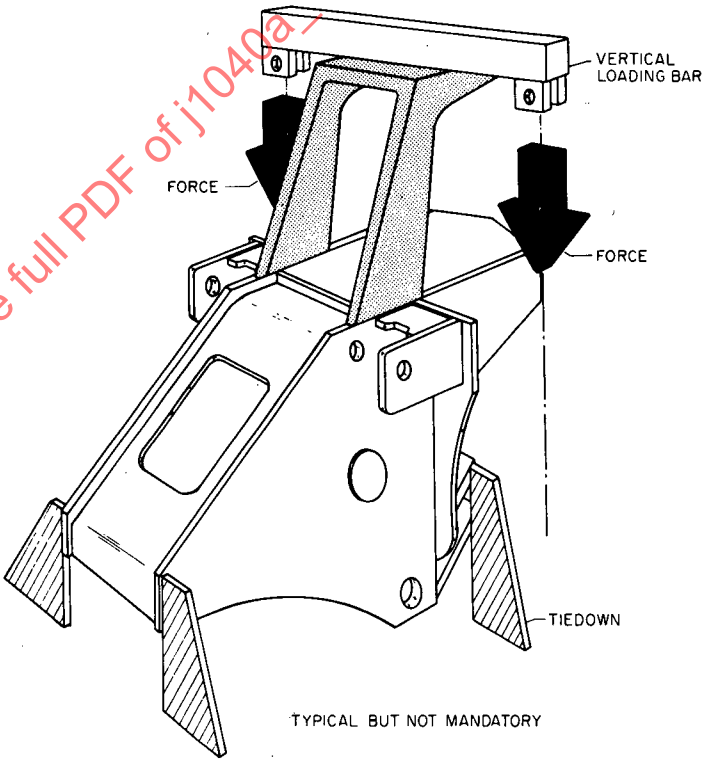
of action of the force(s). Any deflection of members used to support load application devices shall be deducted from total deflection.

6.2 VERTICAL LOADING—After removal of the horizontal load, a vertical load shall be applied to the top of the ROPS. There are no limitations on the manner of distributing this load on the ROPS unless specifically indicated in section 8. Figs. 6-10 show typical vertical loadings. Note that Fig. 6 is loading by *mass* and the others loading by *force*. As requirements are mass based, it is necessary to relate force and mass. The correct relation is newtons = 9.80665 kg, 9.80665 m/s^2 being the gravitational acceleration at the standard conditions of sea level, 45 deg latitude (see SAE J916).



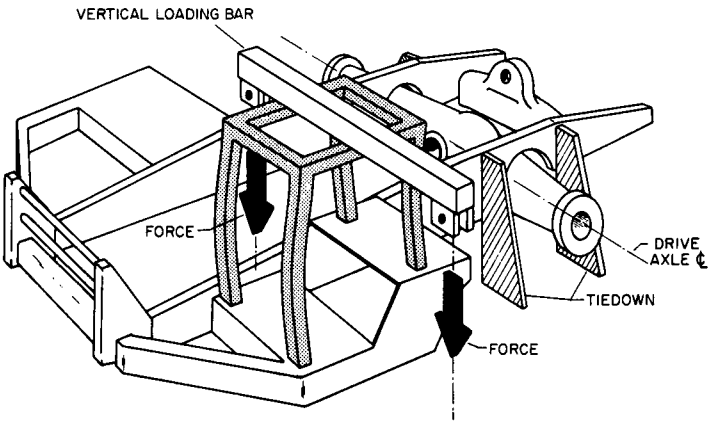
TYPICAL BUT NOT MANDATORY TEST CONFIGURATION

FIG. 8



TYPICAL BUT NOT MANDATORY

FIG. 9



TYPICAL BUT NOT MANDATORY TEST CONFIGURATION

FIG. 10

7. TEMPERATURE-MATERIAL REQUIREMENTS–These requirements shall be met by either performing the horizontal and vertical loadings with all ROPS and vehicle 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 vehicle frame and to connect structural parts of the ROPS shall be SAE Grade 5 or 8 (SAE J429 and J995).

7.2 Structural members of the ROPS and the mounts which attach it to the vehicle 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.

