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

Foreword—This document has been replaced by J/ISO 3471.

1. Scope—This SAE Standard applies to the following off-road work machines of mass greater than 700 kg that are commonly used in earthmoving, construction, logging, and mining applications as identified in SAE J1116 JUN86 and designed for an-board, seated operator:

a. Crawler tractors and loaders (see SAE J1057 SEP88 Sections 3.1 and 7.1 and SAE J727 JAN86 for description and nomenclature).
b. Graders (see SAE J1057 SEP88 Section 6 and SAE J870 JUL84 for description and nomenclature).
c. Wheel loaders, wheel tractors, and their modifications used for rolling or compacting, dozer equipped wheel tractors, wheel log skidders, skid steer loaders, and backhoe loaders (see SAE J1057 SEP88 Sections 3.2, 7.2, and 9 for description and nomenclature).
d. Wheel industrial tractors (see SAE J1092 JUN86 for description and nomenclature).
e. Tractor portion of semi-mounted scrapers, water wagons, articulated steer dumpers, bottom dump wagons, side dump wagons, rear dump wagons, and towed fifth wheel attachments (see SAE J1057 SEP88 Sections 4.1.1.4, 4.1.2, 4.2.1.1, 4.3.1.2, 4.3.1.3, 4.3.2, and 5 and SAE J869 JUL90 and SAE J728 JUL90 for description and nomenclature).
f. Rollers and compactors (see SAE J1017 JAN86 for description and nomenclature).
g. Rigid frame dumpers with full mounted bodies (see SAE J1057 SEP88 Sections 4.1.1.1, 4.1.1.2, 4.1.1.3, 4.1.1.5, and 4.3.1.1 and SAE J1016 JUL90 for description and nomenclature).

NOTE—Additional machine types listed in SAE J1116 JUN86 may utilize these ROPS performance criteria if so directed by other SAE reports such as SAE J1042 JUN93. SAE J1194 MAY89 and SAE J2194 JUN93 cover agricultural tractors (defined in SAE J1150 OCT92).

EXCLUSIONS—Machines whose use is predominantly, or entirely, in manufacturing plants and/or warehouses are specifically excluded. Rough terrain forklifts, 360 degree rotation excavators, and excavator based machines are also excluded along with rollover protection for the operator of an attachment with an alternate seat position from that used for mobile operation (for example, an attachment backhoe).

1.1 Purpose—This document establishes a consistent, repeatable means of evaluating the load-carrying characteristics of ROPS under static loading and prescribes performance requirements of a representative specimen under such loading.

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2. References

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply.

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

SAE J154 JUN92—Operator Enclosures Human Factor Design Considerations
SAE J231 JAN81—Minimum Performance Criteria for Falling Object Protective Structure (FOPS)
SAE J397 APR88—Deflection Limiting Volume—ROPS/FOPS Laboratory Evaluation
SAE J429 AUG83—Mechanical and Material Requirements for Externally Threaded Fasteners
SAE J727 JAN86—Nomenclature—Crawler Tractor
SAE J728 JUL90—Component Nomenclature—Scrapers
SAE J869 JUL90—Component Nomenclature—Construction Two- and Four-Wheel Tractors
SAE J870 JUL90—Component Nomenclature—Graders
SAE J995 JUN79—Mechanical and Material Requirements for Steel Nuts
SAE J1016 JUL90—Component Nomenclature—Dumpers
SAE J1017 JAN86—Nomenclature—Rollers and Compactors
SAE J1042 JUN93—Operator Protection for General Purpose Industrial Machines
SAE J1043 SEP87—Performance Criteria for FOPS on General Purpose Industrial Machines
SAE J1057 SEP88—Identification Terminology of Earthmoving Machines
SAE J1092 JUN86—Nomenclature—Industrial Tractors (Wheel)
SAE J1116 JUN86—Categories of Off-Road Self-Propelled Work Machines
SAE J1119 DEC88—Steel Products for Rollover Protective Structures (ROPS) and Falling Object Protective Structures (FOPS)
SAE J1150 OCT92—Terminology for Agricultural Equipment
SAE J1164 JAN91—Labeling of ROPS and FOPS
SAE J1194 MAY89—Rollover Protective Structures (ROPS) for Wheeled Agricultural Tractors
SAE J1199 SEP83—Mechanical and Material Requirements for Metric Externally Threaded Steel Fasteners
SAE J2194 JUN93—Rollover Protective Structures (ROPS) for Wheeled Agricultural Tractors

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

ASTM A 370—Standard Methods and Definitions for Mechanical Testing of Steel Products

2.1.3 ISO PUBLICATIONS—Available from ANSI, 25 West 43nd Street, New York, NY 10036-8002.

ISO 898/1—Mechanical properties of fasteners—Part 1: Bolts, screws and studs
ISO 898/2—Mechanical properties of fasteners—Part 2: Nuts with specified proof load values
ISO 3164—Earth-moving machinery—Laboratory evaluations of roll-over and falling-object protective structures—Specification for the deflection-limiting volume
ISO 3471—Earth-moving machinery—Roll-over protective structures—Laboratory tests and performance requirements
ISO 3471/1-1986—Earthmoving machinery—Roll-over protective structures—Laboratory test and performance requirements—Part 1: Crawler, wheel loaders and tractors, backhoe loaders, graders, tractor scrapers, articulated steer dumpers

3. Definitions

3.1 Bedplate—A substantially rigid part of the testing fixture to which the machine frame is attached for the purpose of the test.

3.2 DLV—Deflection Limiting Volume, defined in SAE J397 APR88.

3.3 FOPS—A Falling Object Protective Structure complying with SAE J231 JAN81 or SAE J1043 SEP87, as appropriate.

3.4 Machine Frame—Main chassis or main load bearing member(s) of the machine which extend(s) over a major portion of the machine and upon which the ROPS is directly mounted.

3.5 Maximum Recommended Mass, M—The manufacturer's maximum recommended mass including attachments in operating condition with all reservoirs full to capacity, tools, and ROPS; exclusive of towed equipment such as rollers, compactors, and drawn scrapers.

For the tractor portion of semi-mounted scrapers, water wagons, articulated steer dumpers, bottom dump wagons, side dump wagons, rear dump wagons, and towed fifth wheel attachments, M is the manufacturer's maximum recommended mass of the tractor portion (prime mover) only. Kingpins, hitches, and articulated steering components that attach to hitches or towed units are excluded from the mass of these machines.

