LIGHT VEHICLE ROLLOVER PROTECTION STRUCTURE (ROPS)

TEST PROTOCOL

Contents

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1.0 Overview

This test protocol has been developed by RM Asia – Automotive to apply to internal rollover protection structures (ROPS) intended for fitment to the commercially available light commercial vehicles such as; Ford Ranger, Mazda BT50, Ford Everest, Mitsubishi Triton, Nissan Navara, Toyota Hilux, Toyota Landcruiser, Nissan Patrol.

The protocol has been developed because no existing standard is applicable to this class of vehicle. Rollover standards exist for passenger vehicles, racing vehicles, earth moving machinery and tractors. However, light utility vehicles are not covered by any of these.

Primarily the requirement for ROPS fitment to these vehicles arises when they are used in mining, remote and off road environments typically purchased as fleet vehicles.

The typical ROPS for the class of light commercial vehicles is different from other vehicles because the A pillar hoop is frequently not utilised. In this case, the hoop located at the B pillar protects the front seat occupants by virtue of the occupants head being within a line between the top of the hoop and the top of the front edge of the bonnet.

Additionally, the ROPS for this class of vehicle is mounted inside a unitary body and fixed to the body through mounts on the “feet” as well as seat belt mounts and potentially other additional mounting points. Thus, in a rollover, the ROPS is combining with the structure of the unitary body to enhance the inherent strength of the vehicle.

Crushing elements of the unitary body during the rollover also serves the purpose of absorbing roll energy, so that energy absorption by the ROPS itself is less important than in (say) earthmoving machinery where the ROPS is the first point of contact with the ground.

The guiding principle in the creation of this test protocol has been to distill the relevant elements of existing standards that are relevant to the intended vehicles rather than establish a new one.

The ROPS in these installations are designed to augment the existing cabin strength to reduce the cabin crush and therefore reduce the potential for head injuries in a rollover. It is important to note that compliance with this test protocol does not certify that the vehicles are safe in a rollover situation, or that injury to occupants will be avoided or reduced.

Furthermore, it is important to note that fitment of a ROPS does not in any way reduce the requirement to wear seatbelts, which is the single most important piece of safety equipment in the event of rollover.

2.0 Rationale

The protocol has been created with reference to other similar standards, particularly ISO 3471 and FMVSS 216.

This protocol allows for physical testing only. Finite Element Analysis (FEA) is allowed by some standards for demonstration of acceptability of the ROPS. In the case of ROPS covered by this protocol, FEA analysis has been rejected for the following reasons:

a. Physical testing is relatively easy compared with some other applications
b. Manufacturing variances in the components (eg tube diameter changes associated with bends, heat affected zones from welding, etc) are difficult to model and can have a significant impact on performance.
c. The mounting points of the ROPS are complex to model in FEA and small changes in the assumptions of stiffness imparted to the ROPS frame can have a significant effect on the results.

There are some proponents of dynamic rollover testing. The NHTSA in its recent review of FMVSS 216 notes that these tend to be organizations with established facilities for this type of testing. In its recent review of FMVSS 216, the NHTSA considered and rejected dynamic testing in favour of quasi-static testing for the following reasons:

The primary advantage of a static test procedure is the simplicity and repeatability of the test. It is a well known procedure and modifications or adaptations to perform tests on different ROPS are simple to accomplish.

While quasi-static testing is not representative of real world loading rates, there is correlation between real world performance and quasi-static testing. This was the subject of extensive testing by the NHTSA (see Rains & Van Voorhis, 1998) where dynamic & quasi-static test results were correlated over tests performed on a number of vehicles. Furthermore, they determined that the roof failure modes were identical in both tests.

3.0 Terms & definitions

DLV, Deflection limiting volume is the orthogonal approximation of a 95th percentile US male seated occupant, defined in ISO 3164.

Deflection of ROPS is the combined plastic and elastic movement of the ROPS as measured adjacent at the load application point (LAP) at the point of localized maximum deflection excluding any movement of the test fixtures

FEA, Finite Element Analysis is a numerical technique that allows detailed visualization of where structures bend or twist, and indicates the distribution of stresses and displacements.

