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Chicago Transit Authority

5000 Series Cars

Carbody Crash Analysis Report

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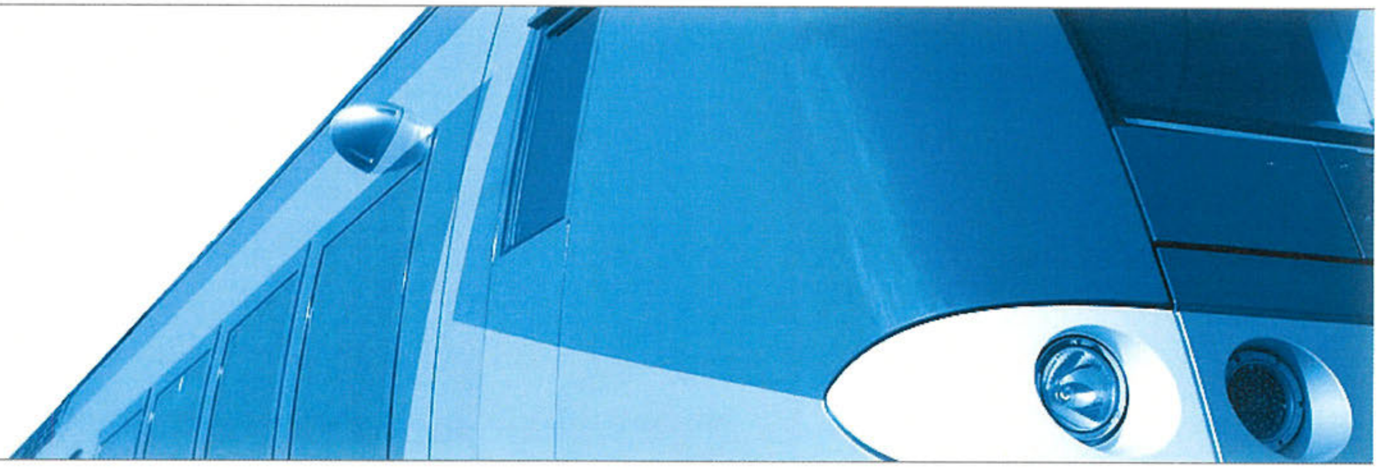
Section **Subject**

APPENDIX A

CARBODY CRASH ANALYSIS REPORT

CTA 5000 Series Carbody Crash Analysis Review



September 26, 2007

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Objective of the present report:

- To verify that the crush behavior of the carbody structure is the crushing of the structure at the extreme ends first, with crush progressing toward the bolster as requested in the Technical Specification, Section 3.01.D.

Scope of work:

- This report shows the crushing behavior of the proposed carbody structure design from the end sill to the middle of the door. The updated design of the end sill includes the advanced holes in the main ribs as well as the use of central top and bottom angles.
- The previous design of the end sill main ribs holes when positioned with respect to the collision posts centerline (rearward) is also compared with the above proposed design (advancing the holes).
- A high speed impact analysis (38 mph) will demonstrate the advantage of adding weakening holes in the draft sill.

Analysis scenario calculations details

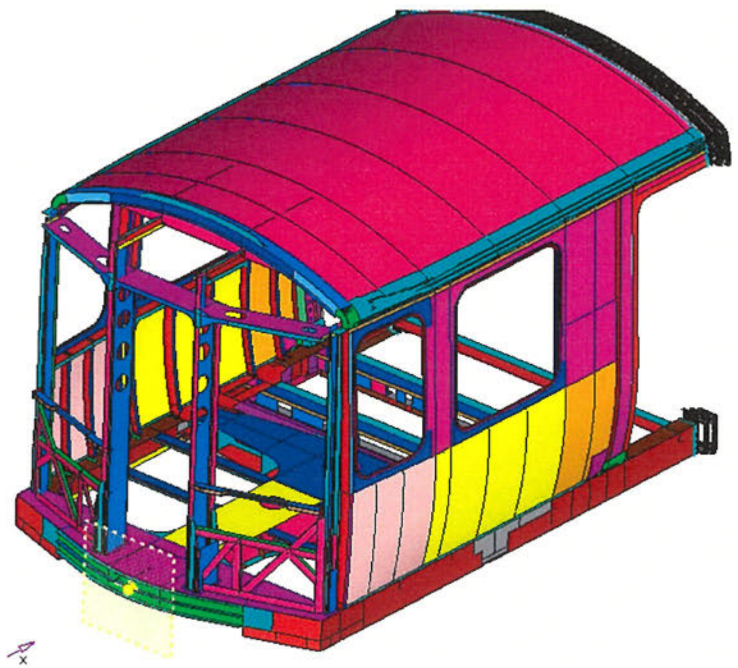
- The scenario is similar to a collision between two trainsets of 2 cars each loaded at AW0 with a relative velocity of 10 mph (energy is absorbed by a total of 4 cars) .

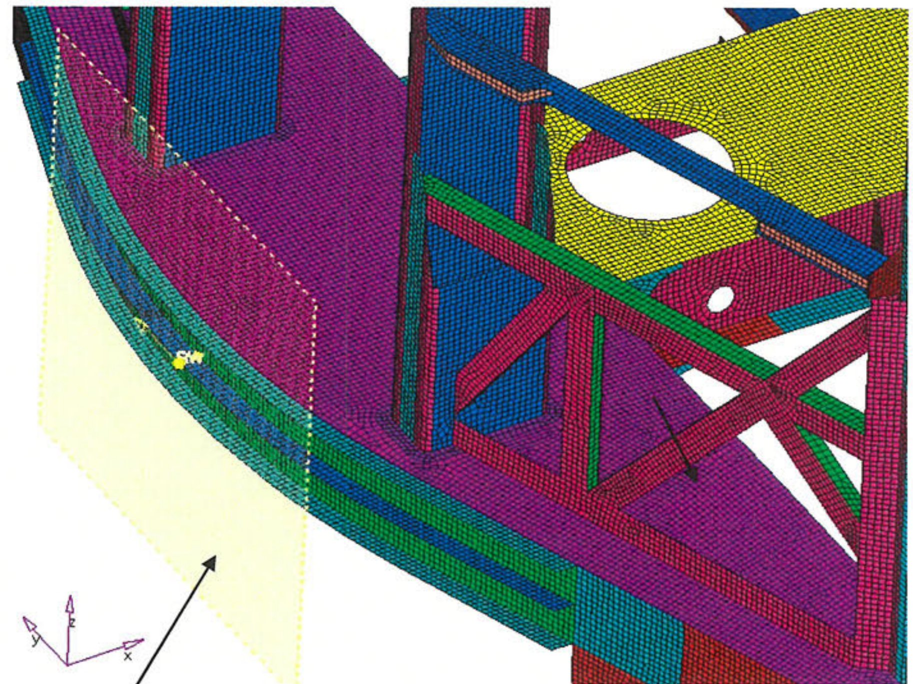
SCENARIO CTA 24 august 2007		Velocity at t=0 m/s (mph)	Masse kg (lb)	Ei Energy at T=0 Mjoules (ft-lb)	Momentum at T=0 M*Vi (kg*m/s)	Vf m/s (mph)	Kinetic Energy at T=Tf Ef Mjoules (ft-lb)	Absorbed Energy Ei - Ef (Mjoules)	Absorbed Energy per train Mjoules (ft-lb)	Equivalent velocity for one train impacting a wall km/h (mph)
A 2 car Train at AW0 collides a similar Train (no brake applied) with a relative speed of 16 km/h (10 mph)	Train 1	4.444 (10 mph)	53636 (118000 lb)	0.530 (0.397 E6 lb-ft)	238358	2.222 (5 mph)	0.265 (0.198 E6 ft-lb)	0.265 (0.198 E6 ft-lb)	0.132 (0.099 E6 ft-lb)	8.0 (5 mph)
	Train 2	0	53636 (118000 lb)	0	0	Trains 1&2 together	Trains 1&2 together			
				Comment: $E_i = 1/2\ [M_i V_i^2]$	Comment: $M_i V_i = M_f V_f$ since Mf = 2Mi (Mi Vi) / 2Mi = Vf		Comment: $E_f = 1/2\ [M_f V_f^2]$			

- The energy absorption is equivalent to the collision of one train against a rigid wall at a velocity of 5 mph.
- Since most of the energy will be absorbed by the first car in the trainset, 75% of the total energy will be considered for the crash analysis at the cab end (0.132 * 75% = 0.1 MJoule).
- Note that passengers weight shall not be included in crash analysis unless they are reacted by car interior structure at the exact time of the impact.

