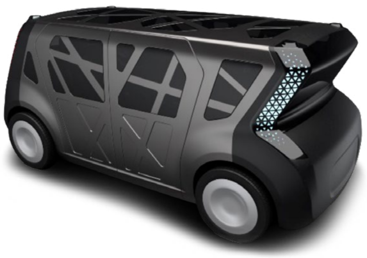
Steel E-Motive
Shaping the Future of Sustainable Transportation ISSUE 1
Technical Microstudies Highlighting Design and Performance Innovations for Steel E-Motive

How Steel E-Motive Body Structure Concepts Meet Global Crash Requirements



INTRODUCTION

Urbanization and Net Zero Emissions targets are key contributors of the transportation shift to mobility on demand in densely populated urban environments. It's here that the mobility industry anticipates significant growth in ride sharing, with emphasis on the use of autonomous vehicle technologies and electrification to achieve that goal.

WorldAutoSteel's Steel E-Motive program demonstrates autonomous ride-sharing concepts that maximize occupancy and comfort through unique seating configurations and easy vehicle access, while offering a clear path to Net Zero.

Steel E-Motive concepts consist of two vehicles, "SEM1", a four-seat urban passenger vehicle and a larger "SEM2" variant, seating up to six passengers. Both can operate in "mixed mode" traffic, with a maximum speed of 130km per hour. With these concept designs, it becomes critical to engineer the vehicles to meet global high speed crash standards.

However, these small, open box designs can present safety challenges. To address this, Steel E-Motive's engineering strategy focused on an expansive application of modern advanced high strength steels designed to meet stringent crash requirements. This report details how those requirements were achieved.

SAFETY PERFORMANCE

The purpose of an electric vehicle crash structure is simple – provide protection for the occupants and battery in the event of a collision. To achieve this, the crash structure must decelerate the vehicle in a controlled and progressive manor, by converting the kinetic (moving) energy of the vehicle to crush/plastic deformation of the body structure. Steels with high elongation and work hardening properties are used in "crushable" elements of the body structure to provide this controlled deceleration, which are characteristics of the USNCAP FFB test.

The front crash structure must also minimise intrusions or penetrations into the cabin and battery modules as a result of the impact. This is achieved by strategic placement of ultra-high strength steels in the required locations and intentional design of the body structure geometry.

These requirements are compounded by the fundamentals of the Steel E-Motive SEM1 vehicle concept. The vehicle is relatively small in overall size, having a front overhang dimension of 730mm. This short length makes it difficult to absorb the vehicle crush energy during a frontal impact, meaning that the magnitude of the deceleration is typically higher than a larger vehicle, resulting in higher forces imparted to the occupants.

Additionally, front occupants are positioned rear-facing, towards the front of the vehicle. While the benefit of this configuration is a more open, spacious interior that invites socialization, the front occupant location is much closer to the impact zone, resulting in a higher risk of injury from crash intrusion. The simulations didn't involve test dummies, so in addition to balancing crush and intrusion resistance, it was important to minimise energy pulse transmitted to the occupants, ensuring their safety. The rear-facing front occupant orientation means that the seat and headrest design play a critical role in containing and decelerating the occupant. Despite these challenges, no compromise for the protection of the occupants was considered for the Steel E-Motive concepts.

