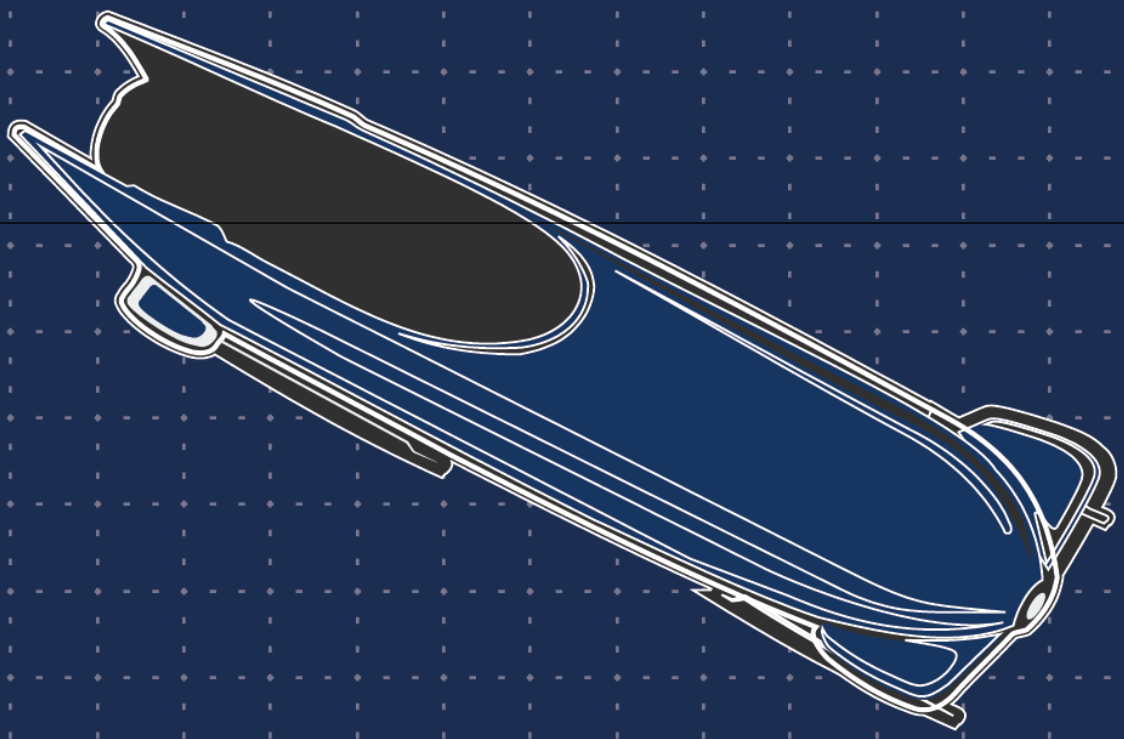
Incident Investigation Report

Passenger Bobsleigh Experience



TECHNICAL SAFETY BC

November 2024

technicalsafetybc.ca

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Incident Summaries

On November 23, 2023, the Whistler Sliding Centre (WSC) was hosting a private company for a holiday event on their passenger bobsleigh sport experience. Employees of the corporation were each given the opportunity to ride the 4-person bobsleigh experience, three at a time, with a professional pilot (employed by the WSC) steering the bobsleigh. During one of the runs, a rider sustained a back injury. Medical care was provided to the individual on site before they were transferred to the Whistler Medical Centre for further tests. A back fracture was confirmed and surgical intervention at Vancouver General Hospital was required. An extended recovery and rehabilitation time was expected.

On February 9, 2024, during regular operation of the passenger bobsleigh sport experience, another individual experienced back pain while riding with two other guests and a professional pilot. Medical care was provided, and the patron was transferred to the Whistler Medical Centre and eventually Vancouver General Hospital for further tests. The tests confirmed the patron had fractured their back during the bobsleigh experience. No surgical intervention was required; however, recovery time was expected to be significant.

Findings Summary

Findings are summarized here for ease of reference. The complete analysis and report findings are found starting on page 17.

Incident Cause and Contributing Factors

The cause of the incidents was compression force from normal ride operation which was concentrated on the front of the patrons' vertebrae as a result of a vulnerable posture which placed the back in a state of "flexion[1]." This increased the stress above the tolerance level of the individuals' vertebrae, resulting in a fracture.

This was contributed to by the ergonomics of seat 4 which promoted a vulnerable posture as a result of:

a) Bobsleigh handholds ending in front of the individual's torso, which required the rider to lean forward, disengaging core muscles which would otherwise support the spine and concentrating the force on a smaller area of the vertebrae.

b) Footrests positioned such that knees are up and legs bent which rotates the pelvis forward, increasing the stress on the front of the vertebrae.

[1] - Flexion in this case is a forward leaning posture such that the angle between the vertebrae is decreased.

Other Considerations

Patron Understanding and Filtering

Injury warnings used by the WSC prior to December, 2023 were exclusive to riders with pre-existing conditions. As a result, riders who identified as healthy (i.e. no pre-existing conditions) did not understand they were also at risk of injury.

Pre-existing conditions

It is unlikely that pre-existing conditions contributed to the likelihood of a fracture occurring in either incident investigated.

Risk Understanding and Incident Response

Initial ride assessments that determined the ride was safe for public use did not identify risks associated with ride ergonomics. Subsequently, when injuries began to occur, the response was focused on filtering out patron vulnerabilities, rather than understanding and mitigating ride risks.

Jurisdiction and Role

British Columbia Safety Authority, doing business as Technical Safety BC (Technical Safety BC) regulates a variety of equipment in BC under the Safety Standards Act and associated regulations, including amusement rides.