Analysis FEA details:

- **Analysis was done with LS DYNA, time dependent transient analysis. The #1 end of the carbody up to the middle of the door was modeled and refined for crash analysis requirements.**





The rigid infinite wall is given a speed of 5 mph with a mass calculated for an equivalent kinetic energy of 73756 lb-ft (0.1 MJ). The two impacting structures also have a 15% friction coefficient between them.

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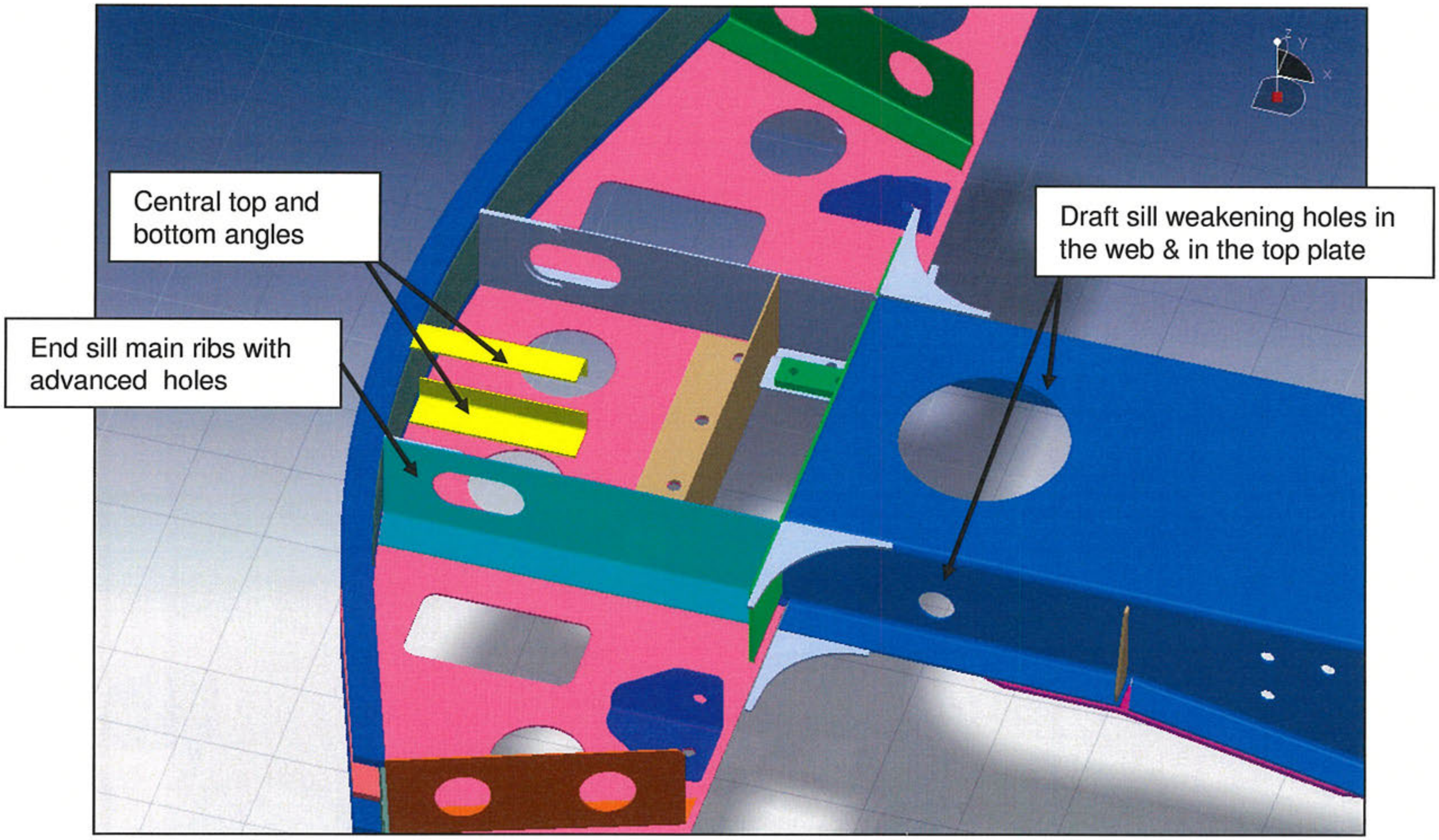
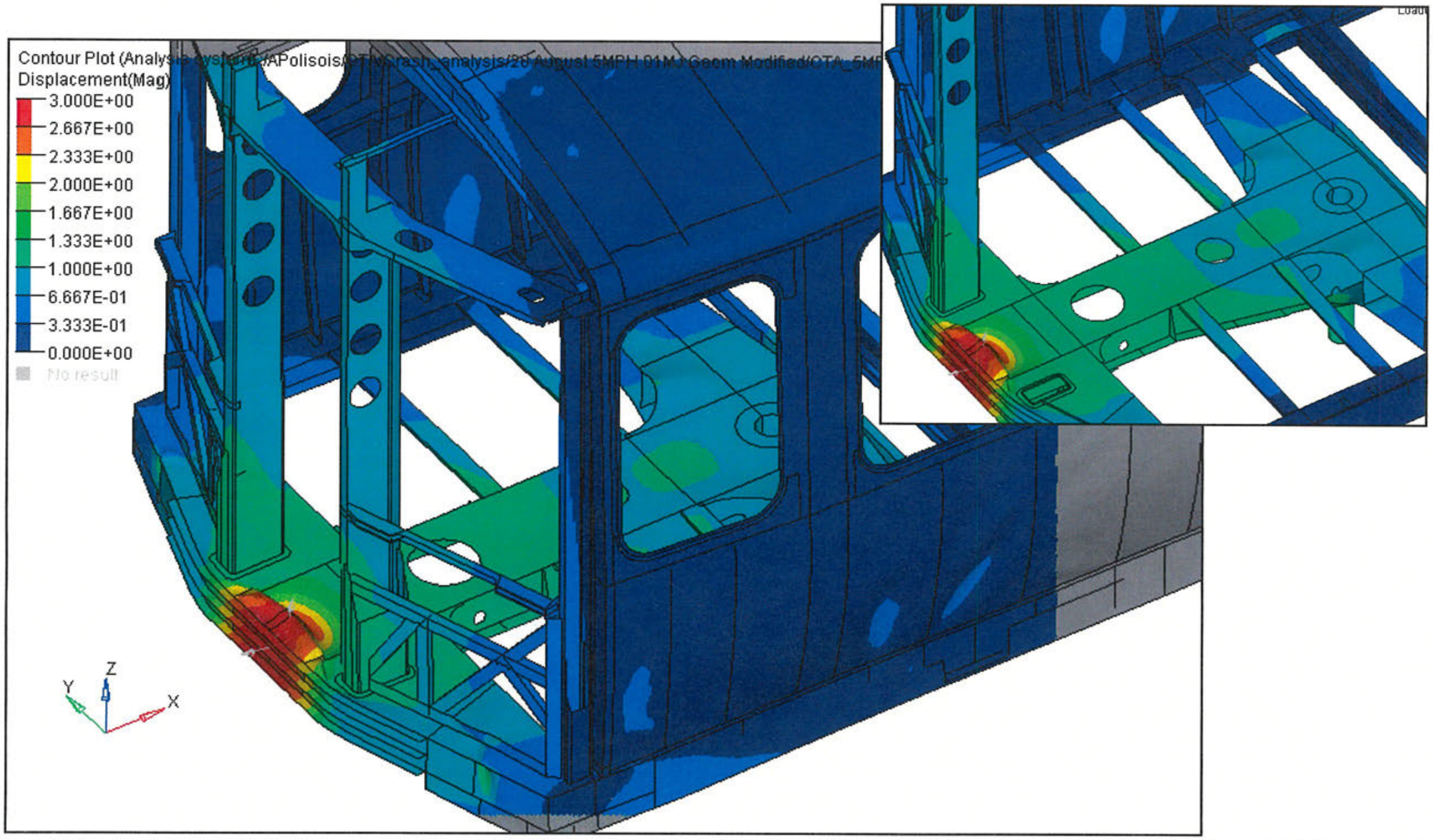
Analysis details (cont.)

