Eschede Derailment (June 3rd, 1998, Munich, Germany)

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Abstract

This gray paper is a result of a private research done by the author in order to understand the causes of Eschede Catastrophe.

The research is based on the number of sources including:

- "Eschede train disaster", the episode from "Seconds from Disaster" documentary television programme (2004)

- Wikipedia article "Eschede derailment", English and German versions

- NASA System Failure Case Study - "Derailed" (2007)

- NASA Safety Message - "Eschede Train Disaster" (2007)

- Paper "Case Description: The ICE Train Accident near Eschede" by Michiel Brumsen (2011).

While each of these sources is a good overview by itself, the author believes that learning from all of them yields a more complete picture of the Eschede accident. In particular, the "Eschede train disaster" documentary film contains video simulations, that illustrate step by step what has happened, the level of detail that the other sources are missing.

The text is based on the narration from "Eschede train disaster" film and also contains quotations from Wikipedia pages, "Derailed" NASA System Failure Case Study, "Case Description: The ICE Train Accident near Eschede" paper and some others.

Disclaimer: This paper is only a compilation - it does not add any new information compared to what has been written before. It is not a replacement for all or any of the abovementioned sources. The reader is encouraged to read the official documents when looking for a reliable information.

Contents

Overview

> “The Eschede derailment occurred on 3 June 1998, near the village of Eschede in the Celle district of Lower Saxony, Germany, when a high-speed train derailed and crashed into a road bridge. 101 people were killed and around 100 were injured. It remains the worst rail disaster in the history of the Federal Republic of Germany and the worst high-speed-rail disaster worldwide. The cause was a single fatigue crack in one wheel that, when it failed, caused the train to derail at a set of points and crash into the pillars of a concrete road bridge, causing it to collapse and crush two coaches. The remaining coaches and rear power car crashed into the wreckage.” Wikipedia (2018a)

Facts

- German ICE (Inter-City Express) is one of the fastest trains in the world renowned for its comfort luxury and safety
- ICE has been launched on June 2nd 1991
- 155 miles per hour are routine
- In 7 years of service before 1998 it has never been an accident
- ICE 884, 7 stops, 530 mile journey from Munich to Hamburg, 12 luxury coaches
- Eschede is a village, 40 minutes from Hamburg
- Carried 287 passengers
- Deaths: 101, Injuries: 105

Event log

10:56 AM, five hours into the journey, ICE is approaching Eschede Road Bridge at 125mphs. A huge metal shard creates a gaping hole in the carriage floor of the coach 1 (Figure 1).

Jörg Dittmann, one of the passengers in the coach 1 with his wife and a 6-year child:

> “A shard of metal came slicing through the armrest between my wife and my son.” Documentary film ”Seconds From Disaster” (2004)

Jörg Dittmann takes immediate action: takes his wife and son out of the damaged coach and leaves the damaged coach to alert the train crew to what he has just wittnessed. He finds a train conductor in the 3rd coach.

Conductor tells Jörg Dittmann that according to the company rules he must investigate the incident before he is authorized to activate the emergency brakes.

Jörg Dittmann leads him back to inspect the damage, it takes 1 minute to get there.

10:58, As Jörg Dittmann and the conductor are moving, the train starts to sway. Jörg Dittmann is trying to persuade conductor to stop the train:

> “Even when the train started to sway about he didn’t show any signs of willigness to pull the emergency brake, he just wanted to find what was wrong… we came to the first coach where we had been sitting and I was just about to point to the spot and show him the damage and that’s when it happened…” Documentary film ”Seconds From Disaster” (2004)

10:59, ICE derails and brittles towards the road bridge.

11:05, six minutes after the crash, the news pictures revealed that the double-lane 300 ton road bridge had totally collapsed.

101 die, 105 are injured.

Investigation

> "Remains of a VW Golf Variant, belonging to the two railway workers killed in the crash, were found beneath the debris of the crashed ICE. Media first speculated that the train had derailed after a collision with the car, a circumstance that caused a train to jackknife in the Ufton Nervet rail crash six years later; this theory was quickly dismissed, however, as the front power car did not receive any damage at all, having continued to coast down the track until it passed the next station." Wikipedia (2018a)

Investigators explore the wreck train: damage to the compartment, where Jörg Dittmann was travelling, indicates where the wheel rim unraveled, splitting the floor open and piercing the armrest.

Figure 1: A huge metal shard creates a gaping hole in the carriage floor of the coach 1 ("Seconds from Disaster"). The image to the left is a simulation.

Investigators find that one of the checkrails, a length of steel, is missing. It is been completely torn away from the track. Only a few meters away from the compartment, in the corridor, investigators find the missing checkrail that left gaping wholes in the floor and ceiling.

Figure 2: Broken rail

Figure 3: Checkrail in wagon (“Seconds from Disaster”). The image to the left is a simulation.

Reconstruction

Wheel fracture

“About 130 kilometres (80 mi) and forty minutes away from Hamburg and six kilometres (3.7 mi) south of central Eschede, near Celle, the steel tyre (wheel rim) on a wheel on the third axle of the first car broke, peeled away from the wheel, and punctured the floor of the car, where it remained embedded.” Wikipedia (2018a)

The train traveled over 3 km before derailing.

