ROLL-OVER PROTECTIVE STRUCTURES AND FALLING-OBJECT PROTECTIVE STRUCTURES FOR TRACKLESS VEHICLES

1 Introduction 3
2 Scope 3
3 Definitions 3
  3.1 Company 3
  3.2 OEM 3
  3.3 ROPS 3
  3.4 FOPS 3
  3.5 DLV 3
  3.6 Mining Equipment 4
  3.7 Light Commercial Vehicles 4
  3.8 Busses 4
  3.9 Surface Operations 5
  3.10 Underground Operations 5
  3.11 Supported and Unsupported Roof 5
  3.12 Certified 5
4 applicable specifications and standards 5
5 Quality assurance 5
6 records and Marking 5
7 maintenance and repair 6
8 Requirements 6
 8.1 Roll-over Protective Structures 6
 8.2 Falling-object Protective Structures 7
Appendix A: Referenced Documents 9
Appendix B: Record of Amendments 10
Appendix C: iso 3471:1994 (E) - Earth-moving machinery – Roll-over Protective Structures – Laboratory tests and performance requirements 11
Appendix D: Iso 3471 And 1 Ton Pick-Up Truck Canopies 15
appendix E: SANS 1563:1992 - The strength of large passenger vehicle superstructures (roll-over protection) 16
appendix F: iso 3449:1992 (e) - Earth-moving machinery – falling-object Protective Structures – Laboratory tests and performance requirements 18
1 INTRODUCTION

This Specification is intended to assure operators and passenger of trackless vehicles in the operations of Anglo American Plc operating companies, reasonable protection during roll-over accidents, as well as from falling objects. The Specification is based on best practice requirements found in existing standards and practices.

2 SCOPE

This Specification details requirements for Roll-over and Falling-object Protective Structures for trackless vehicles in Surface and Underground Operations. The Specification is intended to cover all trackless vehicles, including Light Commercial Vehicles and Busses. The Specification does not contain definition of whether or not Protective Structures shall be required for specific vehicles. This will be established by, the Company through Risk Assessments. Elements of the national and international standards referenced in this Specification are summarised in the Appendices.

3 DEFINITIONS

3.1 Company

Anglo American operating company.

3.2 OEM

Original Equipment Manufacturer of the vehicle.

3.3 ROPS

Roll-over Protective Structures – defined as a system of structural members arranged on a vehicle in such a way as to accomplish the purpose of reducing the possibility of an operator or passenger being crushed, when wearing a seatbelt, should the vehicle roll over. This system may form an integral part of the vehicle body, structure or canopy, or may be an additional structural system with such primary purpose. Structural members include any sub frame, bracket, mounting, socket, bolt, pin suspension, or flexible shock absorber used to secure the system to the vehicle frame.

3.4 FOPS

Falling-object Protective Structures – defined as a system of structural members arranged in such a way as to provide the operator or passenger of a vehicle with reasonable protection from falling-objects. This system may form an integral part of the vehicle body, structure or canopy, or may be an additional structural system with such primary purpose. Structural members include any sub frame, bracket, mounting, socket, bolt, pin suspension, or flexible shock absorber used to secure the system to the vehicle frame.

3.5 DLV

The Deflection Limiting Volume is defined in ISO 3164. It is the volume occupied by the person that may not be penetrated by Protective Structure. Dimensions for this volume is depicted in Figure 1.
3.6 Mining Equipment

Mining Equipment includes all trackless vehicles used for mining operations that are not defined as Light Commercial Vehicles or Busses, such as dozers, dump trucks, front-end loaders, fork-lifts, back actors, tow/service trucks, bobcats, excavators etc.

3.7 Light Commercial Vehicles

Light Commercial Vehicles include pick-up trucks or 'bakkies' (licensed load to 1 ton), mini-busses (less than 18 passengers), light trucks (less than 5 ton) and multi-purpose vehicles (e.g. Land Rovers).

3.8 Busses

Busses carry 18 passengers or more. Included in the specification for Busses would be any truck or trailer that is adapted to carry 18 passengers or more.
3.9 Surface Operations

All plant, open-pit mine and factory operations, or surface activity on a deep mine.

3.10 Underground Operations

Operations in an underground mine.

3.11 Supported and Unsupported Roof

To be defined by the Company.

3.12 Certified

Approved by a competent authority.