- **End sill ribs & draft sill holes configurations.**



Analysis Results (1):

- **Overall deformations of the complete FEA model at the end of the analysis.**



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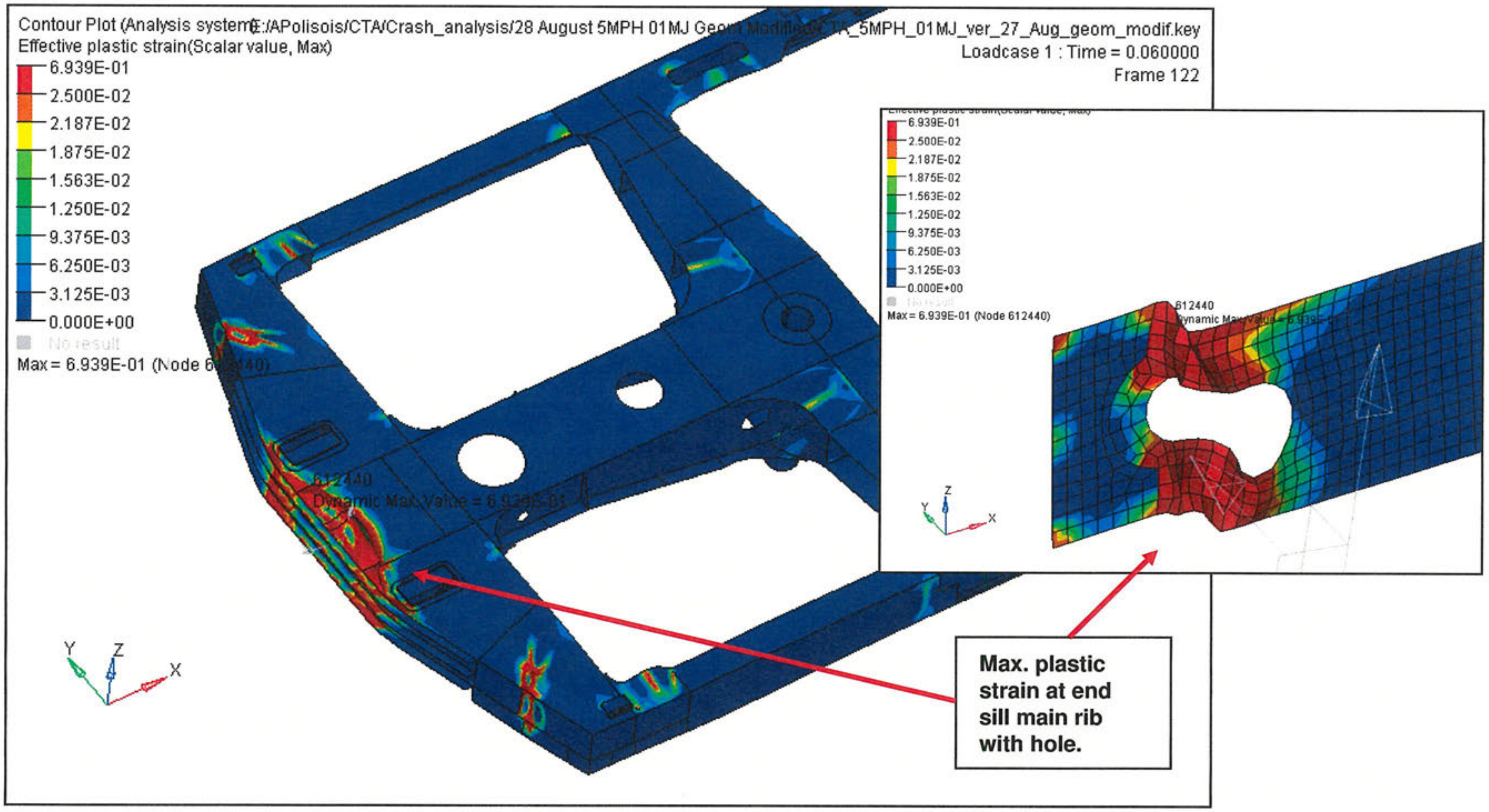
Analysis Results (1, cont.):

- Overall maximum plastic strain 69.39% at the end of the analysis. Maximum plastic strain is at the end sill main rib with the advanced holes.



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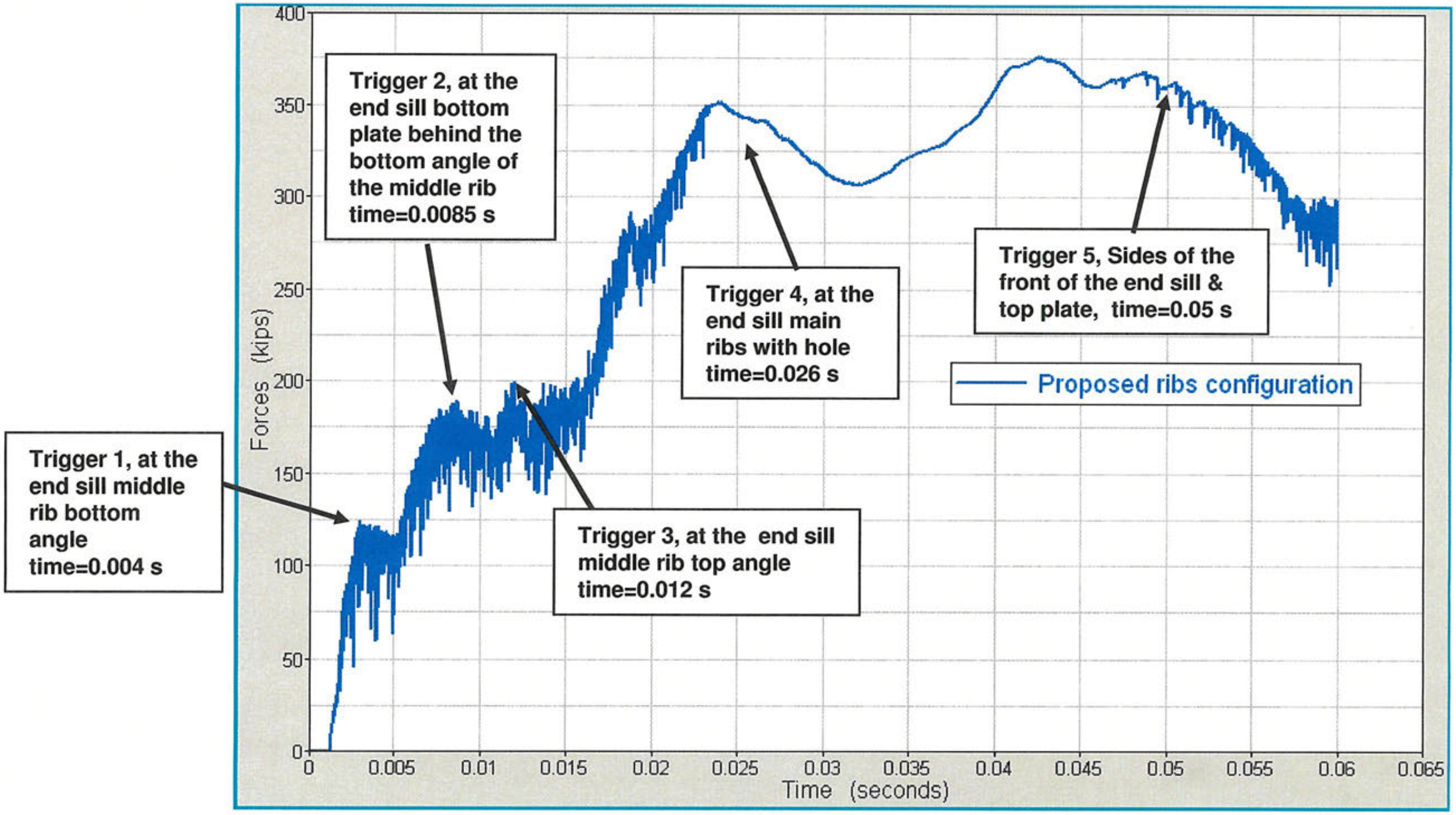
Analysis Results (1, cont.):