LDD, load distribution device is a device used to prevent localized penetration of the ROPS members at the load application point (LAP)

LAP; load application point is a point within a defined range at which the test load force (F) is applied.

Representative specimen is a ROPS complete with all normally supplied mounting hardware that is within the range of material and manufacturing variances designated by the manufacturer's production specifications. The intent is that all ROPS manufactured to these specifications are capable of meeting or exceeding the stated level of performance.

ROPS; rollover protective is a system of mechanical members whose primary purpose is to reduce the possibility of a seat belted vehicle occupant being fatally injured in a vehicle rollover

Hoop; a continuous member of the ROPS that is shaped to follow one of the vehicle pillars (A, B, C or D) from floor to roof, then across the roof and down the corresponding pillar of the other side of the vehicle.

"A" Pillar. The front most roof support pillar containing the windscreen.

"B" Pillar. The second roof support pillar from the front. Between the front & rear doors of a 4 door car

"C" Pillar The third roof support pillar from the front.

Typical mining application ROPS with B & C pillar hoops

4.0 Symbols

F = load force expressed in kilo Newton

GVM = manufacturers specified “gross vehicle mass” in kg

U = energy absorbed by the structure expressed in kilo Joules

Δ = deflection of the ROPS, expressed in mm

g = gravity constant 9.8 m/s^2

5.0 Validation Matrix

Lateral Load Force N	Vertical Load Force N	Longitudinal Load Force N
1.5 x g x GVM	4.0 x g x GVM	1.0 x g x GVM

6.0 Test Methodology

Quasi-static testing has been adopted for this protocol. This protocol follows the US government National Highways Traffic Safety Administration (NHSTA) recommendation of quasi-static testing for the US test standard FMVSS 216. The NHSTA found that a quasi-static test procedure is repeatable and capable of simulating real world deformation patterns. They concluded that dynamic tests can have an undesirable amount of variability in vehicle and occupant kinematics.

The 3 tests are to be conducted on the same ROPS. That is, the second and third tests will be conducted on a deformed structure, except that minor straightening after each test is allowed for the purpose of fitting correctly in the test rig.

6.1 ROPS mounting

The ROPS shall be mounted for the test in a manner that replicates as closely as possible to the manner in which it is fitted to a vehicle. Each mounting plate will be fixed to the test rig in the same location as the mounting bolt points. The method of mounting will be no stronger than the method used in the vehicle (typically grade 8.8 bolts).

Mounting of the ROPS and any test fixtures should not affect the base structure of the ROPS, ie the ROPS may not have fittings welded to it, nor suffer any heat affected zones. The test fittings and / or LDD must not cause localized deformation of the ROPS.

6.2 Lateral loading.

The principal is that the load should be applied as close as possible to the top of the structure in a way that represents the top of the vehicle hitting the ground at the ¼ roll position. The loading point is clear when the top section slopes inward in the car to fit the body shape. The load should be applied across a maximum length of 30% of the total leg length of the hoop of all designs. Where there are 2 hoops the load should be applied to both. There must be provision for articulation of the LDD so that the load distribution is not affected by differential deflections between the hoops.

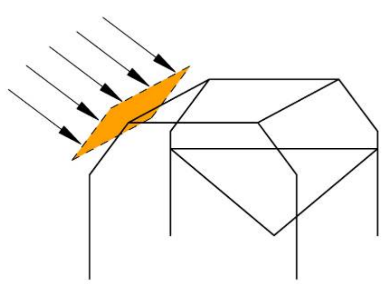
The load application may be complicated by the radius of the ROPS hoops at the top and other components shaped to fit the vehicle interior. The LDD should avoid these components and be constructed in such a way to avoid point loading and local deformation of the tube. The stiffness of the LDD should be high compared with the ROPS.

The initial direction of the lateral loading shall be perpendicular to a straight section of the main hoop upright adjacent to the top bend to the horizontal section.