Amusement rides are defined in the Elevating Devices Safety Regulation (the "Regulation") as a *"combination of components that carries, conveys, or directs an individual over or through a fixed course or within a defined area for the purpose of amusement or entertainment…"*

The WSC 4-person Bobsleigh Experience is classified as an amusement ride and must adhere to the adopted codes in Regulation including CSA-Z267-00, Safety Code for Amusement Rides and Devices.

Under the Safety Standards Act, Technical Safety BC has the authority to investigate incidents involving regulated work or equipment. Technical Safety BC investigates for the purpose of understanding the causes and contributing factors to incidents to inform prevention activities. For additional information related to Technical Safety BC's role and jurisdiction please see Appendix A.

Track History

Ride Description

The WSC operates a bobsleigh, luge, and skeleton ride for the public near Whistler, BC. The track was originally purpose built for professional and amateur athletes for the 2010 Vancouver Winter Olympics. The track was designed according to regulations set out by the International Bobsleigh & Skeleton Federation (IBSF) by IBG + Partner (IBG), an engineering consulting firm

based in Germany (Appendix A). The IBG design incorporated a total of 5 different starting locations depending on the participants and sport using the track. Depending on the start location, the speeds and resultant g-forces vary. The start locations and statistics for several start locations are shown in a table below:

Item	Men's Bob/Skeleton	Luge Lady/Luge Double	Junior (Passenger Bobsleigh)	Tourist (luge only)
Start Height (Meters)	1450	1202	959	544
Curves	16	14	11	6
Calculated Maximum Speed (km/h)	139	128[2]	116	87[3]
Calculated Maximum G-force (G's[1])	4.9	4.1[2]	3.5	2.2[3]

[1] – "G's": A measure of force on the human body using multiples of the natural force existing on your body from the weight of gravity (i.e. 2 "G's" is equivalent to twice the normal force placed on the body by gravity.)
[2] - As luge double has more weight and faster speeds, only these numbers are reported
[3] - Tourist speeds and g-forces were reported for luge only.

The track design documentation stated the following regarding use of the track for public bobsleigh experiences:

"A 4- person bobsled "taxi bobsled" for tourists (max.v = 113 k.p.h. and as a load max.N = 3,3) can also be launched from the Junior Start location."

Following the completion of the Olympic games in 2010, the track was taken over by Whistler Sport Legacies (WSL) to manage its ongoing operation. In 2011, WSL applied to Technical Safety BC (formerly called British Columbia Safety Authority), to open the ride to the public for both Skeleton and 4-person Bobsleigh experiences. In March 2011, Technical Safety BC reviewed a technical information package submitted by WSL and a professional engineer and issued an operating permit for the ride to open to the public.

Track start locations were renamed to suit the purposes of the track and a visual map of the track as laid out for the post-Olympics operation is shown in figure 1 below:

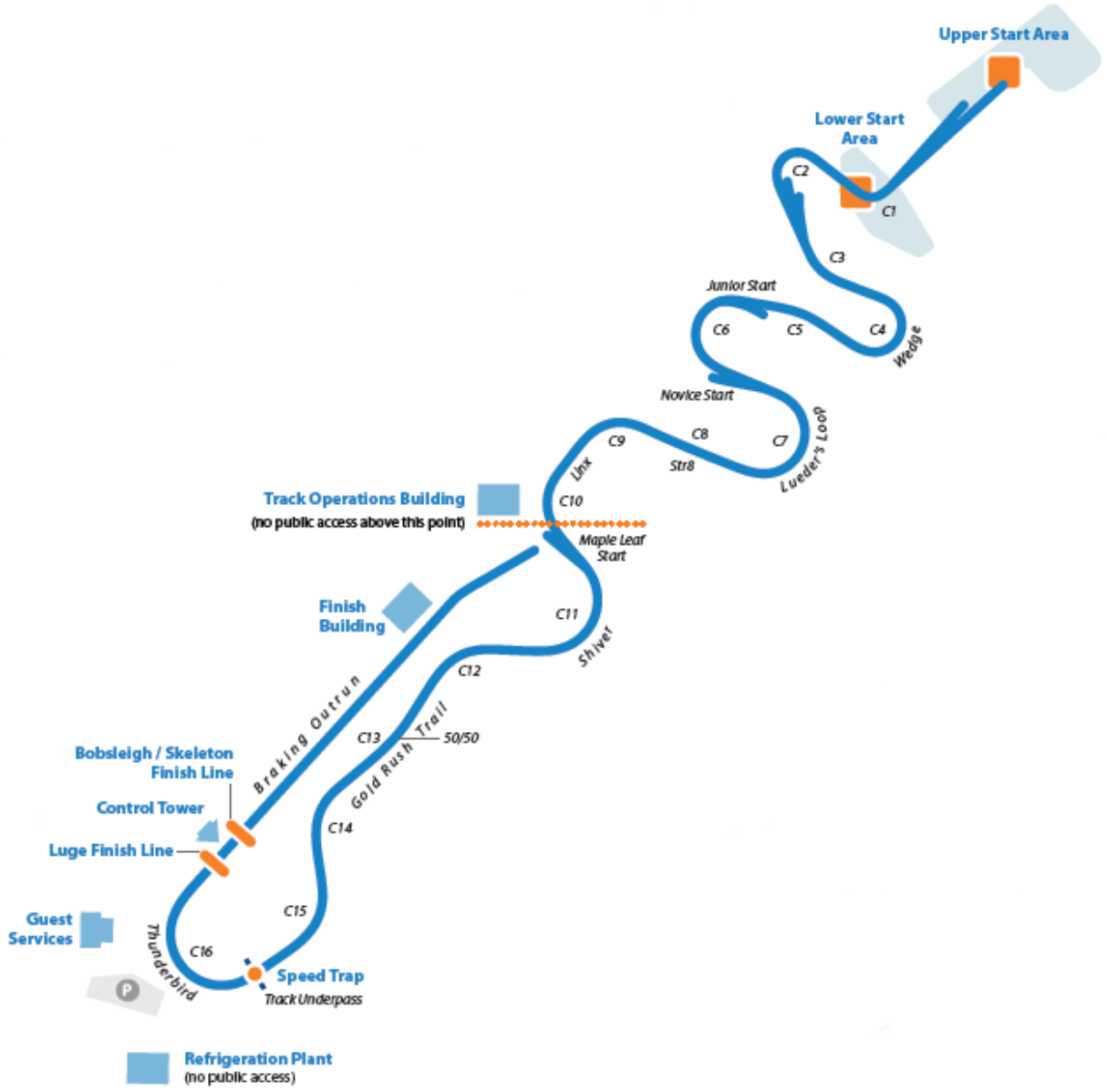


Figure 1 Whistler Sliding Centre Course Map (Provided by Whistler Sport Legacies)

The table below relates to the new start location names with the original names as shown in the IBG documentation:

Start Point	IBG Name	WSL Name
Top	Men's Start (4-Bob)	Men's Bob/Upper Start Area
Before Curve 3	Ladies Start	Dammen (Ladies Start)
Before Curve 6	Junior Start 1	Junior
Before Curve 7	Junior Start 2	Novice
Before Curve 11	Tourist	Maple Leaf

The "Tourist" start point is specifically noted in the IBG documentation for use with tourist luge applications, whereas the public bobsleigh experience was designed to start from the "junior" starting point (although its not clear if this is referencing Junior Start 1 or 2).

Public Ride Evaluation and Acceptance

WSL applied to open the ride to the public in early 2011. As part of the initial acceptance, a technical information package was supplied to Technical Safety BC for evaluation as required by the Regulation (Appendix B). The technical information package was required to include the seal of a professional engineer. For this activity, WSL hired a professional engineer as a consultant. The civil/structural engineer had a background in fall restraint and tie off design. The engineer was also experienced working with zipline anchoring and passenger marshalling which is how they became known to WSL. On February 28, 2011, the engineer issued a letter to the Provincial Safety Manager at Technical Safety BC outlining a summary of their analysis. It included attachments showing the track, estimated speeds from various start positions, and sealed drawings of the bobsleigh components (Appendix C). The following relevant details were stated in the letter:

1. The engineer had reviewed the operations manual for the Bobsleigh sliding experience and confirmed its conformance with CSA Z267 (the adopted code for amusement rides).

2. The chosen start point for the public experience was the novice start point (WSL naming convention), which is just above curve 7 on the track (see figure 1).

3. The calculated maximum speeds developed from this point were in the range of 31 to 33 m/s (112 to 119 km/h).

The letter also stated that *"Bobsleighs travelling at reduced speeds safely utilize about one-half of the available banked curves during this experience"* and that *"A safe and enjoyable sliding experience is offered by the Whistler Sliding Centre for qualified public guests."*

As part of the investigation Technical Safety BC interviewed the engineer to gain context around these statements. The engineer, when asked how it was determined to be safe, stated *that "because it is from the 2/3 point with half the energy of the competition, so the assumption is that people willing to take this ride and have this experience are in physical shape that is appropriate for enjoying this experience."* The engineer also clarified what was meant by *"qualified"* indicating that patrons *"with ability to get on and off the sleds and fall within a weight range"* could be considered qualified.

An attachment to the letter provided a summary of estimated speeds from several start positions as well as a note regarding the *"g-forces"* experienced by patrons. The maximum estimated speed from the novice position was listed as 120km/h. The note regarding g-force did not specify the starting position (either dammen (women's) or novice) but stated that g-forces of *"4-5g"* could be expected.

The engineering assessment did not address the bobsleigh ergonomics, passenger positioning, or restraint as it was not part of their scope. It is unclear if the specific factors contributing to the injuries in this case would have been identified had that analysis been completed given the novel nature of this ride in British Columbia. As a qualitative assessment, the engineer participated in the experience several times themselves to understand the forces that would be experienced.

Following the receipt of the documentation, in addition to in-person inspections, testing and witnessing of bobsleigh runs, an operating permit was granted by Technical Safety BC to open the public bobsleigh experience.

Public Vs. Competition Sleds

As part of the public operation, the WSL commissioned sleds which were altered from the normal competition configuration. In particular, the public bobsleigh sleds had the following characteristics:

1. Wider seats with foam pads.
2. Taller sides that were intended to provide better protection in the event of a rollover.
3. Cables that ran along the interior sides of the bobsleigh to hold on to.
4. Brakes and steering moved to the front of the bobsleigh to be operated by the professional pilot.