For rigid frame dumpers, M excludes the mass of the dump body and the payload when the "ROPS only" criteria are selected. When the "body only" criteria are selected, M includes the mass of the dump body but excludes the mass of the payload.

Soil, mud, rocks, branches, debris, etc., that commonly adhere to or lie on machines in use are not considered as part of the mass of any machine. Material dug, carried, or handled in any manner is not to be considered part of the machine mass in determining test requirements.

3.6 Representative Specimen—A ROPS, mounting hardware, and machine frame (complete or partial) for testing purposes, that is within the manufacturer's specifications.

3.7 Rollbar ROPS—A one- or two-post ROPS without a FOPS or any cantilevered load-carrying structural members.

3.8 Rollover Protective Structure (ROPS)—A system of structural members whose primary purpose is to reduce the possibility of a seat-belted operator being crushed should the machine roll over. Structural members include any subframe, bracket, mounting, socket, bolt, pin, suspension, or flexible shock absorber used to secure the system to the machine frame, but excludes mounting provisions that are integral with the machine frame.

3.9 Simulated Ground Plane (SGP)—The flat surface on which a machine, after rolling over, is assumed to come to rest.

3.9.1 LATERAL SIMULATED GROUND PLANE (LSGP)—For a machine coming to rest on its side, the plane is determined as follows (see Figure 1):

a. Upper ROPS member to which the lateral load is applied.
b. Outermost point in the end view of the above member.
c. Vertical line through the above point.
d. Vertical plane parallel to machine longitudinal centerline through the above line.
e. Rotate plane described in (d), 15 degrees away from the DLV about the horizontal axis within the plane established in (d) passing through the point described in (b). This establishes the LSGP. LSGP is established on an unloaded ROPS and shall move with the member to which load is applied while maintaining its 15 degree angle with respect to the vertical.

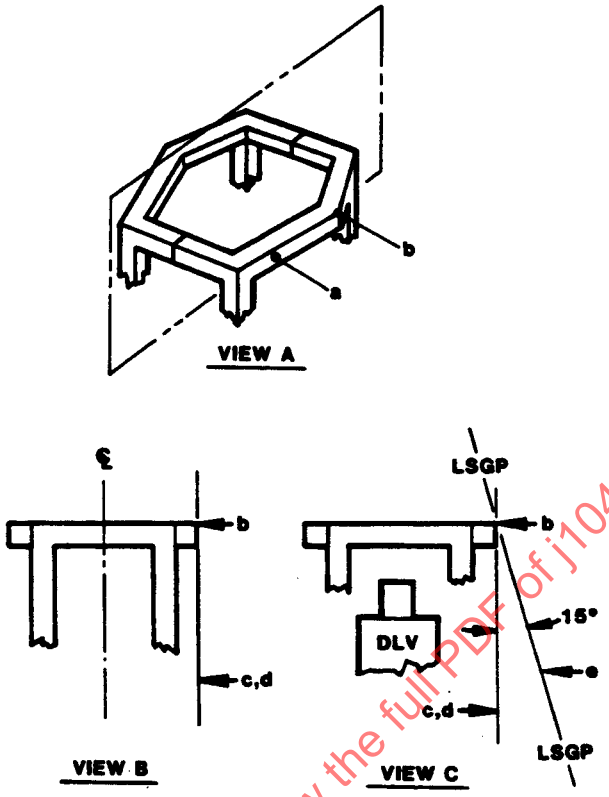

FIGURE 1—DETERMINATION OF LATERAL SIMULATED GROUND PLANE (LSGP)
(Refer to 3.9.1 for description of a, b, c, d, e)

3.9.2 VERTICAL SIMULATED GROUND PLANE (VSGP)—The VSGP applies only to Rollbar ROPS. For a machine coming to rest in an upside-down attitude, the plane is defined by the top crossmember of the ROPS and that front (rear) part of the machine likely to come in contact with flat ground at the same time as the ROPS and capable of supporting the upside-down machine. The VSGP shall move with the deformed ROPS. See Figure 2.

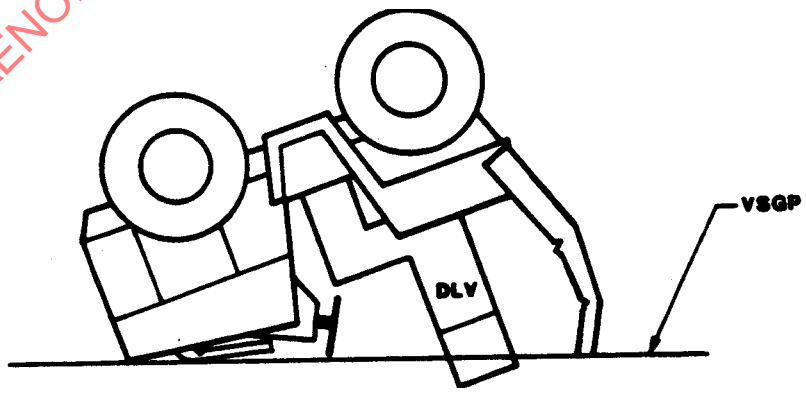

FIGURE 2—INTRUSION OF VERTICAL SIMULATED GROUND PLANE (VSGP) INTO THE DLV

4. Methods and Facilities

4.1 General—The following points are explicitly stated to aid in understanding underlying principles, intention, and application: The requirements are force resistance in the lateral, vertical, and longitudinal directions and energy absorption in the lateral direction. There are limitations on deflections under the lateral, vertical, and longitudinal loading. The energy requirement and limitations on deflection (DLV) under lateral 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.

This evaluation procedure will not necessarily duplicate structural deformations due to a given actual roll. However, specific requirements are derived 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. Therefore, it is expected that crush protection for a seat-belted operator will be assured under at least the following conditions: An initial forward velocity of 0 to 16 km/h on a hard clay surface of 30 degree maximum slope, 360 degree of roll about the machine longitudinal axis without losing contact with the slope.

4.2 Instrumentation—Systems used to measure mass, force, and deflection shall have the capabilities shown in Table 1:

Table 1—INSTRUMENTATION CAPABILITIES

Means to Measure	Accuracy
Machine Mass	±5% of maximum pass
Deflections of ROPS	±5% of maximum deflection
Force on ROPS	±5% of maximum 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.	

4.3 Test Facilities—Fixtures must be adequate to secure the ROPS/machine frame assembly to a bedplate and to apply the required lateral, vertical, and longitudinal loads as determined by the formulas of Table 2. Typical installations are shown in Figures 3 to 9.

