



UWSTD Vehicle Assessment

Body in White Structures

Critical Appraisal of the SEAT Leon TCR Race Conversion

Submitted

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1. Introduction

The vehicle selected for this assessment is the SEAT Leon TCR (Touring Car Racing), a high-performance five-door hatchback produced by SEAT Sport as a homologated racing derivative of the third-generation Leon Road car (Mk3). The Leon Mk3 is manufactured at the SEAT plant in Martorell, Spain, and is powered in road-legal specification by a turbocharged 2.0-litre four-cylinder TSI engine producing approximately 290 bhp, with a kerb weight of 1,440 kg. The vehicle observed in the UWTSD workshops has been converted to FIA TCR specification, built to the 2015 FIA TCR Technical Regulations. The Body in White (BIW) structure is the primary load-carrying assembly of a modern passenger vehicle, governing structural performance, crash safety, NVH characteristics, and occupant protection (Meng and Qin, 2021). The report evaluates the original design intention of BIW through its assessment of race conversion results which impact vehicle stiffness and various aspects of performance including NVH and materials and manufacturing and joining and safety and comfort and regulatory compliance.



Figure 1: SEAT Leon car



Figure 2: SEAT Leon TCR No. 96

SEAT Leon TCR No. 96 (Spiller) full side profile showing orange/black/white race livery, front splitter, and large rear wing in the UWTSD workshop.

1.1 Original Vehicle Design and BIW Structure

SEAT Leon Mk3 is made using a steel monocoque unibody construction with the body shell and the chassis forming a single load-bearing assembly. BIW sub-assemblies include the underbody floor pan, front-end structure, body-side assemblies, roof structure, and closures. The MQB platform provides torsional rigidity values of around 25,000-30,000 Nm/degree, which is significantly higher than the 6,000 -8,000 Nm/degree that is typical of city car platforms (Wang et al., 2025). The forward roof support, which is formed by the A-pillar, transfers the side-impact loads to the sill and roof rail. B-pillar It resists intrusion with UHSS 22MnB5 press-hardened inserts. Torsional stiffness determines the performance of ride, handling, and NVH (Wang et al., 2025). The Leon Mk3 body is composed of mild and HSS stamped panels, resistance spot-welded (primarily) with laser welding at the roof seam and structural adhesive bonding in the underbody. Front and rear longitudinal members are designed as progressive crumple zones.

1.2 How the Vehicle Has Been Modified

The UWTSD conversion transforms the SEAT Leon into an FIA TCR race vehicle. The main modification is to replace the standard ROPS with an FIA spec one which is welded to reinforcement footplates at the sill, A-pillar, B-pillar and roof. This creates a single steel hoop with triangulation to the front suspension turrets and ROPS, the suspension pickups replace the compliant bushes for a direct BIW load path. All sound-deadening, carpets, and headlining are

removed. FIA TCR 2015 regulations require a production vehicle base with modifications limited to permitted areas (FIA, 2015). Engine modifications are highly restricted under FIA TCR regulations, limited to approved areas such as ECU calibration and air restrictor adjustments to maintain class parity.



Figure 3: Side profile of SEAT Leon TCR

Side profile of SEAT Leon TCR No. 96 with bonnet open in the workshop, showing the complete race conversion livery and sponsor branding.

Table 1: SEAT Leon TCR Road-Legal vs. FIA TCR Race Conversion Comparison

Characteristic	Road-Legal SEAT Leon	FIA TCR Race Leon
Torsional Stiffness	Monocoque RSW & adhesive; ~25,000–30,000 Nm/deg	ROPS welded to footplates; +30–50% stiffness gain
NVH Isolation	Butyl pads, foam, carpet, acoustic liners	All insulation stripped; bare metal shell
Joining Technique	RSW (~4,000–6,000 spots) + laser + adhesive	Original welds retained; ROPS MIG-welded to footplates; solid mounts bolted
Interior Comfort	Padded seats, door cards, headlining, climate ctrl	Fixed-back race seat, 6-pt harness, stripped cabin
Structural Materials	Mild DC01/DC04, HSS H220BD, UHSS 22MnB5 B-pillar	Original BIW + CDS/ERW ROPS tube + mild steel footplates
ROPS / Roll Cage	None (road car)	Mandatory FIA-spec ROPS with footplates & turret triangulation

Airbag System	Driver + passenger airbags active	Both airbags disabled/removed
Weight	1,440 kg (kerb weight)	1,230 kg with 45L fuel / 1,196.25 kg dry
Regulatory Status	EU WVTA / UNECE road legal	Not road-legal; FIA TCR closed-circuit only



Figure 4: Rear view of the SEAT Leon TCR

Rear view of the SEAT Leon TCR showing the adjustable rear wing assembly, diffuser, and ACC Carpentry / Mon Timber sponsor branding.