4 APPLICABLE SPECIFICATIONS AND STANDARDS

All equipment referred to in this Specification shall comply with the relevant requirements of the South African Mine Health and Safety Act 29 of 1996 and Regulations (as amended), in South Africa, or the relevant laws and regulations applicable in other countries. The following international standards are referred to in this Specification and should be read in conjunction with this Specification.

- ISO 3471 – 1994
- ISO 3449 – 1992
- ISO 6683 - 1992
- SANS 1563 - 1992

5 QUALITY ASSURANCE

All ROPS or FOPS shall be certified at both the design and production stages. Design certification shall include testing of a prototype and/or a design verification by a professional engineer in terms of the prescribed requirements. Certification after production of each item of the same design shall also be performed. The production certification shall be based on a Quality Assurance Plan required by the Contract and approved by the Company that shall include material certificates and welding inspection.

6 RECORDS AND MARKING

All certificates and other records generated as a result of this Specification shall be stored in a manner, which will insure that they remain legible, readily identifiable and retrievable for a period to be determined by the Company, but not less than the life of the equipment.

All ROPS and FOPS shall be marked according to the requirements in the relevant ISO specifications.
7 MAINTENANCE AND REPAIR

All certified ROPS and FOPS shall have inspection schedules, included in the vehicle maintenance plans required by the Contract and supplied by the OEM. These schedules shall include provision for regular checking of welding, fasteners and for structural damage. In case of damage, the OEM or competent repairer shall either provide a repair procedure on a case-by-case basis, that would ensure that the structure is repaired to its original design, or state that the structure is not repairable.

8 REQUIREMENTS

8.1 Roll-over Protective Structures

8.1.1 General

A distinction is made between three types of vehicles, namely, Mining Equipment, Light Commercial Vehicles and Busses.

8.1.2 Mining Equipment

Mining Equipment vehicles Roll-over Protective Structures shall designed, tested and certified according to the provisions ISO 3471 or equivalent. A general description of these requirements is provided in Appendix C of this Specification.

8.1.3 Light Commercial Vehicles

The Company may require that Light Commercial Vehicles are fitted with Roll-over Protective Structures in addition to their inherent cab structures. Such structures may be roll bars added behind the cabins of pick-up trucks, roll frames or roll bars mounted inside the cabins of minibusses, etc. Such added structures shall be designed, tested and certified according to the provisions of ISO 3471 or equivalent. A general description of these requirements is provided in Appendix C of this Specification.

In the case where one-ton pick-up trucks are used to transport passengers in the load box, canopies shall be provided that are designed, tested and certified according to the provisions of ISO 3471 or equivalent. The required design and testing process is described in Appendix D of this Specification.

8.1.4 Busses

Roll-over Protective Structures (normally inherent in the bus superstructure design) shall be designed, tested and certified according to the provisions of SANS 1563:1992 or equivalent. A general description of these requirements is provided in Appendix E of this Specification.

8.1.5 Seatbelts

All vehicles fitted with ROPS shall also be fitted with seatbelts for operators and passengers according to ISO 6683 or equivalent.
8.2 Falling-object Protective Structures

8.2.1 General

A distinction is made between Surface and Underground Operations vehicles.

8.2.2 Surface Operation

Falling-object Protective Structures required for any trackless vehicle, including Roll-over Protective Structures required in addition to the inherent cab structures of Light Commercial Vehicles and Busses, shall be designed, tested and certified according to the provisions of ISO 3449 or equivalent. A general description of these requirements is provided in Appendix D of this Specification.

8.2.3 Underground Operation

8.2.3.1 General

A distinction is made between vehicles operating under established, Supported Roof and those that are not. The requirements are applicable to all trackless vehicles, including Light Commercial Vehicles and Busses required to have Falling-object Protective Structures required in addition to their inherent cab structures. Two alternative methods are permitted for certification of Underground Falling-object Protective Structures.

8.2.3.2 Vehicles operating under Supported Roof

a) Alternative A

Falling-object Protective Structures shall be designed, tested and certified according to the provisions of ISO 3449 or equivalent. A general description of these requirements is provided in Appendix F of this Specification. Due to the possibility of material detaching from the side wall and impacting the vehicle horizontally, it is required, in addition to the requirements of ISO 3449, that the structures are subjected to a horizontal load of 2 500kg (longitudinal and lateral separately) distributed on the centre third of the canopy roof edge and demonstrating that the maximum deflection does not encroach the deflection limiting volume defined by ISO 3164:1995(E) and the residual (permanent deflection) is less than 10% of the maximum deflection measured.

