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An Analysis of Safety Systems in Stage Rallying

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1.Introduction

Stage Rallying is unique compared to Circuit Racing; stages typically take place on closed public roads. Making it much less of a controlled environment relative to circuits, where even the lowest FIA grade circuits such as Mondello Park, Ireland still have adequate amounts of run off and barriers outlining lining the outer perimeter of the circuit. Whereas stages are lined with various hazards such as trees and posts. Immovable objects that will concentrate all the force of a collision into an extremely small area. Therefore, all the emphasis is on the protection systems of a rally car where the occupants were sat as little as 200mm away from the side of the vehicle up until 2017 in the World Rally Championship. Leaving little room for large side impact structures compared to those found on open wheeled and prototype vehicles etcetera. This report will analyse the safety of rallying, past and present to see how it has evolved. And what needs to be changed in the future.



Figure 1. Mondello Park's gravel traps and tyre barriers going into heavy braking zones

2.Research/Background

2.1. Group 4

Safety prior to the 1970s safety was perceived to be an optional amenity, competitive cars had very little to differentiate themselves from their noncompetitive counterparts. For example, rally cars in the 60s only had minor alterations for performance purposes, with all safety systems being optional as long as it did not affect the handling of the vehicle as stated in Appendix J, Chapter 2, Section 16, Supplementary Accessories (FIA, 1964). The early 70s saw the formation of the World Rally Championship (WRC), improvements were made with Roll Cages, Windshields made with laminated glass, reinforced fuel lines/tanks, and fire extinguishers becoming mandatory, across multiple championships from the Pacific Pro-Rally (SCCA, 1974) and the WRC (FIA, 1974, p. 113) . From 1973-1982 the WRC had an average of 0.3 fatalities per year (Motorsport Memorial, 2024). With relatively lower speeds, this decreased the likelihood/forces of collisions.



Figure 2. A Lancia Fulvia HF at the 1973 Rally Sanremo with a roll bar

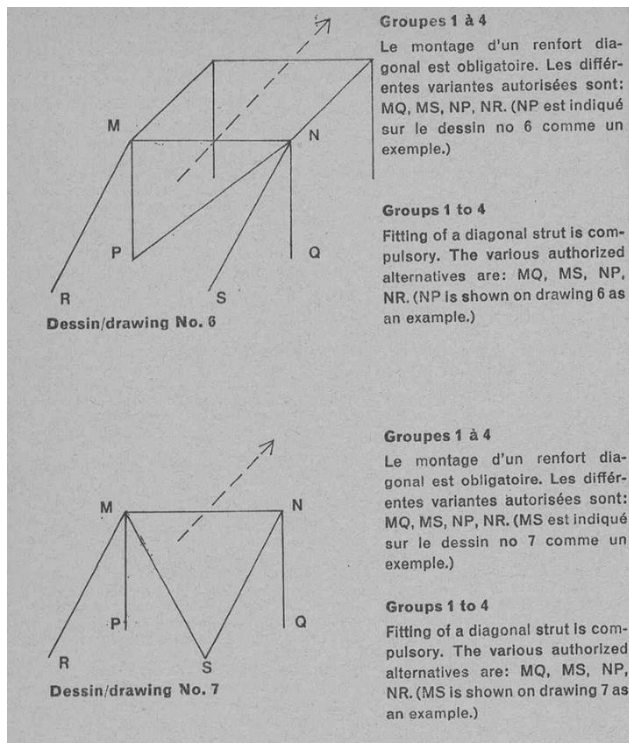


Figure 3. Accepted designs for roll cages 1974 (FIA, 1974)