- The following graph shows the impact force developed on the wall versus time. A drop in the force means that a part of the carbody structure has started to crush and cannot sustain the force. These peaks are important in identifying collapse trigger mechanisms which are reviewed in the report.



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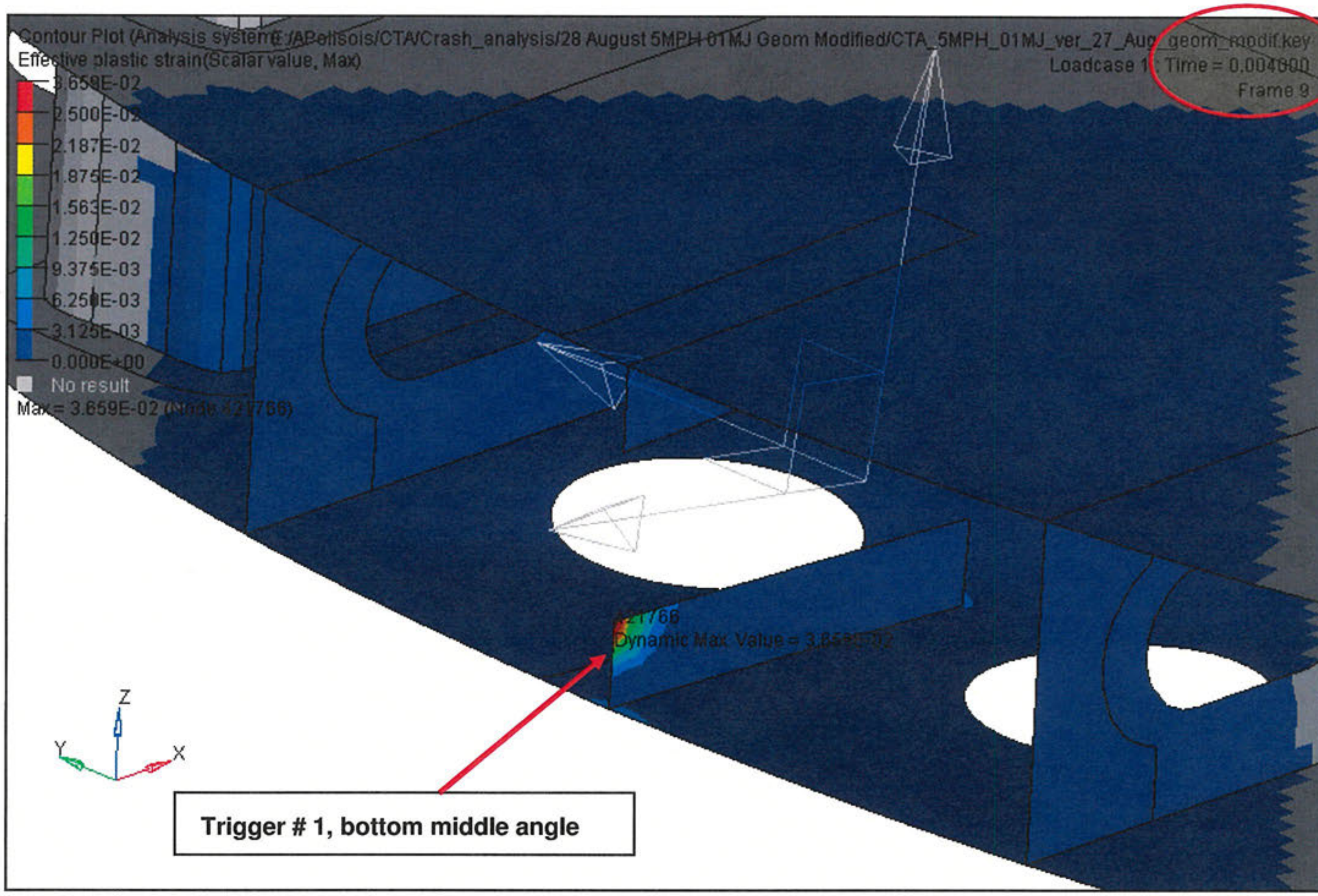
Analysis Results (1, cont.):

- Trigger # 1 represents the starting of the plastic deformation at the middle bottom angle at 0.004 seconds.