2. Stiffness

The road-car BIW derives torsional and bending stiffness from closed-box sill, roof rail, and door aperture ring sections. The MQB platform provides a baseline of 25,000–30,000 Nm/degree, far exceeding the 6,000–8,000 Nm/degree of city car platforms (Meng and Qin, 2021). The welded ROPS increases global torsional stiffness by 30–50% over the standard BIW superior to bolt-in cages (15–30% gain) because welded connections eliminate interface compliance losses. Replacement of suspension bushings with solid mounts removes compliance in the wheel-to-BIW load path, while solid engine and transmission mounts increase structural coupling at the cost of NVH refinement.



Figure 5: Rear hatch view

Rear hatch view of the fully triangulated FIA-specification ROPS cage structure, showing cross-bracing, camera mount, fire suppression system bottle (red), and stripped boot area.

Analytical Model 1 Torsional Stiffness Estimation (Open-Section Thin-Walled Beam Theory)

BIW torsional stiffness (simplified closed-section beam, Bredt-Batho theory):

$$K_t = \frac{G \cdot J_{\text{Bredt}}}{L}$$

$$J_{\text{Bredt}} = \frac{4A_{\text{enc}}^2 \cdot t}{s}$$

Where (Leon Mk3 MQB platform approximate values):

$$\begin{aligned} A_{\text{enc}} &= 0.008 \text{ m}^2 (\text{enclosed cross-section area of sill box}) \\ G &= 80 \text{ GPa} = 80 \times 10^9 \text{ N/m}^2 (\text{shear modulus of steel}) \\ t &= 1.5 \text{ mm} = 0.0015 \text{ m} (\text{sill wall thickness}) \\ L &= 2.636 \text{ m} (\text{vehicle wheelbase}) \\ s &= 0.25 \text{ m} (\text{perimeter of sill cross-section}) \end{aligned}$$

Step 1: Calculate Bredt torsional constant

$$\begin{aligned} J_{\text{Bredt}} &= \frac{4 \times (0.008)^2 \times 0.0015}{0.25} \\ J_{\text{Bredt}} &= \frac{4 \times 6.4 \times 10^{-5} \times 0.0015}{0.25} \\ J_{\text{Bredt}} &= \frac{3.84 \times 10^{-7}}{0.25} = 1.536 \times 10^{-6} \text{ m}^4 \end{aligned}$$

Step 2: Calculate sill torsional stiffness [Nm/rad]

$$\begin{aligned} K_{\text{sill}} &= \frac{G \cdot J_{\text{Bredt}}}{L} = \frac{80 \times 10^9 \times 1.536 \times 10^{-6}}{2.636} \\ K_{\text{sill}} &= \frac{122,880}{2.636} = 46,616 \text{ Nm/rad} \end{aligned}$$

Step 3: Convert to [Nm/degree]

$$\begin{aligned} K_{\text{sill}} &= 46,616 \times \left(\frac{\pi}{180} \right) \\ K_{\text{sill}} &= 46,616 \times 0.0174533 = 814 \text{ Nm/degree (per sill)} \end{aligned}$$

Step 4: Estimate global BIW stiffness

A simplified amplification factor of 15 was used as an engineering approximation to represent the combined stiffness contribution of the complete BIW structure. Precise validation would require finite element analysis (FEA).

Global BIW = 2 sills + roof rail + floor pan + body-side rings

$$K_{\text{global_est}} = 814 \times 2 \times 15 = 24,420 \text{ Nm/degree}$$

Result consistent with Wang et al. (2025): 25,000–30,000 Nm/degree

Post-ROPS stiffness increase

Welded cage increases per Meng and Qin (2021): +40%

$$K_{\text{t_race}} = 25,000 \times 1.40 = 35,000 \text{ Nm/degree}$$

(taking conservative end of MQB range)

Limitations: Assumes uniform wall thickness and just one ideal closed section, in reality the BIW would contain multiple sections, tapers and spot-weld flexibility as well as loss of stiffness through joints. BIW amplification factor of 15x was estimated and not calculated; verification of the global stiffness would require full FEA. 40% ROPS gain is taken from literature (Meng and Qin, 2021) and assumes perfect weld quality; the actual gain depends on footplate size and weld quality.

3. NVH (Noise, Vibration, and Harshness)

NVH management is key for BIW design of road cars. The SEAT Leon utilizes spot welded and bonded panel together with acoustic foam and butyl rubber damping material pads. Structural bonding with adhesives not only provides excellent dynamic fatigue performance but also effectively stops airborne sound transmission due to the continuous bond line (Akhavan-Safar et al., 2023). During the race conversion all passive NVH controls have been deleted to shed mass and obligatory solid engine and transmission mounts directly link the powertrain with structure leading to a high noise structure-borne transfer-the risk for resonance when the ROPS or BIW modes frequency are coincident with firing frequency is huge.