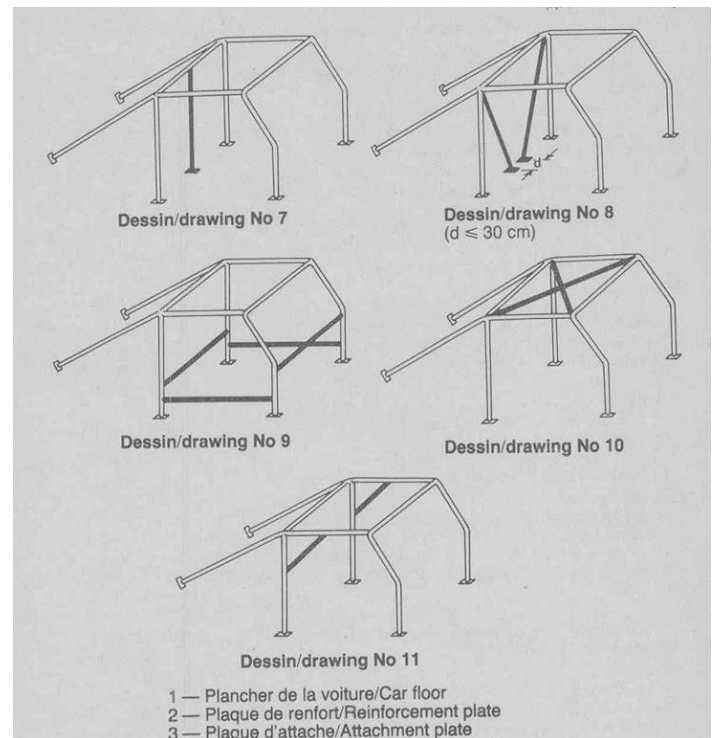


Figure 4. Designs for roll cages with optional struts (in black) 1984 (FIA, 1984)

2.2. Group B

From 1982-1986 saw a new generation of rally car. Silhouette cars based off a lightweight spaceframe chassis with unprecedented amounts of power. Made from revolutionary materials such as carbon fibre and Kevlar. Group B was infamous for their extremely difficult handling characteristics and poor durability. Whilst there were large increases in performance, there was little evolution with safety systems, the roll cage had slight alterations including minimum tensile strengths being introduced (350N/mm^2)/extra supporting struts, a revised harness with more straps/additional fixation points, along with the addition of dual circuit breaking (FIA, 1984, pp. 125-150). Over 4 years the WRC saw an average of 1 fatality per year (Motorsport Memorial, 2024).



Figure 5. The interior/roll cage of the 1985 RAC Rally winning Lancia Delta S4 Group B

2.3. Group A

After Group B came major revisions to the regulations. With decreases in power, shorter stages and going back to production vehicles over silhouettes the focus was put towards safety. Roll cages required extra reinforcement/new suspension anchorage points/ attachment to the chassis of the vehicle, an evolved fire extinguishing system with new minimum discharge times/capacities (FIA, 1991, pp. 139-152). The WRC saw an average of 0.38 fatalities per year over 13 years (Motorsport Memorial, 2024).



Figure 6. Interior of the 1991 Group A Lancia Delta HF with additional longitudinal struts

2.4. 2000cc/WRC

During the 2000 season the FIA mandated (FIA, 2000) that fire extinguishers had to have an increased capacity, an automatic fuel cut off, fuel/oil lines had to be able to hold 70 Bar at 135°C, thicker tubing of the roll cage, new fire screens, along with developments of other systems. Over the past 24 years the WRC has had an average of 0.13 deaths fatalities per year (Motorsport Memorial, 2024).



Figure 7. Interior and Roll Cage of the 2004 Subaru WRX

3. Discussion

3.1 Roll overs/front impact

Roll Cages are a vital part of safety in all forms of motorsport. The roll cage prevents serious deformation of the vehicle in collisions/roll overs. The FIA states (FIA, 2020) that a roll cage homologated as of 2020 must have a main roll bar, at least one diagonal backstay/longitudinal member either side, roof and windscreen reinforcements. The material required is a cold drawn seamless steel with a minimum tensile strength of 350N/mm^2 and a maximum carbon content of 0.3%. The cage design and material are two key factors that determine the structure's likelihood of compromising in a roll over, the material must be strong but ductile. The materials used in (Buddha Eswar S.S. Aakash, 2020) compared the use of chromoly (AISI 4130) /carbon steel (AISI 1065) and the design of the roll cage for use of roll cages in Baja racing to see which design is most the safest. 2 designs were used, one that stood to the minimum standard, and another contained additional supporting struts. Comparisons of the designs and materials can be seen in table 1/2. The designs were stress tested in ANSYS in a variety of collisions, including a rollover and frontal impact simulation with 10KN of force.