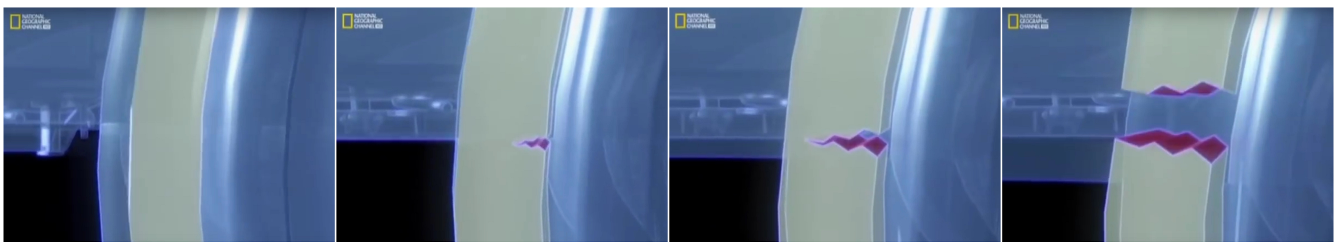

Figure 4: Crack development (“Seconds from Disaster”, simulation)

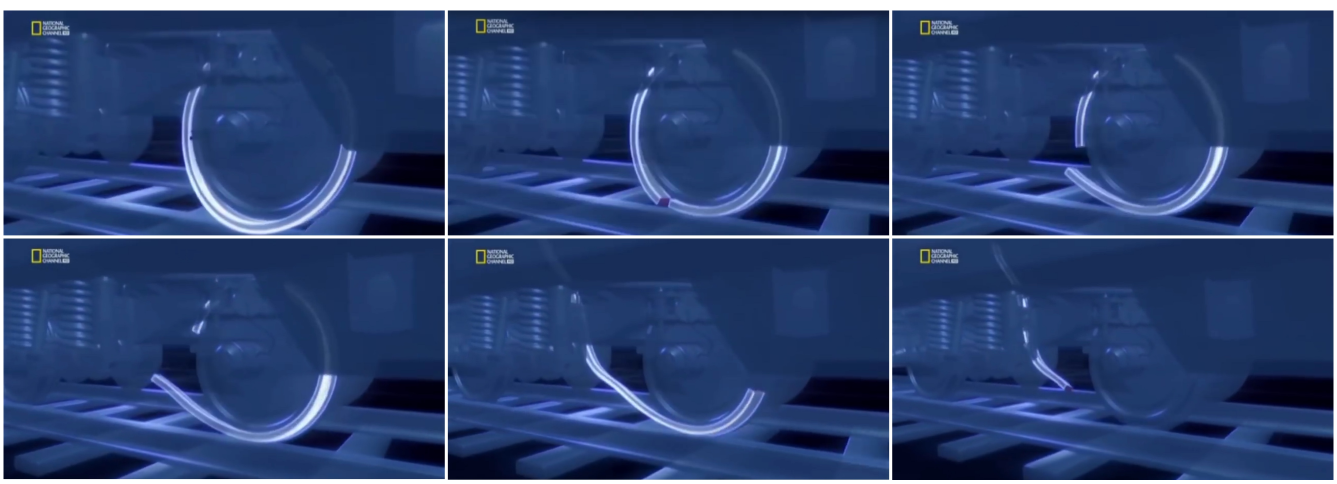

Figure 5: Crack of a wheel rim (“Seconds from Disaster”, simulation)

Checkrail and derailment

ICE traveling at 200kmph with the wheel rim scraping along the track. As the train runs over the first set of points, the end of the rim scoops up the checkrail which smashes through the floor of coach 1. It is this massive impact that causes two of the wheels of the coach 1 to derail. At this point ICE has derailed but this alone is not enough yet to cause the accident.

Figure 6: Crack of a wheel rim (“Seconds from Disaster”, photos)

