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Racetrack SAFER barrier on temporary concrete barriers

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Abstract

Previously, the Steel and Foam Energy Reduction (SAFER) barrier system was successfully developed and crash tested for use in high-speed racetrack applications for the purpose of reducing the severity of racecar crashes into permanent, rigid, concrete containment walls. The SAFER barrier has been implemented at all high-speed oval race tracks that host events from NASCAR's top three race series and IRL's top series. However, there are a number of racetrack facilities in the United States that use temporary concrete barriers as a portion of the track layout during races. These barriers are typically used on race tracks to shield openings or protect portions of the infield. Some of these temporary barrier installations are in areas where current safety guidance would recommend treatment with the SAFER barrier. Thus, a system was successfully designed, tested, and evaluated for a system targeted towards the most pressing need in the US motorsports industry, a system for spanning openings between rigid concrete parapets on the inner walls of various race tracks.

Keywords: racetrack safety; SAFER barrier; temporary concrete barriers

1. Introduction

In the early 2000s, the Steel and Foam Energy Reduction (SAFER) barrier system was successfully developed and crash tested for use in high-speed racetrack applications for the purpose of reducing the severity of racecar crashes into permanent, rigid, concrete containment walls [2,6]. Thus far, the SAFER barrier has been implemented at all high-speed oval race tracks that host events from NASCAR's top three race series and IRL's top series.

However, there are a number of racetrack facilities in the United States that use temporary concrete barriers (TCBs) as a portion of the track layout during races. These barriers are typically used on race tracks to shield

openings or protect portions of the infield. Some of these temporary barrier installations are in areas where current safety guidance would recommend treatment with the SAFER barrier. At the onset of this project, no shielding method had been developed that could effectively cover the openings for racing events while still being removable at other times.

Thus, the objective of the research effort described herein was to design and evaluate a system for installing SAFER barrier on TCB segments that offers race tracks the flexibility to install the barrier wherever TCBs may be employed. This research included design, simulation, and analysis of the new system over a range of potential installation types, as well as design of the necessary TCB and anchorage hardware required for such a system. Full-scale crash testing was used to evaluate the final design.

TCB systems redirect errant vehicles through a combination of various forces and mechanisms, including inertial resistance developed by the acceleration of several barrier segments, lateral friction loads, and the tensile loads developed from the mass and friction of the barrier segments upstream and downstream of the impacted region [3].

The SAFER barrier system consists of a vertical-face, steel impact panel that is spaced away from a rigid parapet with discrete, energy-absorbing foam cartridges [4]. The steel impact panel is fabricated with five steel tubes stitch welded to one another, thus forming a stiff, load distributor beam. The stiff impact panel is utilized to keep the face of the barrier parallel to the track and prevent permanent deformation of the impact surface. Dynamic crush of the foam cartridges dissipates the impacting vehicle's kinetic energy.

2. Design and analysis

Development of a new system for the installation of the SAFER barrier on TCB systems required a considerable design and analysis effort, including: (1) selection of the TCB design for use in the system; (2) development of concepts for the SAFER barrier installed on TCB; (3) finite element analysis using LS-DYNA®[5] on various concepts to evaluate performance, loading, and critical areas; (4) selection of test installation; (5) simulation to design the system to be tested; and (6) development of anchorage hardware for the ends of the system.

2.1. Selection of TCB design

It was deemed advantageous to select a single TCB design for the SAFER barrier system installed on TCB in order to make installations consistent from track to track and to prevent the use of incompatible TCB systems. Review of the TCB designs used at various tracks identified a variety of barrier configurations, including variations in length, barrier reinforcement, and connection design.

The Midwest Roadside Safety Facility (MwRSF) had recently worked with the Iowa Speedway to develop a TCB for use on the track, as shown in Figure 1. The TCB developed for the Iowa Speedway consisted of a 2.44 m long

barrier segment with a vertical front face. The segments were connected with a pin and loop connection with three sets of double shear loops and a 31.75 mm diameter, A36 steel drop pin. This new design was fabricated and put to use at the Iowa Speedway, and it possessed several advantages over the other TCB systems. First, it featured a robust connection and a significant quantity of reinforcing steel. These features increased the overall load capacity of the barrier segment. Second, the barrier used a relatively short length (2.44 m), which allowed it to be easily placed around the curves, and added to its installation flexibility. Based on these advantages, the Iowa Speedway TCB was chosen as the standard TCB design for use with the SAFER barrier.

2.2. Initial design concept

With the design of the supporting TCB segment chosen, the next step of the research effort was to reconfigure the SAFER barrier for installation on the temporary barrier. A design concept was developed to facilitate the connections required between the temporary barrier segments and the SAFER. The barrier design concept was configured for attachment to the 2.44 m long TCB segments using a revised, 7.3 m length for the steel SAFER panels. Similarly, the spacing of the foam energy absorbers was increased by 152 mm as compared to the original design in order to facilitate the installation on the TCB segments. The spacing of retention straps and strap mounting hardware on the SAFER barrier were modified to allow for strap mounting plates to be installed at the midpoint of each TCB segment for ease of installation.

This initial design concept was used as the basis for the computer simulation models. It was realized that the results from the simulations would have the potential to change the design. For example, additional rows of temporary barriers or anchoring hardware at each barrier segment might be necessary to prevent excessive deflection of the system. However, it was desired to make the preliminary evaluation of the design without additional barrier segments or anchorages. In addition, the original design concept did not include any anchoring of the ends of the TCB system. These end anchorages would be added as needed during the simulation analysis.

2.3. Concept simulation

2.3.1. Simulation model

A finite element model was developed for the prototype, freestanding SAFER barrier and TCB system. The system model consisted of seven panels mounted in front of 21 TCB segments. All of the major components of the SAFER barrier installed on TCB were incorporated. The TCB segments were modelled as rigid bodies with a deformable pin and loop connection. The TCB models were defined with appropriate mass and inertial properties as well as proper barrier-ground friction. This approach for TCB modelling has been used with good success in previous MwRSF research projects involving TCB in highway work zones. The SAFER barrier panels, splice connections, and retaining strap brackets were all modelled with shell elements and defined with the

appropriate steel material properties. Models of the retention straps and the foam energy absorbers were also incorporated. The majority of the simulation model components were derived from or improved upon previous models used in the original development of the SAFER barrier system. Thus, there was a large degree of confidence in their ability to predict the performance.