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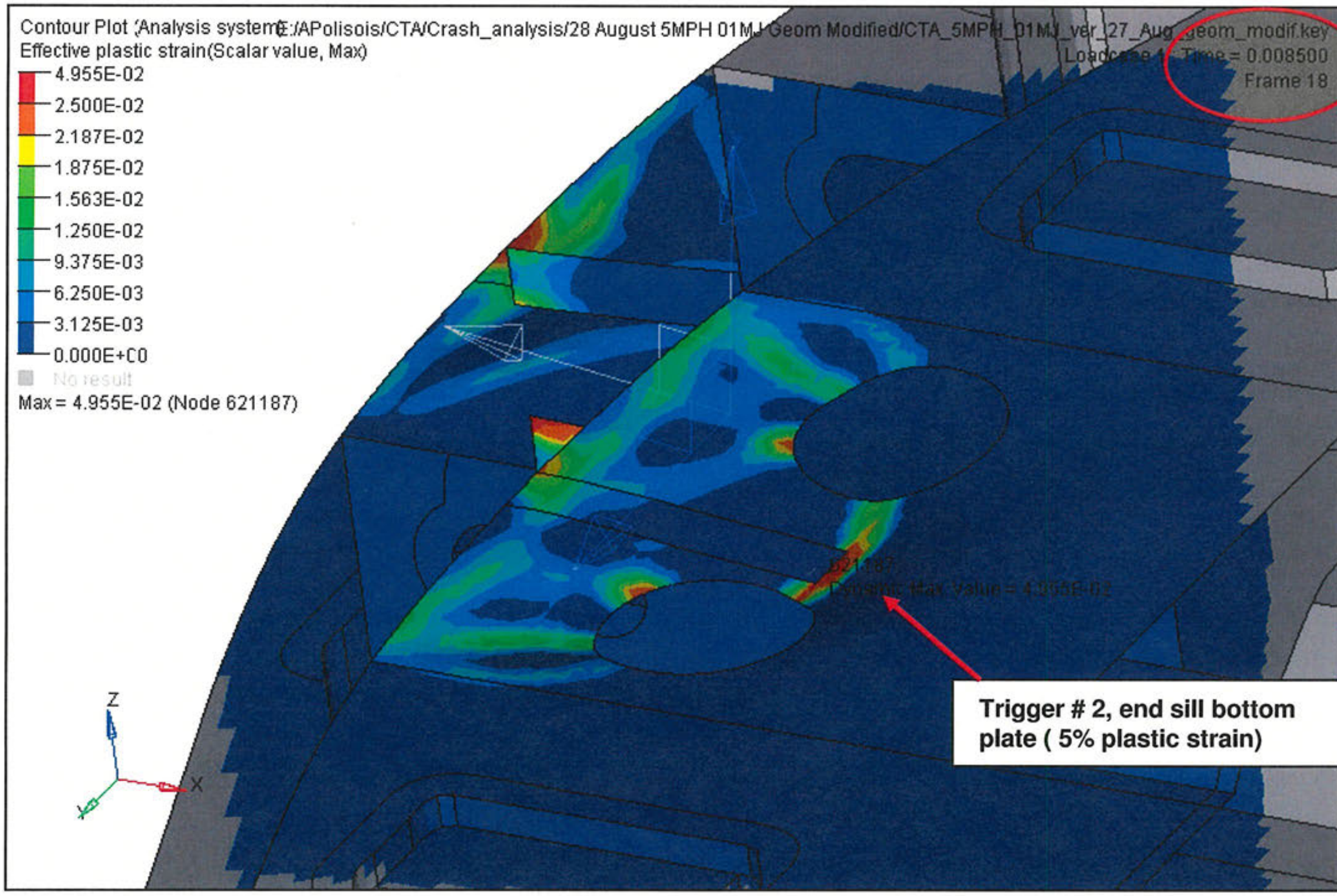
Analysis Results (1, cont.):

- **Trigger # 2 (view from the bottom) shows the starting of the buckling of the end sill bottom plate behind the bottom angle at 0.0085 seconds.**



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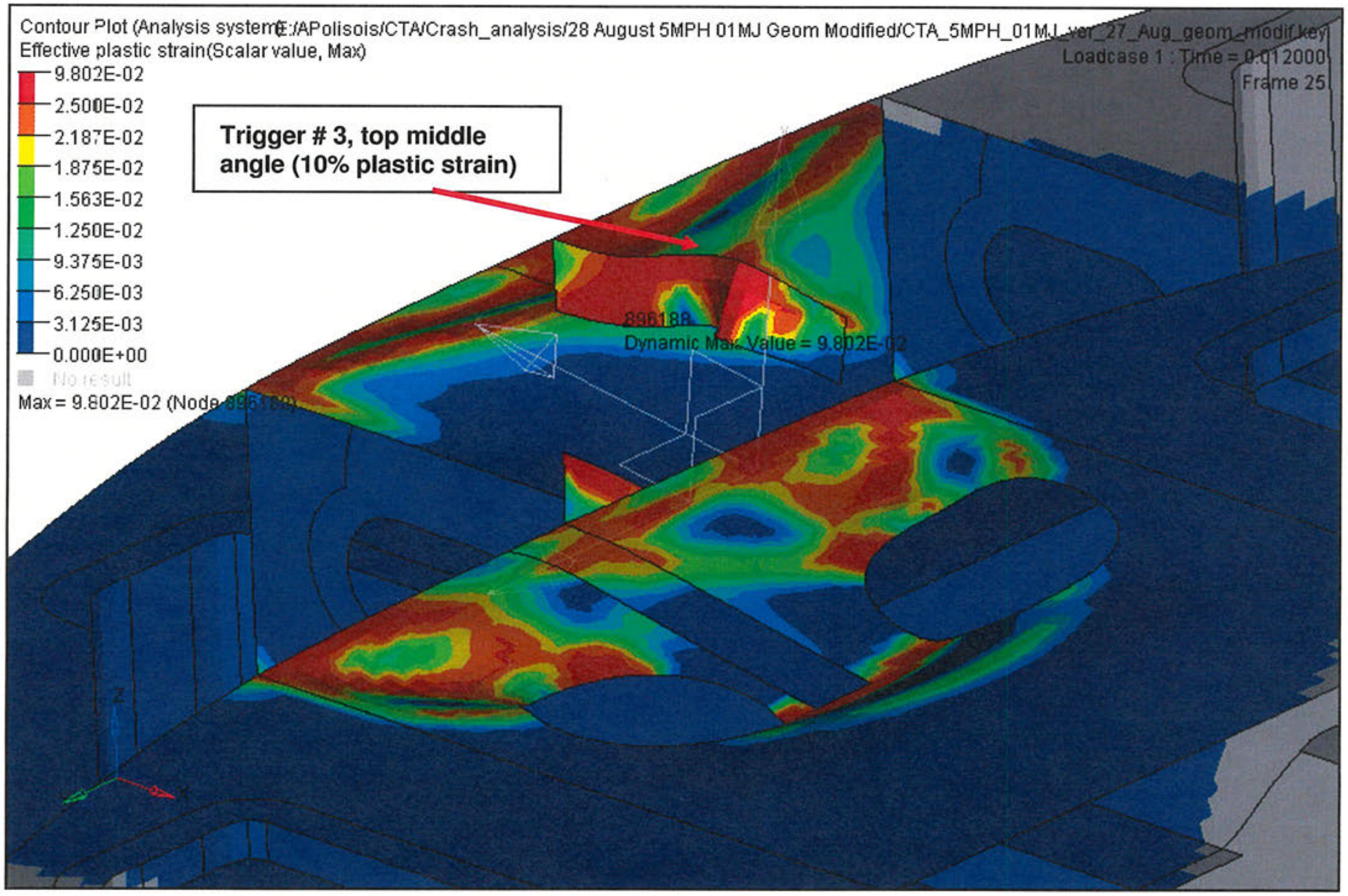
Analysis Results (1, cont.):

- Trigger # 3 (view from the bottom) shows the buckling of the top middle angle at 0.012 seconds.