b) Alternative B

The ISO 3449, drop weight requirement is equivalent to a vertical static load of approximately 10 000kg. This is also close to the requirements the USA Mine Safety & Health Administration 30CFR 75.1719-1, which requires a vertical dead load of 18 000 pounds or 8 200kg. It shall be permitted to design, test and certify the Falling-object Protective Structure by applying 10 000 kg of static loading onto the centre ninth of the area enclosed by the support column locations (refer to Figure 2) and demonstrating that the maximum deflection does not encroach the deflection limiting volume defined by ISO 3164:1995(E) and the residual (permanent deflection) is less than 10% of the maximum deflection measured.
Due to the possibility of material detaching from the side wall and impacting the vehicle horizontally, it is required, in addition to the requirements of a vertical dead load, that the structures are subjected to a horizontal load of 2,500 kg (longitudinal and lateral separately) distributed on the centre third of the canopy roof edge and demonstrating that the maximum deflection does not encroach the deflection limiting volume defined by ISO 3164:1995(E) and the residual (permanent deflection) is less than 10% of the maximum deflection measured.

8.2.3.3 Vehicles operating under Non-supported roof

The same requirements described in Paragraph 8.2.3.2 above shall apply (both Alternatives), except that all force requirements shall be doubled.

Figure 2

Due to the possibility of material detaching from the side wall and impacting the vehicle horizontally, it is required, in addition to the requirements of a vertical dead load, that the structures are subjected to a horizontal load of 2,500 kg (longitudinal and lateral separately) distributed on the centre third of the canopy roof edge and demonstrating that the maximum deflection does not encroach the deflection limiting volume defined by ISO 3164:1995(E) and the residual (permanent deflection) is less than 10% of the maximum deflection measured.

8.2.3.3 Vehicles operating under Non-supported roof

The same requirements described in Paragraph 8.2.3.2 above shall apply (both Alternatives), except that all force requirements shall be doubled.
APPENDIX A: REFERENCED DOCUMENTS

AA SPEC 264073, Roll-Over Protective Structures And Falling-Object Protective Structures For Trackless Vehicles

Unless otherwise specified the latest issue of the following documents shall be deemed to form part of this specification.

AA SPEC 164000 : Users Guideline for Corrosion Prevention : System Selection
AA SPEC 164050 : Corrosion Protection of Steelwork with Coatings
AA REQ 100 : Quality Requirements for Suppliers of Critical Equipment
AA GTS 27 : AFRS 1 - Light Vehicles Standard


ISO 3449 - 2005 : Earth-moving machinery - Falling-object protective structures - Laboratory tests and performance requirements
ISO 3471 - 2008 : Earth-moving machinery - Roll-over protective structures - Laboratory tests and performance requirements
ISO 5700 - 2006 : Tractors for agriculture and forestry - Roll-over protective structures (ROPS) - Static test method and acceptance conditions
ISO 6683 - 2005 : Earth-moving machinery - Seat belts and seat belt anchorages - Performance requirements and tests
SAE J140 : Seat belt hardware test procedure
SANS 1563 - 2005 : The strength of large passenger vehicle superstructures (roll-over protection)
APPENDIX B: RECORD OF AMENDMENTS

Issue 0 : New document based on AAC Specification 264073 Rev 1 with the following amendments:
Added Tractors and Quad Bikes, Updated text on DLV; Appendix B added sections on Standard ROPS, Heavy Duty ROPS and ROPS testing; minor updates (A Lill) November 2008

Issue 1 : Updated text on DLV. Section on ROPS of light vehicles substantially rewritten. Section on FOPS substantially rewritten (A Lill) November 2009

Issue 2 : Updated Clauses 1 and 4.4 in Appendix D (A Lill) November 2009

Version 4 : 

The requirements of ISO 3471 are virtually identical to those of SAE J1040 MAY94 - Performance criteria for rollover Protective Structures (ROPS) for construction, earthmoving, forestry and mining machines.

1 General

The standard applies to crawler tractors and loaders, graders, wheeled loaders and wheeled tractors and their modified versions used for rolling and compacting, dozer-equipped wheeled tractors, skid-steer loaders and backhoe loaders, wheeled industrial tractors, the tractor portion (prime mover) of tractor scrapers, water wagons, articulated steer dumpers, bottom-dump wagons, side-dump wagons, rear-dump wagons and towed fifth-wheel attachments, rollers and compactors, rigid frame dumpers.

The standard does not describe the design process, but rather the performance requirements. The performance of the structure is evaluated through testing.

2 Performance Requirements

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 ensure 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.