The barrier model was impacted in all of the simulations with a surrogate, foam-block vehicle model. The foam block model had similar mass, inertial, and crush properties to a NASCAR stock car vehicle. However, its simplicity allowed it to be computationally very efficient and stable. Use of the surrogate vehicle model allowed the researchers to focus the simulation effort on the barrier details while still providing the proper impact dynamics for a crash event.

2.3.2. SAFER barrier on freestanding TCB

The base model was modified to conduct a series of simulations to quantify the performance of the system when installed on freestanding TCB segments. Simulations on the length of need were conducted with different end constraints on both the TCBs and the SAFER barrier to bracket the performance of the system. All models were impacted near the midspan of the system. The results from these simulations were analyzed to provide insight on critical anchorage requirements as well as guidance on the critical installation for full-scale crash testing. The end constraints on the system were varied to include the following:

- (1) TCB segments with unconstrained or free ends and SAFER barrier panels with tension provided on upstream and downstream ends (Case 1).
- (2) TCB segments with axially constrained or pinned ends and SAFER barrier panels with tension provided on upstream and downstream ends (Case 2).
- (3) TCB segments with unconstrained or free ends and SAFER barrier panels with unconstrained or free ends (Case 3).

In addition to varying the end conditions, simulations were conducted with reduced friction coefficient between the TCB segments and the ground to represent an upper bound for potential barrier deflections.

A summary of the simulation results is shown in Table 1. For comparison, included in Table 1 are results from the SAFER on a fixed concrete wall simulation. Typical simulation results are shown in Figure 2. In these simulations, the overall behavior of the barrier system was positive. The surrogate vehicle was smoothly redirected by the barrier system regardless of the constraints applied to the system, and with no concern for vehicle pocketing. There was some deformation of the SAFER barrier panels, but no plastic hinging of the panels was observed. In addition, the bending moments in the SAFER panels were consistently more than 20% lower than those found in simulation of the SAFER barrier installed on a fixed concrete wall.

The main concern observed in the simulations was the large system deflections. Even with the upstream and downstream ends constrained, the

maximum lateral-system deflections were approximately 0.66 m. These deflections increased to approximately 1.04 m when end conditions were unconstrained. Simulations with reduced TCB segment to ground-friction values demonstrated even higher system deflections. Lateral deflection is undesirable for the racing circuits due to safety concerns related to personnel and equipment located behind the barriers, and the time and effort that would be required to reset the system after a serious-impact event.

Additional simulations were conducted to investigate the benefit of using two rows of TCB segments in lieu of a single row in order to limit lateral-barrier deflections. Results predicted that the use of two rows of TCB segments could reduce deflections by approximately 40%.

2.3.3. SAFER barrier on TCB approach transition

A second series of simulations was conducted to investigate the effects of transitioning the SAFER barrier on freestanding TCBs to a rigid concrete parapet. For this simulation series, the impacting vehicle was configured to strike at varying impact locations as it approached the rigid barrier in order to determine the potential hazards of this type of installation. The main concerns for impacts near the rigid barrier were pocketing, excessive loading of the barrier system, and bottoming out the SAFER barrier on the rigid barrier.

The results from the transition models found that pocketing and excessive loading was not an issue. However, there was some potential for bottoming of the panels at the end of the rigid barrier. The extent of the bottom out is difficult to gauge due to the simplicity of the foam impactor used to represent the NASCAR vehicle in the simulation. Thus, it was difficult to accurately determine the performance of the approach transition with the current vehicle model.

Bottoming of the SAFER barrier at the end of the rigid barrier was undesirable because it would tend to generate increased lateral forces on the barrier and increased impact loading on the vehicle occupant. Several options existed for stiffening the approach transition, including the use of a second row of TCB segments or using beams or plates across the end connection to stiffen it.

2.4. Selection of test installation

Following the initial simulation studies, results were discussed with the project sponsors to determine the appropriate system for full-scale crash testing. Only one full-scale test was budgeted for the project, and there existed a need to select a design that best served the motorsports community and provided a viable solution to meet the most pressing need.

There were two basic options for the full-scale crash test:

- (1) The first option was to test a basic length of need setup. Test setup would consist of a long system length with no end constraints. This would simplify system parameters to inertia, friction, and foam crush. This

option would provide the basic information needed to fine tune the simulation models such that they could be used to further develop viable guidelines for various alternative installations. The premise behind this option was providing a simple test of the system in order to gain understanding and add complexity from there forward. However, it was anticipated that additional analysis and testing would be required to fully develop the SAFER installed on TCB for a wide range of applications.

- (2) The second option was to test a system specifically targeted towards the most pressing need in the motorsports industry in the US, using a single critical test. Discussions with MST, IRL, and NASCAR identified span openings between rigid concrete barriers on the track as the most critical need. As such, this option would proceed with evaluation of a critical opening configuration, design of a system to address that installation, and development of a test setup to evaluate its performance. This type of option would give the sponsors a single answer for using the SAFER barrier installed on TCB, but would yield only limited information on potential alternative installations.

The second option was chosen and researchers proceeded to shift its modelling and design effort to address the revised focus.

2.5. Simulation of SAFER on TCB across openings

New LS-DYNA models were developed for spanning an opening between two rigid, concrete parapets. The motorsports groups provided input regarding the length and configuration of the opening. It was determined that the maximum opening size currently used on the tracks of 33 m was the critical opening size for consideration. This length was considered as critical because the larger opening would tend to maximize the lateral deflections as well as increase the loads imparted to the end anchorage hardware. Ultimately, an opening size of 35 m was chosen for simulation, design, and testing because that allowed for an even number of 2.44 m long TCB segments to be used. It was believed that the performance of the system on smaller openings could be determined based on the selected opening size.