4.4 ROPS/Machine Frame Assembly and Attachment to Bedplate

4.4.1 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 mounted ROPS test specimen must represent the structural configuration of an operating installation. All normally detachable windows, panels, doors, and other nonstructural elements shall be removed so that they do not contribute to or detract from the structural evaluation.

4.4.2 The ROPS/machine frame assembly shall be secured to the bedplate so that the members connecting the assembly and bedplate experience minimal deflection during testing. The ROPS/machine frame assembly shall not receive any support from the bedplate, other than that due to the initial attachment.

4.4.3 The test shall be conducted with any machine/ground suspension elements blocked externally so that they may not contribute to the load/deflection behavior of the test specimen. Suspension elements used to attach the ROPS to the machine frame and acting as a load path shall be in place and functioning at the start of the test.

Table 2—FORCE AND ENERGY EQUATIONS

Machine Classification	Machine Mass (kilograms)	Lateral Load Force (Newtons)	Lateral Load Energy (Joules)	Vertical Load Force (Newtons)	Longitudinal Load Force (Newtons)
Crawler tractors and loaders	700 to 4630	6 M	13 000(M/10 000)$^{1.25}$	19.61 M	4.8 M
	4630 to 59 500	70 000(M/10 000)$^{1.2}$	13 000(M/10 000)$^{1.25}$	19.61 M	56 000(M/10 000)$^{1.2}$
	>59 500	10 M	2.03 M	19.61 M	8 M
See Section 1(a)					
Graders	700 to 2140	6 M	15 000(M/10 000)$^{1.25}$	19.61 M	4.8 M
	2140 to 38 010	70 000(M/10 000)$^{1.1}$	15 000(M/10 000)$^{1.25}$	19.61 M	56 000(M/10 000)$^{1.1}$
See Section 1(b)	>38 010	8 M	2.09 M	19.61 M	6.4 M
Wheel loaders, wheel tractors and their modifications used for rolling or compacting, dozer equipped wheel tractors, wheel log skidders, skid steer loaders, and backhoe loaders	700 to 10 000	6 M	12 500(M/10 000)$^{1.25}$	19.61 M	4.8 M
	10 000 to 128 600	60 000(M/10 000)$^{1.2}$	12 500(M/10 000)$^{1.25}$	19.61 M	48 000(M/10 000)$^{1.2}$
	>128 600	10 M	2.37 M	19.61 M	8 M
See Section 1(c)					
Wheel industrial tractors	700 to 10 000	6 M	12 500(M/10 000)$^{1.25}$	19.61 M	4.8 M*
	10 000 to 128 600	60 000(M/10 000)$^{1.2}$	12 500(M/10 000)$^{1.25}$	19.61 M	48 000(M/10 000)$^{1.2}$*
See Section 1(d)	*Energy absorption must exceed 1.4 M Joules for longitudinal load				
Tractor portion of semi-mounted mounted scrapers, water wagons, articulated steer dumpers, bottom dump wagons, side dump wagons, rear dump wagons, and towed fifth wheel attachments	700 to 1010	6 M	20 000(M/10 000)$^{1.25}$	19.61 M	4.8 M
	1010 to 32 160	95 000(M/10 000)$^{1.2}$	20 000(M/10 000)$^{1.25}$	19.61 M	76 000(M/10 000)$^{1.2}$
	>32 160	12 M	2.68 M	19.61 M	9.6 M
See Section 1(e)					
Rollers and compactors	700 to 10 000	5 M	9500(M/10 000)$^{1.25}$	19.61 M	4 M
	10 000 to 53 780	50 000(M/10 000)$^{1.2}$	9500(M/10 000)$^{1.25}$	19.61 M	40 000(M/10 000)$^{1.2}$
See Section 1(f)	>53 780	7 M	1.45 M	19.61 M	5.6 M
Rigid frame dumpers	700 to 1750	6 M	15 000(M/10 000)$^{1.25}$	19.61 M	4.8 M
	1750 to 22 540	85 000(M/10 000)$^{1.2}$	15 000(M/10 000)$^{1.25}$	19.61 M	68 000(M/10 000)$^{1.2}$
ROPS only option	22 540 to 58 960	10 M	1.84 M	19.61 M	8 M
	58 960 to 111 660	413 500(M/10 000)$^{0.2}$	61 450(M/10 000)$^{0.32}$	19.61 M	330 800(M/10 000)$^{0.2}$
See Section 1(g)	>111 660	6 M	1.19 M	19.61 M	4.8 M
Rigid frame dumpers	700 to 10 000	6 M	6000(M/10 000)$^{1.25}$	19.61 M	4.8 M
	10 000 to 21 610	60 000(M/10 000)$^{1.2}$	6000(M/10 000)$^{1.25}$	19.61 M	48 000(M/10 000)$^{1.2}$
M = Maximum recommended mass (kg) as defined in 3.5.					

Table 2—FORCE AND ENERGY EQUATIONS (continued)

Machine Classification	Machine Mass (kilograms)	Lateral Load Force (Newtons)	Lateral Load Energy (Joules)	Vertical Load Force (Newtons)	Longitudinal Load Force (Newtons)
Body only option	21 610 to 93 900	7 M	0.73 M	19.61 M	5.6 M
	93 900 to 113 860	$420\,000(M/10\,000)^{0.2}$	$16\,720(M/10\,000)^{0.63}$	19.61 M	$336\,000(M/10\,000)^{0.2}$
See Section 1(g)	>113 860	6 M	0.68 M	19.61 M	4.8 M

Rigid frame dumpers Combination of ROPS and Body Option See Section 1(g)	When both ROPS and body are used, the lateral loading force and energy requirements and the longitudinal loading force for each shall be 60% of those indicated by the equations for the ROPS only or body only option respectively. The vertical loading requirements for both ROPS and body shall be 19.61 M. Lateral, longitudinal, 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 six loadings is that the vertical loading of members shall be applied after the lateral loading and the longitudinal loading of members shall be applied after the vertical loading. Figure 9 for further guidance.

M = Maximum recommended mass (kg) as defined in 3.5.

