Quest Engineering & Failure Analysis, Inc.
www.quest-engineering.com

# June 14, 2018 Accident
# Failure Investigation Report
# Sand Blaster Roller Coaster
# Boardwalk Amusements, Daytona Beach, Florida

Prepared for the Florida Department of Agriculture and Consumer Services, Bureau of Fair Ride Inspections

By: Quest Engineering and Failure Analysis, Inc.

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July 3, 2018

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Dear Sirs,

On June 14, 2018 at the subject location, two of three roller coaster cars derailed. The purpose of our work is to determine contributions to the cause of the failure. In performing our investigation, representative of Quest Engineering have inspected the accident roller coaster track and cars. These inspections occurred on June 23rd and 26th, 2018. During our work we extensively photographed the physical evidence and performed detailed measurements of the cars' and track's condition and geometry. Our work also included 3D scans and drone photography. Following the above activities, detailed drawings and calculations were prepared. The following is a list of reference drawings attached:

Drawing 1: Track layout
Drawing 2: Accident location track geometry and evidence
Drawing 3: Track and axle detail drawing
Drawing 4: Accident sequence drawing

BACKGROUND

Reportedly the ride was initially erected in the Northeast in the early 70's, and was refurbished and erected in Daytona Beach in 2013. The ride was built by Pinfari and is classified as a 64m model, and has a single three car train. The ride is 51 feet tall at its peak and the accident occurred at an elevation of 17 feet. Each car is about 7 feet long. After the accident, two cars remained on the track and one was suspended about 10 feet off the ground. See Photos 1-3.

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RIDE OVERVIEW

The Subject rollercoaster is a simple car on wheels design that follows a metal track similar to a locomotive on a train track. The ride is a gravity ride, meaning that the cars are rolling from a location of higher elevation to a lower elevation to generate speed. Simply put, the cars are rolling downhill on specifically shaped wheels to follow along a metal track made of two inch diameter steel pipe. The ride is not intended to perform negative G's, inverted activities or extreme maneuvers. In the event that a car does attempt to lift off the track, the car has "safety wheels" that extend underneath the track to prevent the car from derailing. Photos 4 and 5 show a derailed car and a properly tracked car. The metal safety wheel is visible beneath the track on the left most car and the tan colored nylon primary wheel is visible in the derailed condition on the right most car. See Drawing 3.

ACCIDENT EVENTS

At the time of the accident, the lead car became partially derailed due to over speed and then slid along the tracks until a portion of the car impacted a fixed brake structure leading to a full derailment. The car did not fall to the ground because it was still connected to the second car which had derailed but was still located on the track. The third car did not derail. A more detailed accident sequence is attached entitled "Accident Sequence". See Drawing 4, the Accident Sequence Drawing.

Seatbelts were added to the cars in the 2013 refurbishment; however, one belt was used for both occupants in a seat and the attachment point of the belt was poorly placed allowing for excess slack of the belt in an accident. See Photo 6.

ENGINEERING ANALYSIS

Under close inspection of the track, two fresh and distinctive gouge marks near the underside of the right hand track rail were found. These marks started on the underside of the track, passed along the midline of the track and exited the top of the track. They were about 4 feet long and are identified in this report as safety wheel escape locations. The presence of these marks indicates a partial right side derailment by the lead car. They initiated from a worn strip on the underside of the track, which clearly indicated a long term wear pattern by the safety wheels contacting the track. See Photos 7 and 8 showing the first mark and the track wear. The primary wheels are made of nylon and will wear out over time. Our measurements indicate these nylon wheels are still within their acceptable service life. The safety wheels are made of steel and are not designed to regularly contact the track; they are a safety mechanism only and should only touch the track in the event that a car tries to escape the track.

Additionally, evidence on the track at the location of the fresh gouge marks conclusively demonstrated repetitive and long-term evidence that the basic accident events had happened many times before (but presumably not with similarly injurious results). Photo 9 shows the fresh accident gouge (fresh colored rust) surrounded by freshly chipped paint along with an obvious groove representing a prior gouge that has been painted over. Photo 10 contains 6 purple flags marking obvious painted over grooves, with several unmarked grooves as well.

Subsequent to the partial derailment, the car then slid along the track in this partially derailed condition until reaching the location where an aftermarket magnetic brake system had been retrofitted onto the track. At this location, the car's aftermarket brake fin (which was now misaligned to the tracks magnetic brake channel) struck the track's brake magnet, damaging both and pushing the car off the track to the right. Because the car's right side was elevated, the brake on the left side was misaligned below its channel. See Drawing 4: Impact #1 detail.

There is also evidence that in very recent history an accident very similar to the subject accident involving car derailment and brake structure impact has occurred. Photos 11 and 12 show a painted over groove with painted over chipped paint. Currently, the ride has a fresh coat of blue paint; however, Google imagery demonstrates that the ride was not repainted prior to June 2017. These facts indicate that sometime between the 2013 refurbishment and the date of the subject accident one car derailed and the evidence was painted over.

Further, the accident brake fin showed evidence of significant prior damage requiring part of the fin to be removed. Photos 13 and 14 shows the leading edge of the accident brake fin is missing and bent. Photo 15 shows saw marks which demonstrate part of the fin had been cut off in recent history. This cutting is again consistent with a prior event similar to the accident event.

We located multiple videos of the accident ride following its 2013 refurbishment. In these videos at multiple locations audible reports of the metal safety wheels contacting the underside of the track can be heard. These sounds indicate that the cars are partially lifting off the tracks similar to the accident event; however, the safety wheels were able to contain the cars on the tracks. We also located video footage of other Pinfari 64M model coasters and tabulated where safety wheel contact was noted. Figure 1 catalogs our observations.

We also calculated speed of each ride in the accident area and at the end of the ride's last turn just before entering the boarding area. The Sand Blaster was unique from other 64M rides in that it consistently demonstrated higher speeds, see Figure 2. Figure 3 shows the individual speed calculations for each video analyzed. Again the accident ride showed consistently higher speeds. It also demonstrated speed gain coming through the brakes following the accident location. Note that the highest speeds recorded for the accident Sand Blaster were recorded just after the refurbishment.

We also calculated the effect of speed versus center-of-gravity (CG) height in Figure 4. Fundamentally, the rides that operate above 20 mph are highly subject to safety wheel contact. Additionally, ride loading is likely a contributing factor. Note that manufacturer's literature that we have reviewed does not indicate an appropriate operational speed at any point. It appears because it is a gravity ride, speeds are designed into the ride through controlling the change of elevation.