The new LS-DYNA models focused on two areas. First, models were simulated to examine the impact of a vehicle near the connection between the TCB segments and the rigid barrier in order to determine critical anchor loads, look for potential pocketing of the system, and investigate the potential bottoming of the SAFER panels on the rigid barrier. Second, simulations were conducted near the midspan of the system to estimate maximum deflections.

Initial models were made with a single row of TCB segments supporting the SAFER barrier. These TCB segments were anchored to the rigid walls on the upstream and downstream ends of the system. Results from the impact near the transition to the rigid barrier showed that the system successfully redirected the impacting vehicle, but there was potential for the SAFER barrier to bottom out on the rigid, concrete barrier. In addition, the maximum

lateral deflection of the TCB segments was found to be 0.40 m. Simulation of an impact into the midspan of the system showed that the system successfully redirected the vehicle with an estimated maximum lateral system deflection of over 0.64 m.

The results from these models led to concerns that the overall system deflections were higher than desired, and that there was potential for significant bottoming of the panels on the rigid barrier end. In order to alleviate these issues, a second series of models was developed using a second row of TCB segments behind the original row spanning the opening. The second row of TCB segments was also anchored to the rigid concrete wall on each end with cable tension anchors. Simulation results for these models, when impacted near the transition to the rigid barrier and the midspan of the system, are shown in Figures 3 and 4.

Results from the models with the additional row of TCB segments showed significant improvement over the previous design. For an impact near the transition to the rigid wall, the maximum lateral deflection of the first row of TCB segments was reduced to 0.23 m, and the maximum lateral deflection of the second row of TCB segments was 0.40 m. These deflections represent a significant reduction in overall barrier displacement. In addition, the simulation indicated a significantly reduced potential for bottoming out the SAFER panels against the rigid barrier. Results from the simulation of impact near the midspan of the system showed similar improvement. Maximum lateral deflections of the first and second row of TCB segments were found to be 0.36 m and 0.51 m, respectively. Both impact conditions indicated that the system would successfully redirect a vehicle impacting at 217 km/h and an angle of 25°.

Based on the improved performance with a second row of TCB segments, the system design proceeded with the SAFER barrier mounted on a double row of TCB segments with each row of TCBS anchored to the ends of the concrete barrier. Review of the simulation results also demonstrated that an impact 3.66 m upstream of the end of the concrete parapet produced the highest anchorage loads, the highest barrier loads, and demonstrated some potential for bottoming the SAFER barrier panels on the concrete wall. Thus, MwRSF proposed to run the single full-scale crash test as an impact of a NASCAR vehicle 3.66 m upstream of the downstream concrete parapet end at a speed of 217 km/h and an angle of 25°.

2.6. Anchorage design

In order for the TCB segments to safely support the SAFER barrier, the end segments in each row were anchored to the upstream and downstream concrete parapets. Anchoring the temporary barriers provided for reduced barrier deflection and helped prevent pocketing and bottom out of the SAFER panels near the transition to the rigid parapet. Separate anchorages were required for each row of the TCB segments. The upstream and downstream end anchorages for both rows of TCB segments were designed based on the loads estimated by the simulation effort.

The end anchorage hardware for the first row consisted of a 19 mm thick, 'L' shaped A572 Grade 50 steel plate anchored to the end of the concrete parapet (see Figure 5). The 'L'-shaped steel anchor plate was attached to the end of the parapet with four 22mm(diameter) by 330mm(length) A193 Grade B7 threaded rods that were epoxied in the barrier to a depth of 254 mm. The front side of the 'L'-shaped steel anchor plate was anchored to the front side of the parapet with five 19 mm Hilti HIS-N threaded sleeves with 19 mm (diameter) A325 heavy hex bolts. The end of the 'L'-shaped steel anchor plate had a series of 19 mm thick A572 Grade 50 steel plates welded to it with holes for the end-pin connection. These plates were spaced to match the spacing of the connection loops on the TCB segment. Connection of the 'L'-shaped steel anchor plate to the end TCB segment was completed by passing an oversized 38 mm (diameter) A36 steel pin through the loops of the end TCB segment and the pin plates.

The 'L'-shaped steel anchor plate design was chosen because it allowed anchorage of the TCB segments for walls of varying widths and had sufficient capacity to keep the TCB segments anchored during a high-energy impact. In addition, it was believed that the 'L'-shaped steel anchor plate could be adjusted unto 19 mm by the addition of spacers under the plates to address small variations in the fit up of the anchor plate holes with the TCB segment loops.

Anchorage of the second row of TCB segments was accomplished with a pair of cable anchors that attached to anchor brackets mounted on the concrete parapet on one end and an oversized 38 mm (diameter) A36 steel pin through the loops of the end TCB segment on the other end (see Figure 5). The cable assemblies were comprised of 19 mm (diameter) 6 × 19 IWRC IPS wire rope, with a thimble assembly on one end and a Grade 5 threaded stud on the other end. The anchor bracket on the concrete parapet was made of gusseted 13 mm thick A36 steel plate and was anchored to the parapet using four 19 mm (diameter) by 152 mm long Powers Fasteners wedge bolts. Pipe sleeve spacers were used to keep the cable assemblies attached at a consistent height to the end pin of the TCB segment. The cable anchor assemblies were made taugt prior to crash testing by tightening the nut on the threaded stud.

3. Design details

Photographs of the installation are shown in Figure 6. The basic system configuration consisted of a 35 m long, simulated track opening formed by a 37 m long concrete parapet on the downstream end of the system and a 3 m long concrete parapet on the upstream end. One row of 14 TCB segments was installed flush with the traffic side face of the concrete parapets and anchored directly to the end of the upstream and downstream concrete parapets. A second row of 15 TCB segments was installed behind the first row with a half TCB segment length offset such that the midspan of each TCB in the second row aligned with the connection joint between two TCB segments in the first

row. The second row of TCB segments was anchored to the backside of the concrete parapets. Eight SAFER barrier panels were mounted across the opening.