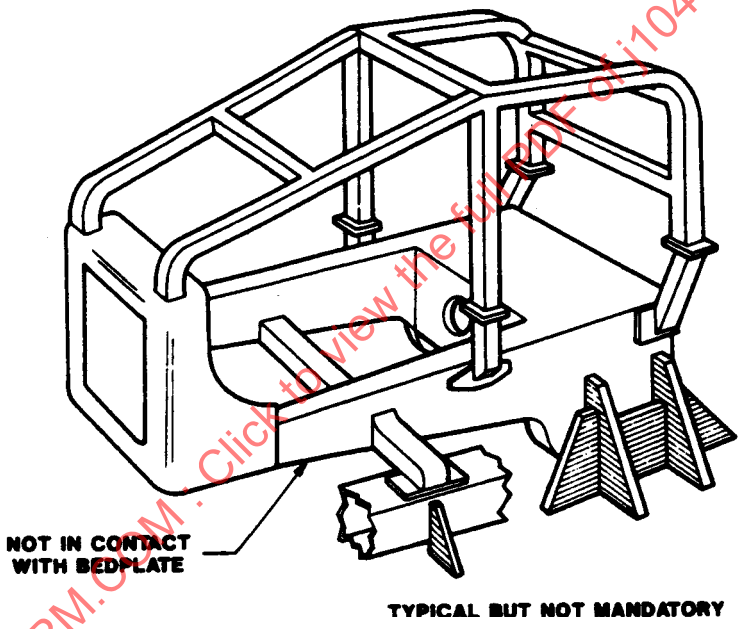

FIGURE 3—TEST BED ANCHORAGE OF TRACK-TYPE TRACTOR

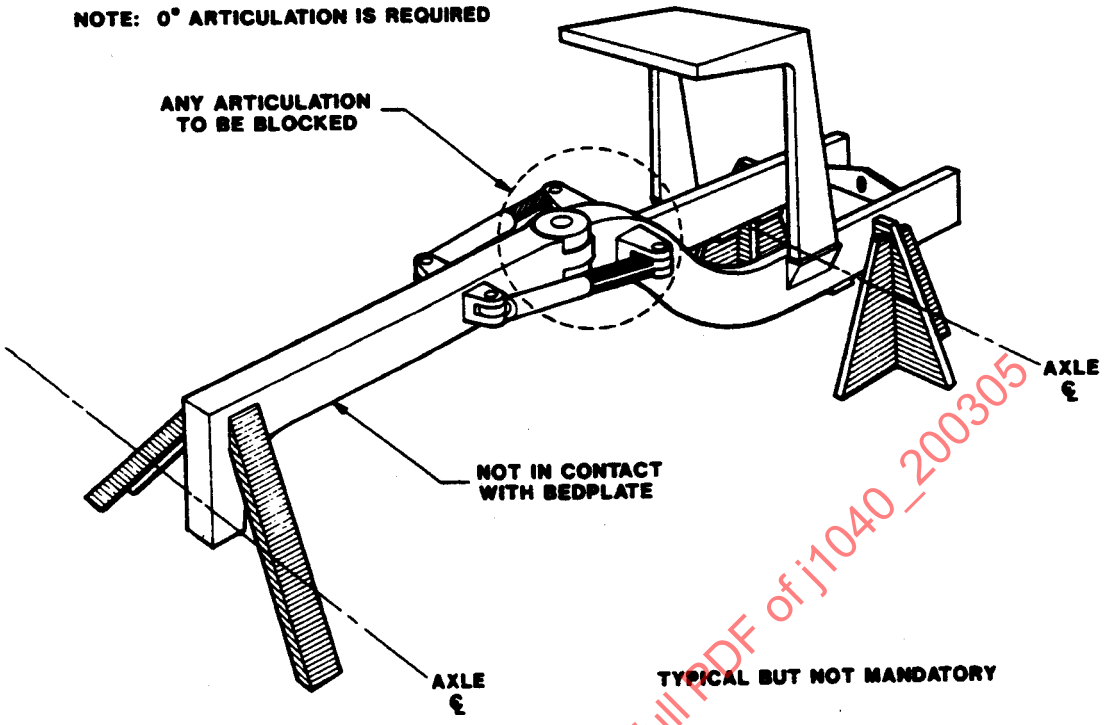

FIGURE 4—ANCHORAGE OF ARTICULATED MOTOR GRADER (Complete Form)