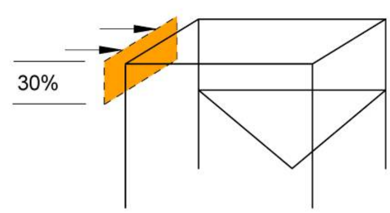
The loading must be applied at less than 5mm/s deflection of the ROPS in order to be considered quasi-static.

The loading is to continue until the specified force level is achieved. The structure shall support this load for a period of 1 minute or until any deflection has ceased, whichever is shorter. The plastic and elastic movement of the ROPS should be measured adjacent at the load application point (LAP) at the point of localized maximum deflection excluding any movement of the test fixtures

The B & C pillar seat belt mounts may not be utilised for this part of the test. This is because the contribution of the body structure to lateral load resistance is indeterminate.



Lateral load (dual cab ROPS shown)



Lateral load (dual cab straight hoop leg ROPS shown)

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6.4 Vertical loading

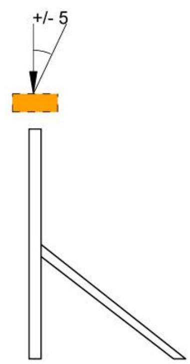
After completion of the lateral loading, a vertical load shall be applied to the top of the ROPS. The ROPS should not be straightened nor any components replaced.

The centre of the vertical load shall be applied symmetrically with both the longitudinal & lateral centrelines of the top of the deformed ROPS. The load should be distributed uniformly along all elements of the ROPS that would contact a horizontal plane laid across the top of the front and rear hoops. There must be provision for articulation of the LDD so that the load distribution is not affected by differential deflections between the hoops.

The vertical load should be applied within +/- 5 degrees of an axis at 90 degrees to the plane of the top of the ROPS (double hoop vehicles) or relative to the roof line of a single hoop vehicle. Therefore, if the hoop is installed in a vehicle at an angle to the roof, the force should not be applied in the plane of the ROPS hoop, but in a manner representative of the rollover impact.

The loading must be applied at less than 5mm/s deflection of the ROPS. The loading is to continue until the specified force level is achieved. The structure shall support this load for a period of 1 minute or until any deflection has ceased, whichever is shorter. The plastic and elastic movement of the ROPS should be measured adjacent at the load application point (LAP) at the point of localized maximum deflection excluding any movement of the test fixtures

The B & C pillar seat belt mounts may not be utilised for this part of the test. This is because the contribution of the body structure to vertical load resistance is indeterminate.



Vertical load (single cab ROPS shown)

6.5 Longitudinal loading

The longitudinal load in the case of ROPS for the class of light commercial vehicles covered by this protocol is different from other vehicles because the A pillar hoop may not be utilised. In this instance, the vehicle's original structure absorbs the longitudinal force during a roll. Therefore the primary requirement for the longitudinal test is to ensure that the ROPS has sufficient strength to maintain the main hoop(s) in a vertical position to sustain the vertical load.

The required longitudinal strength of the stand-alone ROPS is further complicated by the varying longitudinal support given to the ROPS by the body shell. For instance a station wagon body (eg 76 series Landcruiser) offers only the seat belt mounts as longitudinal support. However, a single cab utility where the hoop is closely constrained at the side and rear by the cabin structure will give significant longitudinal support to the ROPS.

After completion of the vertical loading, a longitudinal load shall be applied to the ROPS. The ROPS may not be straightened or components replaced in order to properly connect to the test rig.

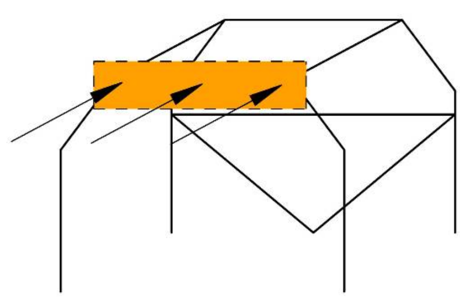
The longitudinal load shall be applied to the upper structural members of the ROPS distributed symmetrically about the longitudinal centerline of the ROPS. In the case of a multiple hoop ROPS, the load shall be applied to the front hoop only.