The SAFER barrier system was modified slightly from previous designs to account for installation on the TCB sections across the opening. First, the panel length was shortened from the original 8.5 m to 7.4 m in order to match the length of three 2.44 m long TCB segments. The foam spacing in the system was increased slightly from the original 1.7 m to 1.9 m to allow for an even spacing of four blocks per panel section while placing the blocks securely on the TCB segments rather than across a TCB joint. Similarly, the retention-strap anchors were moved to facilitate placement on the TCB segments. Two retention-strap anchors were used for each SAFER panel section and located at the midspan of the TCB segments. This modification allowed for easy SAFER placement on the TCB segments while still allowing for sufficient retention straps to constrain the SAFER barrier to the TCB segments. The retention straps and mounting hardware were unchanged from the original SAFER barrier – Version 2. No other changes were made to the original SAFER barrier design. Ends of the SAFER panels were anchored to the concrete parapets to provide the anchorage necessary to simulate a continuous SAFER barrier installation.

The TCB segments were based on a portable concrete barrier design developed for use at the Iowa Speedway. Each TCB consisted of a 2.44 m long by 457 mm wide by 914 mm tall reinforced concrete-barrier section with a vertical front face and a sloped back face. The barrier section was configured with concrete having a compression strength of 34.5MPa. The barrier segments were connected by a pin and loop style connection, with three sets of double shear loops. The rebar loops were comprised of no. 6 A706 Grade 60 steel and were slightly recessed within a circular cutout at the ends to reduce the gap between the barrier segments. A 32 mm (diameter) A36 steel pin was passed through the loops to complete the connection.

4. Full-scale crash test no. SPCB-1

4.1. Test description

On 18 November 2011, a 1701 kg NASCAR stock car vehicle was impacted into the SAFER barrier installed on TCB across an opening at a speed of 240 km/h and at a trajectory impact angle of approximately 26.2°.

The vehicle impacted the SAFER barrier 3.6 m upstream from the end of the rigid concrete parapet. A belted, non-instrumented Hybrid III dummy was seated in the driver seat of the vehicle. The vehicle was safely redirected. Documentary photographs are provided in Figure 7.

The vehicle remained in contact with the SAFER barrier for 7.2 m and exited the barrier at a speed and angle of 193 km/h and 8.4°, respectively. Maximum dynamic deflection of the SAFER barrier panels was 592 mm at the top of the barrier. The maximum dynamic deflection of the first and second row of TCB

segments was 381 and 627 mm, respectively. The maximum permanent set deflection of the first and second row of TCB segments was 292 and 533 mm, respectively.

Damage to the system was moderate. The tubes comprising the SAFER impact plate displayed local deformations and contact marks, and several of the stitch welds connecting the tubes were fractured. One section of the impact plate was permanently bent during the impact with the stock car vehicle. This type of damage has not been typically observed in previous SAFER barrier testing, but the increased impact severity combined with the impact location directly upstream from the rigid parapet likely increased the bending loads on the panel. Even with the slight hinging of the panel, the SAFER barrier retained its overall integrity and safely redirected the vehicle.

Damage to the TCB segments was generally limited to minor concrete spalling and cracking. The downstream end of the last TCB segment prior to the rigid parapet in the first row displayed more damage as several larger pieces of concrete were disengaged around the connection loops. However, the integrity of the TCB connection was not compromised. No significant damage was observed to the anchorage hardware for the first and second row of the TCB segments.

4.2. Discussion and comparison of test results

Following test no. SPCB-1, a data analysis comparison was made with test no. IRL-17, a NASCAR stock car impacting a straight concrete wall. Test IRL-17 was considered a viable baseline test for use in the comparisons. In terms of vehicle decelerations, a significant reduction in decelerations was observed for test no. SPCB-1 when compared to test no. IRL-17, as shown in Table 2. For peak longitudinal vehicle deceleration, a reduction of 39.8% was observed in test no. SPCB-1. While for peak lateral vehicle decelerations, a reduction of 11.7% was observed. These reductions in deceleration levels are even more impressive when one considers that test no. SPCB-1 had an impact severity value 29.2% greater than test no. IRL-17 due to increases in the mass, velocity, and impact angle. Reductions in peak decelerations have been shown to be the key to reducing injuries in high-speed racetrack impacts [2,6].

The results from the experimental crash testing program clearly indicated that the SAFER barrier installed on TCB provided increased safety as compared to the high-speed, vehicular impacts conducted into the rigid concrete containment wall. This fact is not trivial, since rigid concrete walls exhibit some very desirable features not easily produced by deformable barriers, including virtually no risk of vehicle snag nor pocketing, and low levels of sliding friction between the race vehicle and the smooth concrete wall. In addition, even when impacted under significantly higher impact severity, the SAFER barrier installed on TCB demonstrated similar performance to the current SAFER barrier. The system also provides for increased safety as compared to non-treated TCB installations used to span openings, by eliminating the potential for vehicle snag and pocketing on the rigid barrier.

5. Summary, conclusions, and recommendations

5.1. Summary

The objective of this research project was to design, test, and evaluate a system for installing the SAFER barrier on TCB segments. The research effort began with the selection of the TCB section developed for the Iowa Speedway based on its design features and capacity. Next, a design concept for mounting the SAFER barrier on the TCB section was developed. The design concept focused on limiting changes to the SAFER barrier hardware while still providing a method of mounting the system on TCB segments. After a basic design concept was chosen, simulation using LS-DYNA was used to investigate the performance of the proposed system, determine the loads on various system components, and to identify critical impact points. The initial simulations found that the relatively large system deflections were associated with installing the SAFER barrier on a single row of freestanding TCB segments. Further investigation demonstrated that two rows of TCB segments could reduce deflections by approximately 40%.

Following the initial simulation effort, feedback from the sponsors was sought regarding the direction of the research. Two research options were considered. The option chosen involved specific development of a SAFER barrier installed on TCB system targeted towards the most pressing need in the US motorsports industry – a system for spanning openings between rigid concrete parapets on the inner walls of various racetracks. This research effort would give the sponsors a single answer for using the SAFER barrier installed on TCB, but it would yield only limited information on potential alternative installations.