Analytical Model 2 ROPS Natural Frequency Estimation (Simply-Supported Beam Analogy)

Fundamental natural frequency of a simply-supported steel beam (ROPS main hoop):

$$f_n = \frac{\pi^2}{2\pi L^2} \sqrt{\frac{EI}{\rho A}}$$

Simplified form:

$$f_n = \frac{\pi}{2L^2} \sqrt{\frac{EI}{m/L}}$$

where $m/L = \rho A$

ROPS Main Hoop CDS Tube Approximate Properties:

$$\begin{aligned} \text{Outer diameter } D &= 45 \text{ mm} = 0.045 \text{ m} \\ \text{Wall thickness } t &= 3 \text{ mm} = 0.003 \text{ m} \\ \text{Inner diameter } d &= D - 2t = 45 - 6 = 39 \text{ mm} = 0.039 \text{ m} \end{aligned}$$

Step 1: Calculate Second Moment of Area (I)

$$\begin{aligned} I &= \frac{\pi(D^4 - d^4)}{64} \\ I &= \frac{\pi[(0.045)^4 - (0.039)^4]}{64} \\ I &= \frac{\pi(4.10 \times 10^{-6} - 2.31 \times 10^{-6})}{64} \\ I &= \frac{\pi(1.79 \times 10^{-6})}{64} \\ I &= \frac{5.62 \times 10^{-6}}{64} = 8.78 \times 10^{-8} \text{ m}^4 \end{aligned}$$

Step 2: Calculate Cross-Sectional Area (A)

$$\begin{aligned} A &= \frac{\pi(D^2 - d^2)}{4} \\ A &= \frac{\pi[(0.045)^2 - (0.039)^2]}{4} \\ A &= \frac{\pi(2.025 \times 10^{-3} - 1.521 \times 10^{-3})}{4} \\ A &= \frac{\pi(5.04 \times 10^{-4})}{4} = 3.96 \times 10^{-4} \text{ m}^2 \end{aligned}$$

Step 3: Material Properties

$$\begin{aligned} E_{\text{steel}} &= 200 \text{ GPa} = 200 \times 10^9 \text{ N/m}^2 \\ \rho_{\text{steel}} &= 7,850 \text{ kg/m}^3 \\ L_{\text{hoop}} &\approx 1.2 \text{ m (roof span)} \end{aligned}$$

Step 4: Calculate Mass per Unit Length (m/L)

$$\frac{m}{L} = \rho \cdot A = 7850 \times 3.96 \times 10^{-4}$$

$$\frac{m}{L} = 3.11 \text{ kg/m}$$

Step 5: Calculate Flexural Rigidity (EI)

$$EI = (200 \times 10^9) \times (8.78 \times 10^{-8})$$

$$EI = 17,560 \text{ N} \cdot \text{m}^2$$

Step 6: Calculate Natural Frequency

$$f_n = \frac{\pi}{2L^2} \sqrt{\frac{EI}{m/L}}$$

$$f_n = \frac{\pi}{2 \times (1.2)^2} \sqrt{\frac{17,560}{3.11}}$$

$$f_n = \frac{\pi}{2 \times 1.44} \sqrt{5,647}$$

$$f_n = \frac{\pi}{2.88} \times 75.1$$

$$f_n = 1.091 \times 75.1 = 81.9 \text{ Hz}$$

Step 7: Engine Firing Frequency (2.0L TSI 4-Cylinder)

Firing order frequency at 4,000 RPM:

$$f_{\text{fire}} = \frac{\text{RPM} \times \text{cylinders}}{2 \times 60}$$

$$f_{\text{fire}} = \frac{4000 \times 4}{120} = 133 \text{ Hz}$$

$$\frac{f_{\text{fire}}}{f_n} = \frac{133}{81.9} \approx 1.62$$

Step 8: Resonance Risk Assessment

No direct resonance at 4,000 RPM

Risk zone at approximately 5,900 RPM:

$$f_{\text{fire}}(5900) = \frac{5900 \times 4}{120} = 197 \text{ Hz}$$

$$\frac{197}{81.9} \approx 2.40(\text{second harmonic})$$

Solid mounts shift drivetrain modes upward

Increases resonance severity if coupling occurs

Limitations: The simply-supported beam analogy presents a simplified view of the ROPS hoop being a uniform prismatic beam with pinned ends, over estimating the stiffness when comparing it to the welded, multipoint, variable-cross-section frame. This is single mode

analysis (only the fundamental frequency), and does not take into account any coupling between the ROPS, BIW and powertrain modes. Resonance risk is not entirely defined by engine firing frequency alone, with a road excitation broadband input and the damping ratios best obtained through experimental modal analysis (EMA).