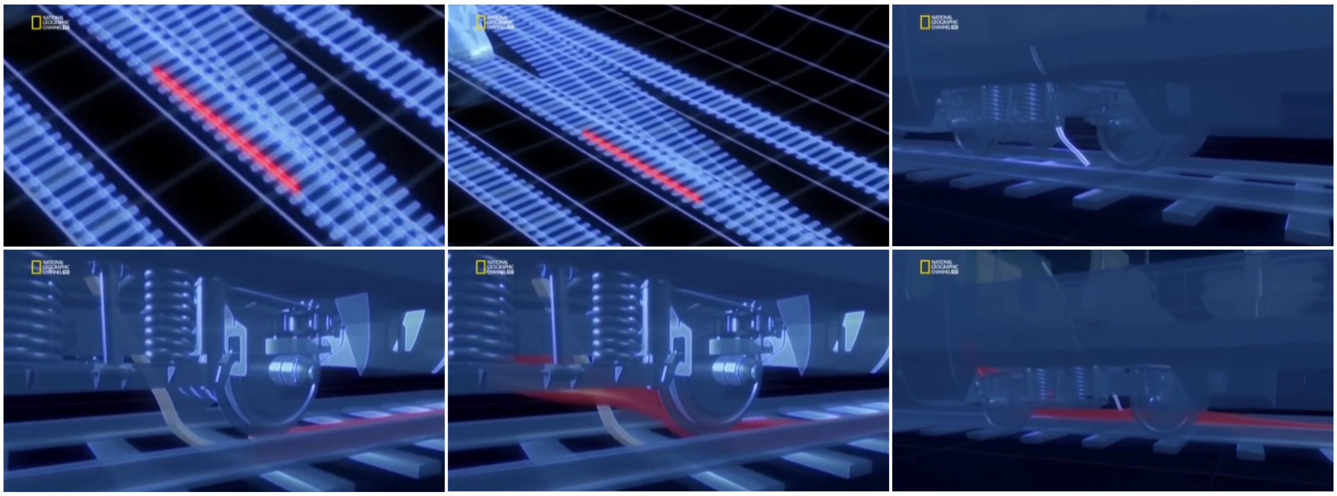

Figure 7: Wheel rim scoops up the checkrail (“Seconds from Disaster”, simulation)

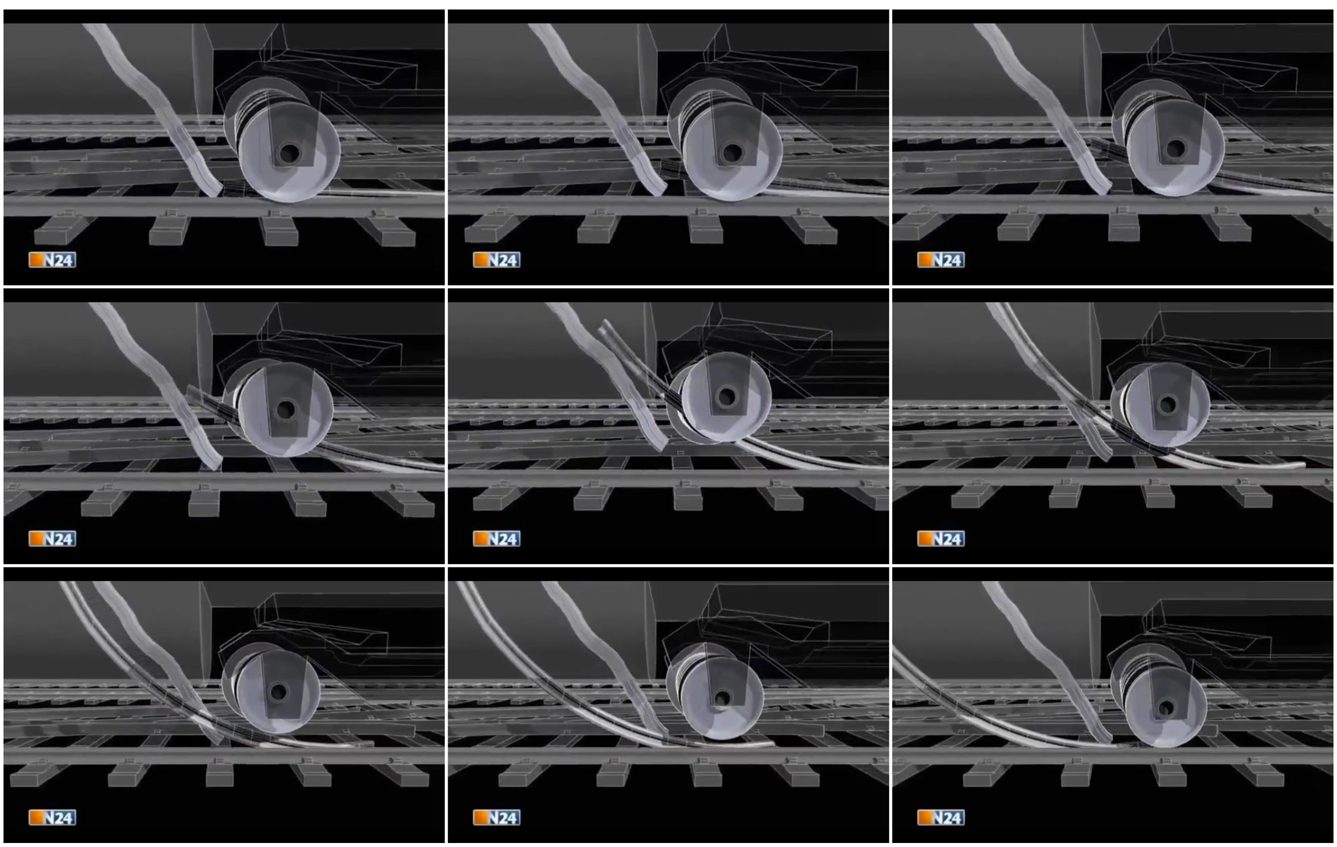

Figure 8: Wheel rim scoops up the checkrail (“Katastrophen und Konstrukte: Züge”, simulation)