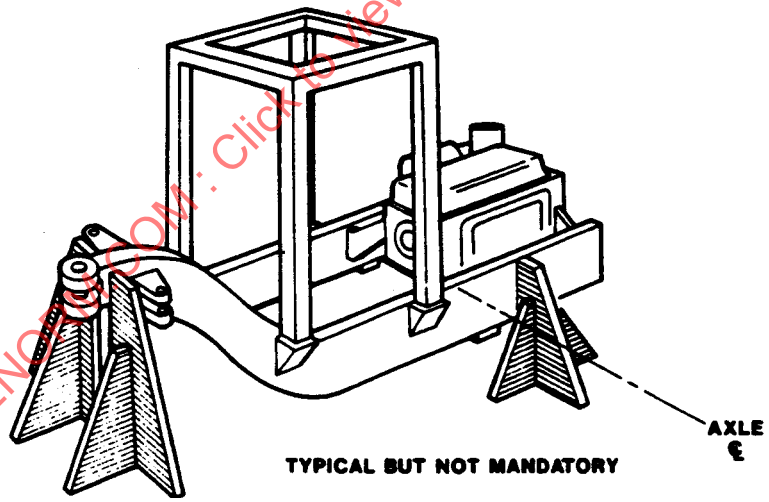

FIGURE 5—TEST BED ANCHORAGE OF HALF AN ARTICULATED FRAME

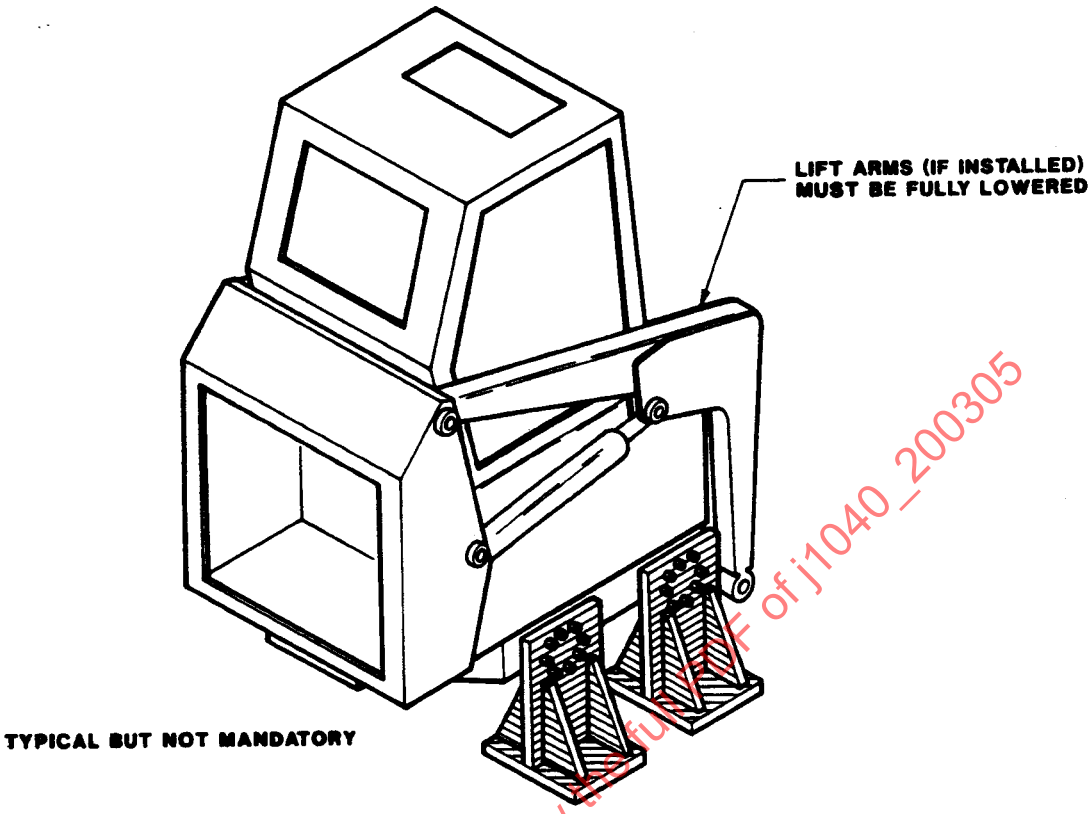

FIGURE 6—ANCHORAGE OF SKID STEER LOADER

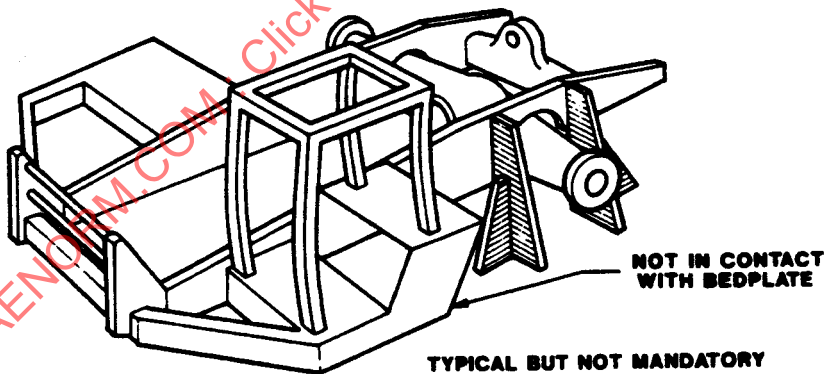

FIGURE 7—TEST BED ANCHORAGE OF TRACTOR PORTION (Prime Mover)

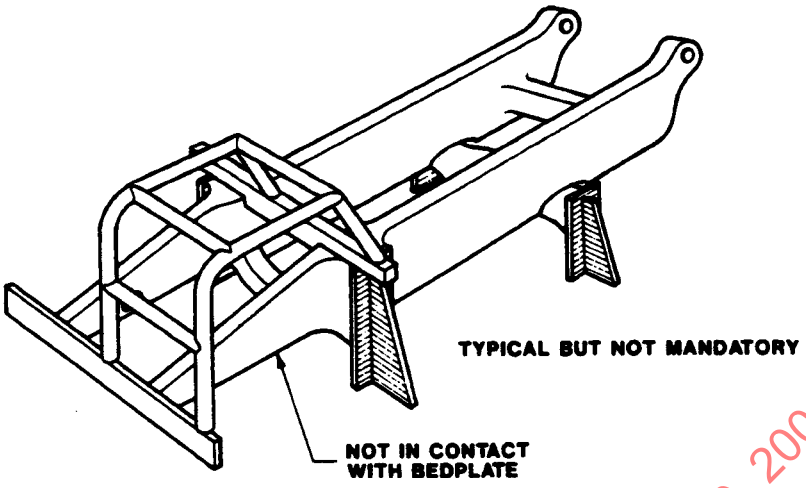

FIGURE 8—ANCHORAGE OF DUMPER FRAME—ROPS ONLY OPTION

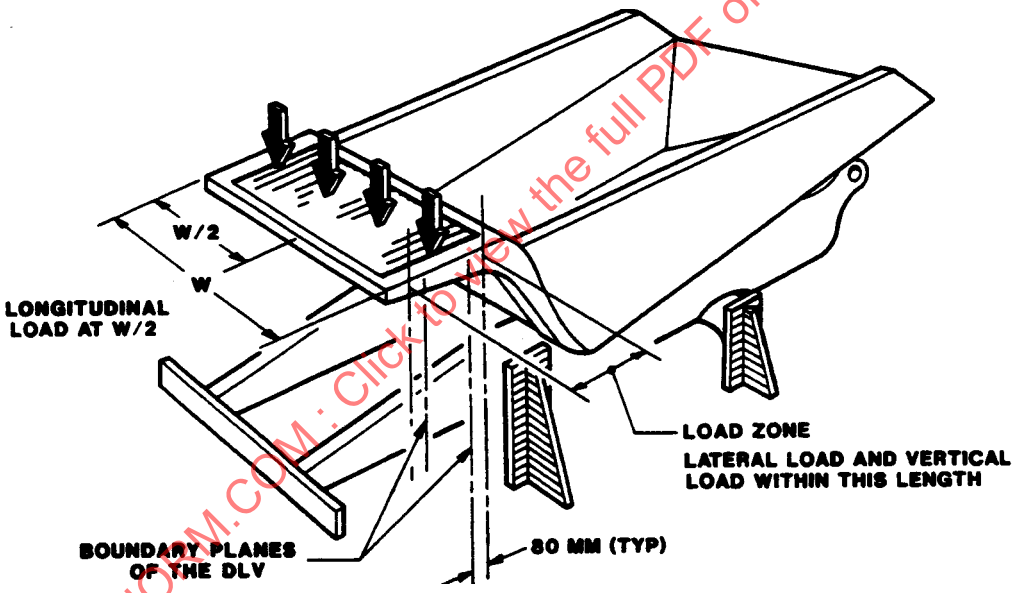

FIGURE 9—LOADING OF DUMPER BODY ONLY OPTION

4.4.4 For nonarticulated machines and articulated machines using both frames, connections to the bedplate shall be directly from the machine frame at or near the front and rear axle supports, or equivalent. 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 articulation joint and axle support (or alternatively at the extreme end of the frame). For single axle prime movers, the support shall be at the drive axle (see Figure 7). Crawler tractors and crawler loads shall be connected to the bedplate through the main housing and/or track frames. See Figure 3 and Figure 13.