Car over speed appears to have been a long term issue with this ride. Over speed can be affected by track lubrication and brake tuning. These are operational parameters that should have been reviewed and defined at the time of refurbishment for safe operation.

Car derailments also appear to have been a long term issue with this ride. For a car to derail, the safety wheel mechanism must be defeated which not only requires car over speed but also requires wear and strain in the axle assembly. During our investigation a track fit-up jig was made and fit onto the accident lead car. See Photo 16. Visual examination and measurements during this process did not reveal an obvious deficiency nor suggest that a derailment was reasonably possible. Simply put, the jig was well captured by the primary and safety wheels. This observation indicates that no single factor in the axle assembly caused the failure but rather the failure was likely the result of the initial design in combination with wear and strain "stacking". Stacking simply indicates that it is not the deficiency of one component but rather small effects of multiple components to produce a larger combined effect.

Inspection of the lead car revealed that the brake fin had been torn off at impact with the magnets. The car had grazed the vertical track support structure (jack stand) with its right side while exiting the track. The right side and handle of the second car wedged against the same jack stand arresting the forward motion of the cars. In total the lead car traveled about 35 feet total from accident initiation to rest. The accident was not a single impact event. The cars were traveling near 22 mph and speed loss occurred throughout the event during derailment, during the slide into the brake, during brake impact and bolt fractures, during jack stand side swipe and during second car derailment. When the car finally exited the track it was likely nearly stopped.

CONCLUSIONS

Based on my work to date and my inspections, analysis, education and training it is my opinion to a reasonable degree of engineering probability that:

- The subject accident initiated because of a lead car derailment.
- The primary cause of lead car derailment was over speed at the moment of the accident.
- Also contributing to lead car derailment was historical over speed which caused damage to the track and axle systems.
- Technically, the accident car appears to have been within specifications for wheel wear and shows no obvious dimensional deficiency.
- The subject ride had experienced car derailments, both before and after the 2013 refurbishment.
- Because the ride shows an extended history of derailments the fundamental safety wheel system is not fully reliable.
- Had the derailment which occurred after the refurbishment, but before the subject accident, been properly addressed by reducing car speed, the subject accident could have been avoided.

This completes our initial investigation which has been based on our work to date. If additional information becomes available or other issues arise, we would be pleased to continue our work as needed.

Sincerely,

QUEST ENGINEERING & FAILURE ANALYSIS, INC.

Brian Van Stratum
Mechanical Engineer

G. Bryant Buchner, P.E.
Chief Engineer

# ACCIDENT SEQUENCE

- The 3 car group was exiting a 540 degree spiral curve near the bottom of the ride. (Photo 2)

- The right side nylon wheels began lifting off of the track due to high speed and centrifugal cornering forces.

- The car's right side safety wheels located beneath the track began rolling along the bottom of the track, thus preventing car overturn. (Drawing 4)

- The edge of the lead car's safety wheels carved an upward gouge or groove in the track. (Photo 11)

- The lead car's safety wheels channeled upward along the track until they became freed above the track. (Photo 11)

- The lead car was now titled to the left as it entered the straight away and slid along the track. (Drawing 4)

- The left side of the car, now being lower due to the tilt, hit a magnetic brake structure with the car's brake fin which severed the brake fin structure from the car and pushed the car off to the right. (Drawing 4)

- The lead car exited the track and struck a vertical support with its right side. (Photo 17)

- The collision forces partially derailed the one of the following cars which remained on the track. (Photo 1)

- The lead car became suspended vertically, hanging from the second car. (Photo 1)