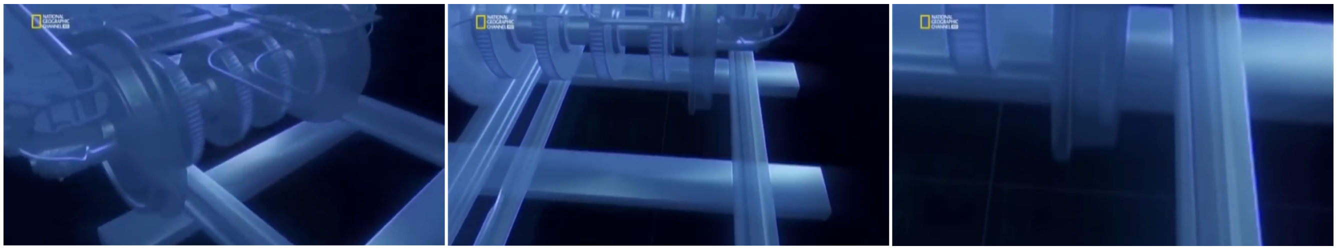

Figure 9: Derailed wheel (“Seconds from Disaster”, simulation)

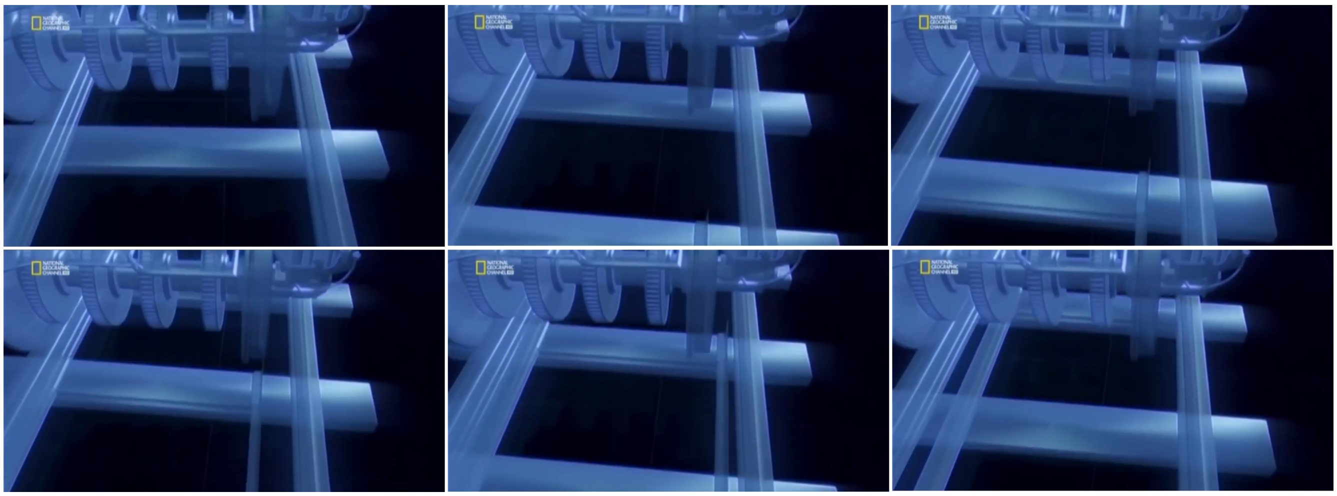

Figure 10: Derailed wheel moves a switch rail (“Seconds from Disaster”, simulation)

Figure 11: Wikipedia - ”Railroad switch”

After passing two set points ICE actually starts traveling on two different sets of tracks: the main line and the branch line. As ICE passes over the second set of points, one of the two derailed wheels of coach 1 smashes into them and forces them to open. This means that the carriages following coach 1 are now guided on to the wrong track: the local branch line rather than the main line. With the front power car still pulling at 200kmph but the coaches behind it slowing as they leave the main line and derail, the connection between the power car and the rest of the train tears apart.

At this point emergency air brakes deploy automatically deploy throughout the train. 1.5 seconds before crash ICE is derailed but essentially undamaged and its emergency brakes could bring the train to a controlled stop but that’s not what happens: the compact nature of the wreckage indicates to investigators that this is a particularly violent accident.

> ”As the train passed over the first of two points, the embedded tyre slammed against the guide rail of the points, pulling it from the railway ties. This guide rail also penetrated the floor of the car, becoming embedded in the vehicle and lifting the axle carriage off the rails. At 10:59 local time (08:59 UTC), one of the now-derailed wheels struck the points lever of the second switch, changing its setting. The rear axles of car number 3 were switched onto a parallel track, and the entire car was thereby thrown into the piers supporting a 300-tonne (300-long-ton; 330-short-ton) roadway overpass, destroying them. Wikipedia (2018a)

Bridge collapse

The bridge is supported by concrete pillars which stand about two meters from the tracks. The power car and coaches one and two pass under the bridge without touching it. But coach 3 is pushed outwards by the momentum of the train and slams directly into the pillars: ICE crashes into the Eschede road bridge.

> “The third card was diverted over to the siding and swung out to the right and at that time struct the supports for the bridge and knocked the supports out from under the bridge.” Documentary film ”Seconds From Disaster” (2004)

> “Car number 4, likewise derailed by the violent deviation of car number 3 and still travelling at 200 kilometres per hour (125 mph), passed intact under the bridge and rolled onto the embankment immediately behind it, striking several trees before coming to a stop. Two Deutsche Bahn railway workers who had been working near the bridge were killed instantly when the derailed car crushed them. The breaking of the car couplings caused the automatic emergency brakes to engage and the mostly undamaged first three cars came to a stop.” Wikipedia (2018a)

When coach 3 destroys the pillars, the bridge starts to collapse. Couch 4 clears the falling bridge but catapults off the track and crashes into nearby trees. As coach 5 passes under the collapsing bridge, it is struck by tons of falling concrete and the rear half is totally destroyed.

