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Meteorology and Physics Analysis of Rail Car Fatality

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Abstract

When borax gets wet, it clumps. In this case, 76,000 pounds of previously wetted borax clumped on the inside of a rail car. The unbalanced load caused the rail car to fall on a yard worker, killing him. Tracking meteorological conditions in transit from Turkey to a port in Deleware, truck transit to a warehouse, handling at the warehouse, and rail transit to an interim transfer station was key to developing the origin and cause for the rail car derailing. There was evidence that clumping had rendered the product unusable by the end-user. However, this event occurred at the interim transfer station where the rail car product was transferred to trucks. This paper describes the process of determining how and where the borax absorbed moisture and shows physics that determined derailing was the result of an unbalanced load. This demonstrates the cause and effect of this event.

Keywords

Borax, shipping, ocean transport, rail transport, truck transport, center of gravity, lean angle, turning moments, suspension stiffness, forensic engineering

Introduction and Background

At approximately 10:15 a.m. on September 4, 2013, a rail car left the track and fell on a rail yard transfer station worker, killing him. The event occurred at a private transfer station in middle Georgia. Rail car NS 253219 was built in May 1970 with a load capacity of 223,300 pounds and an expected life of 50 years. (It will be shown that rail creep was caused by a buildup of 76,420 pounds of borax caked on the side of an otherwise empty car.)

The rail car was transporting bulk borax that clumps when wet. The borax had become wet either during transport from overseas, during transfer, storage, or overland transport. Operations and coincident meteorological conditions (primarily precipitation and humidity) were important to validate the assumption of borax caked on the side of the rail car. Engineering calculations were necessary to verify that the uneven distribution of product resulted in the derailment.

Material

Borax is anhydrous sodium tetraborate ($Na_2B_4O_7$; mol wt. 202), sodium tetraborate pentahydrate ($Na_2B_4O_7$ * 5 H_2O; mol wt. 292), or sodium tetraborate decahydrate ($Na_2B_4O_7$ * 10 H_2O; mol wt. 382). When exposed to water, anhydrous sodium tetraborate hydrates and begins to clump as it hydrates. To prevent clumping, temperatures greater than 85°F and relative humidity greater than 45% should be avoided. Borax occurred naturally in seasonal lakes that evaporated and left deposits millions of years ago[2]. This paper tracks borax mined in Turkey, transported overseas to Delaware, handling and storage near the seaport, and overland transport to a middle-Georgia transfer station.

Six primary steps are required to refine raw ore into refined borates:

1. In the first step of refining, crushed ore is dissolved through steam addition and agitation. Insoluble rocks, sand, and other solids are removed using screens;

2. Next, the saturated borax solution is pumped into large settling tanks called "thickeners" where remaining fine particles settle to the bottom of the tank, leaving a clear, hot borax solution on top;

3. Crystals of borax pentahydrate and borax decahydrate form as this hot solution is cooled in the crystallizers;

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4. The newly formed borax crystals pour out onto special fabric filters where they are also washed to ensure purity. Water is drawn away from the crystals by a vacuum underneath the filter;

5. After this washing, the crystals are transferred to the dryers. These large rotating dryers use hot air to dry the borate crystals;

6. Dry borate crystals exit the dryer and drop onto a conveyor belt. The refining process is complete. The refined borates travel by conveyor to covered hopper cars for transport to the seaport[3].

Transfer Operation

The borax was mined in the Emet[2] region of Turkey. It was refined at the mine, stored in weather-protected bins until loaded into covered hopper rail cars. Transported hundreds of kilometers over land to seaports, the borax is loaded onto bulk container ships by a conveyor, and moved from the rail cars to the ship conveyors that feed hoppers that direct the material into cargo holds.

The average monthly relative humidity in Istanbul, Turkey (port of embarkation) in March (estimated time the ship was loaded) was 55%. These calculations were developed using maximum daily temperature (MXT), minimum daily temperature (MNT), and the average daily dew point (DP) for September 2013 at Sabiha Gocken Airport in Istanbul[4]. Average temperature was estimated by taking the average of the average MXT and MNT.

This statistic was used with the average DP to estimate the average daily relative humidity. The mine operators understood the moisture impact[1] on borax and maintained climate control conditions after drying and during rail shipment to the seaport. Given typically covered hopper loading methods, that prior operation near Emet was the first uncontrolled climate. Moisture may not have significantly affected the borax during the short time on the loading conveyor.