5. Loading Procedure

5.1 General

a. All load application points must be identified and marked on the structure before any loading is applied.
b. The loading sequence shall be lateral, vertical, then longitudinal (exception: wheel-industrial tractors shall be lateral, longitudinal, then vertical).
c. No straightening or repair is permitted during or between loading phases.
d. A load-distribution device may be used to prevent localized penetration. It must not impede rotation of the ROPS.

5.2 Lateral Loading

5.2.1 Load distribution devices may not distribute the load over a distance greater than 80% of the length L, defined as follows: For a one- or two-post ROPS with a FOPS and/or cantilevered load-carrying structural members, the length L is that portion of the cantilevered load-carrying members which predominantly covers the operator. It is measured from the extreme face of the ROPS post(s) to the far end of the cantilevered load carrying members (Figure 10). For all other ROPS, the length L is the total longitudinal distance between the outsides of the front and rear posts (Figure 11).

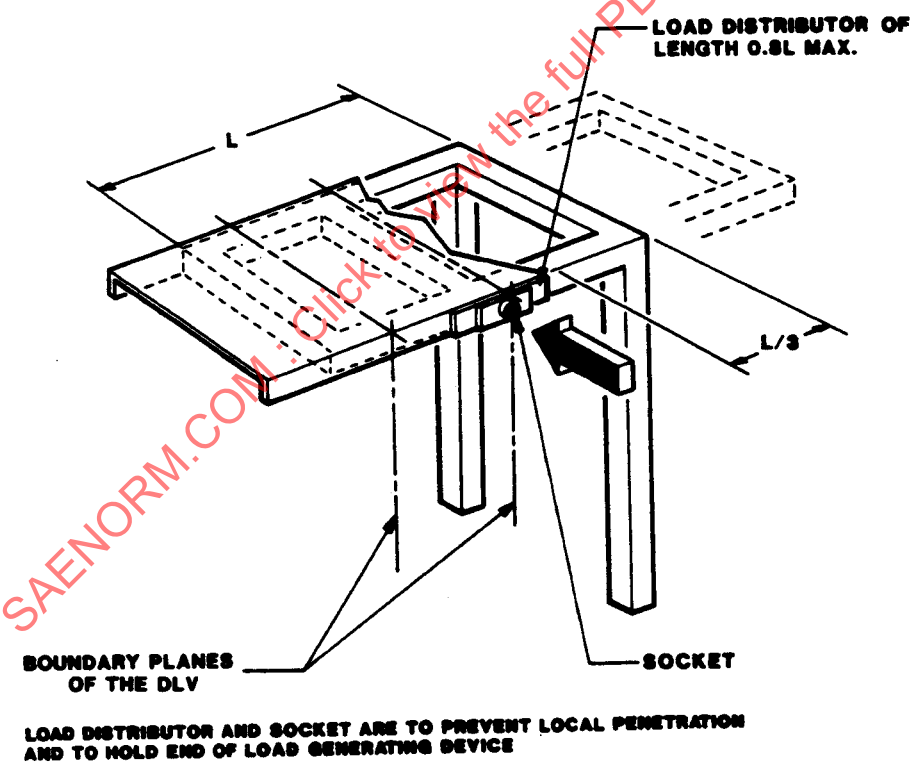

FIGURE 10—TWO-POST ROPS WITH FOPS LATERAL LOAD APPLICATION POINT

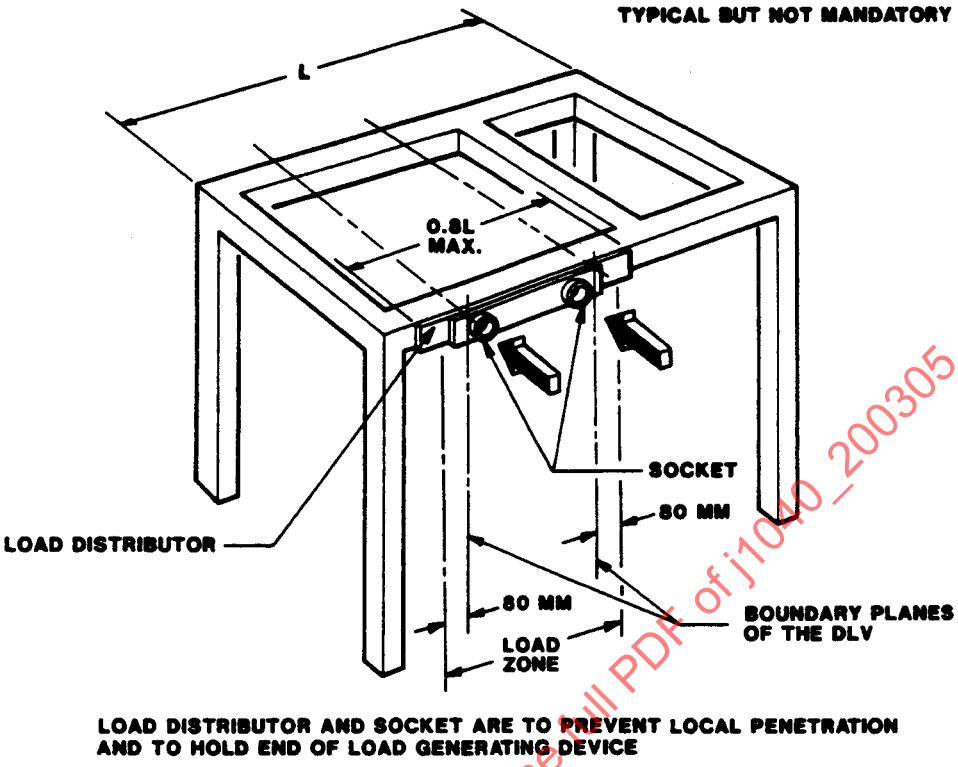

FIGURE 11—FOUR-POST ROPS LATERAL LOAD APPLICATION POINT

5.2.2 For a Rollbar ROPS, the load application point shall be in line with the upper lateral crossmember.

5.2.3 For all other one- and two-post ROPS, initial loading shall be dictated by the length L and vertical projections of the front and rear planes of the DLV. The load application point shall not be within L/3 from the one- or two-post structure. Should the L/3 point be between the vertical projection of the DLV and the one- or two-post structure, the load-application point shall move away from the structure until it enters the vertical projection of the DLV (Figure 10).