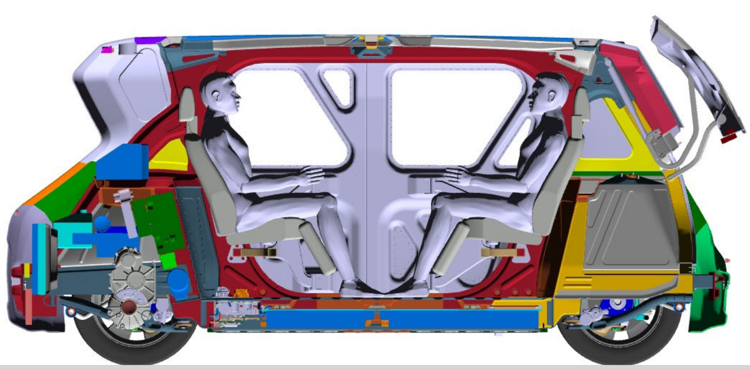
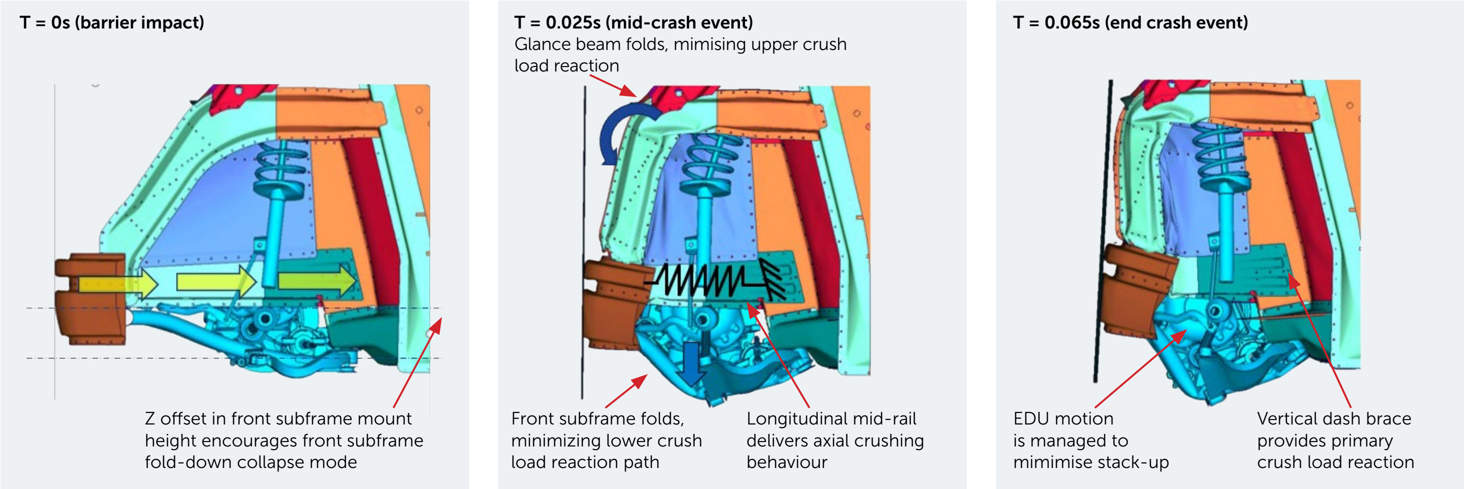


Figure 1. Side view of the front crash simulation timesteps for the USNCAP 56kph Frontal Rigid Barrier (FFB) load case



FRONT CRASH MANAGEMENT AND PERFORMANCE

For Steel E-Motive's SEM1 concept, we conducted crash simulations against the four major front crash standards; their descriptions, along with test results, are shown in Table 1. Our primary focus is two tests: the USNCAP 56kph Full Frontal Barrier (FFB) test and the Insurance Institute for Highway Safety (IIHS) 64kph Small Offset, Rigid Barrier (SORB) test.

The USNCAP FFB test is well-established and the strategies and solutions for achieving performance well understood. The test requires controlled crush and collapse of the front crash structure, attained primarily through appropriate design and material specification of the front crash longitudinals.

In Steel E-Motive's design, hollow-section, AHSS longitudinal mid-rails provide its primary front crush/absorption structure. Tailor Welded Blanks (TWB) offer multiple strength and thickness, enabling tunability of the crush performance for progressive collapse during a frontal impact. Figure 1 shows the USNCAP 56kph FFB crash simulation timesteps and front structure collapse mechanism.