Photo 1

# Ride Overview


Photo 2

DJI_0057


Photo 3

DJI_0060

Photo 4

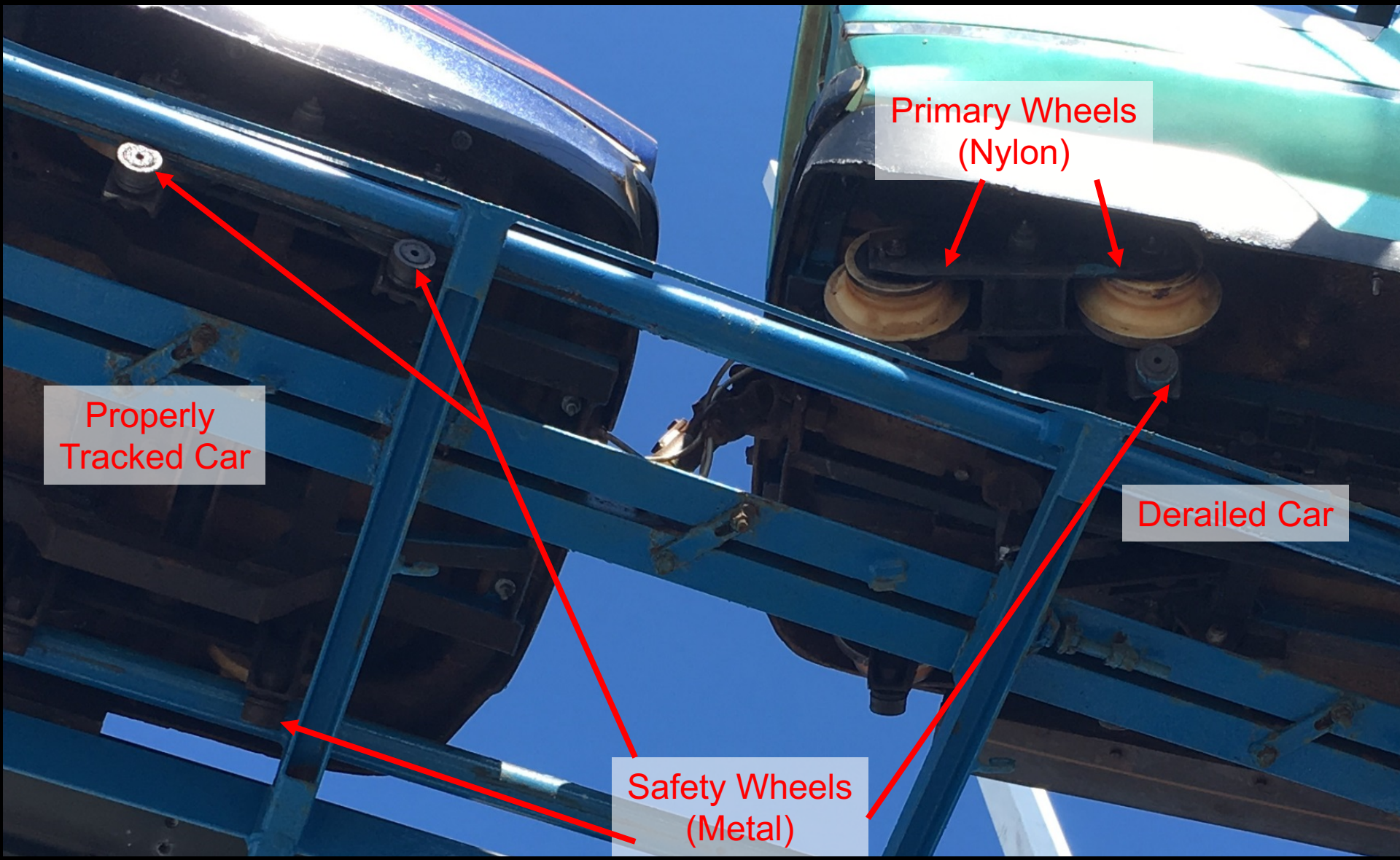

Primary Wheels
(Nylon)
Properly
Tracked Car
Derailed Car
Safety Wheels
(Metal)