> “The rear axles of the third coach were switched onto a parallel track, twisting the coach perpendicular to the rails, and sending the car careening into the pylons of a 300 metric ton roadway overpass just beyond the second switch. Coach four, derailed by the violent deviation of car three, traveled underneath the bridge impacting an embankment, and killing three railway employees who were working nearby.” NASA System Failure Case Studies (2007)

The restaurant coach is crushed to a height of 15 centimeters by the falling bridge. The resulting debris now blocks the path of the remaining six coaches and the rear power coach which are moving in almost 200kmph concertina into the rage (Figure 12).

> “Coach five passed under the weakened bridge as it collapsed, crushing the car completely. The remaining coaches, including the service car, restaurant car, three first-class cars, and the rear locomotive, jackknifed into the collapsed bridge in a zigzag pattern.” NASA System Failure Case Studies (2007)

Rescue efforts

> “By 11:07 AM, only 37 minutes after the WCR left Hanover Station, the police declared a “major emergency” and dispatched rescue teams. Over 1,000 rescue workers descended on the accident site. Despite their efforts, 101 people lost their lives and 88 more were seriously injured in the mishap. The derailment at Eschede was Germany’s worst train accident since World War II.
>
> During the rescue effort, emergency workers found it difficult to remove victims from the wreckage because of pressure resistant windows and the railcar’s rigid aluminum frames. The Deutsche Bahn replaced these windows with a new design that included predetermined breaking points to allow for easier access to trapped passengers.” NASA System Failure Case Studies (2007)

Simulation: Derailment and Bridge Crash (Seconds From Disaster, 2004)

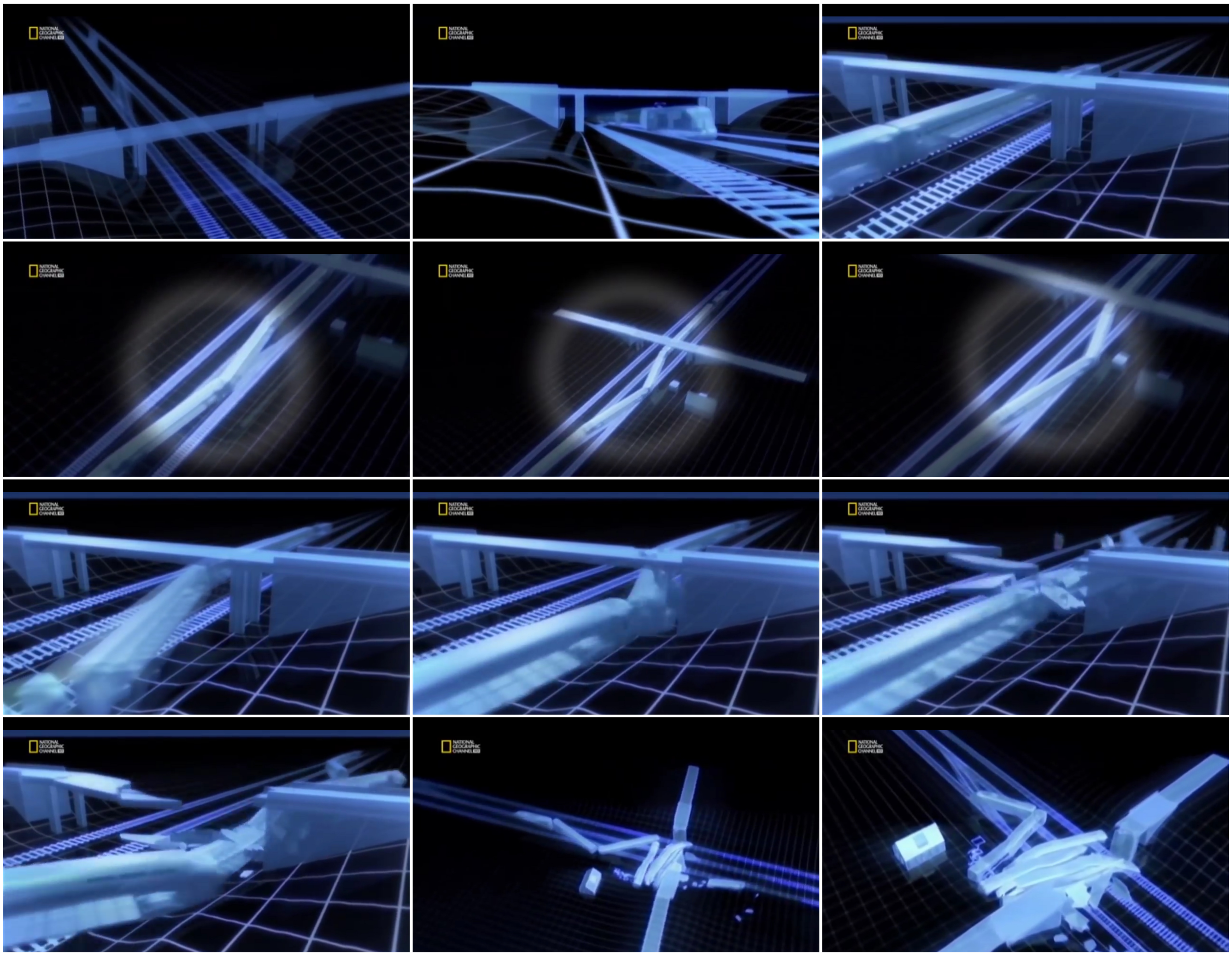

Figure 12: Derailment and bridge crash ("Seconds from Disaster", simulation)