One of the most significant challenges in the development of the Steel E-Motive front crash structure was balancing the conflicting requirements for front crash test compliance. For example, the USNCAP 56kph FFB test and the 64kph test – the two globally recognized standards for compliance – both require a significant amount of strength in the front crash structure. The SORB test reflects a higher impact velocity and only a 25% front barrier overlap, so the test encompasses more of the vehicle structure compared with the FFB test – and the front crash structure must work harder to manage energy and prevent intrusion. A higher strength structure is therefore required to manage the crash loads in the SORB test, but this is too stiff and strong for the FFB test, resulting in a high deceleration pulse in FFB as a smaller crush length is used.

Steel E-Motive's crash simulations centered around the USNCAP 56kph FFB test and the IIHS 64kph SORB test.

Essentially, the front crash structure needs to be engineered for two quite different requirements. In the IIHS 64kph SORB test, with conventional passenger car architectures and package constraints, the SORB barrier position is typically outboard of the main crush longitudinal rail; therefore the wheel, tyre and outer body structure are impacted by the crash event and play a role in the crash event, and the design of these components and system contribute to crashworthiness performance. Specific strategies, body structure components and devices are required to manage SORB loads and energy and deliver the required protection for the occupants.

Table 1. Summary of Steel E-Motive front crashworthiness performance (simulation results)

Crash Loadcase	Test Details	Target Value	SEM1 Performance	Result
USNCAP 56kph Frontal Rigid Barrier (FFB)	100% Overlap, 56 kph	<40g deceleration pulse	35.1g	Target achieved
		<40mm bulkhead intrusion	6.5mm	
IIHS 64kph Moderate Overlap Offset Deformable Barrier (ODB)	40% Overlap, 64 kph	<35 g deceleration	31.7g	Meets requirements for IIHS "good" rating
		Footwell intrusion (pos #1,2,3) mm <150mm	1.8mm	
		Bulkhead intrusion (pos #4,5) mm < 50mm	2.7mm	
IIHS 64kph Small Overlap (SORB)	25% Overlap, Rigid Barrier, 64 kph	<35g deceleration	22.1g	Meets requirements for IIHS "good" rating "glance off" crash behaviour
		Footwell intrusion (pos #2, 9) mm <150mm	11.2mm	
		Bulkhead intrusion (pos#4, 5) < 75mm	70.2mm	
Euro NCAP 50kph Mobile Progressive Deformable Barrier (MPDB)	50% Overlap, 50 kph + 50kph Barrier	<35g deceleration pulse	33.1g	Target achieved
		<40mm bulkhead intrusion	1.3mm	

SORB: SNAG VS GLANCE

A common approach that is applied is to decelerate the vehicle using the vehicle structure. The very high energy levels and small overlap usually result in the complete front structure absorbing the crush energy, up to the A-pillar, with any residual kinetic energy converted to a rotation (yaw) motion around the barrier; essentially the vehicle snags the barrier.

Alternatively, the 25% width overlap provides an opportunity to deflect or "glance" the vehicle from the barrier following the initial impact. This results in the vehicle continuing beyond the SORB barrier with some forward velocity, hence a lower magnitude of pre-impact kinetic energy is converted to crush energy. The reduced crush energy levels subsequently result in lower longitudinal crush forces and deceleration experienced by the vehicle and occupants, translating into reduced occupant injury levels.

Both the glance and snag SORB strategies can deliver the desired IIHS "good" safety ratings. For the Steel E-Motive design concept, the SORB glance strategy was desired, based on the potential for lower deceleration pulse and intrusion magnitudes, deemed especially important, given the proximity of the front occupants to the front impact zone. IIHS confirmed this strategy, noting Steel E-Motive's intrusion location measurements were logical for vehicles with a rear-facing front passenger orientation.

To achieve a "glance off" in the SORB test, the front crash structure must engage the barrier, and based on vehicle loads, initiate acceleration and movement in the lateral (+Y) direction. To provide this lateral load reaction, the front crash structure must maintain overall integrity, with minimum plastic deformation. A front crash structure is therefore required, which permits collapse and deformation in the longitudinal (X) direction (to meet FFB) whilst maintaining integrity and minimizing collapse (i.e., strength) when subjected to very high lateral (Y) forces. High strength in the lateral direction is required along the complete length of the front crash structure such that the barrier to vehicle forces can be reacted, and lateral acceleration of the vehicle can be attained resulting in a full "glance off." The Steel E-Motive concept achieved this by developing an industry-first glance beam, produced from 1500 MPa UTS press-hardened steel.