Photo 5


Photo 6: Composite Lead Car Seat Belts


Photo 7

IMG_9443


Photo 8

IMG_9458

# Safety Wheel Gouges

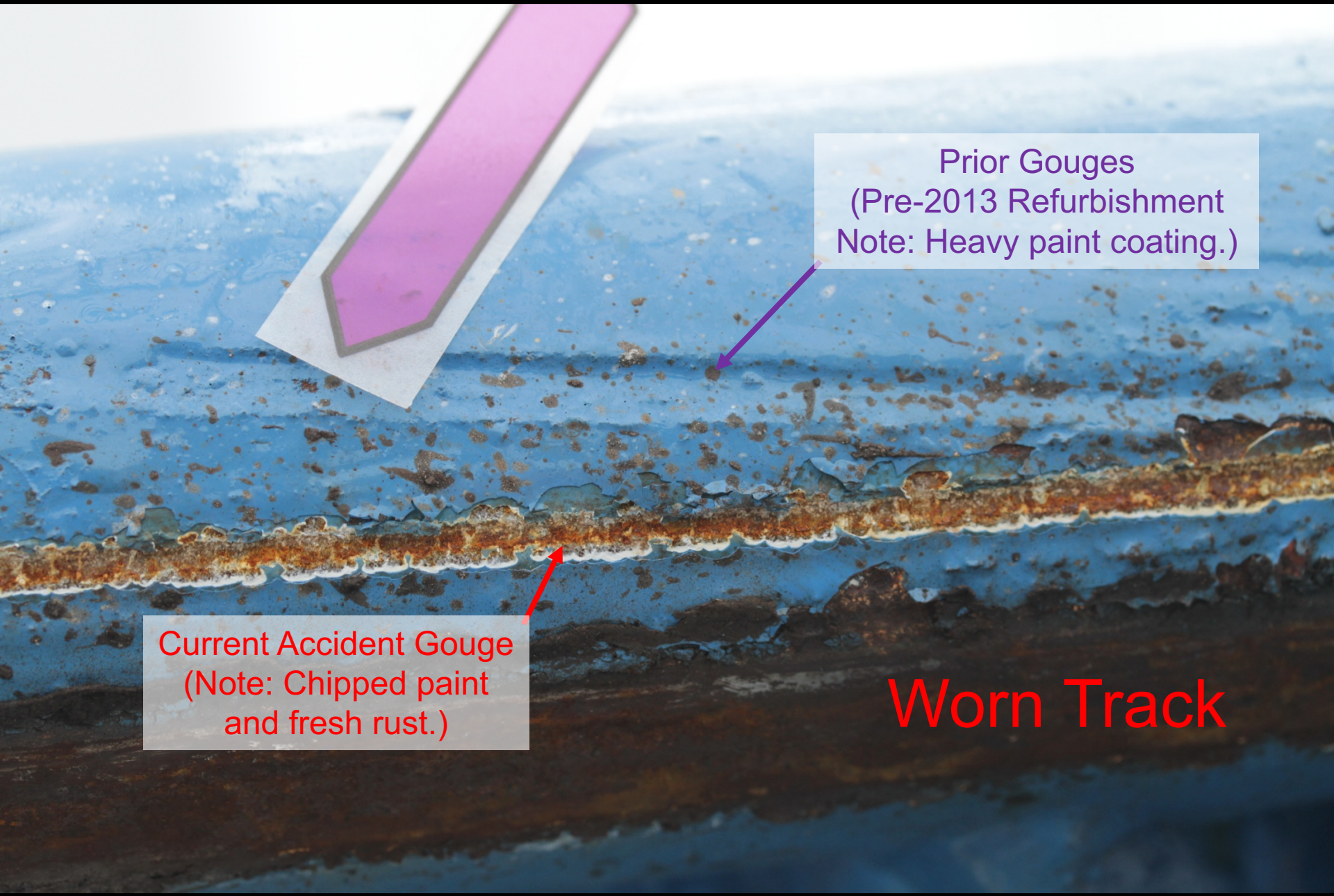



Photo 9

IMG_9622


Photo 10

IMG_9605


Photo 11

IMG_9443

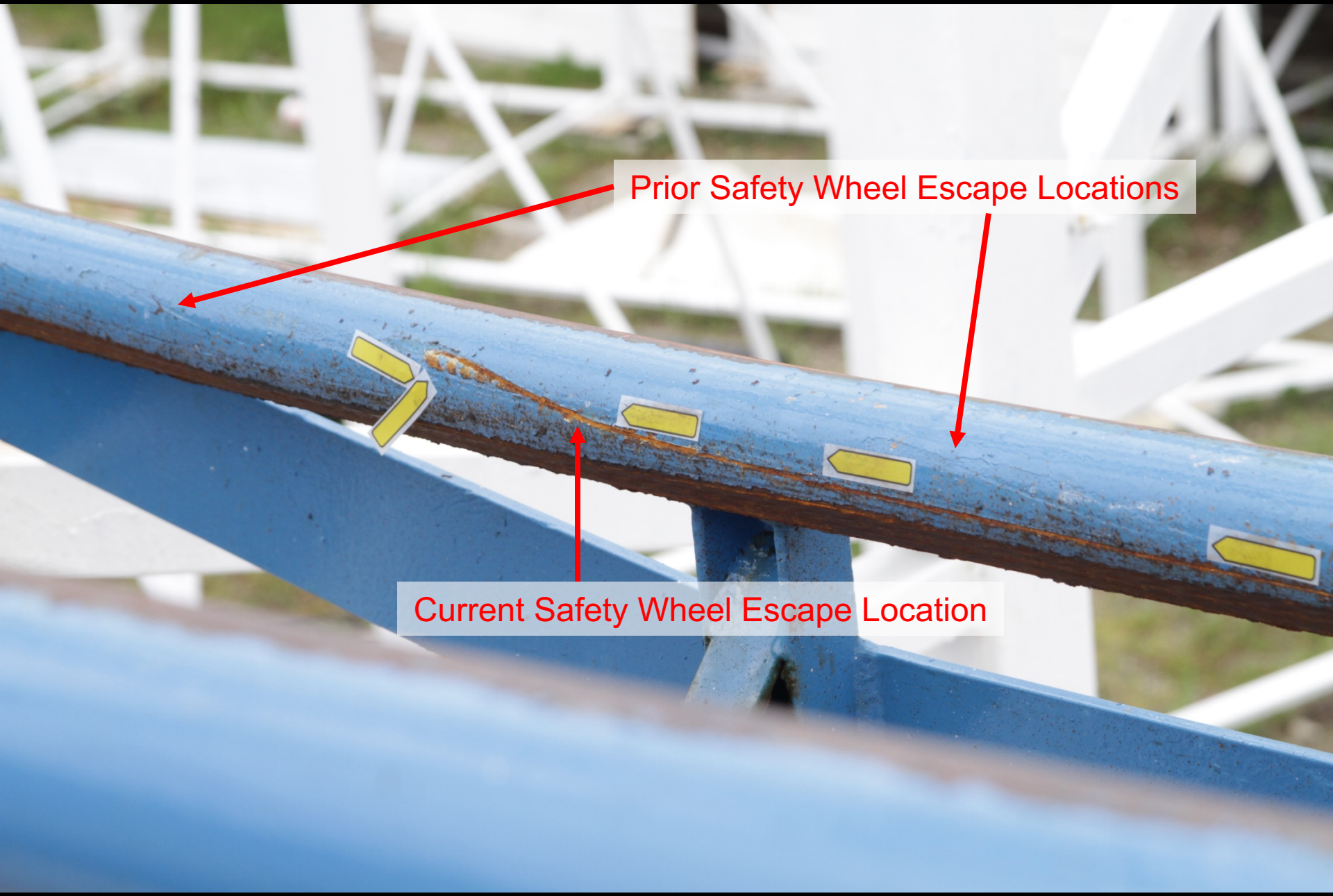



Photo 12

IMG_9478


Photo 13

IMG_9138

# Lead Car’s Damaged Brake Fin

Photo 14

IMG_9118

# Brake Fin Repair Evidence


Photo 15

IMG_9117


Photo 16

IMG_0099

Lead Car


Photo 17

IMG_9915

**Video Analysis: Evidence of Safety Wheel Contact To Track Underside**

| Coaster | Date | Loc 1 | Loc 2 | Loc 3 | Loc 4 | Loc 5 | Loc 6 | Loc 7 | Speed at accident location (mph) | Speed at last turn (mph) |
|---|---|---|---|---|---|---|---|---|---|---|
| Sand Blaster | 8-25-13 | yes | yes | yes | yes | yes | yes | yes | 22.2 | 25.6 |
| Sand Blaster | 8-24-13 | yes | yes | yes | yes | yes | yes | yes | 21.0 | 24.4 |
| Sand Blaster | 4-23-14 | | | yes | | | | | 18.9 | 21.5 |
| Mouse Trap | | yes | | yes | | | | | 21.0 | 13.6 |
| Mouse Trap | | | | | | | | | 17.2 | 7.7 |
| Big Ohhh! | | | | | | | | | 19.9 | 21.5 |
| Big Ohhh! | | | | | | | | | 18.0 | 21.5 |
| Apollo Coaster | | | | | | | | | 18.9 | 19.2 |
| El Bandido | | | | | | | | | 18.0 | 10.3 |
| El Bandido | | | | | | | | | 16.4 | 11.4 |
| **Mean** | | | | | | | | | **18.5** | **15.0** |
| **Standard Deviation** | | | | | | | | | **1.6** | **5.7** |

| | |
|---|---|
| Location 1 | Exiting 1st 540° spiral |
| Location 2 | Entering 2nd 540° spiral |
| Location 3 | Exiting 2nd 540° Spiral |
| Location 4 | Entering last dip and bank |
| Location 5 | Exiting last dip and bank |
| Location 6 | Entering final turn |
| Location 7 | Exiting final turn |