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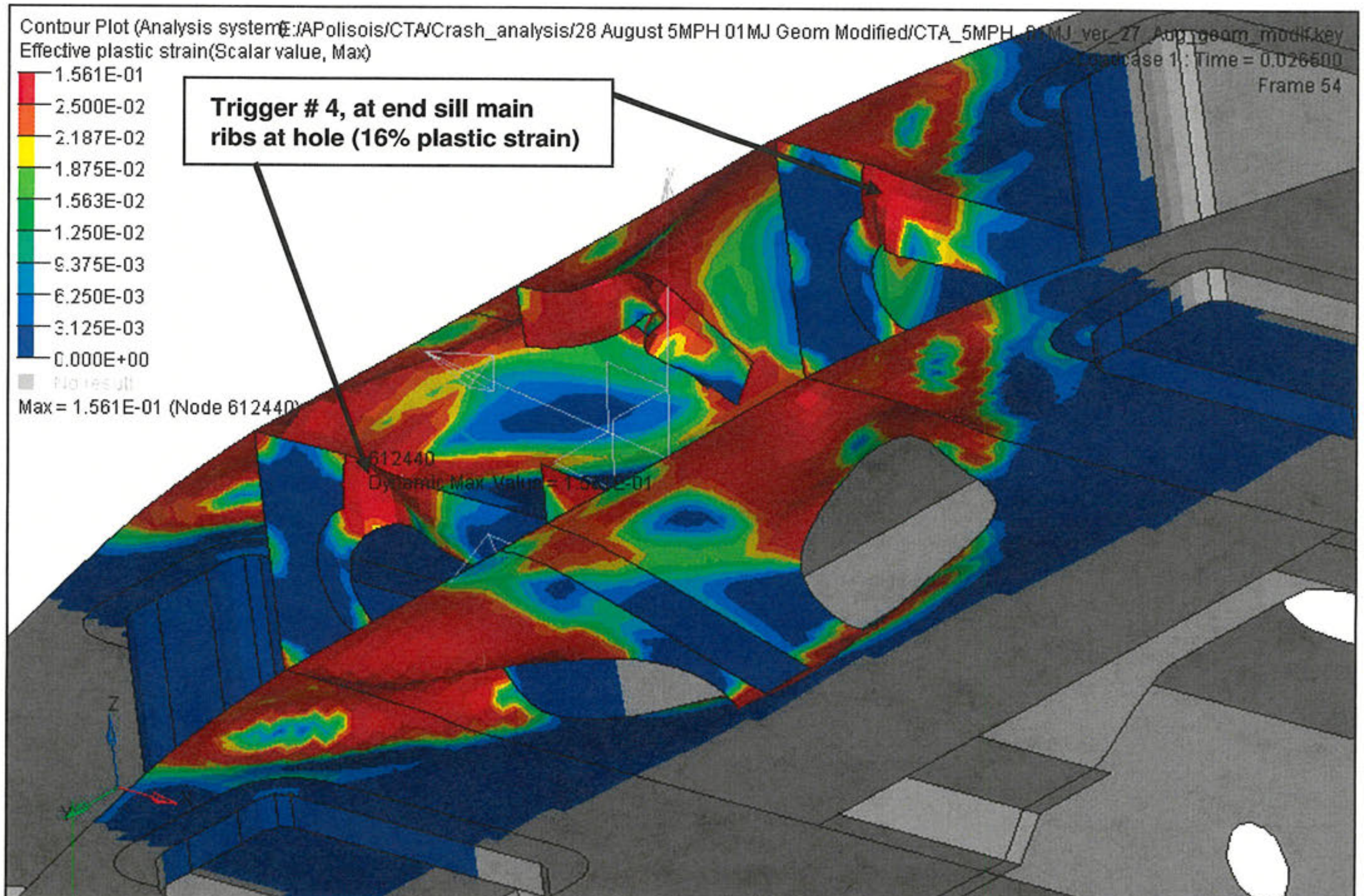
Analysis Results (1, cont.):

- **Trigger # 4 (view from the bottom) shows the buckling of the main rib with the advanced holes. At the same time it initiates the buckling of the end sill top plate at 0.026 seconds. At that point the two middle angles and the end sill bottom plate have completely buckled.**



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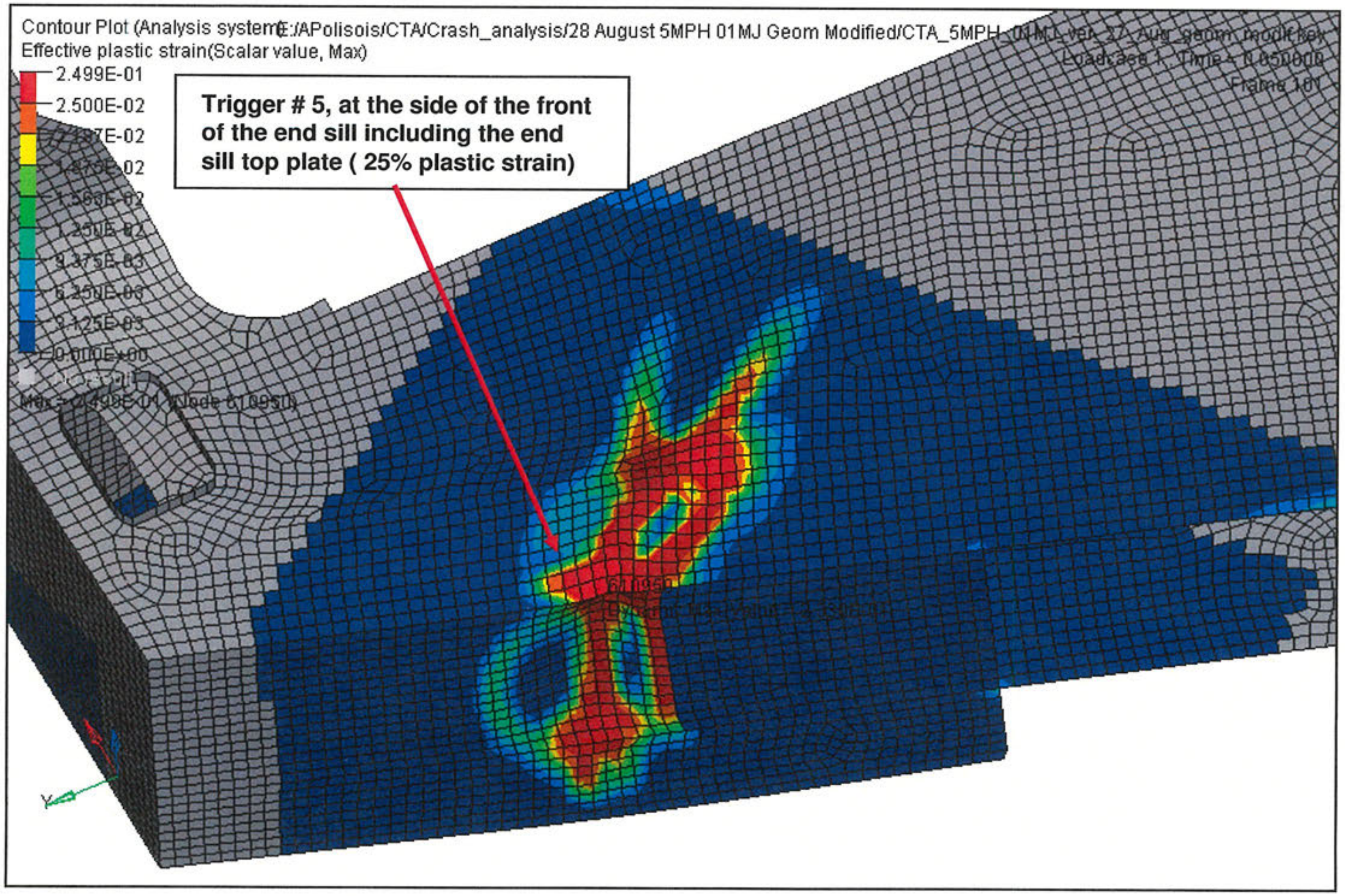
Analysis Results (1, cont.):

- **Trigger # 5 shows the buckling of the side of the front of the end sill which includes the front plate and the top plates at 0.05 seconds.**