Simulation was used to finalize the design concept, determine the load requirements for the anchorage of the end TCB segments, and determine the critical impact point on the system. Subsequently, one full-scale crash test was conducted to evaluate the new system. A slightly modified version of the SAFER barrier was installed on two rows of TCBs used to span a 35 m long, simulated track opening. The test conditions consisted of a 1701 kg NASCAR vehicle impacting at a speed of 240 km/h and at a trajectory impact angle of approximately 26.2°. The vehicle impacted the SAFER barrier 3.6 m upstream of the end of the rigid concrete parapet and was safely redirected. Analysis of the test data found that the new system provided improved safety over rigid concrete parapets and standard TCB installations.

In addition, the performance of the new system was found to be very similar to that of the SAFER barrier currently implemented on racetracks around the country. It should also be noted that similar safety benefits are expected when the system is impacted with IRL open wheel cars. Based on the successful full-scale crash test, the SAFER barrier installed on TCB was deemed acceptable for use on racetracks hosting IRL and NASCAR racing events.

5.2. Conclusions

The new system addressed the need to adapt the SAFER system to TCBs and focused on a specific application of rigid wall openings. Specific conclusions include: (1) special attention is needed for anchorage of such a system in order to limit system deflections and improve transition behavior; (2) an additional row of barriers improves system deflections; (3) the critical impact point was located at the transition between the movable TCBs and the fixed walls, and (4) this system provided similar safety improvement as the original SAFER system, including reduced deflections and risk for occupant injury.

5.3. Installation guidance

As with any piece of safety hardware, the SAFER barrier installed on TCB across an opening system has certain installation parameters and recommendations pertaining to its use as well as pertaining to repair and/or resetting following an impact event. Two such examples are provided here; a detailed list of such is provided in [1].

- (1) The SAFER barrier installed on TCB across an opening system was designed and tested using a 35 m long opening. This opening size represented the largest anticipated opening size currently in use on NASCAR and IRL track facilities. The system can also be used on smaller openings without any modifications.
- (2) The SAFER barrier installed on TCB across an opening system was tested at a critical impact location near the transition to the rigid concrete parapet. While this impact was most critical in terms of the safety performance of the system, it does not represent the maximum lateral deflection of the system. Simulation of impacts near the mid-span of the system at speeds of 217 km/h and an angle of 25° indicated that lateral deflection of the first and second rows of TCB segments could be as high as 381 mm and 533 mm, respectively. Based on these expected deflection levels under severe impacts, a minimum 0.6 m lateral clear area should be maintained behind the second row of TCB segments to allow for barrier motion and prevent interaction of the barrier system with the people and equipment it is designed to shield. The clear area should be clearly delineated to discourage traffic or items from being placed in the area. This clear area should also be paved with asphalt or concrete paving in order to provide a consistent surface for the barriers to slide on during an impact event. Gravel or soil deflection areas for the barrier are not recommended as they may cause the base of the TCB segments to snag on the ground as they deflect and trip backward.

5.4. Future research

The successful design, testing, and evaluation effort for the SAFER barrier installed on TCB demonstrated the potential to use this system in other motorsports applications, such as road or street courses. However, there are certain areas that need further research before the design can be adapted for use in such applications. For example, the geometry, potential impact conditions, boundary conditions, and installation parameters for road courses may be significantly different from those parameters considered for oval tracks, requiring a detailed design and testing program.

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References



Fig. 1. Temporary concrete barrier design for Iowa Speedway.