The B & C pillar seat belt mounts are not utilised for this part of the test. However, a theoretical strength derived from the seat belt mounts is added to the test result.

The certification requirements of seat belt mounts mean that a minimum longitudinal strength of 13.5 kN is required for each seat belt mount (see ADR 5/05 or UN ECE 14/06), so a longitudinal strength of 6.75 kN per anchorage point can be assumed. The test apparatus to apply a force limited to the maximum known limit of the seat belt mounts is complex. An alternative is simply to add 6.75 kN per certified seat belt anchorage to the test result.

Each seat belt mounting point on the ROPS must be demonstrated to have a minimum longitudinal strength of 6.75 kN by either testing or design calculation.

The loading must be applied at less than 5mm/s deflection of the ROPS. The structure shall support this load for a period of 1 minute or until any deflection has ceased, whichever is shorter. The plastic and elastic movement of the ROPS should be measured adjacent at the load application point (LAP) at the point of localized maximum deflection excluding any movement of the test fixtures



Longitudinal load (dual cab ROPS shown)

7.0 Deformation limits

7.1 Deformation limit

The class of light vehicle covered by this test protocol typically has greater headroom than passenger vehicles. The headroom also varies significantly from “troop carrier” type vehicles to single cab utilities. Therefore a survival space or “Deflection Limiting Volume” (DLV) measure of allowable deformation is more appropriate than specific deformation limits.

The DLV should be that defined by ISO 3164, excluding the foot section.

7.2 Lateral energy absorption

Some test standards include a test to determine minimum energy absorption. This is on the basis that deformation of the ROPS to absorb roll energy is desirable. This absorption of the roll energy helps to slow or stop the roll. This requirement predominantly exists in standards for equipment ROPS (eg ISO 3471) or external ROPS. In the case of the internal ROPS covered by this protocol, it is believed that energy absorption through deformation of body panels combined with probable load shedding of the rear load box contents deals adequately with reducing the roll energy and energy absorption of the ROPS does not need to be considered.

8.0 Padding

Any foam or similar padding should be removed from the ROPS prior to testing.

However, the installed ROPS should be fitted with padding in all areas where contact from head and / or limbs is likely. In most cases this will require padding from the elbow point upwards.

The padding should be closed cell foam with a minimum density of 80 kg/m3.

9.0 Component Tracking and Approval

The ROPS submitted for test should be accompanied with specification sheets for:

- All steel material use; tube, mounting plates, etc
- Bolts & other connecting material
- Manufacturing specifications on dimensional tolerances, etc.

These documents should be kept on file as a record of the production level of the tested ROPS.

10.0 Measurement, Tracking and Data Acquisition

Equipment used to measure force and deflection shall be generally in accordance with ISO 9248, except that the force measurement capability shall be within +/- 5% of the maximum value.

Measurements shall be preferably made with electronic data logging equipment at a logging rate of at least 20 Hz. A graph should be prepared of force / deflection so that an analysis of plastic vs elastic deformation can be made. A load / displacement graph should be part of the test report.

11.0 Design Changes, alterations

Any change to the design of the ROPS requires repeat physical testing unless:

a. It can be determined that the design change is a minor change to an existing design which was physically tested, and

b. The changes have no adverse effect on the performance of the ROPS.

12.0 Test Report

The test report shall include:

- ROPS identification details
- Maximum lateral force attained
- Maximum vertical force attained
- Maximum longitudinal force attained
- Test ambient conditions and temperature of ROPS components
- Force – deflection load curve
- Photo of specimen
(before test commencement, at the point of each peak load and after each test stage).
- Date of Test
- Name and address of test facility
- Test Engineer's name

13.0 Reference Documents:

SAE J1100

Anglo American spec 264073

BHP Fatal Risk Protocol

ISO 9248

FMVSS 216

ISO 3471 – 2008

ADR 5/05 (UN ECE 14/06)

ISO 3164