Root cause: broken wheel rim

Historical background

The wheels from this ICE had a “new design”. On the 2nd of June 1991, the ICE project is launched. One of the aims of the cutting edge project is to reach a new standard in luxury and ride quality for its passengers. The train has steel solid wheels known as monoblock wheels but Deutsche Bahn, the company that runs the ICE soon experiences problems with them:

> “Shortly after the trains went into service they found that they had a technical problem: the wheels were wearing in a strange pattern. When this happened, especially when the trains were traveling at high speed, noise and vibration would be generated and transmitted up into the passenger car.” Documentary film ”Seconds From Disaster” (2004)

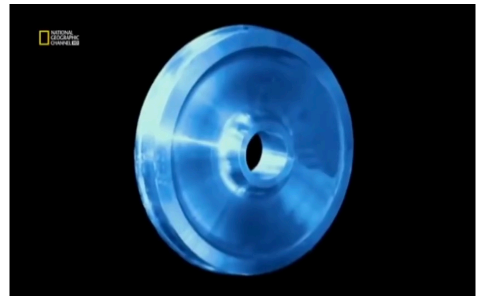

Figure 13: Monoblock wheel

The carriage where this was the most evident was the restaurant car where the plates were shaking and the glasses were spilling.

The problem of vibrations and noise seriously affected the ICE’s reputation for comfort. Within two months of the ICE’s prestigious launch, under pressure to find a solution, Deutsche Bahn decided to replace its original monoblock wheels with duoblock wheels.

Duoblock wheel

Tranditional monoblock or one-piece wheel is made from a single solid piece of steel but a duoblock or two-piece wheel has an inner wheel surrounded by an outer rim. Sandwiched between are sections of rubber designed to help absorb vibrations and provide a smoother ride. On the 31st of August 1992 Deutsche Bahn approves the duoblocked wheel type 064 for use on its ICE trains. The new wheel instantly improves the ride and cups and sauces no longer shake and rattle in the dining car.

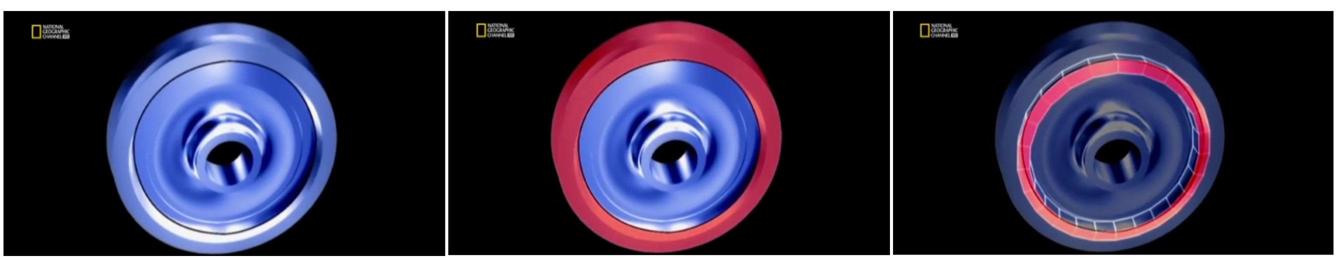

Figure 14: Duoblock wheel

Metal fatigue

The wheel rim fractured thorough a metal fatigue. Fatigue occurs when a movement is repeated over and over again causing a stress break at a weak point in the metal. A wheel on a train actually flexes slightly as it turns because of the massive load it’s under supporting the moving train. These movements are miniscule but the constant flexing of the metal can eventually, given enough usage, cause the wheels destruction through metal fatigue. With a duoblock wheel there is a layer of rubber between the wheel and the rim. The soft rubber allows the outer rim to flex much more than on a monoblock wheel. As the separate rim wears down through use the flexing increases. Without a thorough inspection the wheel rim can become too thin and a small defect can become a crack that eventually fractures causing the outer rim to break away from the inner wheel with devastating results. Metal fatigue fractures in train wheels usually develop over the period of months or years.

Inadequate testing of the wheels by Deutsche Bahn

After the accident, the rim from the wheel in question is taken to the The Fraunhofer Institute for Structural Durability and System Reliability (LBF) in Darmstadt, Germany for forensic testing.

