An Introduction
to
Roll Over Protection Structures

Function and Purpose

A properly designed "Roll Over Protection Structure" (ROPS or roll cage) can significantly enhance occupant survivability and reduce injuries in a competition vehicle which may find itself in a rollover situation either at the race track or on the open road. The roll cage can also assist in reducing injury from front, rear and side impact events particularly where glancing collisions are sustained. However, no matter how rigorous or substantial the structure, a roll cage cannot defy the laws of physics and will provide limited protection against major decelerations resulting from high speed front or rear end collisions, or sideways excursions into immovable objects such as trees or rocks.

Aside from roll over protection, a properly designed roll cage can also provide substantial mountings for safety harnesses and seats which are better able to withstand the very high G loadings experienced in a collision. A further and major benefit is the substantial chassis stiffening that a properly triangulated roll cage can provide. It is not uncommon for vehicle chassis torsional stiffness to increase from say 5,000 NM/deg to over 10,000 NM/deg where a comprehensive 6 point roll cage is installed; providing a much stronger and more stable vehicle platform for suspension tuning and setup.

Minimum Requirements (CAMS Events)

All closed (roofed) competition vehicles in State level or above speed and rally events require a ROPS to Type 3 standard which is a six point roll cage as a minimum. Tarmac rally events will often specify more stringent requirements particularly if there is a requirement for FIA approval. Open top cars may be accepted with a "Solo roll bar" or half cage depending on the category regulations in force. Safety cages are mandatory for open "drift" cars and are strongly recommended for closed cars.

There is no requirement for roll cages to be fitted in road registered, closed cars in club events. There is, however, a clear need for significant protection as some of these vehicles have a performance envelope (particularly with track day tyres) that approaches those levels matching the highest levels of motor sport of just a few years back!

Legislative Requirements

The various State road authorities each have their own requirements in terms of what can be installed in a road registered vehicle. The authorities are generally concerned with having no bars in the head impact zone while also maintaining reasonable access into the driver's and passenger's seating positions. The mandatory CAMS requirements for rear stays from the main hoop will often require a vehicle to be re-registered as a 2 seater vehicle where these stays impede passenger access or safety.

Vic Roads have an excellent document titled "Vehicle Standards Information No 28 -roll cages in road cars" which clearly outlines their requirements for a roll cage in a registered vehicle. This is available from the Vic Roads website.

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CAMS Standard versus FIA Homologated Design

The days of the lightweight aluminium roll cage with built-in plastic hinges has long passed. Schedule J of the CAMS manual of Motorsport specifies two approaches to the design and construction of ROPS; all in steel.

The most common approach is to construct a **CAMS standard cage** using geometric elements as outlined in Schedule J. These elements may be combined and overlayed on a Solo Roll Bar, Half Roll Cage or Full Roll Cage to give the degree of protection required by the driver or the event organiser. The tubing must be of specified minimum diameter and minimum thickness which is typically 44.45mm dia x 2.6mm thickness for main hoops and forward legs, and 38.1mm dia x 2.6mm thickness for all other members. The tubing material is low carbon, cold drawn seamless or cold drawn welded tube which is normalised to provide yield strengths of between 400-500 MPa (350 MPa minimum required by CAMS). This tubing is of consistent high strength and quality and is easily welded without special processes. The disadvantage of a standard cage is that the specified wall thickness can be 1.0 – 1.6 mm thicker than a specially certified cage giving a weight penalty of between 10 – 20 kg for the vehicle depending on the complexity of the cage.

The second approach is to design and construct a **Certified Cage** which must meet minimum requirements laid down by both CAMS and the FIA. These requirements typically relate to plastic deformation of the cage under a set of prescribed loading criteria which require the services of an FIA approved engineer for predictive analysis. This analysis and design typically adds $2000 to the cost of a one off cage but the advantage is that the ROPS can be designed to take advantage of thinner tubing in high strength steel such as chrome moly or Reynolds T45. Some cage manufacturers will often amortise the cost of this analysis across a production run of cage kits and one can often purchase a lightweight design for the more popular vehicles such as the Subaru STI or Mitsubishi EVO from local suppliers or mainstream manufacturers such as Sparco, OMP or Motorquality. A certified cage is usually designed to keep weight to a minimum but can also be optimised within the chassis to maximise strength and stiffness. It must be stressed that higher strength steels will often require specialist welding and heat treatment procedures which are not readily available or impractical in application. Welded chrome moly tube joints should theoretically be heat treated and normalised to minimise residual stresses while maintaining material strength. All NASCAR chassis are fully welded then placed into an oven unclothed to ensure this happens!