Table 1. Properties of metals used in simulation

Properties	AISI 4130 STEEL	AISI 1065 STEEL
Ultimate tensile strength	560 MPa	635 MPa
Yield tensile strength	460 MPa	490 MPa
Modulus of elasticity	190–210 GPa	200GPa
Bulk modulus	140 GPa	140 GPa
Shear modulus	80 GPa	80 GPa
Poisson's ratio	0.27–0.30	0.27–0.30

Table 2. Results of Rollover with AISI 4130 (Buddha Eswar S.S. Aakash, 2020)

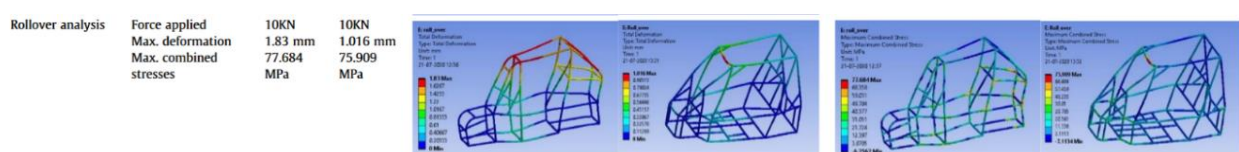


Table 3. Results of rollover with AISI 1065

Roll over	Force applied	10KN	10KN
	Max deformation	0.75987 mm	1.6772 mm
	Max combined stress	47.667 MPa	112.78 MPa

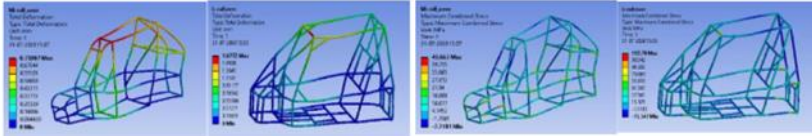


Table 4. Results of frontal impact with AISI 1065

Force applied	10KN	10KN
Max. deformation	0.78454 mm	0.46362 mm
Max. combined stresses	99.746 MPa	52.913 MPa

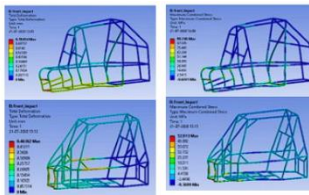
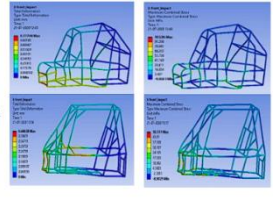


Table 5. Results of frontal impact with AISI 1065

Front impact	Variable	Values
		1 st design 2nd design
Force applied	10KN	10KN
Max deformation	0.77744 mm	0.44638 mm
Max combined stress	103.96 MPa	50.511 MPa



The results show that, the two metals are relatively interchangeable to one another. Design 1 performs better with roll overs considerably when with chromoly. And design 2 performs better with frontal impacts. In a rallying context over Baja, design 2 would be preferable as it performs consistently better with frontal impacts. Showing the importance of additional struts.

3.2 Side Impact Protection

Side impact protection is critical in rallying. A study by Unser quoted in (Elias Nassiopoulou, 2010) there were 67 cases of rally fatalities between 2004-2009 across most major/regional championships. 52% of these cases were against a tree or post, among that 52%, 62% were side impacts, 9% were frontal and 31% were unknown regarding the direction of the collision. Whilst it's difficult to collect data of every rally collision, near a quarter of all fatalities in rallying are against a tree/post without taking into account the collisions involving walls, rollovers and events where the direction of the collision was at the side or unknown. With such a great proportion it can be assumed that this is still relevant today. Currently the side impact protection found on rally cars are the door lining, door bars as a part of the roll cage, and seats.

3.2.1 Door Bars

The minimum diameter for the tubing of the roll cage is 50mm with a thickness of 2mm (FIA, 2020). Using LS-DYNA simulations, a Suzuki Cultus model developed by the National Crash Analysis Centre and Federal Highway Traffic Safety Administration. The model's accuracy was validated for accuracy by comparing it to a Renault Megane's (a vehicle similar in dimension and design) Euro NCAP side impact test imagery. The model then had a roll cage designed to FIA standards to show the difference the tubing thickness makes against a rigid pole at 16.6m/s (Elias Nassiopoulos, 2010). The FIA roll cage saw a 13% decrease in deformation relative to the collision without a roll cage. A same collision with the same roll cage but with tubing thickness of 4mm. The cage with 4mm had a 20% reduction in deformation relative to the car without a cage as seen in Fig 8.