Figure 1

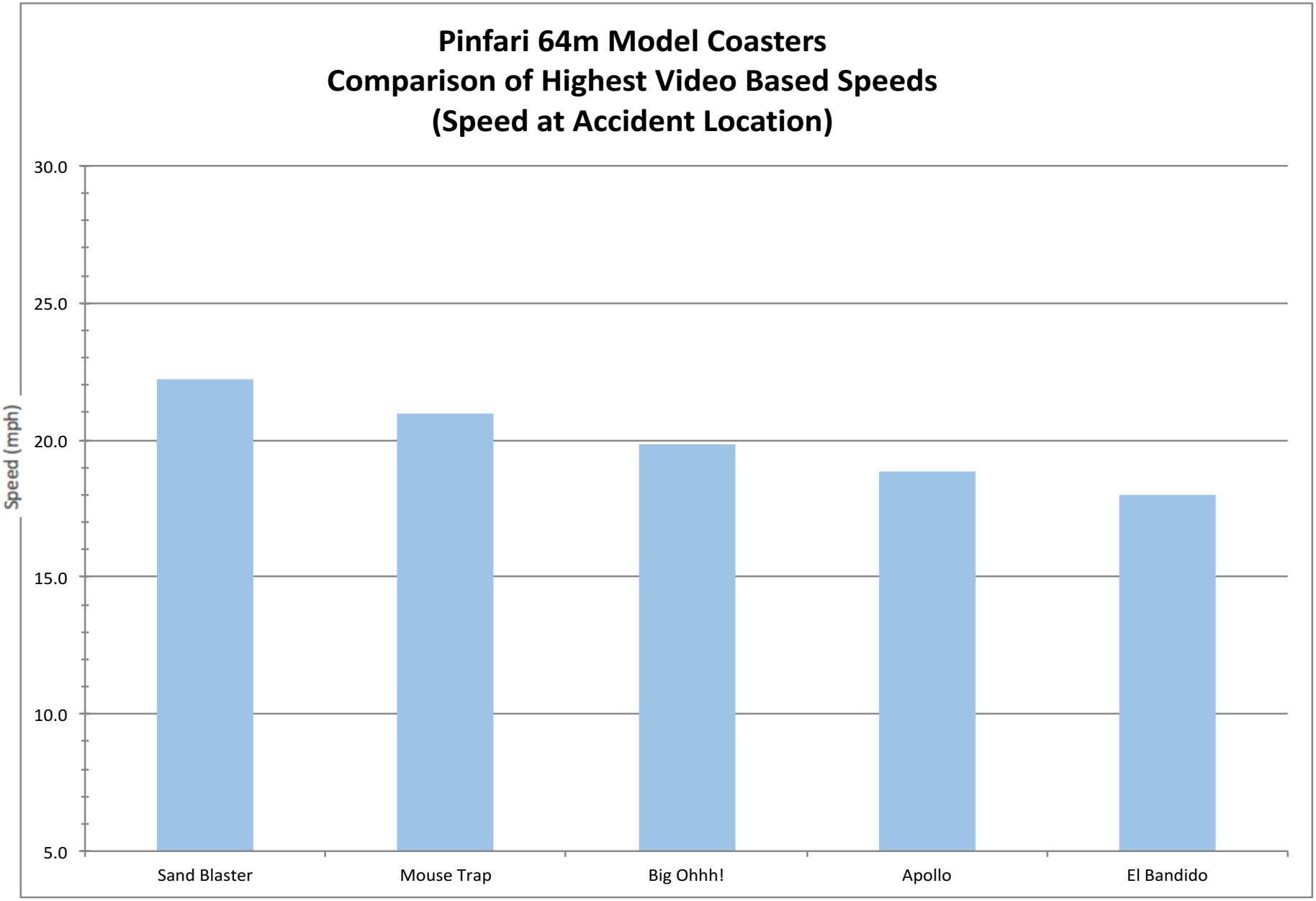

Pinfari 64m Model Coasters
Comparison of Highest Video Based Speeds
(Speed at Accident Location)
Speed (mph)
30.0
25.0
20.0
15.0
10.0
5.0
Sand Blaster
Mouse Trap
Big Ohhh!
Apollo
El Bandido

Figure 2

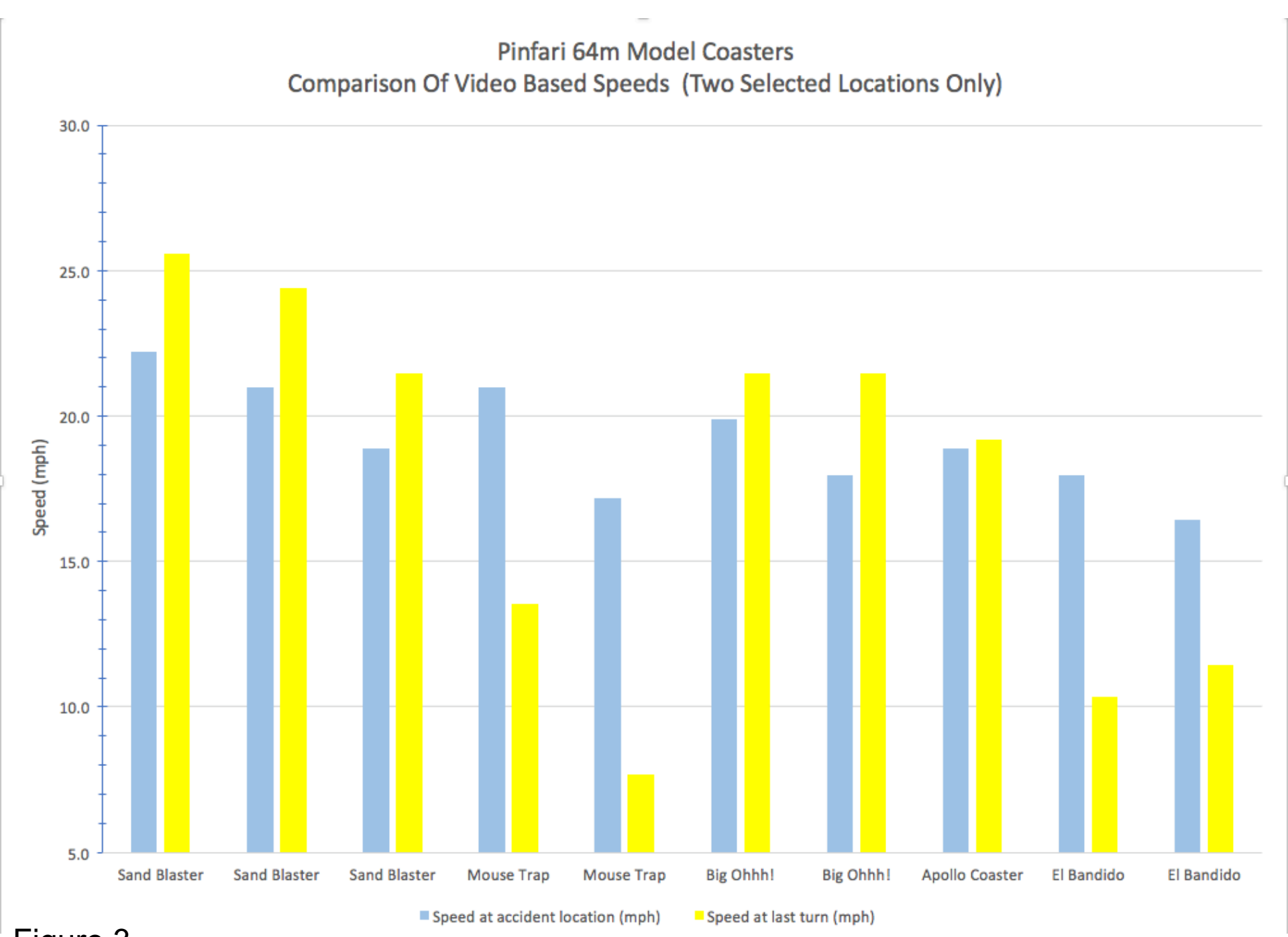
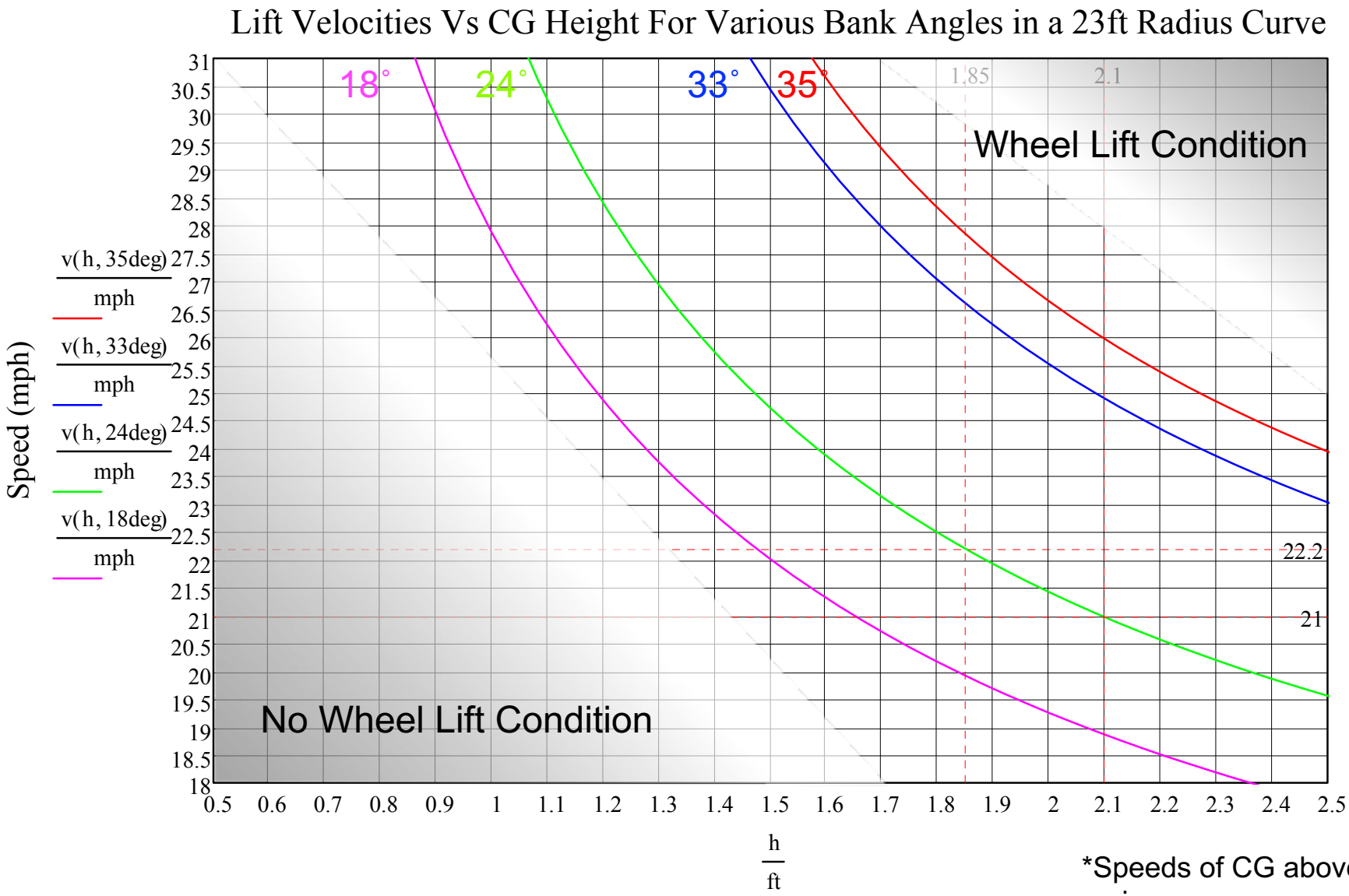