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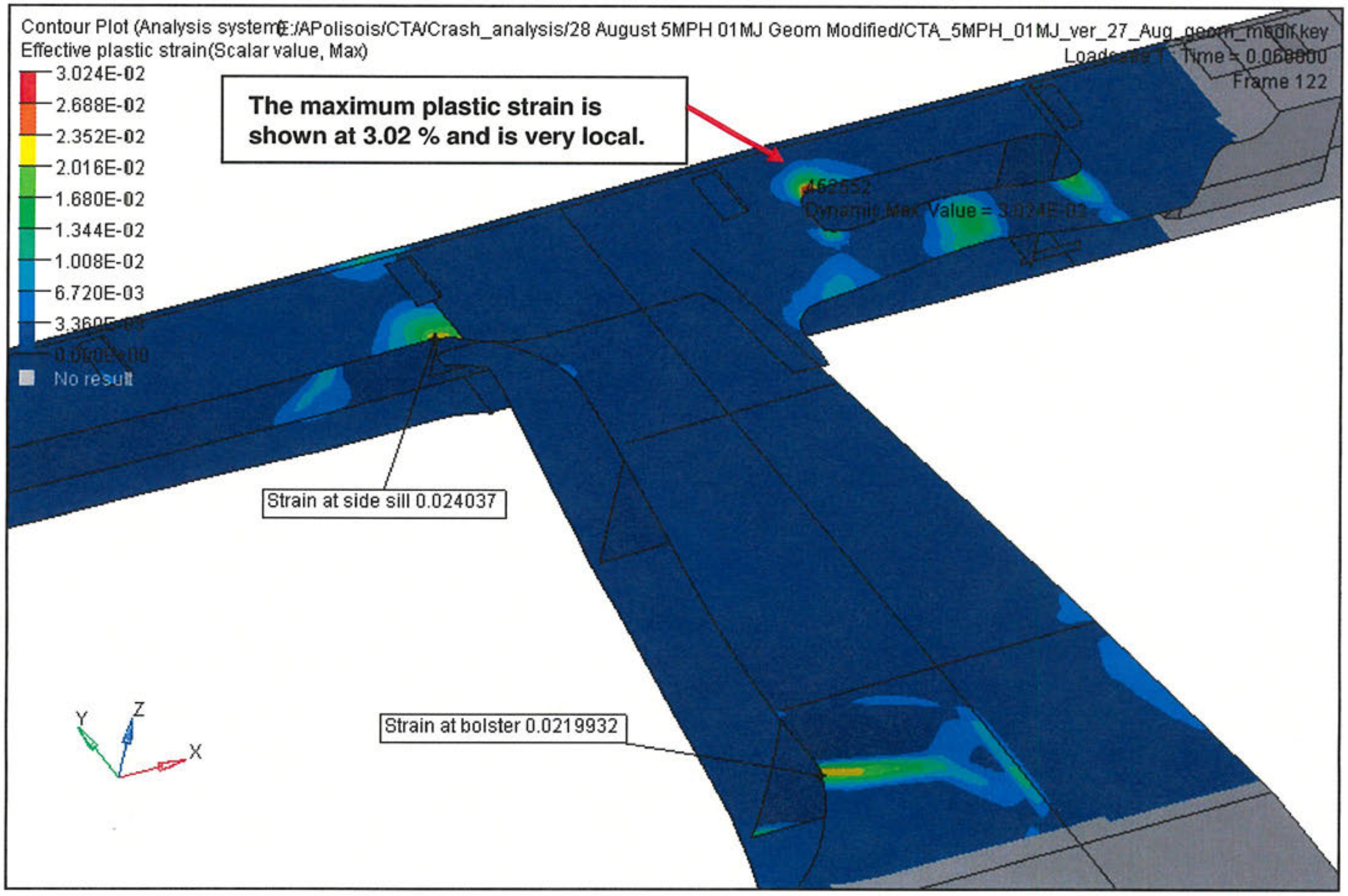
Analysis Results (1, cont.):

- At the end of the analysis the resulting plastic strain for the bolster or the side sill is below 5%. This value is low and will not be apparent as permanent deformation or buckling.



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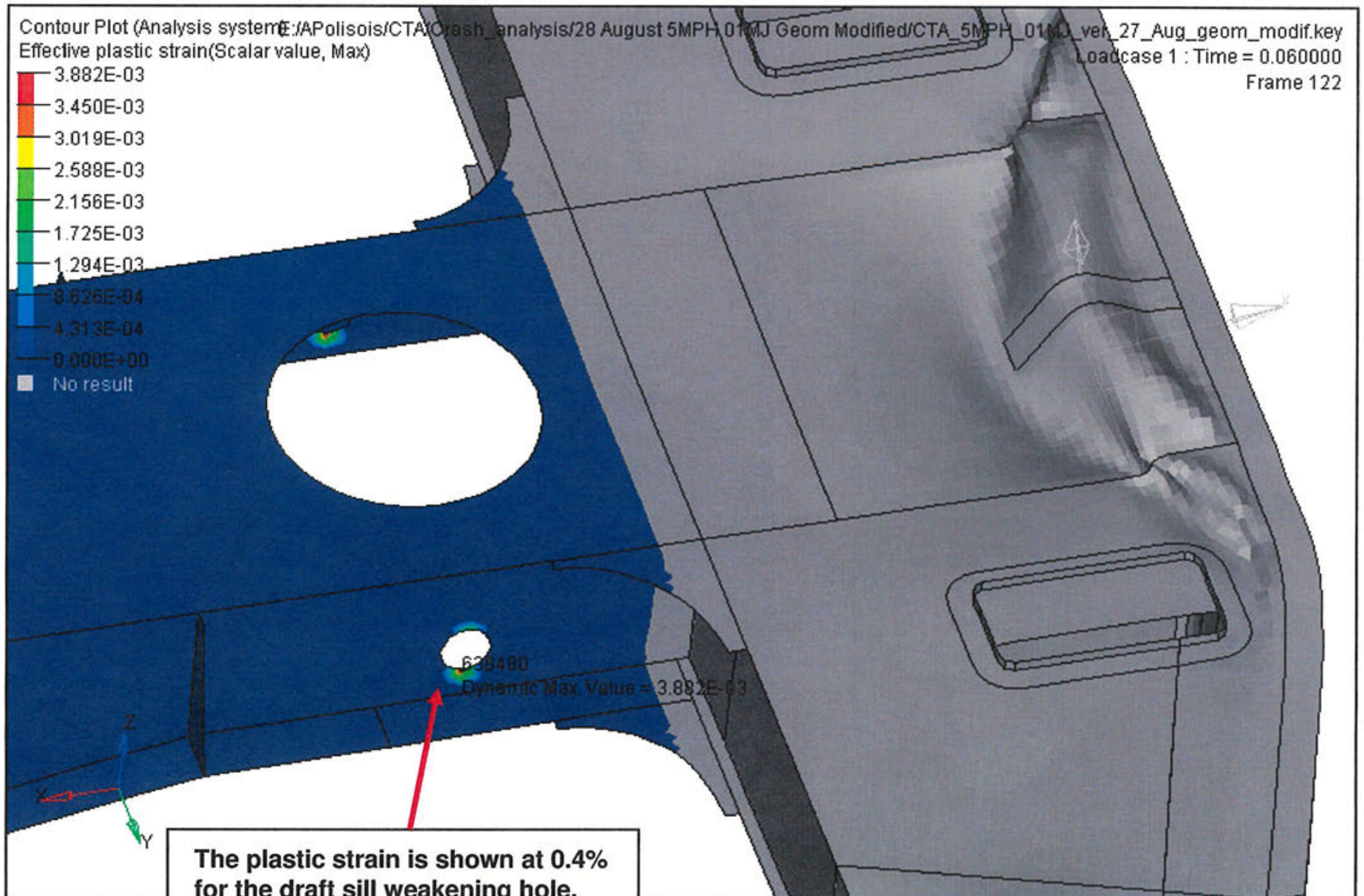
Analysis Results (1, cont.):