Photographs and dimensions of the public bobsleighs are shown in Appendix D

Incident History

Once the ride was opened to the public, requirements for WSL, as the ride owner, to report incidents involving members of the public to Technical Safety BC took effect. It is important to note that between the opening day of the ride and the last significant incident recorded (February 2024), the WSL reported that over 50,000 members of the public have participated in the winter bobsleigh experience. The following table summarizes relevant incidents reported since the ride opened to the Public in 2011:

Date	Patron Age	Patron Gender	Sled	Seat	Pre-Existing Condition Noted?	Injury Description
2012	54	Male	NR	4	None	Pain, hospitalization, fracture not confirmed
2015	40	Male	NR	4	"Poor Posture"	Fracture
2016	55	Female	NR	4	None	Fracture
2016	45	Female	5	2	Previous Fracture	Pain, no fracture
2018	58	Female	NR	NR	None	Strain
2020	50	Female	3	2	None	Fracture
2020	63	Female	1	4	None	Fracture
2023	37	Male	5	4	None	Fracture
2023	51	Female	5	4	None	Fracture*
2024	48	Male	5	4	None**	Back Fracture

NR = Not Recorded

**"Burst" fracture requiring surgical intervention*

***Biomechanical analysis identified a pre-existing condition after the incident; however, this specific condition is unlikely to have been a factor that contributed to the possibility of an injury occurring.*

Two trends are evident from the data collected:

1. Vertebrae fractures, and more specifically, lower or lumbar back fractures have occurred at a steady rate since 2012, shortly after opening.

2. Position 4 in the bobsleigh (also known as the rear seat) appears at a much higher rate than seats 2 and 3 (Note: Seat 1 is occupied by a trained pilot).

Response to Previous Incidents

Over time and as incidents occurred, WSL made several administrative changes to the passenger pre-ride safety orientation as well as changes to the cancellation policy including:

1. Additional warning language in the “Know Before You Go” information bulletin presented to passengers prior to the experience (Appendix E).

2. The addition of a passenger checklist to filter out passengers based on certain known medical conditions (Appendix E). These medical conditions were based on advice from their Medical Director (a medical doctor) who recommended certain diseases or conditions could lead to a heightened risk of the injury they were observing.

3. The addition of a 100% refund for passengers who opt out due to concerns for safety.

No documented physical changes to the track, track starting position, or bobsleighs were made until late 2023. At that time, it was identified that the handhold positions for bobsleigh 5 were slightly lower than other bobsleigh handhold locations. The bobsleigh handholds were re-located to match existing sleds; however, following this relocation, another injury occurred in February 2024.

Following the November 2023 incident additional warning language was added to the passenger orientation information to ensure passengers properly understood any risk associated with the ride; as well as possible factors that could increase their personal risk. A comparison of warning language from before and after the November, 2023 incident are shown in Appendix E.

G-Force Testing by the WSC

Following the February 2024 incident, WSL hired a consultant who completed speed and g-force testing for the Passenger Bobsleigh Experience. Upon review of the data obtained, the investigation identified the information that was relevant to the report:

1. Maximum G-forces occurred in curve 16 of the track. Depending on the combined sled and rider weight the maximum g-forces ranged from 4 to 4.5 G.

2. G-forces steadily increased in each curve as the ride went down the track with approximately 1 second breaks between the onset of g-forces between curves.

3. G-forces in seats 2 and 3 were not measurably different from those in seat 4.

It is important to note that the g-forces measured in the testing were approximately in-line with those reported by the responsible engineer in the letter sent to Technical Safety BC for track acceptance.

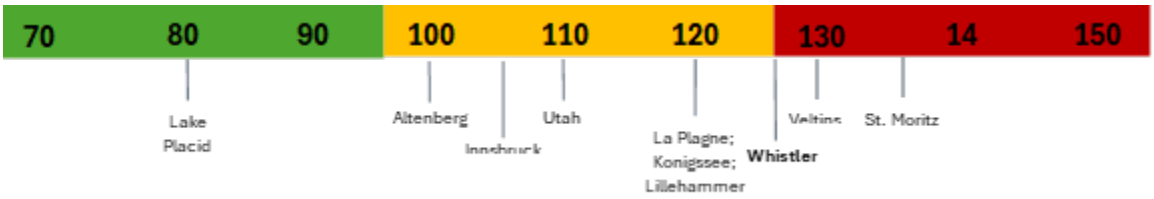
International Comparison Research

The WSC is currently the only passenger bobsleigh experience operating in Canada. Other experiences exist in other parts of the world including the USA and Europe. Technical Safety BC's surveyed several other Passenger Bobsleigh Experiences as well as regulators in other jurisdictions around the world to better understand how the operation of the WSC compared to paid public experiences in other jurisdictions. The research identified the following important information:

1. The speed and forces experienced on the passenger experience at the WSC were average compared to other courses, with some courses having higher speeds, and others lower.

   Estimated Top Speed (KM/hour)

   This graph plots the top speeds in KM/hour posted on each sliding centres' website.

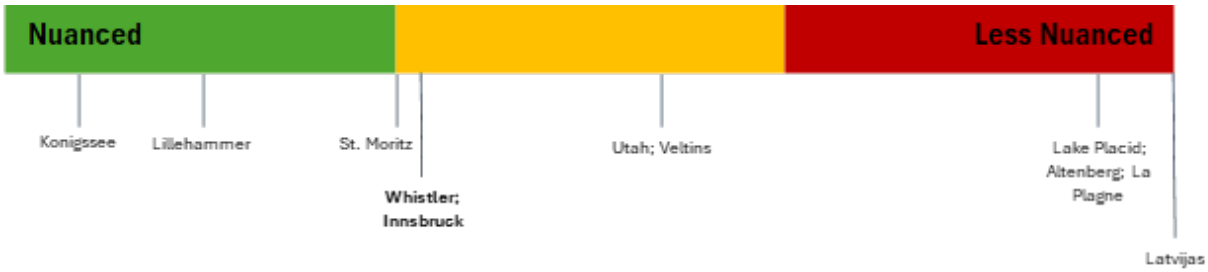


   Estimated G-force

   This graph plots the estimated G-force reported on each sliding centre's website.