TABLE 1 - MINIMUM CHARPY V-NOTCH IMPACT STRENGTHS

Specimen Size, mm	J	ft-lb
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 A 370-68, Standard Methods and Definitions for Mechanical Testing of Steel Products.)

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 dimension, not to include welds.

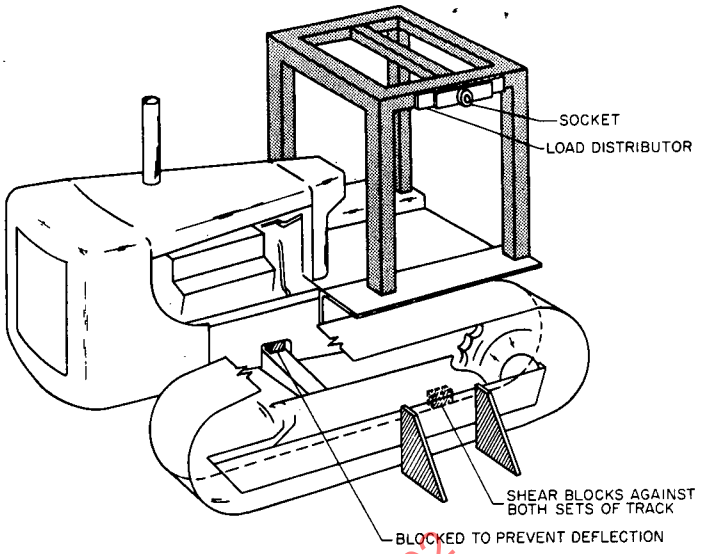
8. VEHICLE DESCRIPTION–ATTACHMENT TO BEDPLATE–FORCE/ENERGY/VERTICAL LOAD REQUIREMENTS

8.1 Force-energy and vertical load requirements shall be met within the deflection(s) permitted by the deflection limiting volume (DLV, SAE J397) 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.

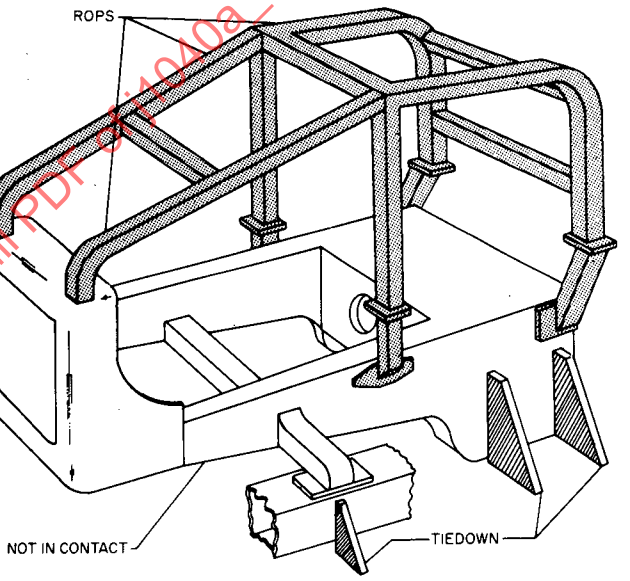
8.3 TRACK-TYPE TRACTORS USED ONLY FOR BULLDOZING, RIPPING, PUSHLOADING, FRONT-END LOADING, LOG SKIDDING, OR PULLING A DRAWBAR LOAD–(See SAE J727, J729, and J731 for description and nomenclature.)

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



TYPICAL BUT NOT MANDATORY TEST CONFIGURATION

FIG. 11



TYPICAL BUT NOT MANDATORY CONFIGURATION

FIG. 12

8.3.2 Requirements for vehicles whose mass is 60 000 kg (132 280 lb) or less are:

Force (side load):

$$F = 70\ 000 \left(\frac{M}{10\ 000}\right)^{1.20} \quad \text{units: N and kg}$$

$$F = 6090 \left(\frac{M}{10\ 000}\right)^{1.20} \quad \text{units: lbf and lb}$$

Energy (side load):

$$U = 13\ 000 \left(\frac{M}{10\ 000}\right)^{1.25} \quad \text{units: J and kg}$$

$$U = 42\ 830 \left(\frac{M}{10\ 000}\right)^{1.25} \quad \text{units: in-lbf and lb}$$

Vertical: The ROPS-vehicle assembly shall support a vertical load of 1M after the side load is removed.