Figure 2 demonstrates the front crash structure design and AHSS usage. The glance beam contributes to SORB performance and is engineered to fold and collapse in the FFB test, minimising influence and contribution to the deceleration characteristics in the FFB test. The glance beam design helps guide the vehicle along the SORB barrier and distributes the crash loads into the body structure. Additionally, a significant Ultra High Strength Steel structure wraps around the front shock tower area of the body structure. It maintains a high level of lateral force reaction between the SORB crash barrier and vehicle, continuing the lateral acceleration, which also causes a front wheel detachment enabling the glance-off behaviour.

Figure 2. Steel E-Motive front crash structure, key design features and AHSS grades

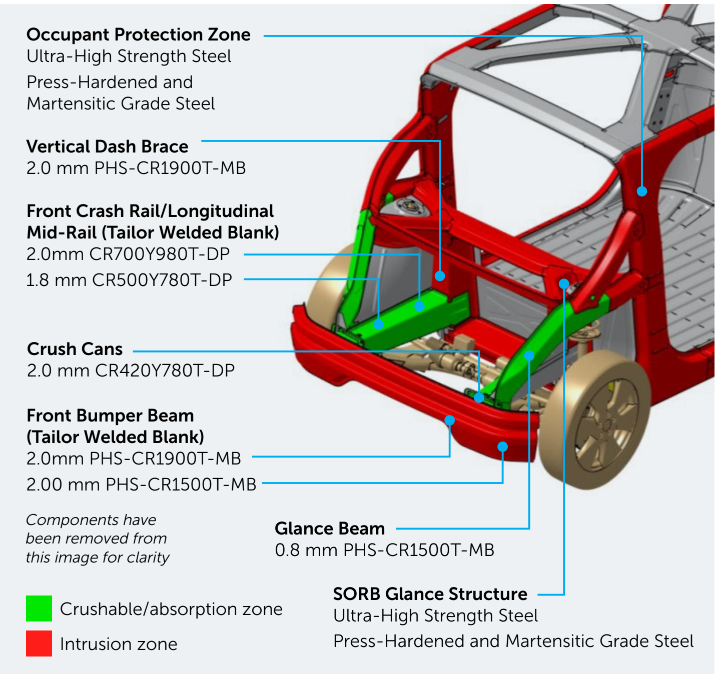
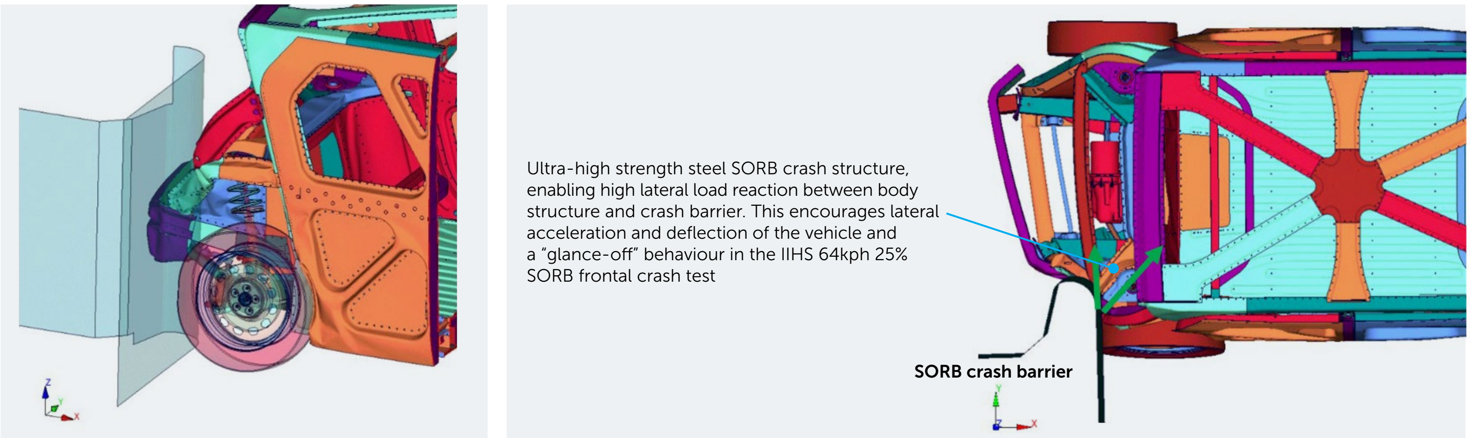