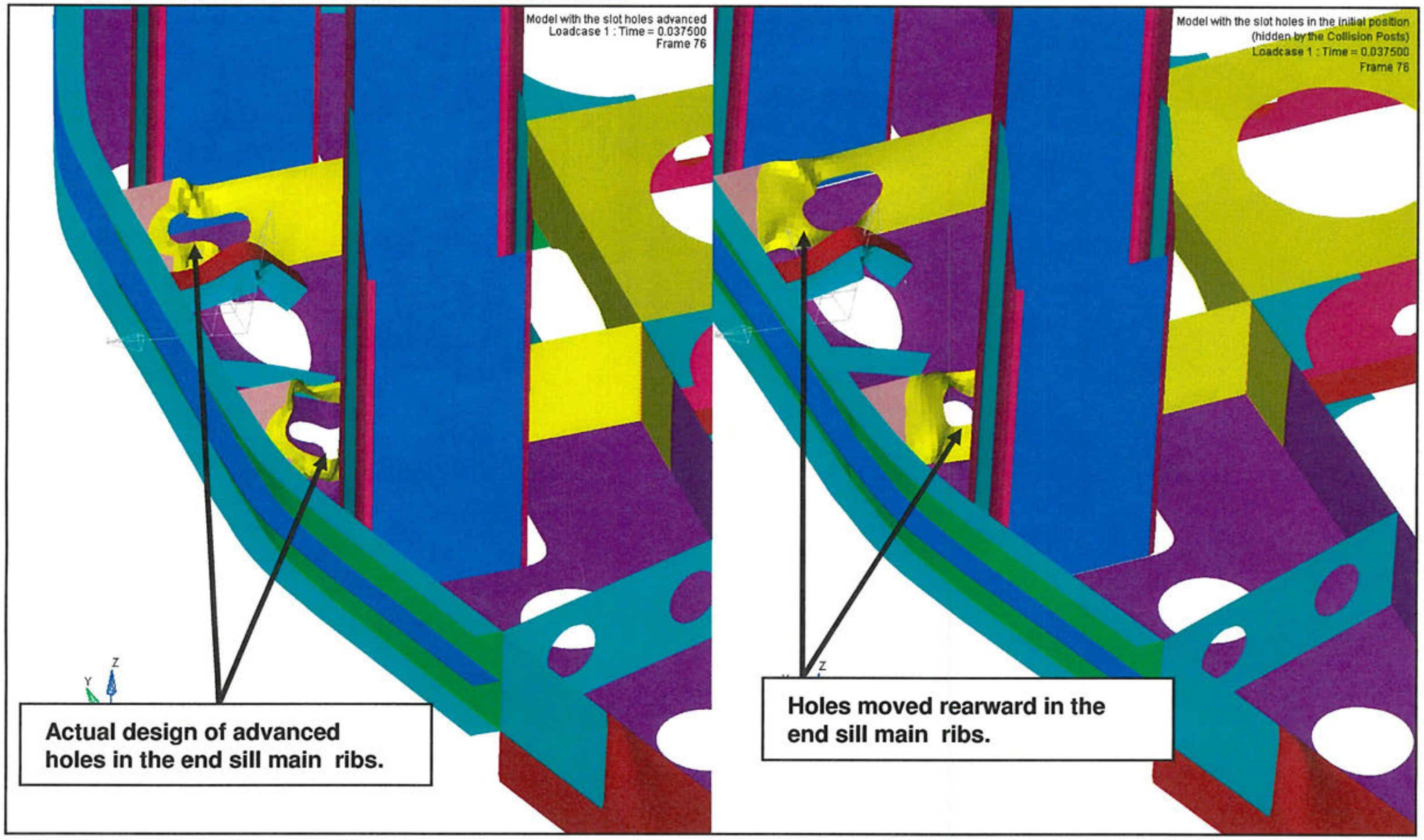
- At the end of the analysis the resulting plastic strain at the draft sill weakening holes is very low, less than 0.4%. The holes in the draft sill do not have any significant effect at low speeds and low energy levels.



The plastic strain is shown at 0.4% for the draft sill weakening hole.

Analysis Results (2):

- The following plots show the comparison of the crushing of the actual design end sill main ribs with the advanced holes and holes moved rearward in the ribs. The effect of the holes position is important as we can see the greater buckling and deformations of the main ribs and the end sill with the advanced holes.



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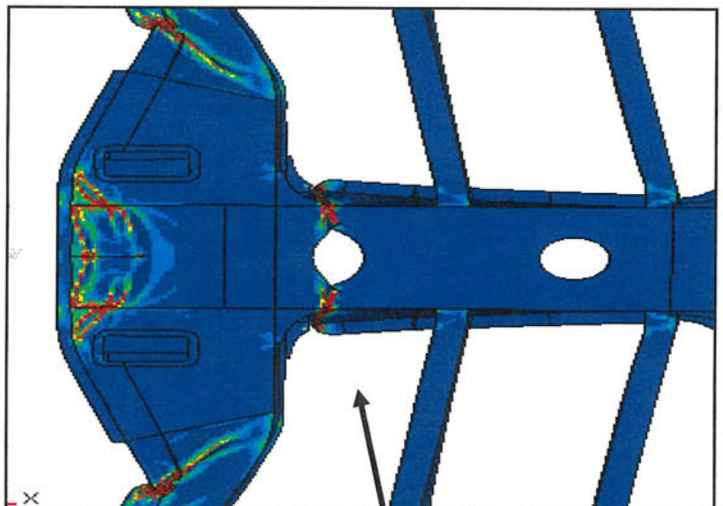
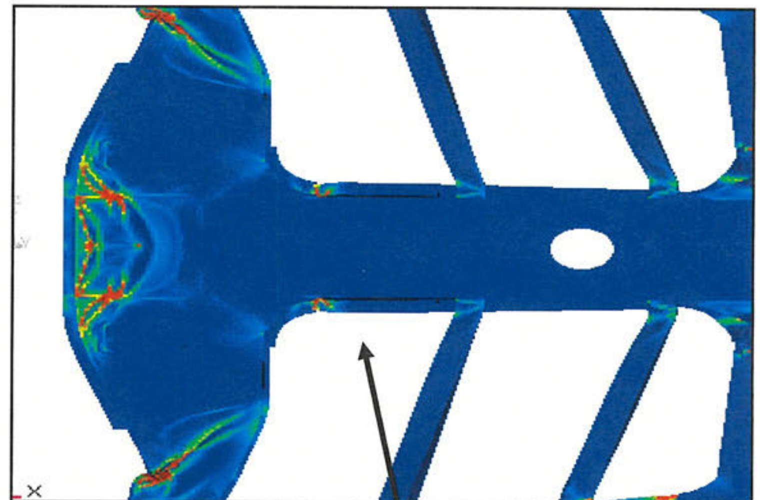
Analysis Results (3):

- The following plot shows the crushing of the draft sill for a crash analysis at 19 mph (high speed) with an equivalent kinetic energy of 737560 lb-ft or 1 Mj. The weakening holes in the draft sill will permit the draft sill to crush like an energy absorption unit.



Crushing of the draft sill weakening holes.



Draft sill with no weakening holes.

Conclusions

- Crash analysis results show that the end sill crushing starts at the extreme ends first (triggers #1 to #5, p. 8 to 13). This crush behavior complies with the CTA specifications requirement of the crushing of the structure at the extreme ends first.

- Plastic strains at the bolster and side sill regions away from the end sill are low (p. 13). Values of plastic strains below 5% will not be apparent. Furthermore, the analysis is considered conservative since the plymetal is not included in the model for simplification reasons.

- A comparative analysis was conducted with respect to the relative position of the weakening holes in the end sill main ribs. Results (p.15) show that the actual configuration of the advanced holes is much more efficient for the crushing of the front of the end sill when compared to when the holes are moved rearward.

- High speeds analysis (19 mph, 1 Mj) also show that with added holes in the draft sill we are creating a trigger mechanism which behaves like an energy absorber (p. 17). Without the holes the draft sill is rigid pushing the bolster further and creating higher strains in the region of the bolster (p. 17). At low speeds and low energy levels, the draft sill weakening holes do not have any effect on the crash behavior of the structure, showing very low plastic strains in the regions of the hole (0.4%, p.15).