8.3.3 Requirements for vehicles whose mass is greater than 60 000 kg (132 280 lb) are:

Force (side load):

$$F = 420\ 000 \left(\frac{M}{10\ 000}\right)^{0.20} \quad \text{units: N and kg}$$

$$F = 80\ 610 \left(\frac{M}{10\ 000}\right)^{0.20} \quad \text{units: lbf and lb}$$

Energy (side load):

$$U = 78\ 000 \left(\frac{M}{10\ 000}\right)^{0.25} \quad \text{units: J and kg}$$

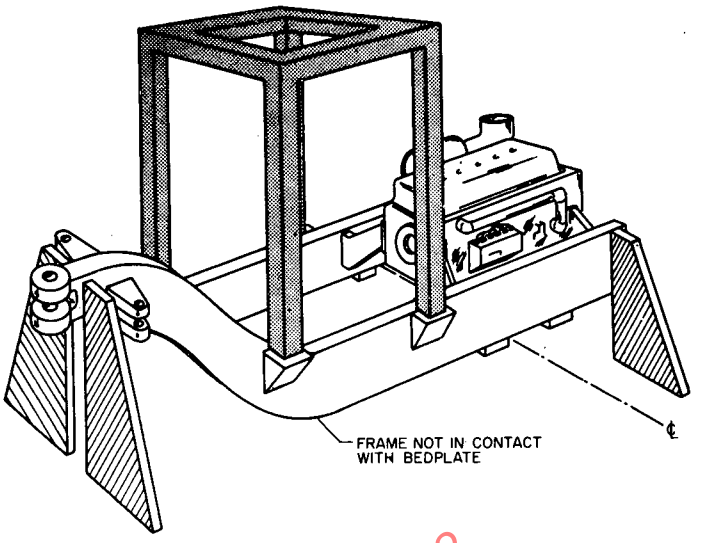
$$U = 566\ 480 \left(\frac{M}{10\ 000}\right)^{0.25} \quad \text{units: in-lbf and lb}$$

Vertical: The ROPS-vehicle assembly shall support a vertical load of 1M after the side load is removed.

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

8.4 PNEUMATIC-TIRED, SELF-PROPELLED MOTOR GRADERS–(See SAE J870 for description and nomenclature.)

8.4.1 For nonarticulated vehicles and articulated vehicles using both frames, connections to the bedplate shall be directly from the vehicle frame at or near the front axle support and the rear drive support. For articulated vehicles, 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 (Figs. 13-16).