The borax was shipped to Delaware where it was received by a warehousing company. The product was unloaded on April 16 and 17, 2013 by a crane-mounted grab that drops the mineral into a hopper. The hopper opened and loaded trucks with the loose product. The trucks were then covered with a screen and driven to the warehouse where the borax was delivered to an uncovered way station.

Borax was exposed to humidity while unloading from the ship and during transport to the warehouse yard. The daily average relative humidity on April 16 and 17 was 76% and 71%, respectively[5]. There, the borax was screened to get out any lumps or foreign material. After screening, the warehousing company transferred the product to another warehouse a few blocks away. The warehouse was covered, but not climate controlled. From there, it was loaded on rail cars using a conveyor belt.

The warehousing company was advised by email from the product owner that borax would clump if it got wet — and that it should be stored in a climate-controlled warehouse. At each transfer after delivery to the trucks, borax was exposed to atmospheric moisture. As the borax was being loaded into the rail cars for shipment, loading was stopped for two days because light precipitation started late on August 12 and continued the next day. Loading was started on August 12 and completed on August 14, 2013. There was only a trace of rain on August 12. However, on August 13, there was 3.10 inches of rain. There was no rain on August 14. The load was then shipped by rail to a middle Georgia transfer station. The relative humidity on August 12 was 73% and 58% on August 14[4].

Quantifying the Amount of Material

Two companies worked in concert to transfer borax from rail cars to trucks for delivery to the end-user. A local railroad company moved the cars into and out of the transfer station. Transfer station workers unloaded the rail cars and loaded the product into trucks. Borax flowed out of the hopper cars when opened from the bottom. A mechanical unloader moved the material from the bottom of the rail car to load trucks. The hopper chutes were equipped with shakers that helped free the product so it would flow more easily into the enclosed conveyor that lifted the load to drop into trucks. The shaker was not operational on the unloader that was used to transfer the borax. The transfer station workers used hammers to aid the flow of material into the conveyor.

Transfer station workers were in the process of unloading the subject rail car when the locomotive came on that track to move cars. The free product had flowed out onto the conveyors and loaded in trucks. As the cars sat on the track, they appeared stable, although one of three cars was leaning. Unloading was stopped, and the unloader was removed from under the rail car so the locomotive could move cars.

After unloading was completed, 76,000 pounds of borax remained in one rail car (clumped on one side). The weight of borax remaining in the rail car was determined by weigh scale measurements before and after unloading. There were three cars coupled together. When stationary, static friction held the wheels on the rails. Once the locomotive moved the cars, the drop in friction from static levels to dynamic levels facilitated wheel climb, releasing the wheels. The last rail car (NS 253219) immediately fell, pulling the other two cars with it. Witnesses observed borax clinging to the side of the rail car.

The timeline for these transfers — from unloading to the transfer station — was documented. A timeline for mining, processing, and transport to the Turkish seaport was not available.

Workers' Roles

The railroad had three employees on site: the engineer, conductor, and flagman. The engineer operates the locomotive. The conductor oversees the train and gives instructions to the crew on what needs to be accomplished and how. The flagman walks down and checks the train for chocks that are put under the wheel sometimes (for anything hanging off a car), checks hoses, and identifies any safety appliance that is defective on the car. The flagman's primary responsibility was to observe the train's right of way.

There were two transfer station workers at the time. When the locomotive pulled onto the yard, they were unloading the rail car. When the locomotive pulled the cars, one of these workers was walking along the side of the track. At the first movement, the rail car derailed and landed on that worker, killing him.

The transfer station workers did not notice the lean of the rail car from their vantage point near the base of one side. The flagman was responsible for a general inspection to assure the car was safe to pull.

Rail Car Derailment Calculations

There were two main factors that caused the derailing accident. The main factor of rail car derailment was the shifting of the mass center due to the unbalanced weight of borax (caked on one side); the other one was friction. Static friction held the car upright until the locomotive moved forward slowly at a speed of 4 to 5 miles/hr (kinetic friction). The wheels on the light side rode up on the rail, and the car derailed when the wheel lip left the rail (as shown in **Figure 1**).