Pinfari 64m Model Coasters
Comparison Of Video Based Speeds (Two Selected Locations Only)
Speed (mph)
30.0
25.0
20.0
15.0
10.0
5.0
Sand Blaster
Sand Blaster
Sand Blaster
Mouse Trap
Mouse Trap
Big Ohhh!
Big Ohhh!
Apollo Coaster
El Bandido
El Bandido
Speed at accident location (mph)
Speed at last turn (mph)

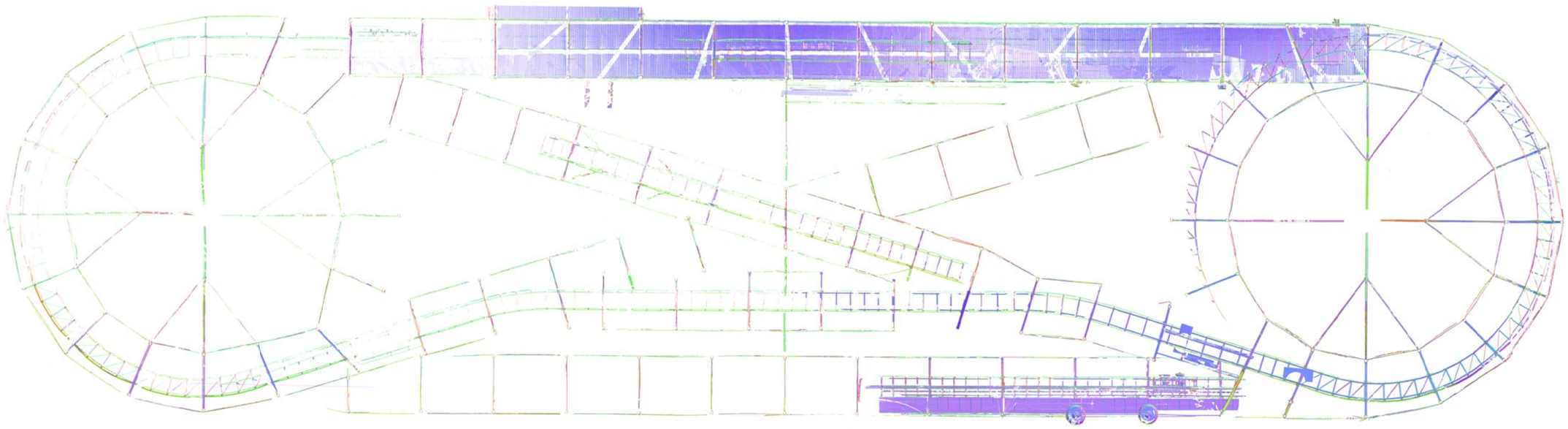
Figure 3

$\rho := 23ft \quad h := 0in, .5in .. 3ft \quad tw := 2.23ft \quad \gamma(h) := \operatorname{atan}\left(\frac{2 \cdot h}{tw}\right) \quad v(h, \theta) := \sqrt{\frac{\rho \cdot g}{\tan(\gamma(h) - \theta)}}$