   The current language used by the WSC to warn and filter passengers was comparable to many other sliding centres that offer "pay-to-ride" experiences. Although, some sliding centres offered more nuanced language on their public webpages to help participants self-assess risk. For example, some describe injury rates directly on their public facing webpage.

Warning and Safety Language



2. Some sliding experiences in Europe have “mid-tier” experiences available utilizing passenger sleds that are slowed down and built differently relative to the “professional” bobsleigh. These rides provide the public an alternative sliding experience that is less intense than a “professional” bobsleigh experience while still enabling them to experience the ride and not opt out completely.

3. Many of these tracks are designed for professional athletes, typically for Olympic games and therefore have certain requirements to meet the standards for the governing sport body. However, there does not appear to be any set worldwide standard for the safe transition of the track into public use after the Olympic games. Despite the unique nature of this attraction, standards for the rides’ safety are often left to track management or local regulatory requirements.

The full study can be found in Appendix F.

Patron Interviews

Technical Safety BC interviewed the injured patrons from the November 2023, and February 2024 incidents to understand the experience from their perspective.

November 2023 Incident Patron Interview

The patron from November 2023 was asked about the warnings provided beforehand. They recalled signing a waiver, but they didn’t *“recall them saying anything about possible injuries.”*

From the interview with the patron, it was clear that the injury occurred near the end of the track, likely close to or in curve 16. They stated, *“Going down the bobsleigh was fine, until the very last curve, and as we were coming out of the curve I felt a very. . . Strong pain in my middle back.”*

Further, the patron indicated there was a consistent, downward pressure on the spine throughout the ride. They stated, *“The more g’s you have . . .the more the feeling of slumping down”* indicating that the pressure from the ride increased as one progressed down the track.

The patron indicated that, before the ride, they were told to sit up, look ahead, and make yourself look big in the seat. However, they indicated, the consistent downward force was fatiguing and stated, *“For the most part going down I was able to follow their instructions. . .by the end, if I’m being transparent, it was pretty difficult near that final curve.”*

February 2024 Incident Patron Interview

The experience of the injured patron from the February 2024 incident had many similarities to that of the patron from the November 2023 incident.

They indicated that the downward g-force is constant stating, *"They compare it to a rollercoaster, but in a roller-coaster the g-force isn't sustained, you get weightlessness, g-force, uphills, etc. The g-force on the bobsled is constant."* They clarified the location of their injury stating, *"As you went down, the pressure increased, it was the 2nd or 3rd to last I could feel my back get more and more compressed and then at one point I felt like I got the wind knocked out of me."*

They also provided some information on their position in the bobsled. They indicated that due to the position/size of the patrons in the seats in front of them, they had to move back. They stated, *"I was pretty much at the very end of the cables for handholds."*

Pre-Slide Documentation

The pre-slide documentation was filled out by the patrons prior to experiencing the ride.

November 2023 Pre-Slide Documentation

As the injured patron was attending as part of a corporate event, a spreadsheet with the required pre-slide questions was provided for all patrons as opposed to the typical individual forms. All of the patron's answers indicated they met the requirements to participate in the experience. The patron indicated they had no pre-existing conditions, met the physical requirements, and were in good general health. They also met the height and weight requirements.

Since the checklist was in a spreadsheet in this case, the normal warnings associated with it (shown in Appendix E) were not included.

If the official document was used, the wording would still not have warned the patron they could be at risk. The warning language indicated that the risk of compression fractures was limited to those with osteoporosis, which the patron did not have.

February 2024 Pre-Slide Documentation

Following the injury in November, the sliding centre implemented additional warnings as shown in Appendix E. These warnings were signed by the patron. They specifically referenced the possibility of injury to all patrons, the risk of back injury, and the increased risk of injury associated with seat 4 and certain demographics. Similar to the first incident, the patron indicated they had no pre-existing conditions and met the pre-qualification requirements to participate in the experience.

Public Bobsleigh Examination and Analysis

Technical Safety BC attended the WSC on October 2, 2024, to measure, document, and analyze the seating positions of the public bobsleigh experience. The photographs are shown in Appendix G. The following was identified through measurements and qualitative assessment of the rider position in each seat:

1. All five (5) of the public bobsleighs had very similar structures including frame dimensions, fiberglass walls, handhold locations, footrest locations, and seating positions. Some minor discrepancies of about ½ an inch or less were noted between the bobsleighs including handhold height and footrest locations (Photographs 1 through 4).

2. The pilots seat consisted of a fairly rigid but padded backrest bolted to the frame and was mainly situated under the cowl of the bobsleigh. The backrest was inclined rearward to allow the pilot to lean back and ensure their face had clearance with the fiberglass cowl (Photograph 5)

3. Slack cable handholds were provided that started at the footrest of seat 2 (next to the pilot) and ended at the back of seat 3. The cables were connected to the bobsleigh via a swaged thimble connected to an eye bolt (Photographs 6 and 7).

4. Seat padding for all three passenger seats consisted of an aircraft grade foam sourced from the United States and was custom fit to the seats.

5. The second and third positions were a single padded section in the middle of the sled located between the front and rear axle and was approximately 3 ft (36 inches) long (Photograph 8).