Center of Gravity Calculation

The specific density of borax is 1.73 grams/cubic centimeter (gm/cc^3).[6] After converting and increasing the specific density to 76,420 pounds, the volume of borax is 20.3 m^3. The center of gravity (CoG) was calculated in two pieces: one with an empty car; the other with the borax caked-on the left-hand side. The length (L) of the hopper car is 65 ft.[7]

H = 15.5 ft [7]

Borax Volume = 20.3 = L x W x H

W = 0.2168 m, CoG of borax from the left edge of the car is located at l_2 = W/2 = 0.1084 m and Y = H/2 = 2.3628 m (as shown in **Figure 2**).

Moments Calculation

F_1 = Borax Weight = 76,420 lb = 339,314 N

Figure 1
Rail car derailed from the tangent track (left); another view of the derailed rail car (right).

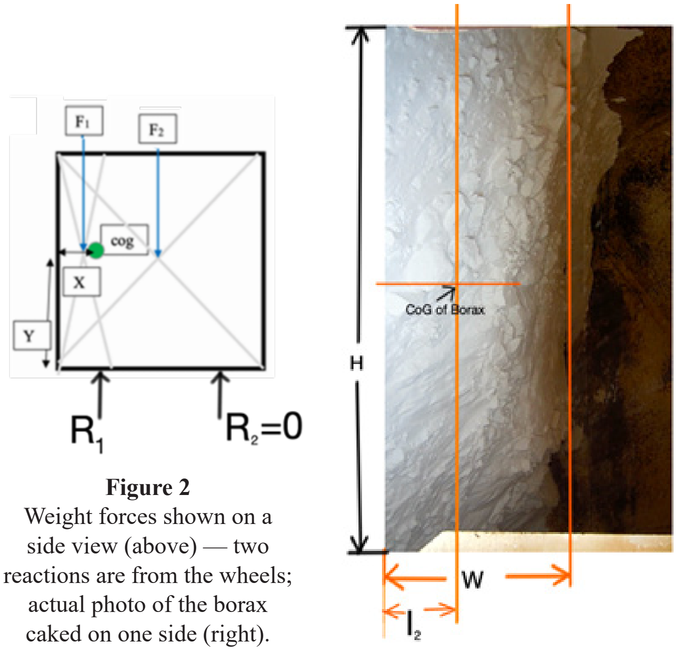

Figure 2
Weight forces shown on a side view (above) — two reactions are from the wheels; actual photo of the borax caked on one side (right).

F_2 = Empty Rail Car Weight = 62,700 lb = 278,396 N

Gauge Length = 1.435 m

Total Car Width = 3.23 m; $l_1 = ½$ (car width) = 1.615 m; $l_2 = 0.1804$ *m*

$a = ½$ *(gauge length) = 0. 7175;* $b = l_1 - a - l_2 = 0.79$ *m* (as shown in **Figure 3**).

$M_{R1} = F_1 (b) - F_2 (a) =$ *339414 *0.79 - 278396 * 0.7175* = 68088 N-m

Maximum Load to Avoid Tipping Over-Calculation

The condition for the moments about to tip the rail car

$M = F_2 * a - F_1 * b = 0$

$F_1 = F_2 * a/b = 253130$ N

Borax; $F_1 = 339414$ N

Extra load that caused the tip over = 339414-253130 = 86284 N = 19047 lb

Lean Angle Calculation

The lean angle is the threshold angle beyond which it will tip over (as shown in **Figure 4**). It is calculated from the left side of the rail car, which is 26.3˚.

$\Phi = \tan^{-1}(1.925/0.95) = 63.7^{\circ}$

Lean angle, $\theta = 90 - \Phi = 26.3^{\circ}$

The pivot point of the rail car is the location of wheel-to-rail contact. The tipping angle was found to be 26.3˚. The rail car was pulled in place by the railroad locomotive while it was fully loaded. It was emptied by transfer station workers using an unloader placed under the car at the drop chute. The unloader conveyed borax up to drop in the dump trucks. Unloaders had shakers to help loose material in the rail car, so it fell freely into the unloader. The shaker on this device was not working.

