Session: 30. Damage Assessment on Bridges

Dynamics and causes of the collapse of the Morandi viaduct in Genoa

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Abstract

The mistaken conjectures formulated for the collapse of the Morandi viaduct in Genoa may have been formulated in the sudden search for a scapegoat or, perhaps more painfully, for economic and political reasons: but the data collected, the studies carried out, the elements reported in my analysis do not prove the structural collapse as the cause of the fall of the viaduct on Polcevera. The collapse was tragic and perhaps could have been avoided: the road managers, with a high-level weather warning system and an electric storm warning in extraordinary circumstances, should have put in place all the security procedures. The study presented here, with precise photographs and analyzes, explains how the impacts of climate change with the inability to predict risk have led to the collapse of the viaduct

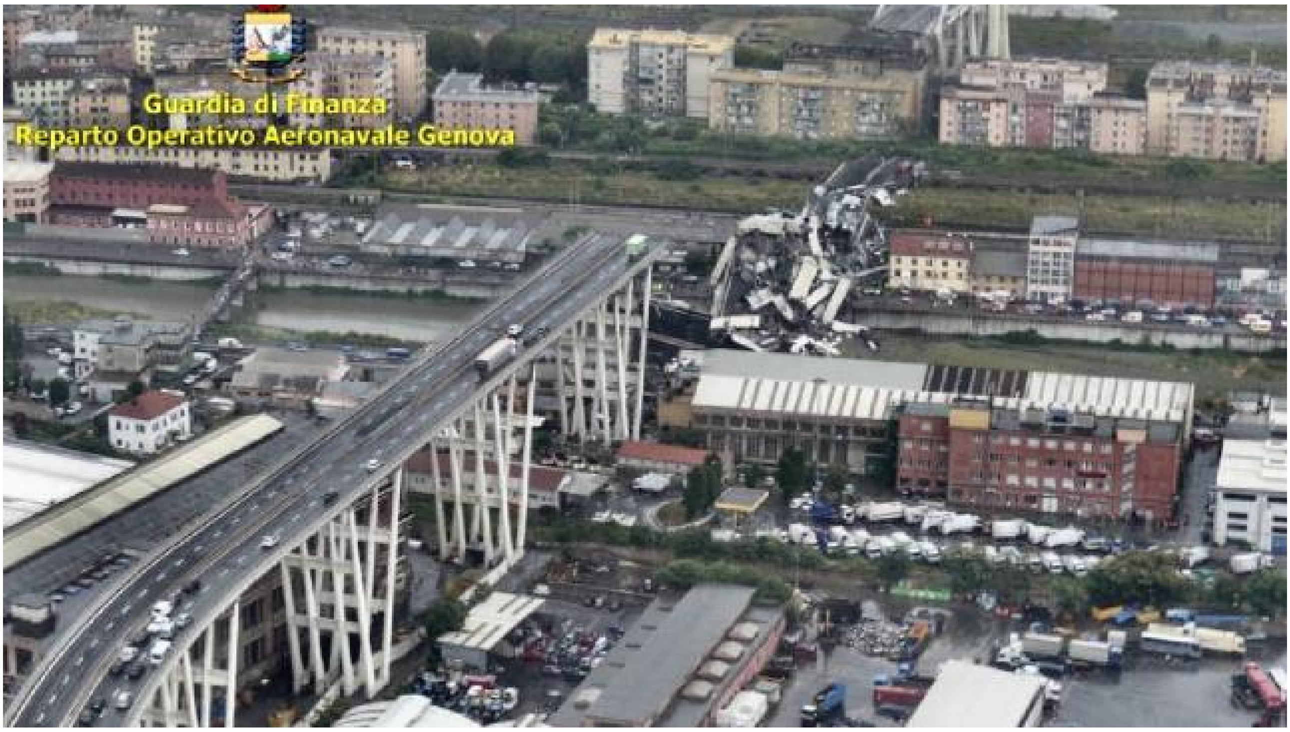

Figure 1 The collapse of the Morandi viaduct in Genoa on the photo taken by the Guardia di Finanza helicopter

1. Description of the bridge status

Polcevera viaduct has been continuously investigated and consolidated over the years.
The Morandi Bridge over the '90s has a state of damage due to chemical and physical attacks on materials [1]. Around tie-rods were found symptoms of superficial degradation (strongly carbonated concrete, local cracks). In 1992, a detailed inspection have shown damage state characterized by continuity solutions localized near the suspension tower as well as by a high level of oxidation of the internal cables, with numerous sheared strands and / or significant section reductions. For this reason the towers 9 and 10 have had structural retrofitting interventions [Note 1]. Torsion nodes were also observed on the ties of the pylon n.9 due to the different constraint conditions between the prestressed concrete around tie-rods and the prestressed concrete deck. [Note 2].
This is why many engineers have cited the viscosity of concrete which has resulted in a non-horizontal carriageway pavement.

