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P4 3 Snowpiercer: Ice impact analysis

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Abstract

In this paper we investigate the Icepiercing ability of the 'Great Ark' train in Snowpiercer (2013) by modelling the shear forces required to carve a train size hole through an ice wall, assuming rigidity dominates in the harsh cold conditions. We determine that the average force applied by the speeding train through its collision, 2.069×10^{10} N, would meet the threshold of shear separation of the required volume of ice, 1.05×10^{8} N, and break through.

Introduction

In Snowpiercer (2013), 'The Great Ark' is a fictional train travelling at high speed around the world after a geoengineering mishap plunges the surface temperature of the Earth to $-120°$ C [1]. In this film the train is shown to break through various ice like obstacles that have formed over its track, in this paper we will be attempting to validate the trains ability to punch through these brittle and incredibly cold ice walls.

Theory and Results

First we must lay out the starting conditions of the train and the ice prior to collision. The train is travelling at an average speed of 170 kmh^{-1} (47 ms^{-1}) [2] and has a total mass from its 1001 cars equal to $37,458,791$ kg, from modelling the cars as identical standard boxcars with individual weight of $82,500$ lbs ($37,421$ kg) [3]. We assume the train is a rigid structure with connections that remain taut.

Freshwater ice at $-30°$ C has a shear modulus of ≈ 2.48 GPa [4]. The plastic shear failure (point of deformation failure, i.e. 'breaking off') of freshwater ice can be observed at an angle of $45° \pm 5$ [5]. For freshwater ice, the peak measured shear strength is about 2.438 MPa at $-30°$ C [6], this value is known to increase as temperature decreases like with shear modulus so we assume a higher value of ≈ 3 MPa.

For ease of investigation we are using the fact that the ice is well anchored prior to impact and likely formed with minimal imperfections (low temperature, fast freeze). This allows us to consider exclusively shear interactions as the train 'punches' a hole through the ice. For our ice wall obstacle we assume a thickness of 2 m and a height and width that exceed the dimensions of the train (considering train cross-section as area of 'hole').

The dimensions of a cargo car gives a cross-section area of around 13.5 m^2 [7] from dimensions 2 m by 6.75 m, giving us a comparable cross-section area of the train front assuming the train is dimensionally symmetrical throughout and a train cross-sectional perimeter of 17.5 m.

Using this cross-section perimeter, P_σ, and an assumed ice wall 'depth', D_{Ice}, of 2 m, we have a total interacting surface area, A_{Int}, of $A_{Int} = P_\sigma \times D_{Ice} = 35$ m^2. Shear modulus, G, is defined by the equation below;

$$G = \frac{\tau}{\gamma} = \frac{F/A}{\Delta x / l} \tag{1}$$

Where τ and γ stand for shear stress and shear strain respectively, Δx is the horizontal displacement of the material, l is the depth of the material. Using this equations expression for shear stress, τ, and the known shear strength at failure we can find the required force for plastic separation, F_{sep}, for our given interaction area;

$$F_{sep} = A \times \tau_{failure} = 35 \times 3 \times 10^6 \tag{2}$$

This yields a separation force of 1.05×10^8 N for our 'hole' block of ice. Assuming that work done on wall is equal to loss in train kinetic energy (neglecting other loses), if the trains average imparted force exceeds 1.05×10^8 N it should be able to puncture the ice wall. If we assume the maximum average imparted force, the train would stop on the other side having imparted all of its kinetic energy into wall deformation work therefore The Great Ark's maximum average force on the wall is calculated as such with existing known variables assuming that all of the kinetic energy of the train is converted to work done on the ice wall, an ideal case, and the train stops as it penetrates the wall, a displacement of 2 m;

$$F_{avg} = \frac{\frac{1}{2}mv^2}{s} = \frac{\frac{1}{2} \times 37,458,791 \times 47^2}{2} \tag{3}$$

The maximum average force on the wall is found to be 2.069×10^{10} N. This maximum average force value appears to exceed the determined separation force needed to 'punch' through the ice wall.

Discussion

During a real interaction ice would most definitely not separate as uniformly as modelled here, with fracturing and shattering very likely to occur as ice is very brittle. Realistically, the profile area of the train interacting with the ice would evolve as it carves through resulting in a varying interaction surface. A real wall of ice would likely contain air pockets and existing fault lines that would facilitate the trains puncturing, but in the assumed flawless case with no shattering it seems that a 2 m wall of ice would still not be strong enough to stop the speeding train.

Conclusion

We find that the average force applied by the train on the ice wall during collision does appear to meet the threshold of calculated minimum separation force required to dislodge the appropriate volume of ice, determined through shear strength at deformation failure, for the train to pass through cleanly. In a realistic scenario other material events would occur, such as compression and flaw shattering, and the force profile of the train would evolve as it moved into the ice wall which may allow the train to displace the ice with a lower minimum force requirement, but it seems even in an ideally strong case the wall would not stop the train. Increased loading rate can increase peak stress but tends to produce catastrophic cracking that lowers the work needed to punch through (because fragmentation consumes less energy than uniform plastic shear), so the required force is likely even lower than we found it to be.

References

[1] Snowpiercer Wiki. The freeze, 2025. Accessed: 2025-10-26.

[2] Snowpiercer Wiki. The engine, 2025. Accessed: 2025-10-26.

[3] Norfolk Southern Corporation. Railcar guide. `https://www.norfolksouthern.com/en/ship-by-rail/shipping-tools/equipment/railcar-guide`, 2025.

[4] Xiaomin Chang, Wenhao Liu, Guangyu Zuo, Yinke Dou, and Yan Li. Research on ultrasonic-based investigation of mechanical properties of ice. *Acta Oceanologica Sinica*, 40:97–105, 2021.

[5] E.M. Schulson. Compressive shear faults in ice: plastic vs. coulombic faults. *Acta Materialia*, 50(13):3415–3424, 2002.

[6] Yongjie Zhang, Yunhui Zhang, Renzhong Guo, and Bo Cui. Method for testing shear and tensile strengths of freshwater/seawater ice. *Water*, 14(9), 2022.

[7] Maryna Bulakh. Freight wagon body design with increased load capacity. *Scientific Reports*, 15, 2025. Accessed: 2025-10-26.