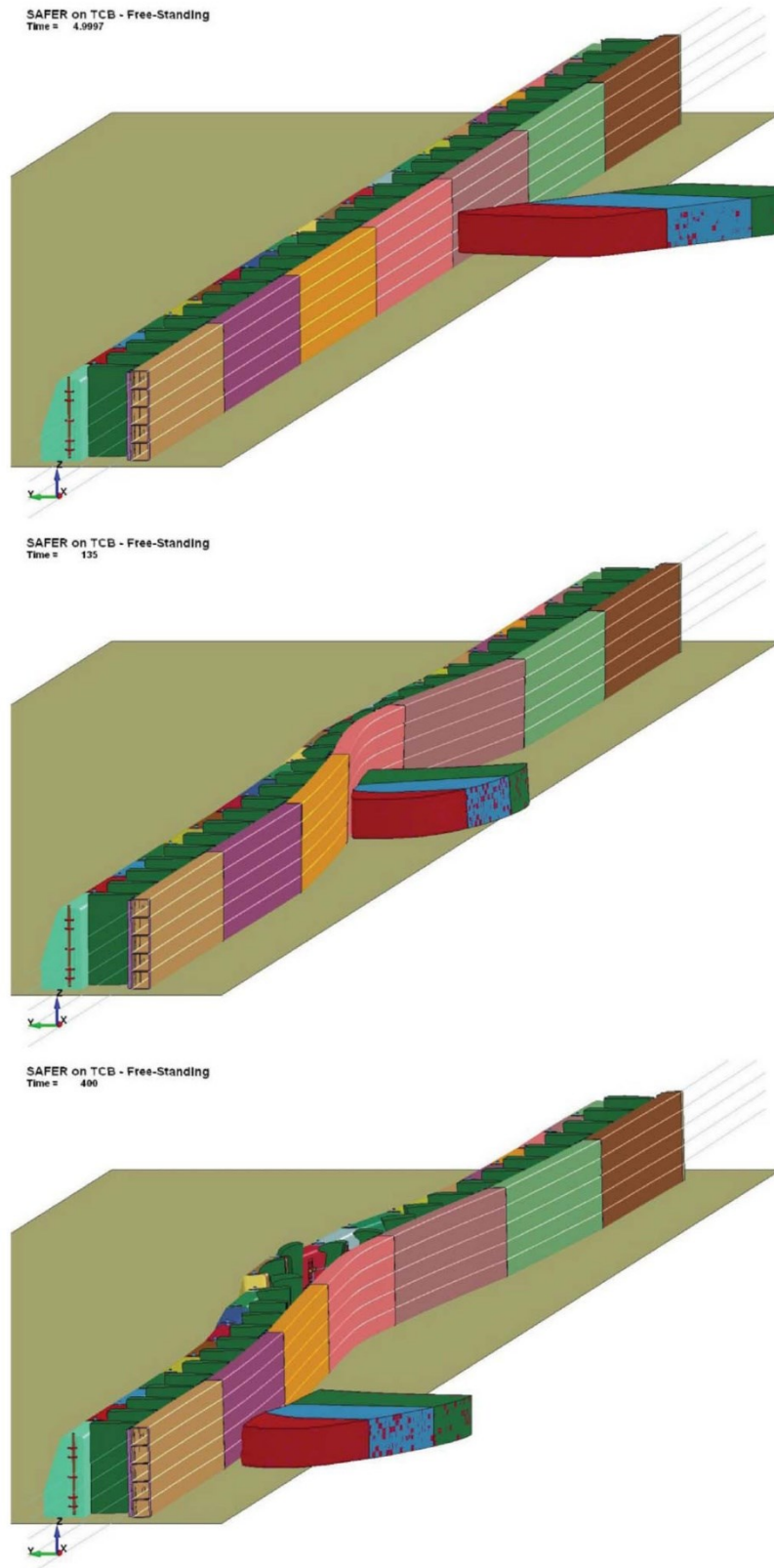


Fig. 2. Simulation of SAFER on freestanding TCB: isometric view.

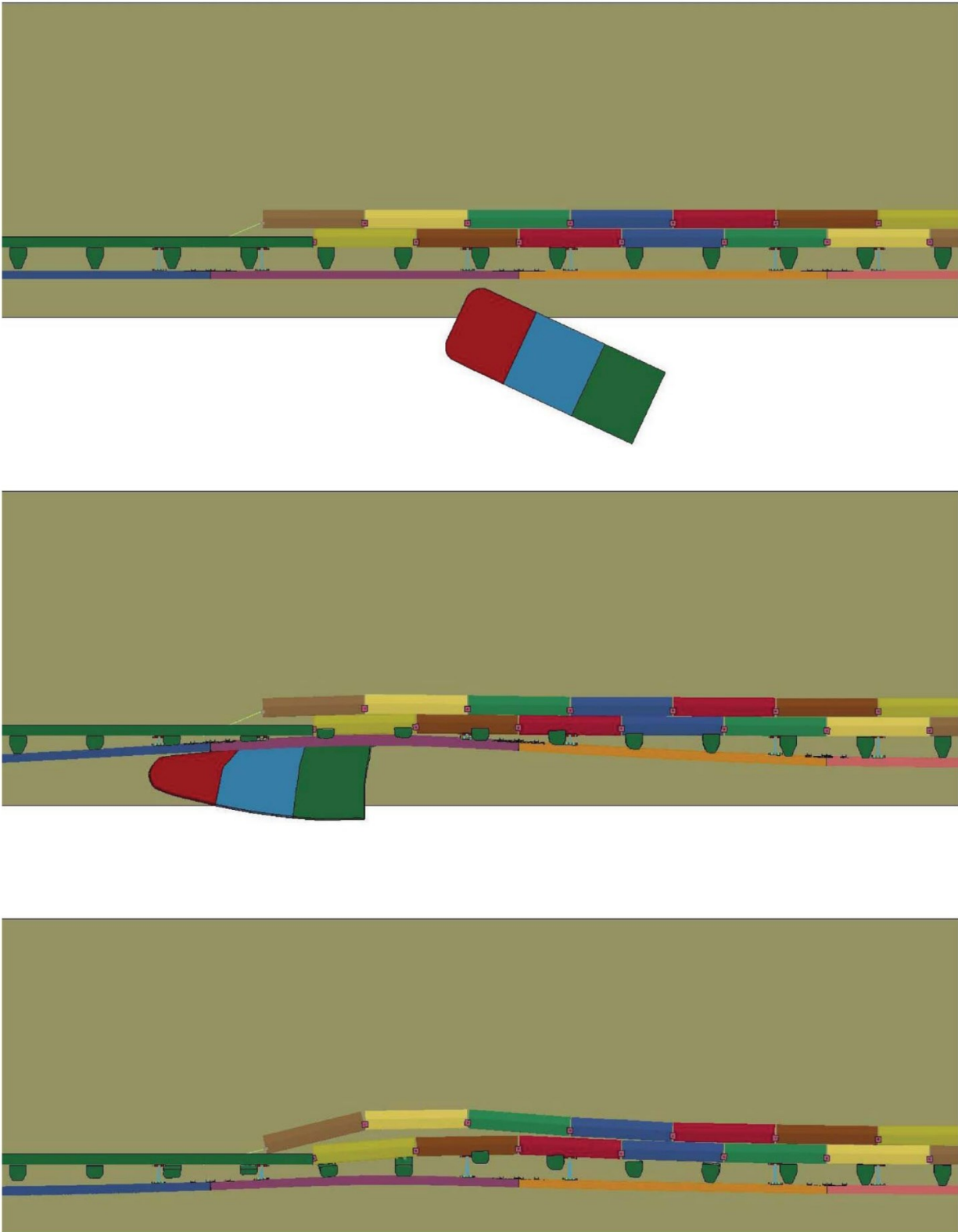


Fig. 3. System across opening, double row of PCBs, impact near rigid barrier end.