> ”We studied press releases from the District Attorney’s office (Staatsanwaltschaft Lüneburg) and the Deutsche Bahn AG, both of which contained comments and expert testimonies. The Fraunhofer Institute LBF Darmstadt (sister of the FHG-IZfP, Fraunhofer’s NDT Institute Saarbrücken) presented 300 pages of expert testimony and another 300 pages of literature references.
>
> A cracking inside the ring of the wheel was responsible. There was no indication of material or production failure. This crack was caused by excessive load and wear. When ICE began operations, there was no certification in place that would document appropriate design and reliability. Moreover no fracture mechanic calculation was done that could prove the strength of the wheel during its lifetime. According to the experts such wheels should not be operated at less than 880 mm diameter (new condition = 920 mm), subject to annual testing for inner and middle zone cracks. (An important NDT fact!) The diameter of the accident wheel was 862 mm. The limit set by Deutsche Bahn is 854 mm.
>
> We interviewed District Attorney Jürgen Wigger, who explained that the wheel in question was first put into operation in 1994 and ran 1,8 Mill km until the accident in June 1998. In terms of assessing responsibility for the accident, it is significant that during its 4 years of operation, the wheel was never tested.” Web’s Largest Portal of Nondestructive Testing (NDT) (2000)
>
> “Findings released by the Fraunhofer Institute suggest that poor design and insufficient testing were to blame for the accident. The rubber cushioned wheels, which had been used successfully on streetcars, were not suitable for the heavier load of ICE trains operating at much higher speeds. At the time, Germany did not have the facilities to adequately test such designs, so many of the wheel design decisions were based on analysis and theory rather than test data. The limited testing that was done did not account for the dynamic, repetitive forces that result from extended wear, extreme loads, and high speed operation.” NASA System Failure Case Studies (2007)

The answer given to the investigation team by Deutsche Bahn: instead of relying on a special metal fatigue detection equipment it turns out that the engineers at Deutsche Bahn’s Munich maintenance facility had been carrying out safety checks on ICE’s wheels with “nothing more advanced than a flashlight”.

Figure 15: Fraunhofer Institut

> “The use of torches will only pick out the largest and most dangerous of cracks. It won’t pick out tiny fatigue cracks at an early stage of their life. In terms of detecting potential cracks on the inner side of the rim of a dual block wheel is completely useless technique.” Documentary film ”Seconds From Disaster” (2004)

The engineers at Deutsche Bahn’s Munich Depot had also been carrying out some tests with their high-tech testing machines but the data was considered unreliable as the equipment constantly came up with the error messages (“false positives”).

> The workshop where the inspection was done was equipped with ultrasonic equipment to check the wheels for cracks. There, the train rode through a measurement setup at 6 km/h. In principle, this equipment permitted discovery of cracks not visible to the eye because a surface fracture would reflect sound. However, this equipment was unsound for two reasons. First, it could only detect cracks in the tread. It could not detect cracks arising from within, a distinct pos- sibility certainly given the second mechanism explained above. Worse was that the equipment was so sensitive that in addition to raising an alarm when it found cracks, it also did this for innocuous surface irregularities. That resulted in nearly 20% of the tested wheels falling in the “needs replacing” category. That was impossible given the time pressure in the workshop. That is why the wheels were tested the old-fashioned way: by eye (with a lamp) and ear. This last method consisted in hitting the wheel with a hammer and assessing the sound of the wheel. However, it is unlikely that this method, often used on block-cast wheels, was suitable for this type. The rubber ring against which it is pressed muffles the vibrations in the steel tire. One obvious conclusion is that no suitable testing equipment was present.

In the week leading up to the Eschede train crash the wheel that would have become the cause of the accident was highlighted as being defective in three separate automated checks.

Flawed problem reporting process

The maintenance reports from the crashed train's onboard computer contained reports of two months before the crash: the conductors and other train staff large as many as eight separate complaints about the unusual noise and vibration coming from the bogie that carries the defective wheel. Deutsche Bahn didn't replace the wheel.

Figure 16: Metal fatigue

Monoblock wheels have been in use for 40 years but Deutsche Bahn's duoblock wheel is of a new design and has never been used on a high-speed train before. In fact, the duoblock wheels are traditionally found on one of the slowest moving forms of rail transport: the tram. In July 1997 almost a year before the Eschede train crash the company that runs the tram network in the German city of Hannover discovers dangerous metal fatigue cracks occuring in its duoblock wheels, even though they are running at speeds of only 24 kmph. They decide to change the duoblock wheels well more often before metal fatigue has a chance to develop. The train company contracts the other rail operators running on the duoblock wheels to inform them of the metal fatigue problem and it's simple solution. In Autumn 1997 only months before the accident they notified Deutsche Bahn. According to the tram company, Deutsche Bahn said they haven't experienced any problems with metal fatigue.