TYPICAL BUT NOT MANDATORY TEST CONFIGURATION

FIG. 14

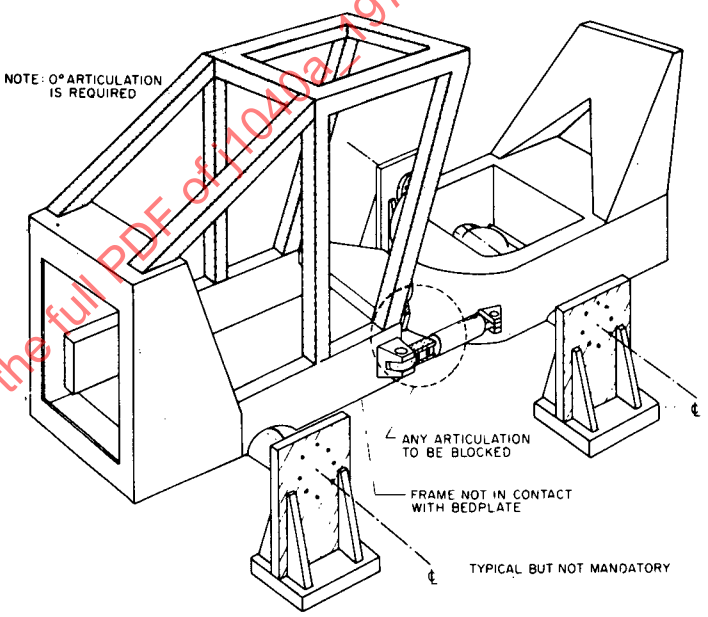


FIG. 15

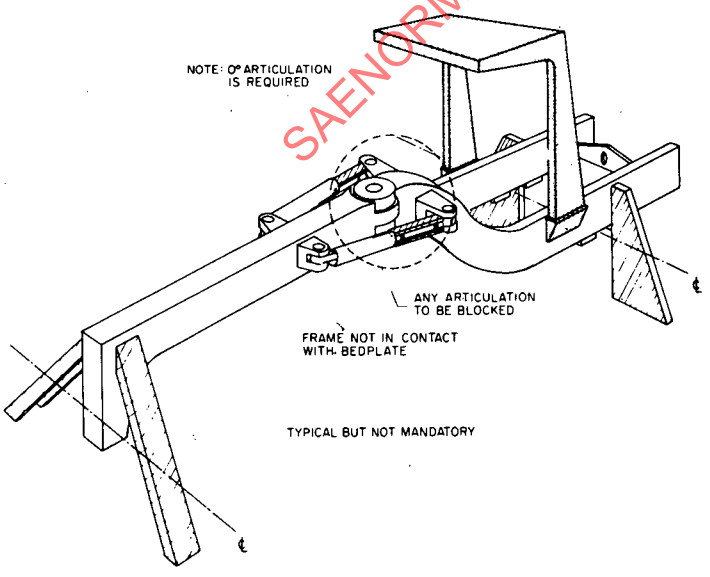


FIG. 13

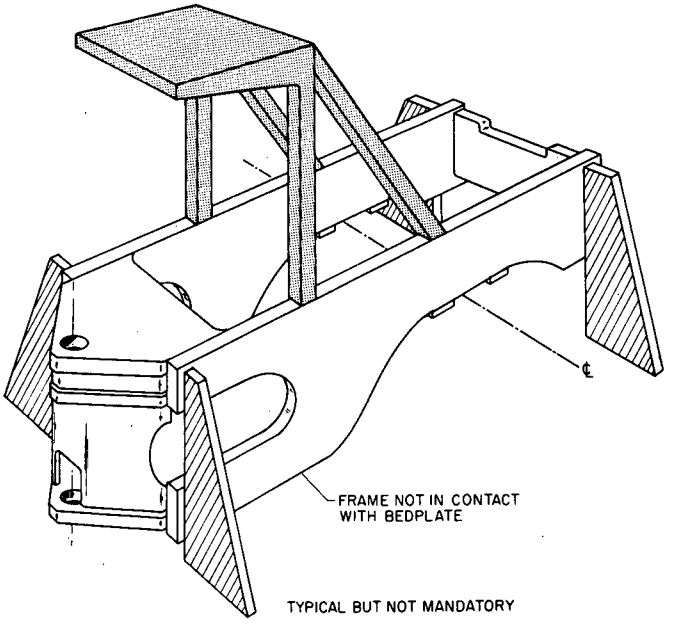


FIG. 16

8.4.2 Requirements for vehicles whose mass is 30 000 kg (66 140 lb) or less are:

Force (side load):

$$F = 70\ 000 \left(\frac{M}{10\ 000}\right)^{1.10} \quad \text{units: N and kg}$$

$$F = 6600 \left(\frac{M}{10\ 000}\right)^{1.10} \quad \text{units: lbf and lb}$$

Energy (side load):

$$U = 15\ 000 \left(\frac{M}{10\ 000}\right)^{1.25} \quad \text{units: J and kg}$$

$$U = 49\ 410 \left(\frac{M}{10\ 000}\right)^{1.25} \quad \text{units: in- lbf and lb}$$

Vertical: The ROPS-vehicle assembly shall support a vertical load of 1M after the side load is removed.