6. The footrests for the second seat were vertical frame members that were situated next to the pilot's seat (Photographs 9). When seated in seat two, the knees were bent and the back reclined slightly (Photographs 10 and 11). The core muscles automatically engaged to hold the torso in position. The natural arm position was at the side of the body, with arms bent, holding onto the slack cable. Arms could also be extended a bit further forward allowing the rider to straighten their arms somewhat. The natural tendency in order to brace would be to push down on the slack cable and push outward on the sled walls with the elbows.

7. Seat 3 was very similar in terms of body position to seat 2 (Photographs 12 and 13). The footrests were bolted on to the frame and were noticeably closer than in seating position 2 creating more knee bend. Similar to seat 2, there was a large variability in where riders could place their arms, either bent, at their sides, or extended partially in front of them to grip the rope handholds.

8. Seat 4 was noticeably different in body position than the previous two seats (Photographs 14 through 16). As the handholds ended in front of the body, the natural tendency was to lean forward to grip the handholds (Photograph 17). In addition, that steel thimble from the rope connection to the bobsled interfered with the ability to grip the end of the rope. This created a natural tendency to lean further forward and grip the smooth rubber coated section further up. The footrest locations felt similar to seat 3 creating a significant bend in the legs. Overall, the posture created by the ergonomics of seat position four was leaning forward with the head approximately over the pelvis. The core did not naturally engage in this position.

The bobsleigh measurements and qualitative position assessments, along with injured patron medical records, were provided to a biomechanical expert for analysis as to whether body position played a significant role in the likelihood or severity of the injuries occurring.

Biomechanical Analysis

An independent biomechanical engineer was engaged to assist Technical Safety BC's investigation. The scope of the biomechanical expert's analysis was to review the details of the injuries and provide discussion on the factors most likely to have contributed to the injuries in these two specific cases. Specifically, the biomechanical engineer was engaged to review the likely forces experienced by the riders, the ergonomics of the bobsleigh ride (including rider positioning), and any additional medical or demographic factors that may have contributed.

The full biomechanical analysis report can be found in appendix H, and the findings are summarized here:

1. Both fractures consisted of anterior wedge fractures to a vertebra. In simpler terms, anterior is in reference to the front side of the vertebrae, and the fracture occurred at an angle forming a wedge from front to back. See the diagram below:

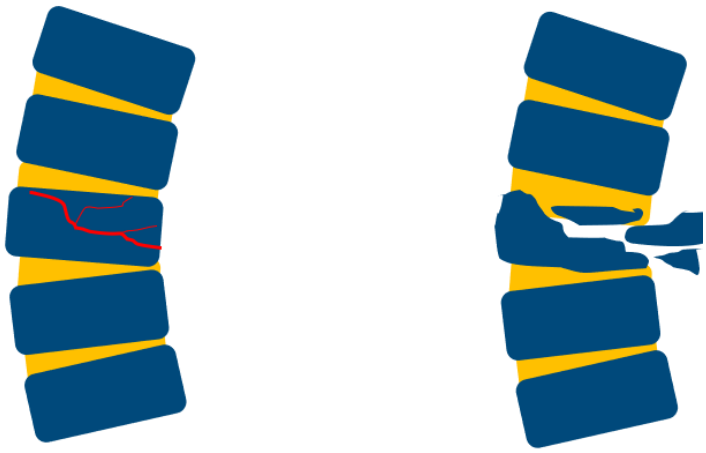


Figure 2 -Representation of the fracture type experienced in the November 2023 incident

2. The measured forces of 4-4.5g would be below the expected tolerance level of the vertebrae and would not be expected to result in a fracture without other aggravating factors.

3. Anterior wedge fractures, as seen in these two cases, occur due to a combination of vertical loads being placed on the spine along with loads from flexion (i.e. the forward curvature of the spine that occurs when leaning forward). Vertical loads on the spine are expected due to acceleration resulting in “g-forces” on the patrons.

4. Leaning forward to grab support handles, in particular, from the 4th seating position, likely predisposes the occupants to a significantly flexed posture. In addition, being seated with legs up and bent rotates the pelvis forward, further flexing the spine.

5. While in a state of flexion, research and testing have shown the tolerance level of the spine to compression force is significantly reduced. Conversely, while in a state of extension, the tolerance of the spine to compression force is increased.

6. Thus, the position of the handles, and resulting posture of the occupants is likely a factor in these fractures occurring.

7. A fracture occurs when the applied load to the vertebrae is greater than the strength of the spine. Different demographics have different fracture tolerances, or strength, in their vertebrae.

8. Factors, including patron age, disease history, gender, and/or prior injury can affect the tolerance of the spine to fracture. In these two cases, there was no evidence suggesting any pre-existing conditions abnormally reduced their tolerance. Although there likely would have been some natural reduction from age.

9. In the November 2023 incident, there were no documented pre-existing conditions in reviewed medical records that contributed to the incident.

10. In the February 2023 incident it is likely that certain pre-existing conditions altered the location of the fracture; however, it is unlikely they affected the likelihood of a fracture occurring under the applied loads.

11. The physical inability to maintain the posture suggested by the sliding centre for the duration of the bobsleigh run may increase the risk in some riders.

In summary, it is likely that a combination of the magnitude and duration of applied loads from the ride, as well as the posture of the occupants dictated by the ergonomics of the bobsleigh, particularly in seating position 4, likely resulted in the vertebrae tolerance of these two individuals being exceeded and the subsequent fractures occurring.

Codes and Standards

Adopted Codes and Standards

In British Columbia, the adopted code for amusement devices is CSA Z267 (2000), Safety Code for Amusement Rides and Devices which was adopted in 2004 (the code). Although there are some general clauses that apply to patron safety and owner responsibility, the passenger bobsleigh experience is a relatively unique experience that made only a few clauses relevant or applicable. The investigation found that the bobsleigh experience was compliant with these code clauses.