Already in the early 80's, those who crossed the viaduct were forced to make ups and downs because of the displacement of the deck structures, problems not foreseen during the design phase.
Repeated corrections of the asphalt leveling course have reported the road plan to acceptable semi-horizontal conditions.
Also in 2018, work was underway to reinforce the prestressed concrete deck and plans were made to modernize the tie rods. The lack of horizontality is indicative of a progressive extension of the tie rods. Each tie rod consists of 352 ½ "diameter strands while the main girder is devoid of longitudinal reinforcement except for the cantilever ends and the areas close to the intermediate supports [Note 3].

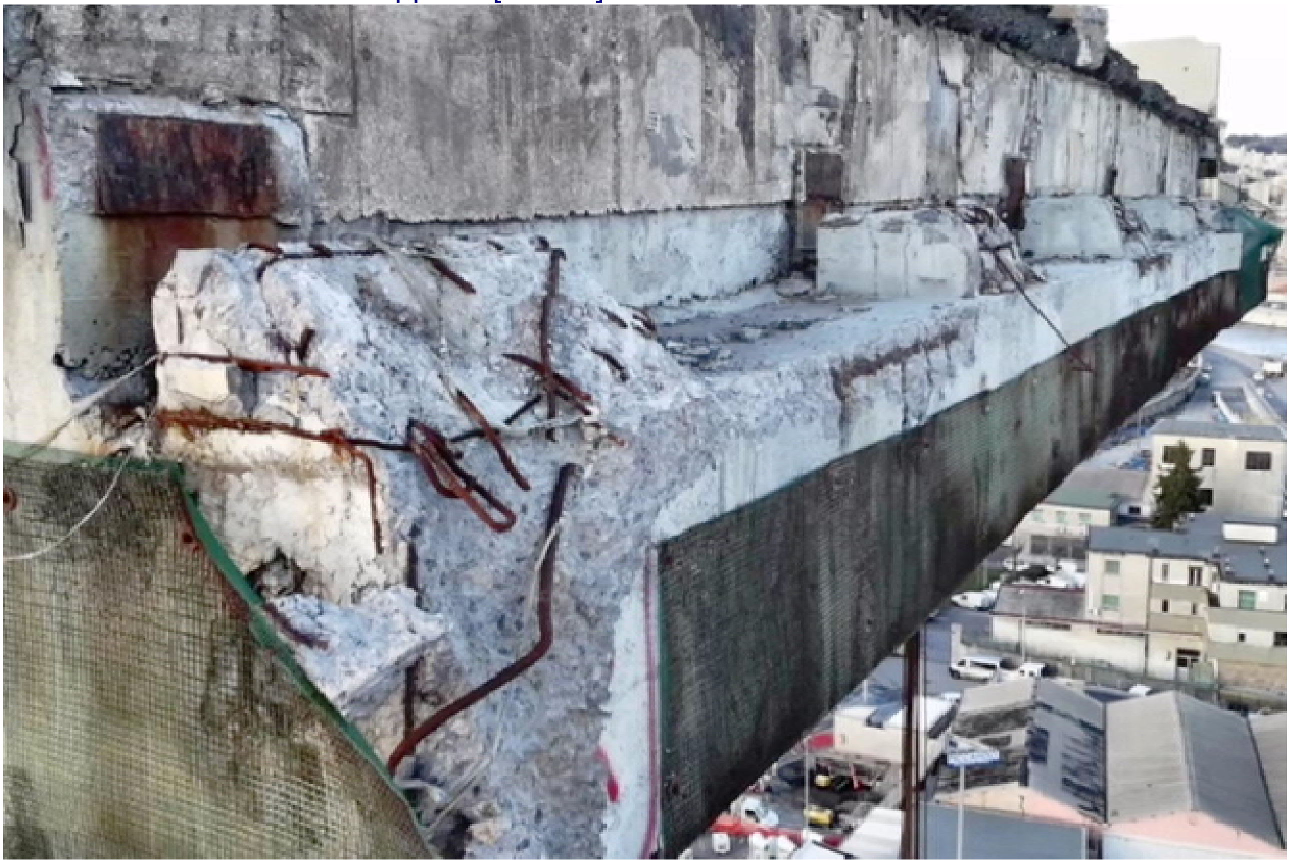

Figure 2 Detachment of the concrete cover, carbonation and oxidation of the reinforcements