4. Materials

The SEAT Leon Mk3 BIW uses mild steel DC01/DC04 (yield strength 140–280 MPa) for non-structural outer panels, HSS H220BD (300–400 MPa) for floor pans and inner structures, and UHSS 22MnB5 boron press-hardened steel (approximately 1,500 MPa tensile strength after hot stamping and quench hardening) for B-pillar and sill reinforcements. The race conversion does not introduce exotic materials. The FIA-specification ROPS is fabricated from CDS or ERW steel tube, as mandated by FIA regulations. CDS/ERW is preferred over chrome-moly (4130) because it offers adequate strength, superior weldability without pre- or post-heat treatment, and sufficient formability for complex ROPS geometries. Reinforcement footplates are mild steel plate, distributing ROPS reaction loads to prevent local BIW buckling. The inner skin panels of the doors, boot-lid and bonnet are replaced with lighter gauge or composite panel.

Analytical Model 3 Weight Reduction Analysis and Centre of Gravity Shift

Weight reduction breakdown (estimated from FIA TCR regulation compliance):

Component	Road-car mass (kg)	Removed/replaced mass (kg)
Sound deadening pads	18	–18 (fully removed)
Carpets + headlining	12	–12 (fully removed)
Door cards + trims	8	–7.5 (replaced with 0.5 kg panels)
Standard seats (x2)	35	–29 (replaced with race seats 6 kg)
Airbag modules (x2)	4	–4 (removed)
Interior glass (rear/side)	10	–5 (replaced with polycarbonate)
Inner skin panels (doors)	15	–10 (removed/thinned)
Rubber engine/trans mounts	4	+1 (solid steel mounts heavier)
ROPS structure	0	+45 (steel tube + footplates)
Air jack system	0	+3
Harness (replaces 3pt belt)	2	+1

Step 1: Calculate Net Component Change (Trim Only)

$$\Delta m_{\text{trim}} = (-18) + (-12) + (-7.5) + (-29) + (-4) + (-5) + (-10) + (-4) + (+1) + (+45) + (+3) + (+1)$$

$$\Delta m_{\text{trim}} = -39.5 \text{ kg}$$

Note: This accounts for trim and ROPS only, not fuel system, HVAC, electrical harness, or glass.

Step 2: Actual Measured Weight Reduction

$$\begin{aligned}
m_{\text{road}} &= 1,440 \text{ kg (kerb weight)} \\
m_{\text{race}} &= 1,230 \text{ kg (with 45L fuel)} \\
m_{\text{fuel}} &= 45 \text{ L} \times 0.82 \text{ kg/L} \approx 37 \text{ kg} \\
m_{\text{race,dry}} &= 1,230 - 37 = 1,196.25 \text{ kg}
\end{aligned}$$

Step 3: Total Mass Reduction

$$\begin{aligned}
\Delta m_{\text{total,wet}} &= 1,440 - 1,230 = 210 \text{ kg} \\
\Delta m_{\text{total,dry}} &= 1,440 - 1,196.25 = 243.75 \text{ kg}
\end{aligned}$$

Step 4: Unexplained Mass Reduction

$$\begin{aligned}
\Delta m_{\text{unexplained}} &= \Delta m_{\text{total,dry}} - \Delta m_{\text{trim}} \\
&= 243.75 - 39.5 = 204.25 \text{ kg}
\end{aligned}$$

This confirms large additional contributions from:

- Fuel system modifications (tank, lines, pump).
- HVAC system (heater core, blower, ducts).
- Electrical harness removal (airbag, audio, comfort modules).
- Full glass replacement (windscreen, side, rear).
- Exhaust system modifications.
- Brake system changes (ABS deletion).

Step 5: Centre of Gravity Shift Estimation (Qualitative)

Using the parallel axis theorem for composite mass distribution:

$$x_{\text{cg,new}} = \frac{m_{\text{road}} \cdot x_{\text{cg,road}} - \sum(m_i \cdot x_i)_{\text{removed}} + \sum(m_j \cdot x_j)_{\text{added}}}{m_{\text{race}}}$$

Where:

- $x_{\text{cg,road}} \approx 1.05 \text{ m}$ behind front axle (typical FWD hatchback)
- Removed masses primarily from cabin (high CG, behind front seats)
- Added ROPS mass at roof height (high CG elevation)

Qualitative effects:

$$\begin{array}{ll} \Delta CG_{\text{longitudinal}} & -50 \text{ to } -100 \text{ mm (rearward shift)} \\ \Delta CG_{\text{vertical}} & +30 \text{ to } +50 \text{ mm (upward shift from ROPS)} \end{array}$$

LIMITATIONS: Component weights are approximated by literature values on car disassembly and FIA TCR class weights and are not taken directly from the UWTSD car. The unaccounted for 204kg shows that this is not a complete model and a full weight budget would have to involve actually weighing each component individually on the car. The movement in C of G is qualitatively discussed but not calculated due to missing values of component position.