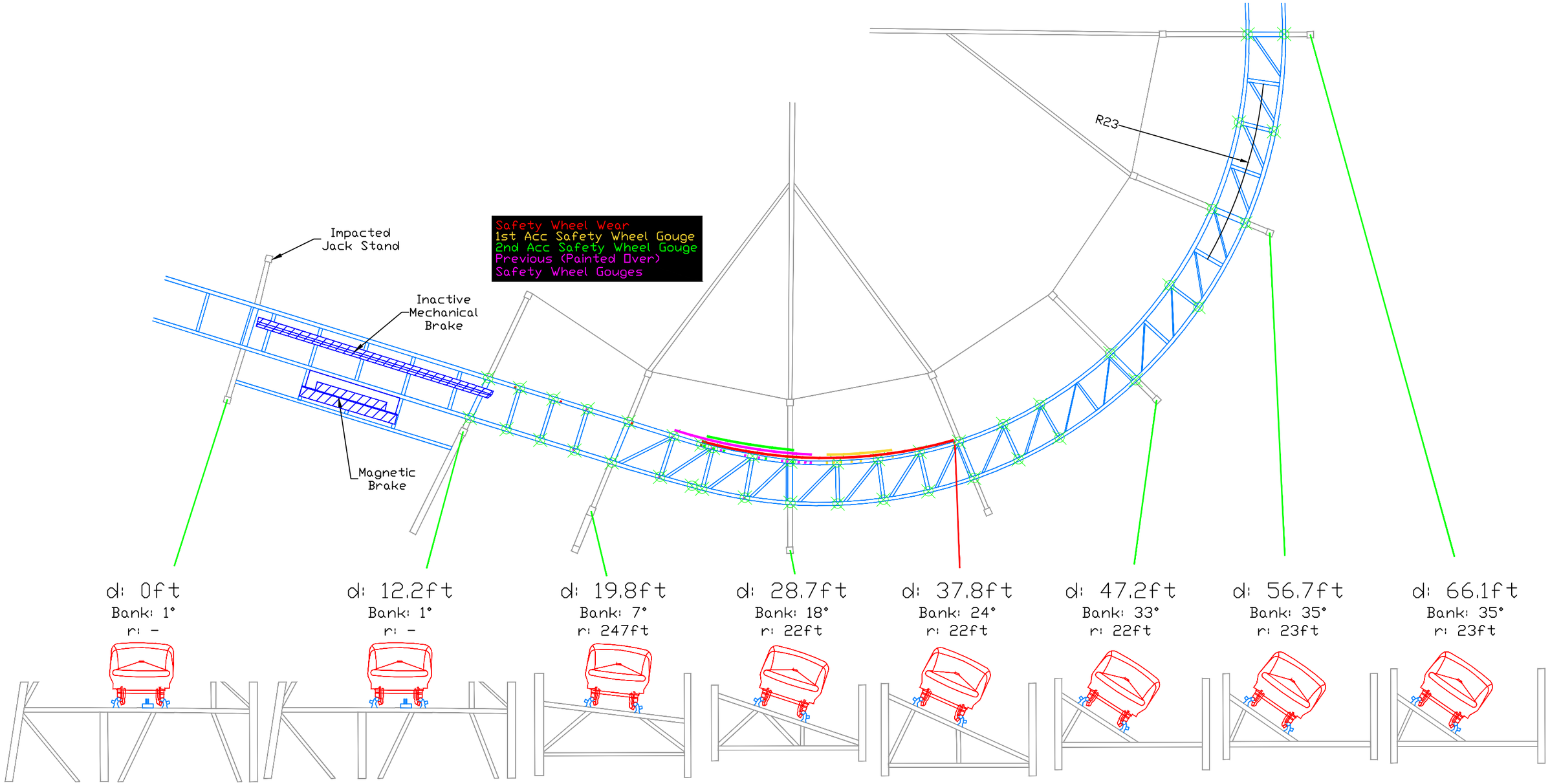



*Speeds of CG above a given curve represent a wheel lift condition

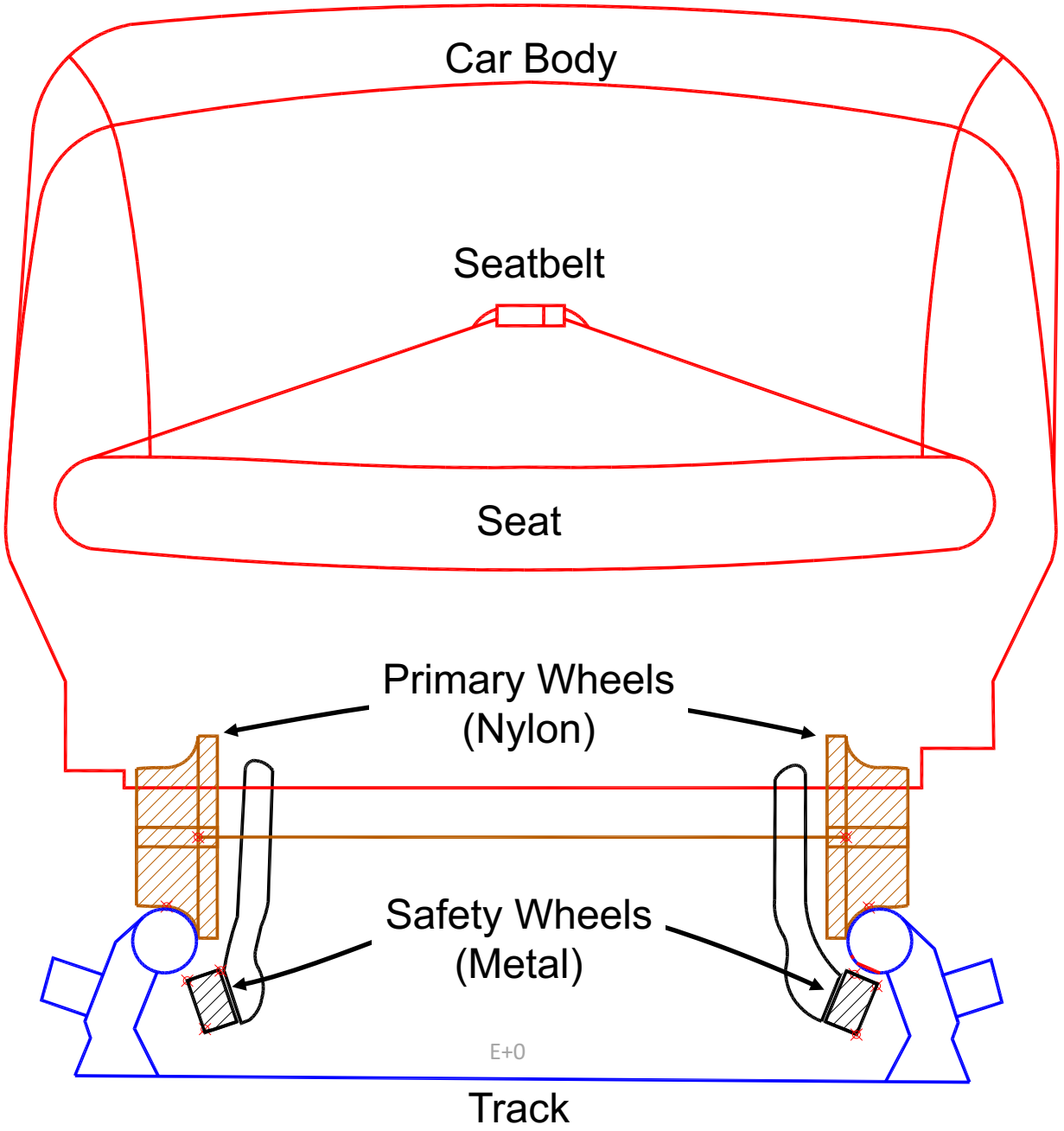
Figure 4



# Accident Level Overview Dwg 1




# Track Geometry Dwg 2




# Track and Axle Detail Dwg 3

Impact #2
With Jack
Stand

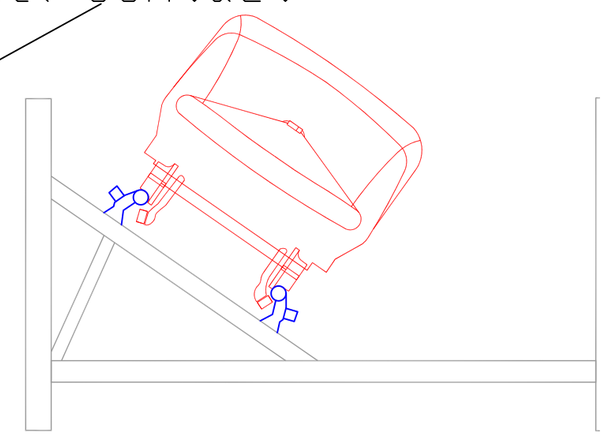
Safety Wheel Wear
1st Acc Safety Wheel Gouge