8.4.3 Requirements for vehicles whose mass is greater than 30 000 kg (66 140 lb) are:

Force (side load):

$$F = 210\ 000 \left(\frac{M}{10\ 000}\right)^{0.10} \quad \text{units: N and kg}$$

$$F = 43\ 620 \left(\frac{M}{10\ 000}\right)^{0.10} \quad \text{units: lbf and lb}$$

Energy (side load):

$$U = 45\ 000 \left(\frac{M}{10\ 000}\right)^{0.25} \quad \text{units: J and kg}$$

$$U = 326\ 810 \left(\frac{M}{10\ 000}\right)^{0.25} \quad \text{units: in-lbf and lb}$$

Vertical: The ROPS-vehicle assembly shall support a vertical load of 1M after the side load is removed.

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

8.5 PNEUMATIC-TIRED FRONT-END LOADERS, DOZERS, AND LOG SKIDDERS–(Description and nomenclature being developed.)

8.5.1 For nonarticulated vehicles and articulated vehicles using both frames, connections to the bedplate shall be directly from the vehicle frame at or near the front axle support and the rear drive support. For articulated vehicles, 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 (Figs. 13-16).

8.5.2 Requirements for vehicles whose mass is 60 000 kg (132 280 lb) or less are:

Force (side load):

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

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

Energy (side load):

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

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

Vertical: The ROPS-vehicle assembly shall support a vertical load of 1M after the side load is removed.

8.5.3 Requirements for vehicles whose mass is greater than 60 000 kg (132 280 lb) are:

Force (side load):

$$F = 360\ 000 \left(\frac{M}{10\ 000}\right)^{0.20} \quad \text{units: N and kg}$$

$$F = 69\ 100 \left(\frac{M}{10\ 000}\right)^{0.20} \quad \text{units: lbf and lb}$$

Energy (side load):

$$U = 75\ 000 \left(\frac{M}{10\ 000}\right)^{0.25} \quad \text{units: J and kg}$$

$$U = 544\ 690 \left(\frac{M}{10\ 000}\right)^{0.25} \quad \text{units: in-lbf and lb}$$

Vertical: The ROPS-vehicle assembly shall support a vertical load of 1M after the side load is removed.

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

8.6 PNEUMATIC-TIRED PRIME MOVERS, such as those used to pull scrapers, water wagons, bottom dump wagons, side dump wagons, rear dump wagons, and towed fifth-wheel attachments–(See SAE J869, J728, and J734 for description and nomenclature.)

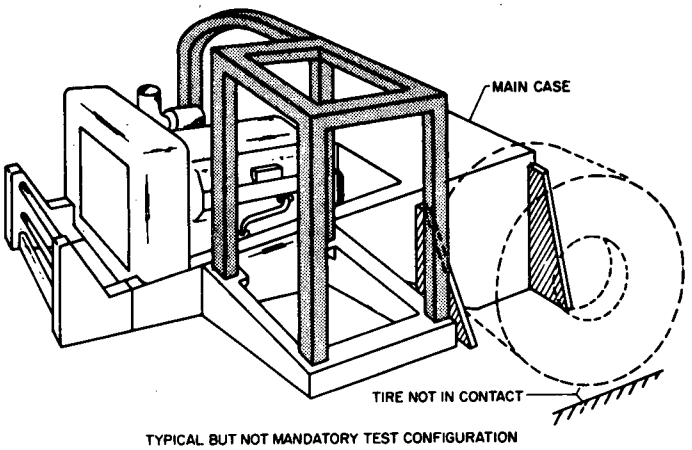
8.6.1 Connection to the bedplate shall be directly from the vehicle frame (or case) at or near the drive tire or axle connection. (For prime movers that are adaptations of another basic vehicle–that is, trucks, wheel tractors, etc.–the attachment shall be as specified under the ROPS criteria for the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

8.6.2 Requirements for vehicles whose mass is 35 000 kg (77 160 lb) or less are:

Force (side load):