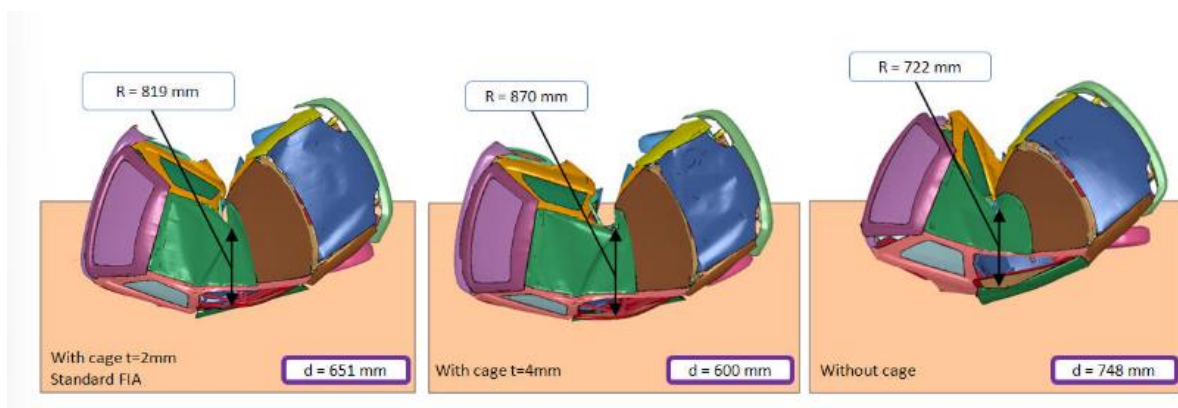


Figure 8. Simulations of side impact with varying thickness of roll cage (Elias Nassiopoulos, 2010)

Without taking into account additional reinforcements used in the floor and the fact that the materials/dimensions of tubing on roll cages haven't changed all that much since the 80's (FIA, 1984), where cold drawn seamless steel has been used in roll cages since the 70s. With cold drawn seamless steels price so low the FIA could increase the thickness of the cage by 2mm. With CDS steel prices being relatively low this could be a cost-effective solution of reducing the force experienced by occupants in side collisions.

3.2.2. Composite side structures.

With there being such a small space between the occupants and side of the vehicle there is little room for crash structures. However, with the advancement of materials and the development of sandwich structures. It is now possible to make small structures that can absorb lots of energy. 6 different sandwich structures were tested (G. Pitarresi, 2005) as seen in figure 9. Including: Single/Double Corrugated, Dimpled, Webs diagonal and perpendicular/tubes. All of these structures are to be used in a foam cored sandwich.

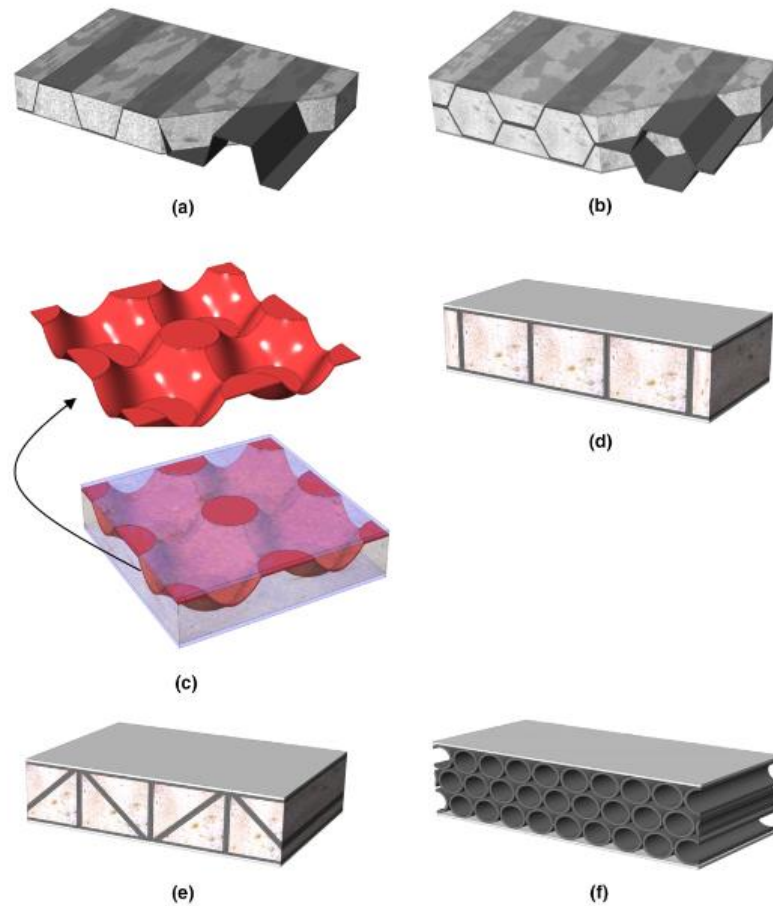


Figure 9. The types of sandwich structure used
(G. Pitarresi, 2005)