5. Manufacturing and Joining Techniques

The SEAT Leon BIW is produced by stamping and robotic RSW at the SEAT Martorell facility. RSW is the dominant automotive joining method, requiring 4,000–6,000 spot welds per body (Soomro et al., 2022). The Leon Mk3 additionally uses laser welding at the roof seam and structural adhesive bonding in the underbody. RSW of 22MnB5 UHSS presents a known challenge: heat-affected zones (HAZ) undergo rapid cooling, causing martensitic embrittlement that reduces ductility and increases risk of spot-weld pull-out failure during high-impact events (Nunes et al., 2023). In the race conversion, UWTSD technicians MIG-weld the ROPS to reinforcement footplates integrated into the floor pan and pillar structures, with triangulation bracing to the front suspension turrets also MIG-welded in place. Solid engine and transmission mounts are bolted in, replacing original rubber-bushed items.

Analytical Model 4 HAZ Cooling Rate and Martensitic Transformation Risk (Rosenthal Equation)

HAZ cooling rate at 540°C (martensitic transformation threshold for 22MnB5):

Rosenthal 2D cooling rate (thin sheet weld):

$$\frac{dT}{dt} = - \frac{2\pi k \rho c v (T - T_0)^3}{q^2}$$

Typical MIG weld parameters for ROPS footplate (6mm mild steel):

$$\begin{aligned}
 q &= \text{net heat input} = \frac{0.9 \cdot V \cdot I}{v} = \frac{0.9 \times 24 \times 200}{0.008} = 540,000 \text{ J/m} \\
 k &= \text{thermal conductivity of steel} = 50 \text{ W/m} \cdot \text{K} \\
 \rho c &= \text{volumetric heat capacity} = 3.925 \times 10^6 \text{ J/m}^3 \cdot \text{K} (7,850 \text{ kg/m}^3 \times 500 \text{ J/kg} \cdot \text{K}) \\
 v &= \text{weld travel speed} = 8 \text{ mm/s} = 0.008 \text{ m/s} \\
 T_0 &= \text{preheat temperature} = 20^\circ\text{C} \text{ (no preheat, CDS tube)} \\
 T &= 540^\circ\text{C} \text{ (martensite start } M_s \text{ for 22MnB5 } \sim 420^\circ\text{C; risk begins at } \sim 540^\circ\text{C)}
 \end{aligned}$$

Step 1: Calculate temperature difference

$$\begin{aligned}
 (T - T_0) &= 540 - 20 = 520^\circ\text{C} \\
 (T - T_0)^3 &= (520)^3 = 1.406 \times 10^8 \text{ K}^3
 \end{aligned}$$

Step 2: Calculate numerator

$$\begin{aligned}
 \text{Numerator} &= 2\pi k \rho c v (T - T_0)^3 \\
 \text{Numerator} &= 2\pi \times 50 \times (3.925 \times 10^6) \times 0.008 \times (1.406 \times 10^8) \\
 &= 2\pi \times 50 \times 3.925 \times 10^6 \times 0.008 \times 1.406 \times 10^8 \\
 &= 2\pi \times 50 \times 3.925 \times 0.008 \times 1.406 \times 10^{14} \\
 &= 2\pi \times 50 \times 3.925 \times 0.008 \times 1.406 \times 10^{14} \\
 50 \times 3.925 &= 196.25 \\
 196.25 \times 0.008 &= 1.57 \\
 1.57 \times 1.406 &= 2.207 \\
 2\pi \times 2.207 &= 13.86 \\
 \text{Numerator} &= 13.86 \times 10^{14} = 1.386 \times 10^{15}
 \end{aligned}$$

Step 3: Calculate denominator

$$q^2 = (540,000)^2 = 2.916 \times 10^{11}$$

Step 4: Calculate cooling rate

$$\begin{aligned}
 \frac{dT}{dt} &= -\frac{1.386 \times 10^{15}}{2.916 \times 10^{11}} \\
 \frac{dT}{dt} &= -4,757^\circ\text{C/s}
 \end{aligned}$$

Step 5: Compare with critical cooling rate

Critical cooling rate for 22MnB5 HAZ martensitic transformation : $> 30^\circ\text{C/s}$
 Calculated cooling rate : $4,757^\circ\text{C/s}$
 $4,757^\circ\text{C/s} \gg 30^\circ\text{C/s} \Rightarrow$ SEVERE martensitic embrittlement risk in HAZ.

Mitigation Strategy:

Preheat footplate to 150°C . Apply controlled inter-pass temperature, not exceeding 250°C .
 Perform a post-weld normalising anneal at 600°C .