Bolted versus Fully Welded

Roll cages can either be bolted into position, or fully welded into the vehicle. A bolt-in cage has minimal impact on the vehicle shell as sub assemblies and separate tubes are progressively bolted together to form the ROPS. Mounting holes must be drilled into the floor and rear parcel shelf to receive the bolting and reinforcement plates both in and under the vehicle. Bolt-in cages are less stable than weld-in ROPS as the bolted joints can act as hinges under certain load situations. They can also be more expensive to

manufacture because of the complex nature of some of the joints which may require machining and additional fabrication. They have the advantage of being easily removed from the vehicle although the tell tale bolt holes will always be a reminder!

Weld-in cages are a more permanent solution being more rigid as an assembly. The mounting points for the main hoop and forward legs are usually much stronger than the equivalent bolted plates and removal does require the cage to be cut out with the floor doubler plates being left in position; no holes in the floor however!

Fabrication and Workmanship

Roll cages are safety critical structures which require the highest levels of workmanship to maximise survivability under the duress of a major accident. Anyone can build these structures but CAMS recommends that you utilise companies that have a proven track record.

Welding must be of the highest quality and while a good looking weld is no guarantee of integrity it certainly beats a ratty weld with little penetration, too much penetration with undercuts or inconsistent fillet width. Welding can be either using the MIG or TIG processes. A MIG weld will generally have a raised bead and is not generally as uniform or as attractive as a properly applied TIG weld, but will be as strong. TIG welds can equally have a beautiful appearance with a small fillet or bead but may have little penetration. You have been warned …….! Footplates are generally welded to the floor using the MIG process as it handles the plating protection applied to some body steels much better than TIG.

Welding of chrome moly tubing requires specialised procedures. You should speak to your fabricator to understand their processes. Be wary of anyone that treats this material the same as normal CDS/CDW mild steel tube!

Of equal importance is the fit-up of tubes prior to welding up joints. Tubes should be properly fish mouthed using angle fixtures and hole saws or a milling machine to give consistent gaps of less than 1.0 mm. This is a time consuming business which will require a careful eye and a lot of filing. Whilst it is possible to span big gaps with filler rod while welding, this will lead to large residual stresses in the joint (potentially leading to premature failure). A by-product of filling gaps is excessive weld shrinkage that can seriously distort and permanently twist an otherwise OK chassis. We recently saw this on a show car where a badly fabricated roll cage necessitated refitting the hang on panels and re-setting panel gaps.

CAMS have a requirement for all joints to be fully welded. In past years, joints may only have been welded where it was physically possible to get to the joint once the cage was installed into the car. There are many tricks to enable full welding. This may include removing a vehicle roof (very common on Subaru's) or alternatively, pre-assembling the cage in the vehicle and then allowing it to drop through the floor (though pre-drilled

holes) to enable access to the top of the structure. In most cases it is necessary for the windscreen to be removed to allow welding of the A pillars to the front legs of the ROPS.

Roll Bar Padding

Cages must be fitted with deformable foam padding in those areas where the occupant is likely to come into contact with tubes as a result of an accident. The most widely used padding (around $15 per metre length) is foam tubes which are split, allowing application to the roll cage tubing. The hole down the middle is offset allowing the thicker portion of the cross section to be directed towards the occupant. This is normally attached using zip ties.

FIA approved padding is also available. This padding is cleverly designed to provide a controlled deceleration during deformation. The padding is designed in a horse shoe section or shape but is very expensive, typically costing up to $100 per metre length.

Painting and Trim

Painting a roll cage must be one of the most tiresome jobs imaginable. The economic approach is to spray the cage using pressure packs of satin black enamel. This will provide an excellent finish if properly applied and the colour black allows the cage to fade into the interior; touch-ups are easily made!

The second approach is to have the interior of the car and the cage, "2 packed" by a professional body shop. Expect to pay up to a couple of thousand dollars to achieve an OEM finish!

In any case all joints should be wire brushed and the tubes wiped down with Prepsol or acetone to remove all traces of oil and grease. Masking up the entire vehicle will normally take 3-4 hours depending on how thorough you wish to be. Black paint is particularly pervasive and has a habit of finding its way onto light coloured duco.