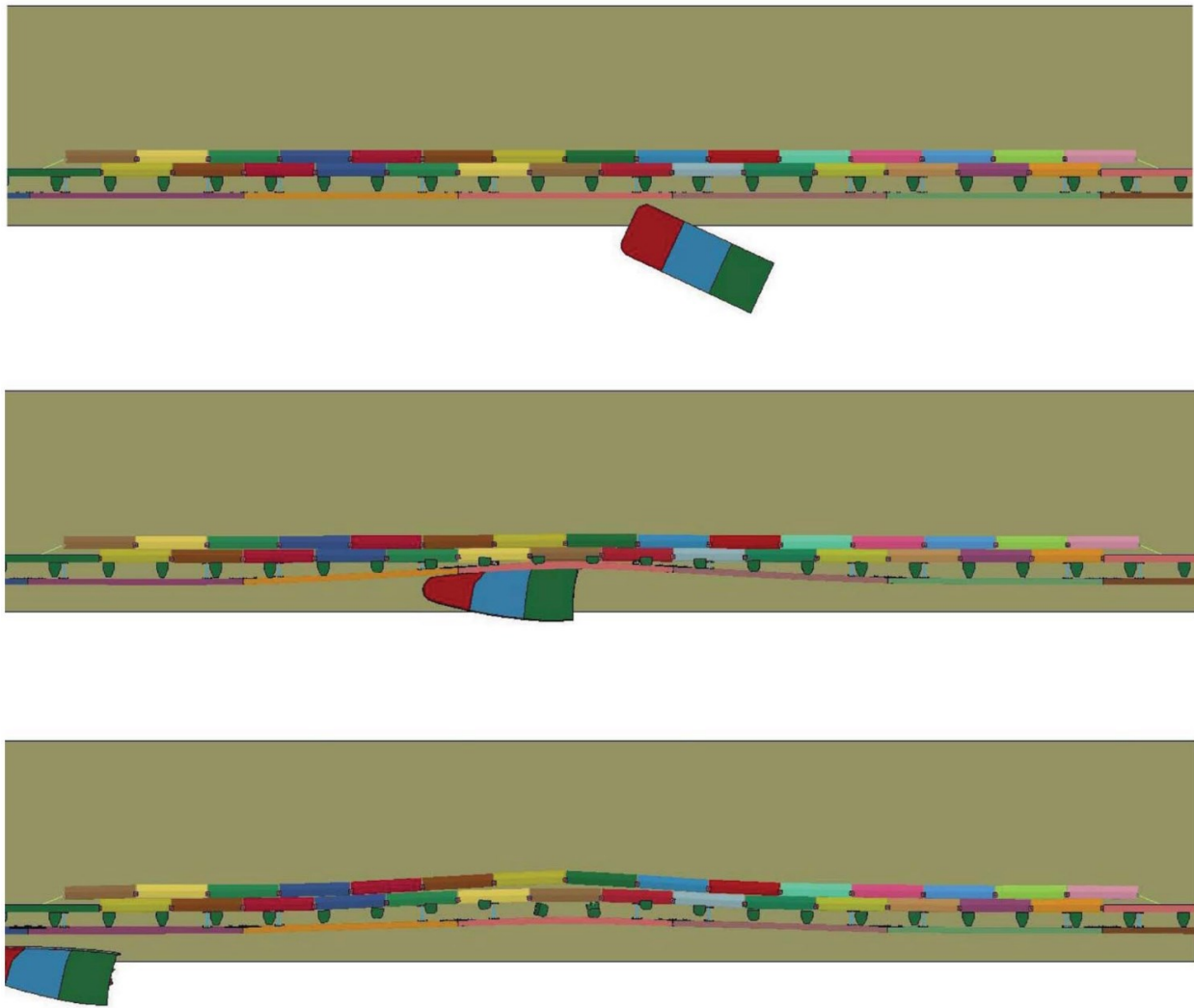


Fig. 4. System across opening, double row of PCBs, impact near midspan.



Fig. 5. Anchor designs.

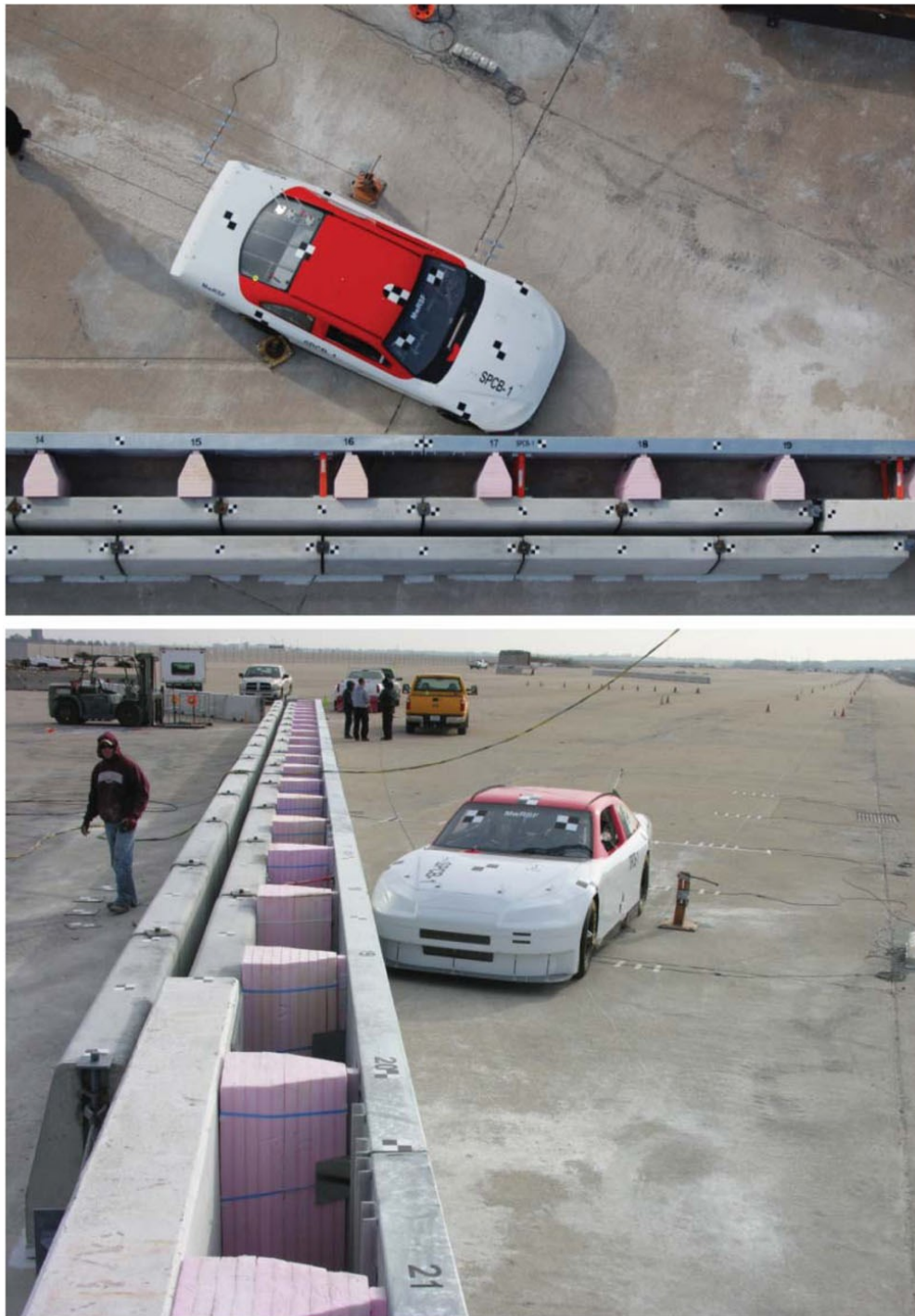


Fig. 6. SPCB-1: pre-test.