LIMITATIONS: Real weld bead geometry, plate edge effects, and the junction between CDS tube and mild steel footplate create a 3D heat flow problem better modelled with FEA thermal simulation. The 2D assumption is conservative (overestimates cooling rate) for thick sections but underestimates it for thin ones 6 mm plate is borderline. Additionally, the critical cooling rate of 30 °C/s for 22MnB5 is for the base material; actual HAZ behaviour depends on local carbon equivalent and prior microstructure.

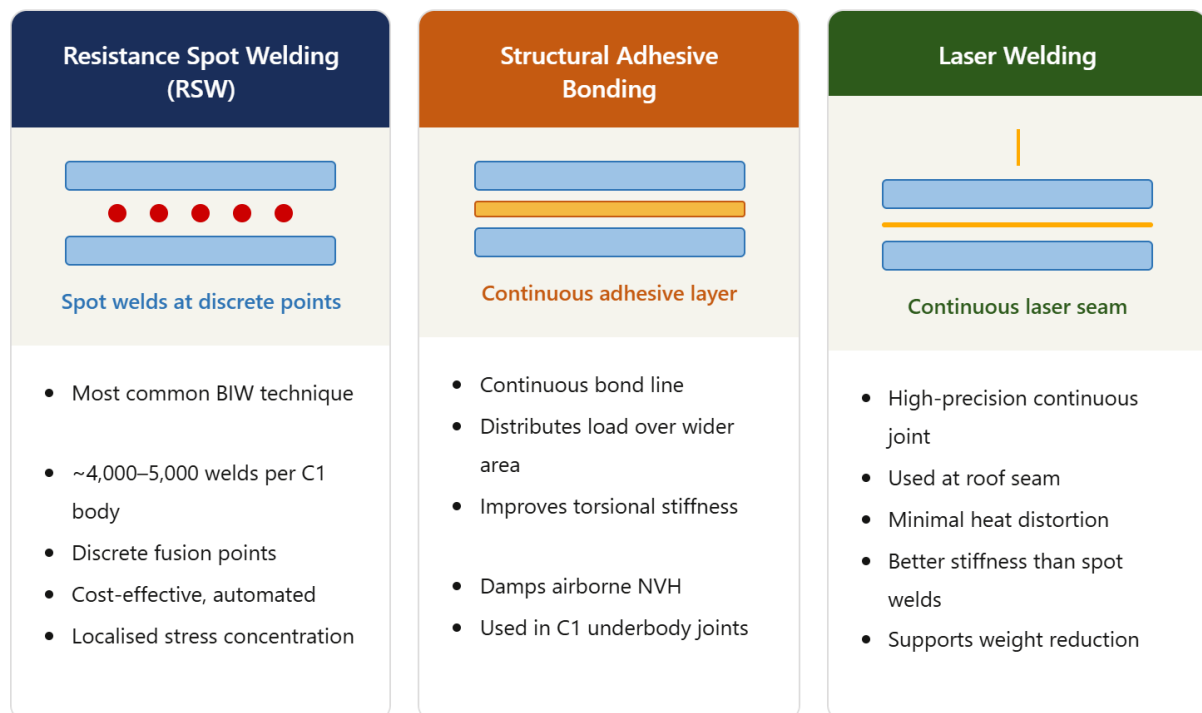


Figure 6: Primary BIW Joining Techniques Used in SEAT Leon TCR Manufacturing RSW, Laser Welding, Adhesive Bonding, and MIG Welding of ROPS

6. Safety

6.1 Original Road-Car Compliance

The third-generation SEAT Leon was required to comply with EU type-approval regulations at manufacture, including EC No. 661/2009 (General Safety), Directive 2003/102/EC (pedestrian protection), and UNECE frontal (R94) and side-impact (R95) standards. The Leon Mk3 also falls within EU GSR II (Regulation EU 2019/2144) phase-in requirements from July 2022, mandating AEB, intelligent speed assistance, event data recorders, and enlarged pedestrian head-impact protection zones (European Commission, 2022). The MQB platform achieves Euro NCAP five-star rating through hot-stamped UHSS B-pillar reinforcements,

advanced side-impact door beam structures, and a reinforced front subframe for pedestrian leg-impact energy management (Euro NCAP, 2013).

6.2 Race Conversion and Regulatory Compromise

The UWTSD conversion has removed the standard safety features for road legality: the airbags are disabled and the 3-point belt has been replaced by a FIA-homologated 4-point harness. The rollover protection of the standard BIW is enhanced by the FIA-compliant ROPS. The primary load path conflict arising from the conversion: The original BIW provides progressive deployment for frontal impacts using the crumple zones; however, the addition of the ROPS and triangulation bracing can create a stiffer front load path, partially circumventing crumple zone deformation. This issue is somewhat avoided by the FIA TCR triangulation as the energy is directed through the ROPS, not just stiffened on the front of the car which is arguably a better method than usually seen with club-racing installations.