Figure 3: Crash simulation of the IIHS 64kph 25% Small Overlap Rigid Barrier

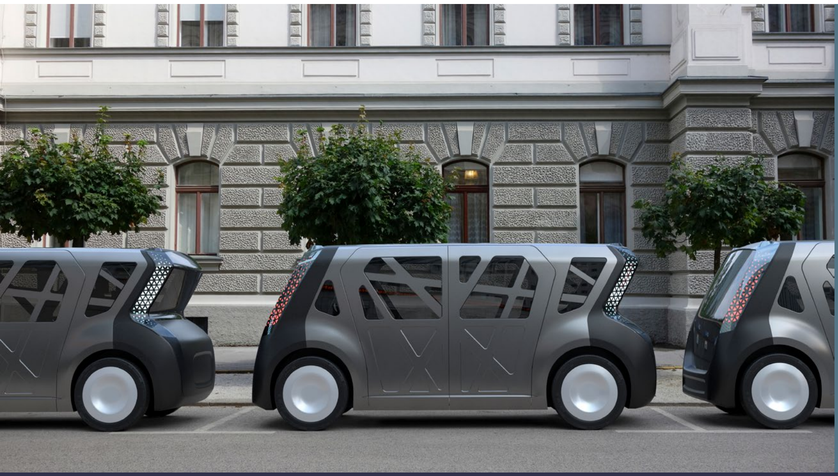


The front subframe is engineered to fold, so as not to contribute as a main load path in FFB and ODB load cases. The collapsing motion of the front subframe encourages the front electric motor to move downwards and away from the front bulkhead, minimising the risk of contact and intrusion.

Vertical dash braces support the longitudinal mid-rails, providing the primary load reaction to the longitudinal crush rails. These braces utilize 1900MPa UTS press-hardened steel for the necessary strength required and to minimise intrusion to the passenger compartment. UHSS glance components were placed towards the rear of the crash structure, ensuring there is no interference between high strength/limited crush performance and the longitudinal crush required for the FFB and ODB load cases.

Figure 3 shows the crash simulation result for the IIHS 64kph SORB load case. On initial contact between the vehicle and SORB crash barrier, the front bumper beam deforms and contacts with the front subframe lateral cross member. This initiates a lateral (Y direction) force reaction in the vehicle structure, resulting in a lateral acceleration and a lateral deflection of the complete vehicle.

The properties of AHSS and geometrical design of the glance beam structure combine to deliver full 25% vehicle lateral deflection, meeting desired glance-off behaviour for the IIHS SORB load case, without compromising the longitudinal crush performance required for other frontal crash load cases.



CONCLUSION

With its AHSS-intensive body and front crash structure, the concepts deliver excellent crashworthiness performance. The high strength/high ductility characteristics of AHSS support the requirements for both high energy absorption for crush zones and intrusion prevention.

These capabilities enable the most relevant, global high-speed crash standards to be met. This includes the IIHS "Good" rating for their 64kph small overlap rigid barrier test, where SEM1's glance off reduces vehicle deceleration pulse and with lower intrusion levels.

For additional details on the Steel E-Motive project, including specific design and simulation results, visit **steelemotive.world/information**