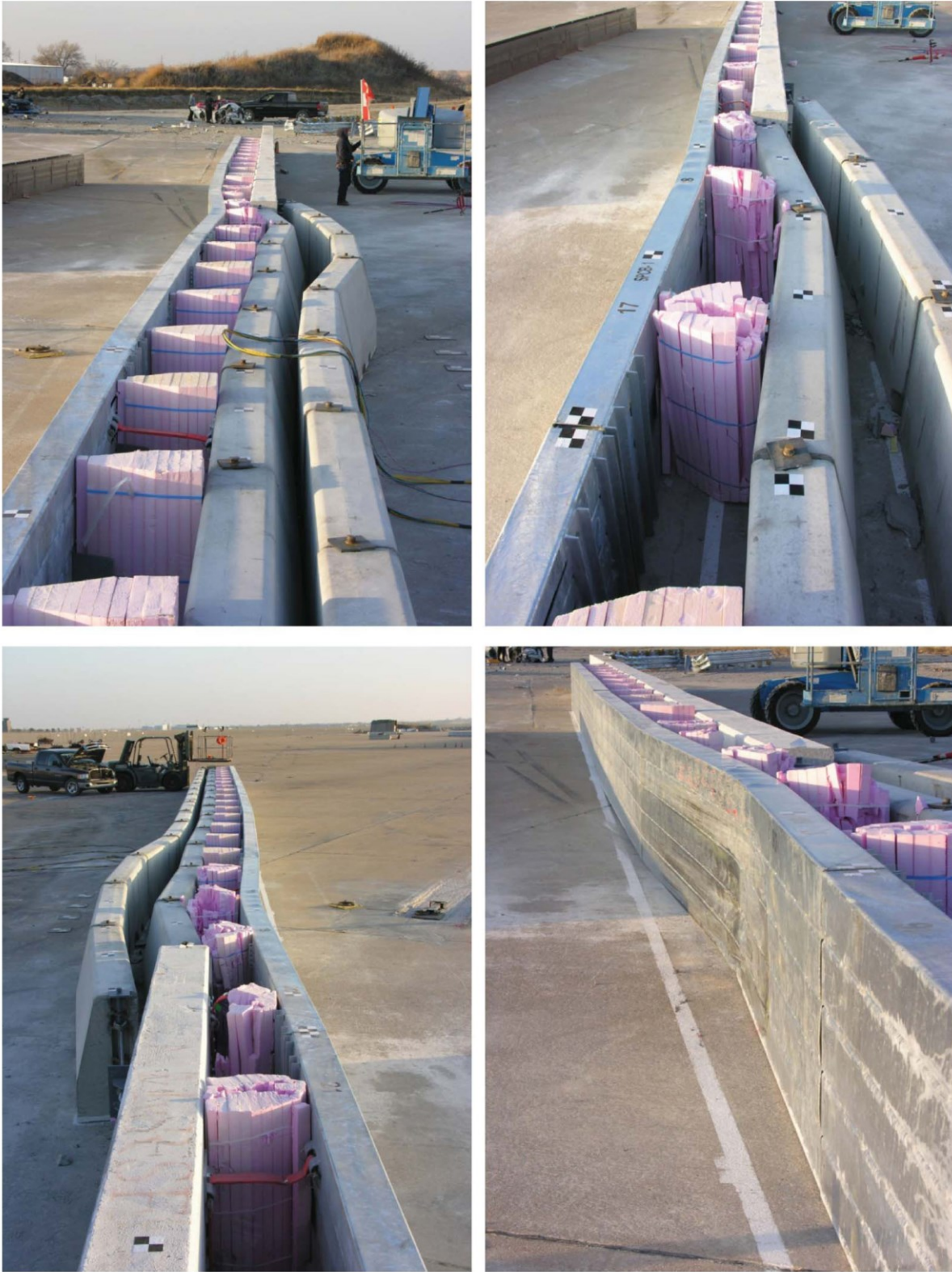


Fig. 7. SPCB-1: post-test.

Table 1. SAFER barrier on freestanding TCB – simulation comparisons.

Model description	Maximum longitudinal lateral TCB CG deflection (mm)	Maximum relative displacement of SAFER to TCB (mm)	Maximum SAFER panel deflection (mm)	Maximum lateral displacement of TCB end (mm)	Maximum displacement of TCB end (mm)
SAFER on concrete wall	NA	465	465	NA	NA
Case 1 (SAFER on TCB with longitudinal constraint of SAFER panels)	829	508	777	28	52
Case 2 (SAFER on TCB with longitudinal constraint of SAFER panels and pinned TCB ends)	653	508	722	0	0
Case 3 (No constraint on SAFER panels or TCB)	1049	508	1018	61	115
Repeat of Case 1 with 1 2 friction	973	508	917	65	113

Table 2. Selected test results for test nos. IRL-17 and SPCB-1.

Test no.	Peak decelerations % difference from baseline concrete wall testing			Vehicle mass (kg)	Impact speed (km/h)	Impact angle (deg)	Impact severity (kJ)
	Longitudinal	Lateral	Resultant				
IRL-17 (straight concrete wall)	NA	NA	NA	1640	225	24.9	570
SPCB-1 (SAFER on TCB across opening)	-39.8%	-11.7%	-19.0%	1701 3.7% increase	240 6.6% increase	26.2 5.0% increase	737 29.2% increase

Impact severity = $\frac{1}{2}$ mass * $[\sin(\text{impact angle}) * \text{impact speed}]^2$.