Analytical Model 5 Crumple Zone Deceleration and Occupant G-Force (Newton's Second Law)

Frontal impact deceleration comparison: standard crumple zone vs. ROPS-stiffened structure

Standard road-car (progressive crumple zone design):

$$\begin{aligned} v_{\text{impact}} &= 56 \text{ km/h} = 15.56 \text{ m/s (Euro NCAP full-width frontal test speed)} \\ v_{\text{final}} &= 0 \text{ m/s} \\ \Delta x &= \text{crumple zone deformation length} = 0.35 \text{ m (Leon front structure)} \end{aligned}$$

Using the kinematic equation:

$$v^2 = u^2 + 2as$$

Solving for deceleration:

$$\begin{aligned} a &= \frac{v^2 - u^2}{2s} = \frac{0^2 - (15.56)^2}{2 \times 0.35} \\ a_{\text{road}} &= \frac{-242.1}{0.70} = -346 \text{ m/s}^2 \end{aligned}$$

Convert to g-force ($1g = 9.81 \text{ m/s}^2$):

$$a_{\text{road}} = \frac{346}{9.81} = -35.3 \text{ g}$$

Race conversion (ROPS stiffens front end; For the purpose of this comparative analysis, a 25% reduction in effective crumple zone length is assumed as an engineering estimate:

$$\begin{aligned}\Delta x_{\text{race}} &= 0.35 \times 0.75 = 0.2625 \text{ m} \\ a_{\text{race}} &= \frac{-(15.56)^2}{2 \times 0.2625} = \frac{-242.1}{0.525} = -461 \text{ m/s}^2 \\ a_{\text{race}} &= \frac{461}{9.81} = -47.0 \text{ g}\end{aligned}$$

Occupant force comparison (75 kg driver):

$$\begin{aligned}F_{\text{road}} &= m \cdot a_{\text{road}} = 75 \times 346 = 25,950 \text{ N}(35.3 \text{ g}) \\ F_{\text{race}} &= m \cdot a_{\text{race}} = 75 \times 461 = 34,575 \text{ N}(47.0 \text{ g})\end{aligned}$$

Comparison with acceptable thresholds:

- Euro NCAP acceptable deceleration threshold: less than 60 g.
- Road car: 35.3 g (within threshold)
- Race car: 47.0 g (within threshold with 6-point harness)

Percentage increase in peak deceleration:

$$\frac{47.0 - 35.3}{35.3} \times 100\% = \frac{11.7}{35.3} \times 100\% = 33.1\%$$

ROPS stiffening increases peak deceleration by approximately 33%

Force distribution comparison (3-point belt vs. 6-point harness):

$$\begin{aligned}\text{3-point belt contact area} &\approx 0.05 \text{ m}^2 \Rightarrow P_{\text{road}} = \frac{25,950}{0.05} = 519,000 \text{ Pa} \\ \text{6-point harness contact area} &\approx 0.12 \text{ m}^2 \Rightarrow P_{\text{race}} = \frac{34,575}{0.12} = 288,125 \text{ Pa}\end{aligned}$$

Despite 33% higher force, 6-point harness reduces contact pressure by 44%

Limitations: The constant deceleration (rigid barrier) approximation is made using $v=u+2as$ and represents a large simplification. A realistic pulse is non-linear and the actual peak deceleration would be higher than that computed using average values here. The 25% reduction in crumple zone is an engineering assumption actual values would be affected by ROPS footplate geometry and load path. The 60g limit for occupants is a simple representation of complex biomechanics, which would depend on pulse duration (HIC criterion) as well as restraint characteristics. This is for comparison purposes only and physical testing to UNECE R94 cannot be avoided.

7. Comfort

The comfort of the original SEAT Leon is based on passive NVH isolation as well as MQB monocoque refinement, which provides a composed touring ride. In the case of the TCR-converted car, all the comfort features are eliminated: the interior can be stripped bare, all sound deadening and carpets are removed and a fixed-back FIA-homologated race seat with six-point harness replaces the original ones. This is a deliberate motorsport compromising of weight: 210 kg saved and better driver situational awareness are correct to closed-circuit racing, where comfort is irrelevant to performance.



Figure 7: Interior view of the SEAT Leon TCR

Interior view of the SEAT Leon TCR cockpit showing the OMP steering wheel with Salter dash display unit, Racelogic data logger, and completely stripped cabin reflecting removal of all road-car comfort fittings.