5.2.4 For ROPS of more than two posts, the load application point shall be located between vertical projections of planes 80 mm outside of the front and rear boundary planes of the DLV (Figure 11).

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

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

5.2.7 The rate of deflection shall be such that the loading can be considered static. At deflection increments no greater than 15 mm (at the point of application of the resultant load), the values of force and deflection are to be recorded. This loading is to continue until the ROPS has achieved both the force and energy requirements. See Figure 12 for method of calculating energy. The deflection used in calculating energy is to be that of the ROPS along the line of action of the force. Any deflection of members used to support load application devices shall not be included in the total deflection.

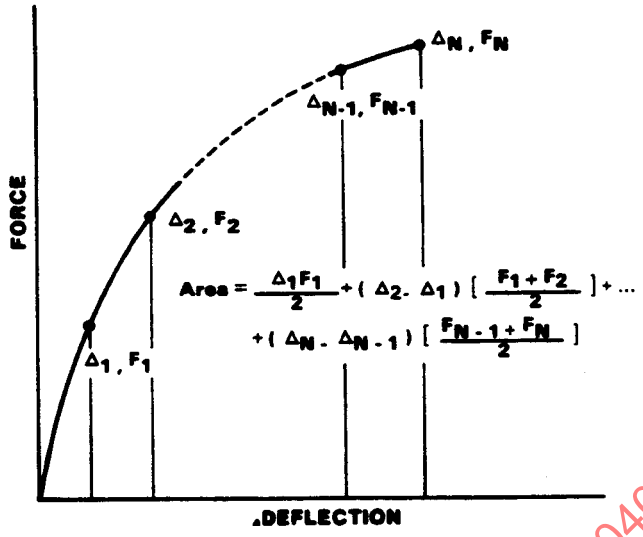

FIGURE 12—ENERGY EQUATION

5.3 Vertical Loading—After removal of the lateral load, a vertical load shall be applied to the top of the ROPS (exception: wheel-industrial tractors shall have longitudinal load applied prior to vertical loading, refer to 5.4).

5.3.1 For a Rollbar ROPS, the vertical load shall be applied in the same plane on the undeformed structure as the lateral load of 5.2.2. For all other one- or two-post structures, the center of the vertical load shall not be applied any nearer to the posts than was the lateral load of 5.2.3.

5.3.2 In no instance is there any further limitation on the manner of distributing this load on the ROPS. Figure 13 shows a typical vertical loading.

5.3.3 The rate of deflection shall be such that the loading can be considered static. Loading is to continue until the ROPS has achieved the force requirement. The structure shall support this load for a period of 5 min or until any deformation has ceased, whichever is shorter.

5.4 Longitudinal Loading—After removal of the vertical load, a longitudinal load shall be applied to the ROPS (exception: wheel-industrial tractors, see 5.4.3(d) for test sequence).

5.4.1 The longitudinal load must be applied at the deformed location of the originally established point, since the lateral (and vertical) loading of the ROPS likely results in permanent deformation of the structure. The load-distribution device may span the width in cases where no rear (front) crossmember exists. In all other cases, the device may not distribute the load over a length greater than 80% of the width W of the ROPS. See Figure 14.