> ”It was revealed later that the institute had told the DB management as early as 1992 about its concerns about possible wheel-tyre failure.
>
> It was soon apparent that dynamic repetitive forces had not been accounted for in the statistical failure modelling done during the design phase, and the resulting design lacked an adequate margin of safety. The following factors, overlooked during design, were noted:
>
> 1. The tyres were flattened into an ellipse as the wheel turned through each revolution (approximately 500,000 times during a typical day in service on an ICE train), with corresponding fatigue effects.
> 2. In contrast to the monobloc wheel design, cracks could also form on the inside of the tyre.
> 3. As the tyre became thinner due to wear, the dynamic forces were exaggerated, resulting in crack growth.
> 4. Flat spots and ridges or swells in the tyre dramatically increased the dynamic forces on the assembly and greatly accelerated wear.” (Wikipedia 2018a; Documentary film ”Seconds From Disaster” 2004)

Other contributing factors

Emergency brake visibility

Dittmann could not find an emergency brake in the corridor and had not noticed that there was an emergency brake handle in his own compartment. Documentary film ”Eschede Zug 884” (2008)

The track's design

> ”In many other countries where high-speed trains are used – France for instance – these run on specially built tracks. This has several advantages: The faster the train's speed, the straighter, flatter and more stable the track has to be. Older tracks often do not satisfy these requirements. Moreover, fewer switches and crossings are needed because tracks are seldom if ever shared with other lines. Tunnels are often placed at road crossings.
>
> The tracks for ICE trains were, and are, mixed. The ICE trains ride over normal tracks shared with other types of trains as well as on special high-speed tracks. The route near Eschede was not a special high-speed track; there were four track lines. The ICE trains rode on the innermost two tracks. However, other trains also used these tracks; that is why it was necessary to be able to move trains from the

> innermost to the outermost tracks and back. This track design played a large role in the accident near Eschede. The switch whose frog the broken steal tyre tore off and where the wheel derailed lay just 300 meter before the viaduct. The switch that the derailed wheel turned lay only 120 meter before the viaduct. It should be clear that if there had been no switches to the adjacent track, the accident would not have taken on the grave proportions that it did. On 21 December 1993, a TGV train on France's Paris-Lille line derailed at 300 km/h. Only two people received slight injuries. The train did run off the track, but nothing much else happened even though the train jolted on a few kilometres alongside the rails before it came to a halt. A similar accident with the TGV occurred in 2001, again without fatalities and just a few wounded. Comparisons between this and the accident at Eschede regularly point to the more rigid couplings between the carriages that we mentioned above." Michiel Brumsen (2011)

Legal

Figure 17: Manual inspection with flashlights ("Seconds from Disaster")

Investigators started to question the inspection procedure for the duoblock wheel type 064. On August 8th, 2002 a trial begins against three engineers accused of a negligent homicide: two engineers from Deutsche Bahn and an employee from the wheel manufacturer BVV. The engineers' defense was that they had followed the technical standards of the time and that the fracture in the wheel could not have been predicted. Deutsche Bahn is not in the dock itself because in Germany only people can be tried not companies. After eight months the trial ends in controversy: no one was found guilty. In German law, when there is no substantial guilt a trial may be concluded with no guilty verdict and a fine can be paid as a compromise and that's what happens in the case of Eschede train crash. The prosecution and defense agree to a compromise: no one is found guilty of a negligent homicide but the Court fines the three engineers ten thousand euros each. Families of the victims and the survivors of the accident are furious: the court's decision makes their fight for the compensation much harder.

Soon after the accident, Deutsche Bahn did make initial good-will payments to the families who had lost loved ones in the accident. The amount of 30000 deutsche marks for each person killed. This offer was met by some with anger and derision. Deutsche Bahn later settled financially with many victims.

Aftermath

Today Deutsche Bahn has removed the duoblock wheel type 064 from service and replaced them with traditional monoblock wheels. They maintain that the wheels and the inspections met the standards required at the time and that their engineers could not have predicted a wheel fracture.

The original problem of vibration has been solved on a different level:

> "Also, the [ICE2] train has been equipped with air suspension to circumvent the wheel noise problems of the ICE 1, which led to the installation of rubber-buffered wheel rims on the ICE 1 units and therefore the Eschede train disaster." Wikipedia (2018b)

As of November 2002, Deutsche Bahn claims to have paid more than 30 million euros in compensation to the victim families and survivors of the crash.

Summary

The summary by “Failure Knowledge Database / 100 Selected Cases: InterCity Express Accident”:

> “The wheel-tire design was originally developed for streetcars traveling at significantly lower speeds. Its relatively simple structure had been employed successfully in streetcars, eliminating resonance and vibration at cruising speed. The wheel-tire design had neither been tested nor been in service at high speed. The accident may have simply exposed the characteristics of rubber; its relatively inferior wear and abrasion resistant properties.”

NASA System Failure Case Studies - “Derailed” (2007):

Proximate Cause

- Wheel Rim Delaminating
- Failure to stop the train immediately after wheel delaminating

Contributing Cause

- Flawed Emergency Operating Procedures

Underlying Issues

- Insufficient testing under operational condition
- Ineffective maintenance requirements
- Poorly designed overpass collapse

Illustrations

Figure 18: “The front power car and coaches one and two cleared the bridge. Coach three hit the bridge, which began to collapse. Coach four cleared the bridge, moved away from the track, and hit a group of trees. The bridge pieces crushed the rear half of coach five. The restaurant coach, six, was crushed to a 15-centimetre (6 in) height. With the track now obstructed completely by the collapsed bridge, the remaining cars jackknifed into the rubble in a zig-zag pattern: cars 7, the service car, the restaurant car, the three first-class cars numbered 10 to 12, and the rear power car all derailed and slammed into the pile. The resulting mess was likened to a partially collapsed folding ruler. An automobile was also found in the wreckage. It belonged to the two railway technicians and was probably parked on the bridge before the accident.”

Figure 19: Eschede catastrophe

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