The 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 ensured under at least the following conditions:

An initial forward velocity of 0 km/h 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.

The magnitudes of the lateral, vertical and longitudinal loads and the lateral load energy are as follows:

Lateral load force (N). Ranging from 0.5 to 1.3 times the machine gross weight, depending on the machine type and machine mass.

Lateral load energy (J). See ISO 3471 Table 1 – Force and energy equations.

Vertical load force (N). Two times the machine gross weight.
Longitudinal load force (N). Ranging from 0.4 to 1.0 times the machine gross weight, depending on the machine type and machine mass.

The reader is referred to ISO 3471 Table 1 – Force and energy equations for full details regarding the magnitudes of the lateral, vertical and longitudinal loads and the lateral load energy.

3 Design and Testing Procedure

The ROPS is designed to conform to the performance requirements. The finite element analysis method is normally used for this purpose. The bottom frame and attachments to the machine frame are designed to remain elastic during testing. The upper frame is designed to deform plastically during the lateral load test. Plastic yielding of the upper frame structural members is preferable to failure in the connections or the machine attachments during certification testing or during a rollover situation.

Manufacturing drawings are compiled to document the design.

A prototype ROPS is manufactured according to the manufacturing drawings.

The prototype ROPS is subjected to the evaluation testing. The testing is destructive – the ROPS experiences plastic deformation during the test.

If the prototype ROPS passes the evaluation testing, the design is accepted and manufacturing of ROPS according to the design can continue.

4 Testing

4.1. Attachment

The ROPS is attached to the machine frame, as it would be on an operating machine. A complete machine is not required, as long as the machine frame and mounted ROPS test specimen represents the structural configuration of an operating installation. The assembly is secured to the testing machine bedplate so that the members connecting the assembly and bedplate experience minimal deflection during testing.

4.2. Lateral loading

Lateral load is applied to the ROPS specimen, at a rate of deflection that may be considered static. Values of force and deflection are recorded during the loading. The loading is continued until the ROPS has achieved both the force and energy requirements. See Figure A1.

4.2.1. Vertical loading

After removal of lateral load, vertical load is applied to the top of the ROPS at a rate of deflection that may be considered static. The ROPS has to support this load for 5 minutes or until any deformation has ceased. See Figure A2.
4.2.2. Longitudinal loading

After removal of the vertical load, longitudinal load is applied to the ROPS at a rate of deflection that may be considered static. The ROPS has to support this load for 5 minutes or until any deformation has ceased.

4.3. Limitations on deflections

The limitations on the deflections are absolute – no part of the ROPS shall enter the Deflection Limiting Volume defined in ISO 3164 at any time during the lateral, vertical or longitudinal loading phases of the test.

Figure A1 – Four-post ROPS lateral loading example
Figure A2 – Vertical loading example
APPENDIX D: ISO 3471 AND 1 TON PICK-UP TRUCK CANOPIES

The ISO 3471 standard does not apply to pick-up truck canopies. However, due the lack of a standard that does apply to pick-up truck canopies, the requirements and testing procedures of ISO 3471 are used for the design and testing of canopies for pick-up trucks.

The performance requirement formulae (ISO 3471 Table 1) of all the machine types are evaluated for the Gross Vehicle Mass of the pick-up truck under consideration. The worst case lateral load force, lateral load energy, vertical load force and longitudinal load force are then used for the design and evaluation testing of the pick-up truck canopy.

The lateral, vertical and longitudinal loads are applied at locations on the ROPS that are considered to be the weakest.

Since the canopy seats could be mounted against the side of the ROPS, the structure would intrude into the DLV for the smallest ROPS deformation during the lateral load test. However, according to ISO 3471, for side-mounted seats, it is permissible for the upper portion of the DLV to be rotated forward up to 15 degrees about its locating axis, to prevent intrusion of ROPS members. A maximum allowable rotation of 15 degrees of the structure side is therefore used during the lateral load testing of the pick-up truck canopies.
Bus rollover is analysed in accordance with the SANS 1563:1992 code “The strength of large passenger vehicle superstructures (roll-over protection)”. Commercial bus manufacturers are required to have their busses “homologated” or approved by the SANS before they can be sold in South Africa. This approval covers aspects such as the aisle width, seatbelt design, etc. as well as compliance with the SANS 1563 code.