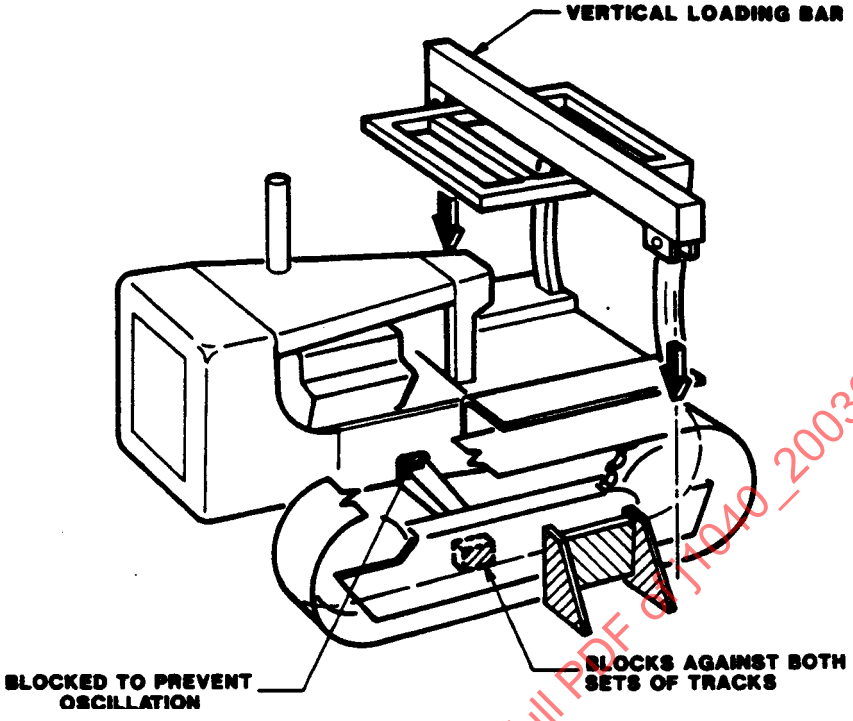

FIGURE 13—VERTICAL LOADING EXAMPLE

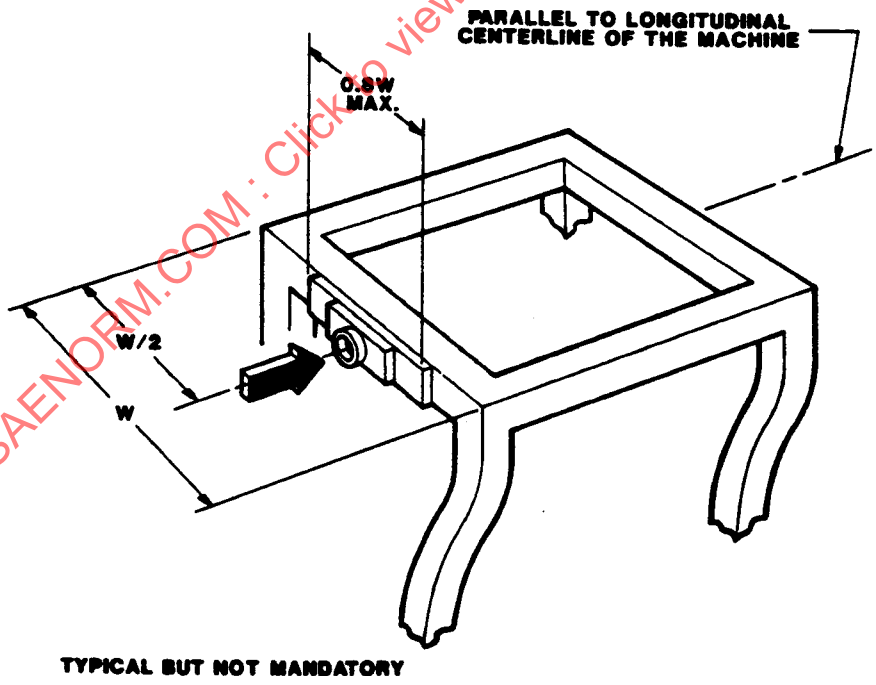

FIGURE 14—FOUR-POST ROPS LONGITUDINAL LOAD APPLICATION POINT (INDUSTRIAL TRACTOR = W/4)

5.4.2 The longitudinal load shall be applied to the upper structural members of the ROPS along the longitudinal centerline of the ROPS, except for wheel-industrial tractors. This machine classification shall have longitudinal (rear) load applied one-quarter of the width W of the ROPS from either rear post.

5.4.3 The direction of loading (fore or aft) must be selected to place the most severe requirements on the ROPS/machine frame assembly. The initial direction of loading shall be horizontal and parallel to the original longitudinal centerline of the machine. Some additional factors to consider in arriving at the direction to apply the longitudinal load are:

a. Location of ROPS relative to DLV and the effect that longitudinal deflection of the ROPS would have on providing crush protection for the operator.
b. Machine characteristics that can limit direction of the longitudinal component of loading on the ROPS.
c. Experience which may indicate the possibility of longitudinal tipping or the tendency of a particular classification of machine to skew as it rotates about a longitudinal axis during an actual rollover as described in 4.1.
d. Wheel-industrial tractors shall have longitudinal load applied from the rear to cover the possibility of a rear upset. For this machine classification only, the test order shall be lateral, longitudinal (rear), then vertical loading. A longitudinal energy requirement also applies (refer to 5.2.7 for guidance and Section 7 for acceptance criteria).

5.4.4 The rate of deflection shall be such that the loading can be considered static. This loading is to continue until the ROPS has achieved the longitudinal requirement(s).

6. Temperature-Material Requirement—In addition to the loading requirements, there is a Temperature-Material requirement to assure that the ROPS will have meaningful resistance to brittle fracture. This requirement may be met by applying the static loadings with all structural members at, or below, –18 °C if materials specifications and procurement assure that materials in ROPS subsequently manufactured will have toughness characteristics similar to those in the tested representative specimen. Alternatively, the requirement may be met by applying the loadings at higher temperature if all ROPS structural members are fabricated from materials that meet the following mechanical requirements. (See SAE J1119 DEC88 for additional information.)

6.1 Bolts and nuts used structurally shall be SAE Grade 5, 7, or 8 (SAE J429 AUG83 and SAE J995 JUN79) or metric property class 8.8, 9.8, or 10.9 bolts (SAE J1199 SEP83 and ISO 898/1) and property class 8, or 10 nuts (ISO 898/2).

6.2 Structural members of the ROPS and the mounts which attach it to the machine frame shall be made of steels that meet or exceed one of the Charpy V-notch (CVN) impact strengths at –30 °C shown in Table 3. (The Charpy V-notch evaluation is primarily a quality control check and the indicated temperature does not directly relate to operating conditions.) 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.

6.3 Steel less than 2.5 mm in thickness with a maximum carbon content of 0.20% shall be considered to meet the Charpy requirement.

7. Acceptance Criteria

7.1 The specific lateral force and energy, vertical load carrying capacity, and the longitudinal requirement(s) are to be met or exceeded in the testing of a single representative specimen. The equations for the various machine classifications are given in Table 2.

Table 3—MINIMUM CHARPY V-NOTCH IMPACT STRENGTHS

Specimen Size, mm	Energy, J
10 x 10 (1)	11.0
10 x 9	10.0
10 x 8	9.5
10 x 7.5[1]	9.5
10 x 7	9.0
10 x 6.7	8.5
10 x 6	8.0
10 x 5[1]	7.5
10 x 4	7.0
10 x 3.3	6.0
10 x 3	6.0
10 x 2.5[1]	5.5

1. Indicates preferred size. Specimen size shall be no less than the largest preferred size that the material will permit. (Reference: ASTM A 370.) More data on specifics of CVN specimen size/test temperature interaction that meet the intent of the basic requirements of Table 3 can be found in SAE J1119 DEC88.

7.2 The force and energy requirements under lateral loading do not need to be attainable simultaneously; accordingly, one may be significantly exceeded before the other is attained. If the force is attained before the energy, the force may decrease but must again attain the required level when the lateral energy requirement is met or exceeded. (Longitudinal loading of wheel-industrial tractors shall also meet the requirements of this section.)

7.3 The limitations on the deflections are absolute; no part of the ROPS shall enter the DLV at any time during the lateral, vertical, or longitudinal loading phases of the test.

7.4 The lateral simulated ground plane (LSGP) shall not enter the DLV (upright mode) at any time during lateral loading phase of the test (except as noted in 7.6). See Figure 1.

7.5 For a Rollbar ROPS only, the vertical simulated ground plane (VSGP) shall not enter the DLV at any time during vertical loading phase of the test. See Figure 2.

7.6 During lateral loading with a side-mounted operator or for longitudinal loading with the operator facing the direction that the ROPS will deflect under load application, it is permissible for the upper portion of the DLV to be rotated "forward" up to 15 degrees about its locating axis (LA) to prevent intrusion of ROPS members (or the LSGP in lateral loading only). Forward rotation of the DLV shall be limited to less than 15 degrees if interference with any machine component or controls occurs at a lesser angle. See Figure 15.