In terms of patron safety, the code indicates that, if in the opinion of the owner/operator, a person may be at an increased risk of discomfort or injury, they must deny entrance to that passenger.

The WSC had a pre-qualification checklist that was titled “Know-Before-You-Go” that asked several questions regarding any physical attributes that could increase an individual’s risk including osteoporosis, pregnancy, or heart conditions (Appendix E).The questions relied somewhat on a patron having a good understanding of their own physical health.

In addition, the code indicated that owners have a responsibility to display a sign indicating there are inherent risks to the ride that people should be aware of if they decide to participate.

The WSC not only had a slideshow, but also included video presentations, and checklists prior to the ride. At the time of the November 2023 incident there was no mention of any previous injuries sustained on the ride or that an average person could be at risk of an injury during the normal operation of the ride. Warnings at that time identified risks that existed only if a passenger had, and were aware of, a short list of pre-existing conditions (See Appendix E). The investigation found that riders without pre-existing conditions did not understand that they could still be at risk of an injury. To make an informed decision around participating in a ride that contains inherent risk, a passenger should understand the likelihood of a risk materializing for them, and the consequences if it does. In this case, the warnings excluded those passengers without known pre-existing conditions, which resulted in a misunderstanding of their personal risk when they made the decision to ride.

Section 5 of the Code stated that engineering analysis during design shall include, but not be limited to, “forces on passengers due to the action of the ride or device, based on design loading.” In this case, the engineer who provided assurances of safety evaluated the ride dynamics by partaking in the ride and doing a comparative analysis with the forces experienced by professional athletes. There was no explicit threshold available in the code for the engineer to determine whether the forces observed were safe for the average passenger. However, as stated in the biomechanical report the forces were well below the forces required to cause injury in the average passenger without other aggravating factors such as posture, pre-existing conditions, etc.

The code also contained a general requirement that seats provide adequate support and containment. There is no evidence identified in this investigation that suggests that insufficient containment or support was a contributing factor to the investigated incidents.

The Code did not have any relevant requirements for patron ergonomics or posture.

Industry Standards Available

Although not adopted, other Standards were available at the time for reference purposes though not widely used in British Columbia. ASTM F2291 (2009) Standard Practice for the Design of Amusement Rides and Devices contained some useful requirements around the evaluation of acceleration and its effect on passengers. Specifically, it stated in section 7.1.3 that "Accelerations can vary greatly depending on the type and design of the amusement ride or device and the effect of those accelerations is dependent on many factors that may be considered in the design. Accelerations shall be coordinated with the intended physical orientation of the patron during the operating cycles. Rides and devices with patron containment systems shall be suitably contained and positioned to accept the accelerations."

Although more specific than the requirements in the adopted code, the requirement is still general and requires the designer to apply the requirement to the specific ride or device in question to determine the suitability.

Analysis and Findings

The following findings relate to the investigation of the back injuries that occurred in November 2023, and February 2024. Previous injuries were looked at to inform the investigation; however, due to the passage of time, the same information was not available to fully assess the cause of previous incidents.

Incident Cause

The cause of the incidents was vertical stress from normal ride operation which was concentrated on the front of the patrons' vertebrae as a result of a vulnerable posture which placed the back in a state of "flexion." This increased the stress above the tolerance level of the individual's vertebrae, resulting in a fracture.

Vertical g-forces on the ride are well-documented (both prior to the injuries, and in testing done since) to exceed 4 to 4.5 G. These forces translate to compressive force on the vertebrae for patrons. The g-forces steadily increase throughout the ride peaking in the final curve before the end (curve 16). However, it is unlikely that the g-forces alone were sufficient to create the injuries experienced by either patron. As a comparison, rollercoasters, with proper restraint systems, can at times reach temporary forces of 6 G's without abnormal risk of injury. The biomechanical analysis concluded that the fracture characteristics indicated that the posture of

the individual, with their back in a state of flexion (rounded) contributed to a stress increase on the front side of the spine only. Stress is defined as a force over a specified area. In this case, the force experienced by each patron was similar, but the posture of seat four caused the force to concentrate on a smaller area of the vertebrae, increasing the stress in that location. This additional stress, coupled with the significant compressive forces was sufficient to cause a fracture.

As noted in the biomechanical report in Appendix H, the tolerance of the spine against fracture varies between individuals, and also varies based on certain factors such as age, gender, and pre-existing conditions or injuries. In order to prevent an injury, the stress exerted on the spine must be kept below the tolerance level for that individual. Postures with the spine in a state of extension, with the core engaged can maximize an individual's tolerance level; conversely, vulnerable positions (such as flexion) can decrease the tolerance level resulting in injuries at lower forces.

In addition to varying posture, if forces are lowered, making them less likely to exceed the tolerance levels of individuals partaking in the ride, the risk of injury can also be lowered; however, this reduction in speed would come at the expense of the thrill that riders seek when booking the experience and could introduce other risks in the process.

Contributing Factors

The ergonomics of seat 4 promoted a vulnerable posture which contributed to the likelihood of an injury occurring primarily due to:

a) Bobsleigh handholds ending in front of the individual's torso, which required the rider to lean forward, disengaging core muscles which would otherwise support the spine and concentrating the force on a smaller area of the vertebrae.

b) Footrests positioned such that knees are up, and legs bent which rotates the pelvis forward, increasing the stress on the front of the vertebrae.