The test specified in the code is basically intended to cover a simplified bus rollover accident. The test determines what would happen if a stationary bus were to be tilted over sideward from a ledge at least 0.8m high. This replicates what would happen if, for example, the bus were to go off the road into a ditch. The “residual space” is defined as a volume of space inside the bus assumed to be occupied by the passengers and driver. The basic idea of the test is that the bus should be able to tilt over sideward without any part of the bus structure penetrating into the residual space. This is intended to ensure that the passengers are not seriously injured by the bus structure collapsing.

One method of determining compliance with the code is to perform an actual physical test on a complete bus frame. The bus is tilted sideways from a ledge and high-speed photography, deformable templates or other means are used to determine whether the residual space is penetrated. Such a test is obviously expensive as an entire bus frame is destroyed, and, should the bus fail the test, another frame has to be built and tested.

As a full test is expensive, the code also allows verification of the rollover requirements by calculation. Numerical requirements are given for the total energy absorption capacity of the bus hoops, and also for the longitudinal distribution of this capacity. The total energy absorption capacity requirement depends on the mass, centre of gravity position and dimensions of the bus. The energy absorption capacity of each of the hoops of the bus can then be determined by calculation, and the bus compared with the requirements for rollover compliance. In practice, accurate determination of the strength of the hoops by calculation only is difficult due to the highly non-linear behaviour of the hoops. For this reason, a hybrid method is used by leading consulting engineers in South Africa: laboratory tests are performed on key joints in the structure, and the results combined with computer analysis of the remainder of the structure to determine compliance with the roll-over requirements.

As the total energy absorption capacity is very sensitive to the mass and centre of gravity position of the bus, these parameters must be determined by a suitable test rather than merely estimated. The test involves lifting the front axle of a bus into the air and measuring the changes in load on the two axles as the bus is lifted. The mass and centre of gravity position can be calculated from this.

A rollover analysis of an existing or proposed bus performed by an external consulting engineer typically involves the following steps:

- Drawings of the bus are supplied to the consulting engineer
- If a similar bus exists, its mass and centre of gravity position are measured. If no bus exists, the engineer must estimate these parameters.
- The engineer specifies samples to be prepared for the laboratory tests. These samples are prepared by the bus manufacturer, using the same procedures (welding, etc.) that will be used in the final bus. The samples typically consist of a joint with a 1m length of tubing on each side.
• The samples are tested and the engineer combines the results of the tests with a computer model of the bus to determine compliance with the code.

• If the bus does not comply, the engineer proposes modifications and new samples are prepared and tested. This procedure is repeated until a satisfactory solution is obtained.

The engineer prepares a report stating that the bus complies with the SANS 1563 code and also detailing the test results, any required modifications that were made, etc.

If the mass and centre of gravity position were not measured at the start of the process, a bus is manufactured and these parameters measured.

Commercial bus manufacturers then include the engineer’s report among the paperwork that is submitted to the SANS for homologation of the bus.
The requirements of ISO 3449 are virtually identical to that of SAE J231 - Performance criteria for falling-object Protective Structures (FOPS) for construction, earthmoving, forestry and mining machines.

1 General

The standard applies to crawler tractors and loaders, graders, wheeled loaders and wheeled tractors and their modified versions used for rolling and compacting, dozer-equipped wheeled tractors, skid-steer loaders and backhoe loaders, wheeled industrial tractors, the tractor portion (prime mover) of tractor scrapers, water wagons, articulated steer dumpers, bottom-dump wagons, side-dump wagons, rear-dump wagons and towed fifth-wheel attachments, rollers and compactors, rigid frame dumpers.

The standard does not describe the design process, but rather the performance requirements. The performance of the structure is evaluated through testing.

2 Performance Requirements

The requirements test crush-resistance when the structure is hit by a blunt object dropped from a sufficient height to develop an energy of 11 600 J. The falling object may either be a cylinder, or a sphere, as prescribed by the specification. The Deflection Limiting Volume defined in ISO 3164 may not be penetrated by either the Protective Structure, or the falling object during the test.

3 Design and Testing Procedure

The FOPS is designed to conform to the performance requirements. The finite element analysis method is normally used for this purpose. The bottom frame and attachments to the machine frame are designed to remain elastic during testing. The roof structure is designed to either also remain elastic, or to deform plastically within the specified limits during the test.

- Manufacturing drawings are compiled to document the design
- A prototype FOPS is manufactured according to the manufacturing drawings
- The prototype FOPS is subjected to the evaluation testing. The testing is destructive – the FOPS experiences plastic deformation during the test.
- If the prototype FOPS passes the evaluation testing, the design is accepted and manufacturing of FOPS according to the design can continue