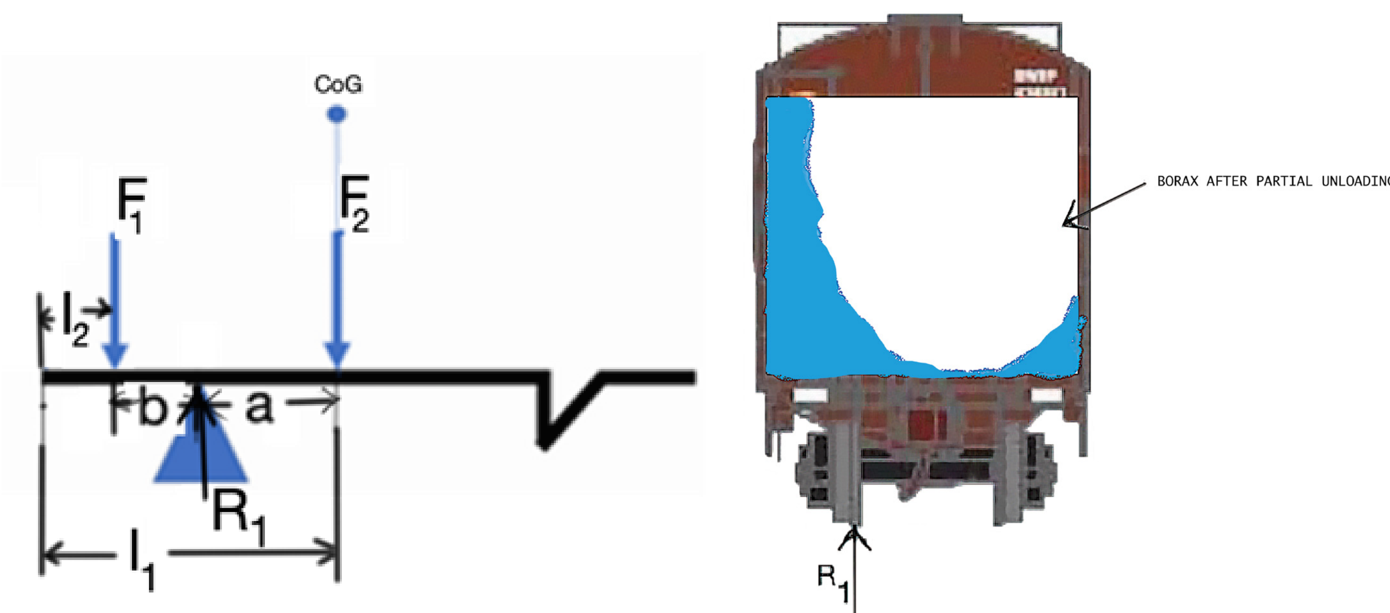

Figure 3
Moments calculations with moment arms.

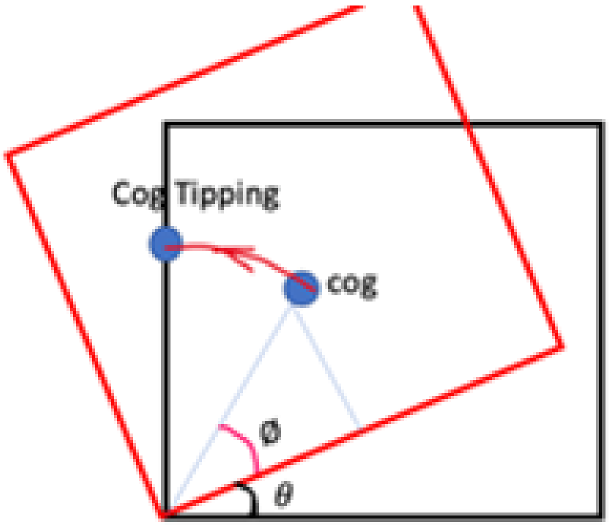

Figure 4
Lean angle calculations.

Conclusion

Anhydrous borax absorbed moisture from the ambient relative humidity, which caused the borax to clump and adhere to the side of the rail car. This caused an unstable situation. With the limited information available to the yard workers, they could not have known the rail car was not empty — and, from their perspective, could not see the rail car was leaning.

The flagman was responsible for ensuring the work crews and equipment were clear and the train was unobstructed to travel. The uneven load was not apparent to the flagman or other workers in the rail yard. Once the train began to move, the static friction forces no longer restrained the borax car wheels, and the car tipped over. The origin of this event was lack of climate control in the warehouse that resulted in borax clumping to unbalance the load. The cause was the train beginning to move resulting in loss of static friction.

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