Table 6. The materials used in each structure

The constituent materials used to fabricate each of the sandwich designs				
Core reinforcement geometry	Core reinforcement (E-glass)	Foam core	Facing reinforcement (E-glass)	Resin
Single corrugation	 [0°/90° stitched non-crimp biaxial mat (300/300 g/m²)] _k (Ahlstrom 42007)	PVC & polyurethane co-polymer (Klegecell R45, 45 kg/m³)	[0°/90° stitched non-crimp biaxial mat (300/300 g/m²)] _k e (Ahlstrom 42007)	Modified acrylic (Modar® 865)
Double corrugation	 45°/90°/-45°/0° stitched non-crimp quadriaxial mat (195/192/195/216 g/m²) (Ahlstrom 64004)	PVC & polyurethane co-polymer (Klegecell R45, 45 kg/m³)	Randomly oriented continuous filament mat (450 g/m²) (Unifilo® U812)	Unsaturated orthophthalic polyester (Aropol TM FS 6912)
Dimpled	 Chopped strand mat (1800 g/m²)	Rigid polyurethane (Isofoam RM 6259, 140 kg/m³)	Outer (surface) layer: [0°/90° stitched non-crimp biaxial mat (300/300 g/m²)] _k (Ahlstrom 42007) Inner (core) layer: chopped strand mat (450 g/m²)	Modified acrylic (Modar® 836S)
Webs	 Woven roving (510 g/m²) (Ahlstrom ^d)	PVC & polyurethane co-polymer (Divinycell H45, 48 kg/m³)	Woven roving (290 g/m²) (Ahlstrom R3-290 9677)	Epoxy (PRIME TM 20 ^b with 25% slow hardener)
Tubes	 0°/90° woven biaxial mat (warp/weft 2400/2400 tex) (Ahlstrom ^d)	Soft polyethylene ^e (Fawolon PT-228, 28 kg/m³)	Woven roving (450 g/m²) (Ahlstrom R12-450 9634)	Epoxy (PRIME TM 20 ^b with 25% slow hardener)

^a Trademark of Ashland Inc.

^b Trademark of SP Systems.

^c Trademark of Saint-Gobain Vetrotex.

^d Custom fabric, not commercially available.

^e Supplied by Fagerdala Tuotanto OY (Finland).

The materials were tested by quasi-static axial compression from a hydraulic press. There are three different ways of initiating a composite structure to collapse. They are no trigger, modification of one end of the structure itself, and an external metallic trigger.

Table 7. Results of the Compression Test (G. Pitarresi, 2005)

Core reinforcement geometry	ρ (kg/m ³)	$\sigma_{\max}$ (MN/m ²)	$\bar{\sigma}$ (MN/m ²)	E_s (kJ/kg)
Single corrugation	520	15.6	10.6	20.3
Double corrugation (type 1)	360	8.1	6.1	17.2
Double corrugation (type 2)	330	10.2	6.4	19.1
Dimpled	650	12.8	9.2	15.3
Webs, perpendicular	220	11.5	4.2	18.7
Webs, diagonal and perpendicular	295	9.5	5.4	18.3
Tubes (10mm tubes)	600	35.2	27.6	45.8
Tubes (20mm tubes)	390	12.8	15.7	40.2

The results show that tubular ties were by far the best. It had a energy absorption of levels greater than 40Kj/Kg. The failure of the tubes was “progressive” (G. Pitarresi, 2005)which means its ideal for absorbing energy in the event of a collision and could be used in areas of the door skin. And where composite crash structures within door linings are not mandatory. This could be vital in absorbing lots of energy, in what is the most dangerous form of collision.

4.Conclusion

In conclusion safety in rallying has come a long way since the days of early group 4/group B. However, there are still some potential oversights and room for improvement in the current FIA regulations. With additional reinforcements not being required on roll cages and sandwich structures not being implemented in championships where money is less of an issue. Where small percentages can make all the difference.

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