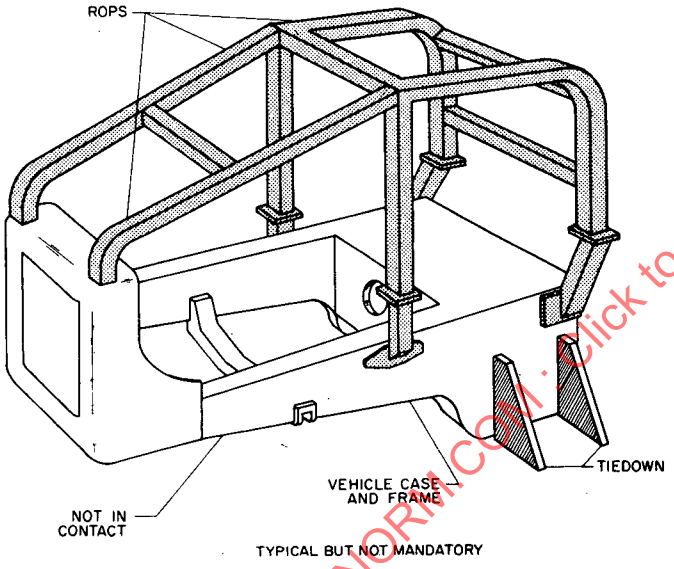
$$F = 95\ 000 \left(\frac{M}{10\ 000}\right)^{1.20} \quad \text{units: N and kg}$$

$$F = 8270 \left(\frac{M}{10\ 000}\right)^{1.20} \quad \text{units: lbf and lb}$$



TYPICAL BUT NOT MANDATORY TEST CONFIGURATION

FIG. 17



TYPICAL BUT NOT MANDATORY

FIG. 18

Energy (side load):

$$U = 20\ 000 \left(\frac{M}{10\ 000}\right)^{1.25} \quad \text{units: J and kg}$$

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

Vertical: The ROPS-vehicle assembly shall support a vertical load of 1M after the side load is removed.

8.6.3 Requirements for vehicles whose mass is greater than 35 000 kg (77 160 lb) are:

Force (side load):

$$F = 332\ 500 \left(\frac{M}{10\ 000}\right)^{0.20} \quad \text{units: N and kg}$$

$$F = 63\ 820 \left(\frac{M}{10\ 000}\right)^{0.20} \quad \text{units: lbf and lb}$$

Energy (side load):

$$U = 70\ 000 \left(\frac{M}{10\ 000}\right)^{0.25} \quad \text{units: J and kg}$$

$$U = 508\ 380 \left(\frac{M}{10\ 000}\right)^{0.25} \quad \text{units: in-lbf and lb}$$

Vertical: The ROPS-vehicle assembly shall support a vertical load of 1M after the side load is removed.

8.6.4 M in the above equations is the vehicle manufacturer's maximum recommended mass of the prime mover.

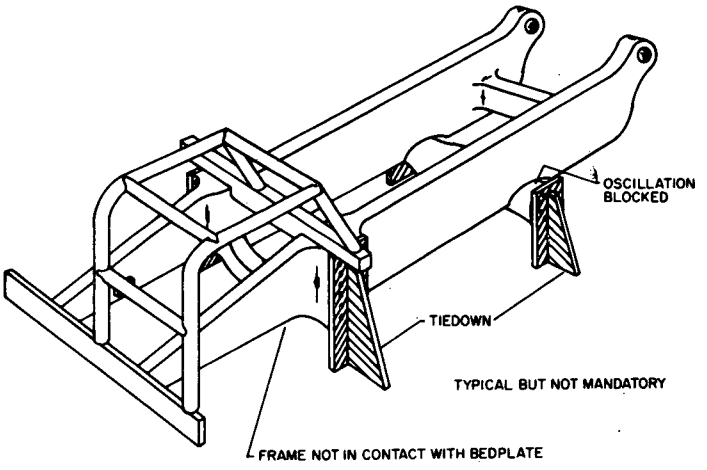
8.7 PNEUMATIC-TIRED, OFF-HIGHWAY, NON-TRAILED HAULING UNITS WITH REAR OR SIDE DUMP BODIES—(Description and nomenclature being developed.)

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 verticle load of 1M less the body tare mass.

8.7.4 For a body only, side load force-energy requirements indicated by the equations of paragraph 8.7.8 shall be met.



TYPICAL BUT NOT MANDATORY

FIG. 19

After meeting these requirements, the body canopy shall support a vertical load of 1M.

8.7.5 When both ROPS and body are used, the side load 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 each member shall be as specified in paragraphs 8.7.3 and 8.7.4, respectively.