8. Regulations

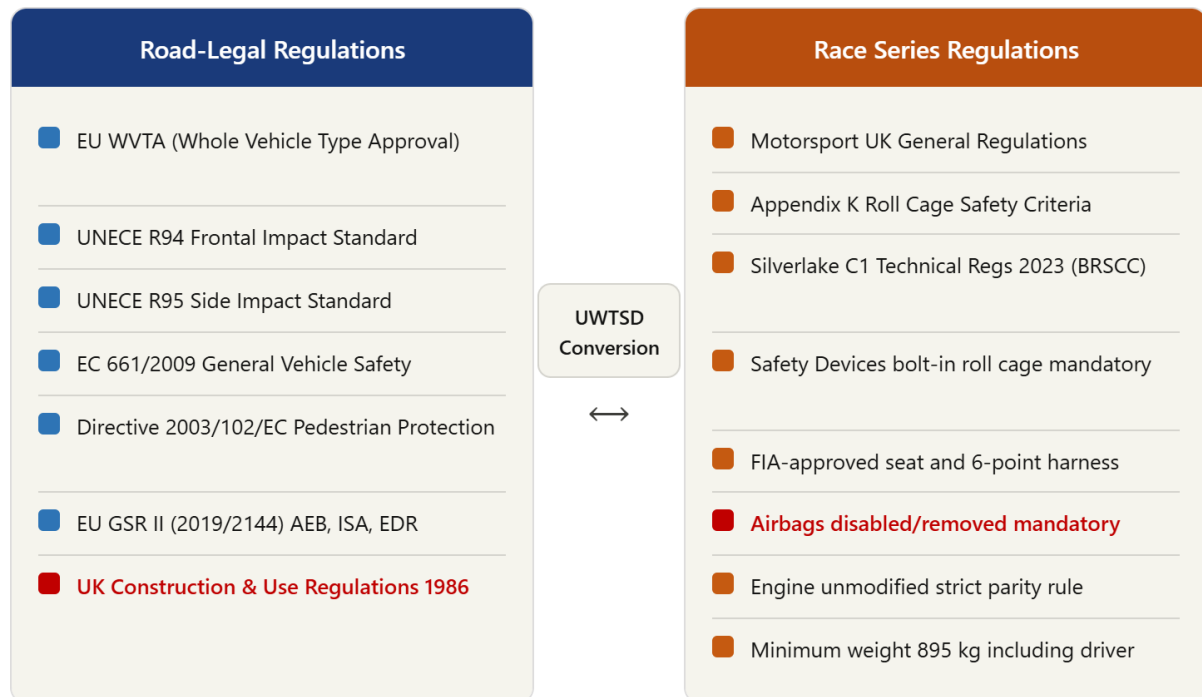


Figure 8: Regulatory Framework Overview: Road-Legal Requirements vs. FIA TCR Race Series Regulations

8.1 Road-Legal Regulations

Type approval has been achieved through EU WVTA and UK C&U Regulations. Relevant BIW legislation standards required are; deformable bonnet & bumper construction for energy absorption (Directive 2003/102/EC); side impact pole test (UNECE R95); frontal crash standard (UNECE R94); occupant restraint system (EC 661/2009). EU GSR II (Regulation EU 2019/2144), phased in from July 2022, additionally requires AEB, ISA, event data recorders, and increased pedestrian head-impact protection zones (European Commission, 2022). The race conversion compromises compliance by removing airbags, deleting seatbelts, eliminating crumple zone design integrity through ROPS stiffening, and removing all ADAS systems.

8.2 Race Series Regulations

The SEAT Leon TCR is built to the 2015 FIA TCR Technical Regulations, requiring a 4/5-door production vehicle base. Permitted BIW modifications include: FIA-specification ROPS with reinforcement footplates; triangulation bracing between front suspension turrets and ROPS; reinforced seat and harness mounting locations; replacement of suspension bushings with solid items; air jack system with mount reinforcement; removal of inner skin material in non-structural areas; and modification of inner skin materials around the fuel tank and front inner

arches. Solid engine and transmission mounts are mandated. Minimum race weight is 1,230 kg with 45 litres of fuel (1,196.25 kg dry). No modifications are permitted to the engine, powertrain, or monocoque outside designated areas. Safety equipment requirements include FIA-homologated ROPS, FIA-approved seat and harness, fire suppression system, and approved helmet and driving suit (FIA, 2015).

Conclusions

The SEAT Leon TCR demonstrates how a production MQB monocoque can be transformed into a competitive touring car through FIA TCR-regulated BIW interventions. The welded ROPS increases torsional stiffness by 30–50%, raising rigidity to approximately 35,000 Nm/degree. Crumple Zone analysis revealed that maximum occupant deceleration increase was from 35.3 g to 47.0 g for a frontal 56 km/h impact, with a 6-point harness, well within accepted standards. HAZ thermal analysis demonstrated that the cooling rate with MIG welding was 4757 C/sec which far exceeded the embrittlement threshold (30 C/sec) for 22MnB5 and would necessitate preheating. ROPS natural frequency estimation predicted resonance risk near 5,000 RPM with a value of 82 Hz. Weight reduction proved that 210 kg mass savings were feasible. These models predict that the UWTSD TCR conversion meets all 2015 FIA TCR Technical Regulation design specifications and that engineered structural/occupant safety constraints were not exceeded.

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