A seated position, with legs outstretched in front of oneself forces the lower back to round outwards, placing the vertebrae into a state of flexion. In addition, the handholds for the public bobsleighs ended in front of the patron sitting in the fourth seat. This results in the patron placing their arms and hands in front of their torso in order to grab the handholds. As the rider tenses in this position (to brace themselves for the experience), it can create the effect of pulling the spine further into flexion, and increasing the compression force on the spine, rather than relieving it. The ability to push down with the arms and relieve the compression on the spine was significantly limited by the location of the handholds (ending well in front of the patron), and their construction (flexible cable). Of note, the majority of injuries occurred in seat 4 where the handholds ended well in front of the torso. However, those in seats 2 and 3 had a significantly lower rate of injury, and could brace themselves with handholds directly beside their body.

Both patrons indicated that the g-forces experienced on the ride are constant, and considerable. They also indicated that, by the end of the ride, as they neared the maximum speeds and g-

forces, that holding the proper position was very difficult. Patrons identified that sustained g-forces, coupled with their body position made it difficult to hold the upright position identified in the sliding centre's pre-slide instructions.

Other Considerations

Patron Understanding and Filtering

Injury warnings used by the WSC prior to December 2023 were exclusive to riders with pre-existing conditions. As a result, riders who identified as healthy (i.e. no pre-existing conditions) did not understand they were also at risk of injury.

Prior to December 2023 (including at the time of the November 2023 incident), the pre-experience warnings around compression fractures were exclusive to those who knew they had osteoporosis. All other warnings of g-force related injury were specific to patrons who were aware they had a known medical risk factor including pregnancy, heart conditions, or previous neck or back injury. The only warning that applied to those individuals who believed themselves to be healthy was a non-specific list of possible injuries that could occur on the ride without any mechanism of injury described. In addition, since a compression fracture was only a listed outcome specifically for those with known osteoporosis, the warning likely provided a sense of security to those who did not have it, rather than increased their concern.

In the November 2023 incident, the "Are you ready for passenger bobsleigh?" document was filled out in a spreadsheet and the warning language typically present was omitted. In this document, the patron indicated they were free of pre-existing conditions. This was consistent with the patron's statement that they were never informed of the risk of injury. Since the warnings on the "Are you ready for passenger bobsleigh?" document were exclusive to those with pre-existing conditions, it's unlikely that, had they been reviewed as written, they would have materially changed the patron's understanding of their personal risk.

The warnings provided were consistent with the WSC's theory of the injury mechanism at the time and were meant to filter out a population with an elevated risk. A review of the records associated with the back fracture incidents did not show a pattern of patrons identifying a common pre-existing condition that supported this position; however, since many conditions could be unknown or undiagnosed (such as osteoporosis), this theory was also not disproven. When inherent risk factors associated with the patrons could not be ruled out, it likely diverted attention from a dedicated attempt to understand inherent risks associated with the ride.

Pre-Existing Conditions

It is unlikely that pre-existing conditions contributed to the likelihood of a fracture occurring in either incident investigated.

In the November 2023 incident, the biomechanical analysis found that no pre-existing conditions were present, or contributed to, the injury.

In the February 2024 incident, the biomechanical analysis found that a pre-existing condition was present (probable rheumatoid arthritis), but likely did not meet the threshold where it would contribute to the likelihood of the back injury occurring.

Risk Understanding and Incident Response

Initial ride assessments that determined the ride was safe for public use did not identify risks associated with ride ergonomics. Subsequently, when injuries began to occur, the response was focused on filtering out patron vulnerabilities, rather than understanding and mitigating ride risks.

In 2010, A professional engineer was engaged to confirm compliance with the applicable code at the time (CSA Z267) and to provide assurances as required by the Safety Standards Act and Regulation for acceptance of an amusement device in British Columbia. As part of those assurances, a qualitative analysis was completed by experiencing the ride and by comparing the speeds and forces to those experienced by competitive athletes.

Ergonomics were not part of the ride assessment at that time as they were not part of the engineer's scope or expertise, nor were they required by Code or regulation. Industry standards available at the time did provide some guidance around designing patron positioning to accept the expected accelerations; however, they were not prescriptive, and still based on the designing professional's judgement. Consequently, how ride forces would impact the human body, or how rider position or variability in that position may affect the patron's safety on the ride were not analyzed and factors that significantly increased the risk to riders, including the ergonomics of seat 4, went unidentified.

When injuries did begin to occur following the ride opening, follow-up actions focused on identifying what was different about the patrons that were injured (i.e. possible pre-existing conditions), and did not seek to understand possible risks associated with the ride itself. Administrative steps were taken to try and reduce the risk of injury including changing opt-out policies and altering warning language to identify certain pre-existing conditions associated with an elevated risk of back injury. These steps likely did help to increase rider awareness and filter out some vulnerable persons; however, the changes did not alter the underlying risk associated with the ride ergonomics and therefore did not significantly reduce the rate of injury.

An effective response to incidents includes an approach that looks at, and attempts to mitigate multiple facets of risk, most notably those under the control of the responsible party. The

presence of one risk factor (ex. a pre-existing condition) does not preclude the existence of others and each can be evaluated for possible improvement.

Investigation Report Follow-Up and Ride Improvement

After the most recent incidents examined in this report, WSL engaged a third party to conduct a risk analysis which independently identified similar risk factors as those identified in this report. This investigation report has been provided to the WSL for review to further their knowledge of any risks associated with the ride and to support their work in advancing safe outcomes for all passengers on their bobsleigh experience.