2nd Acc Safety Wheel Gouge
Previous (Painted Over)
Safety Wheel Gouges

Inactive
Mechanical
Brake

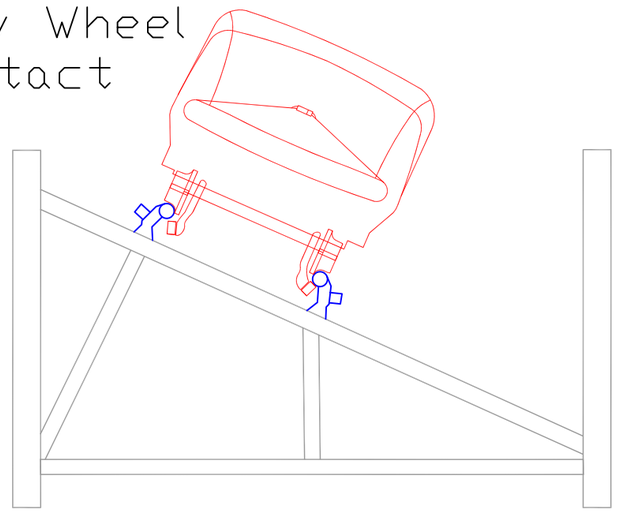
Magnetic
Brake

R23

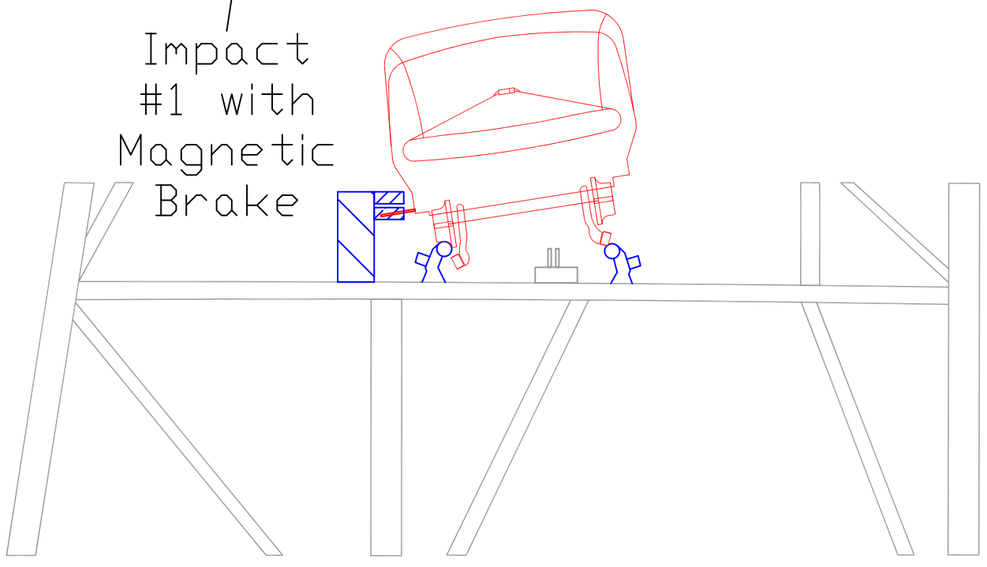
Normal Primary
Wheel Contact



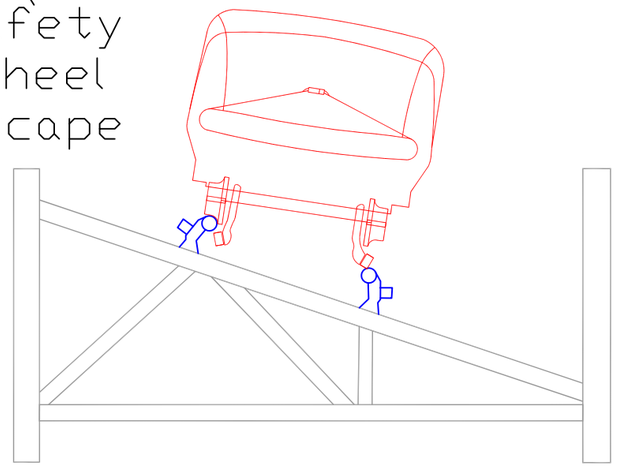
Car Lifted
Safety Wheel
Contact



Impact
#1 with
Magnetic
Brake



Safety
Wheel
Escape



# Accident Sequence Dwg 4