Already in 1994 two tie rods of the pile 9 had a modal deformation that did not conform to expectations.
The prestressed concrete tie rods protected the steel of the strands from corrosion (marine environment subject to attack by chlorides). About the tie rods repair the following tests were made:
- on the concrete: ultrasounds; pull-out; Windsor; crushing of carrots; strength investigations; determination of the thickness of the concrete affected by carbonation
- on the steel : laboratory tests made on samples of bars and strands

The viaduct has undergone continuous verification and monitoring activities, which continued even after 1994; periodic inspections and diagnostic investigations made it possible to keep under control the whole viaduct as a whole (tie rods, caissons, slabs, beams, supports, pylons)
- Reflectometric surveillance of the tie rods prestressing cables
- Diagnostic investigations on the stack ties 9 and 10
- Dynamic characterization of balanced systems 9 and 10
- Diagnostic investigations on the external board reinforced and prestressed concrete beams

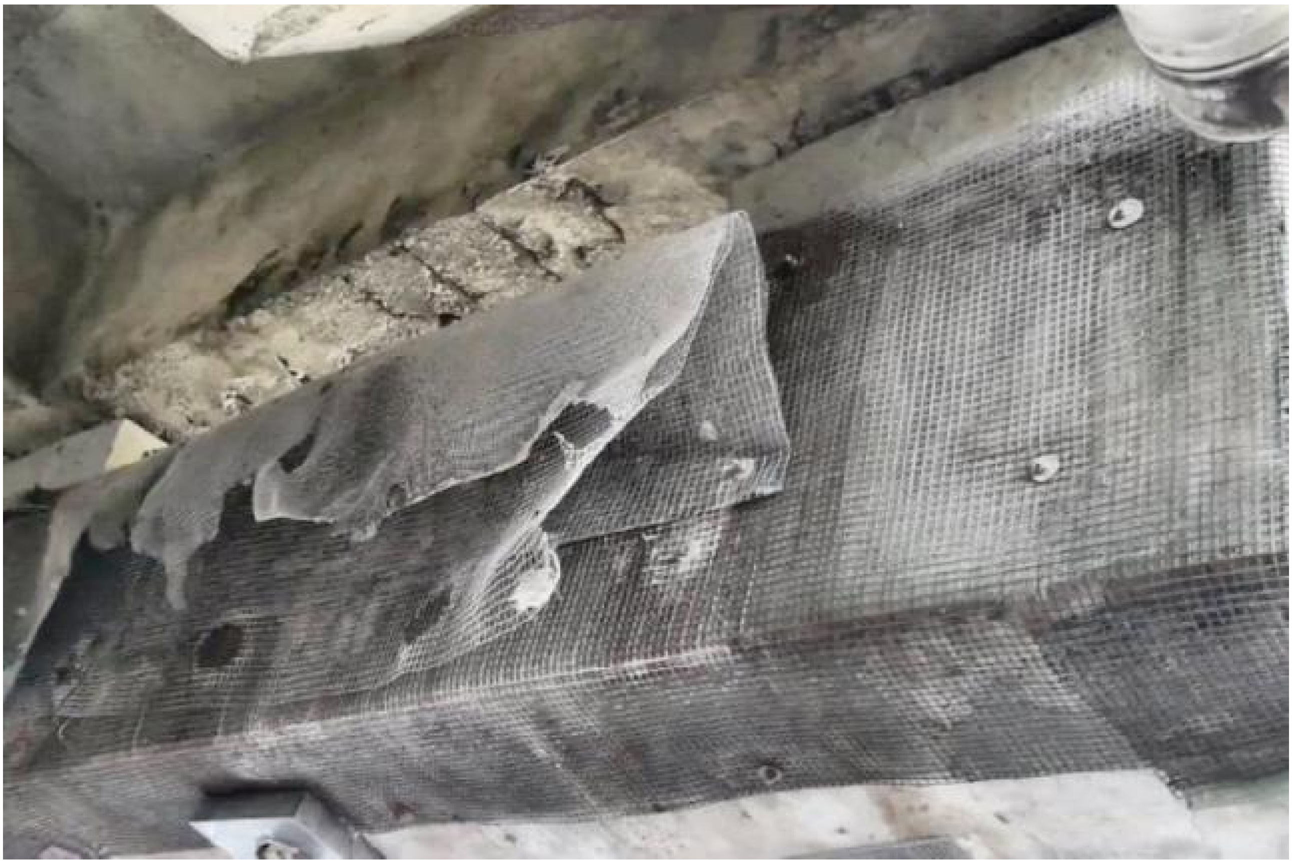

Figure 3 Networks were placed to avoid material losses

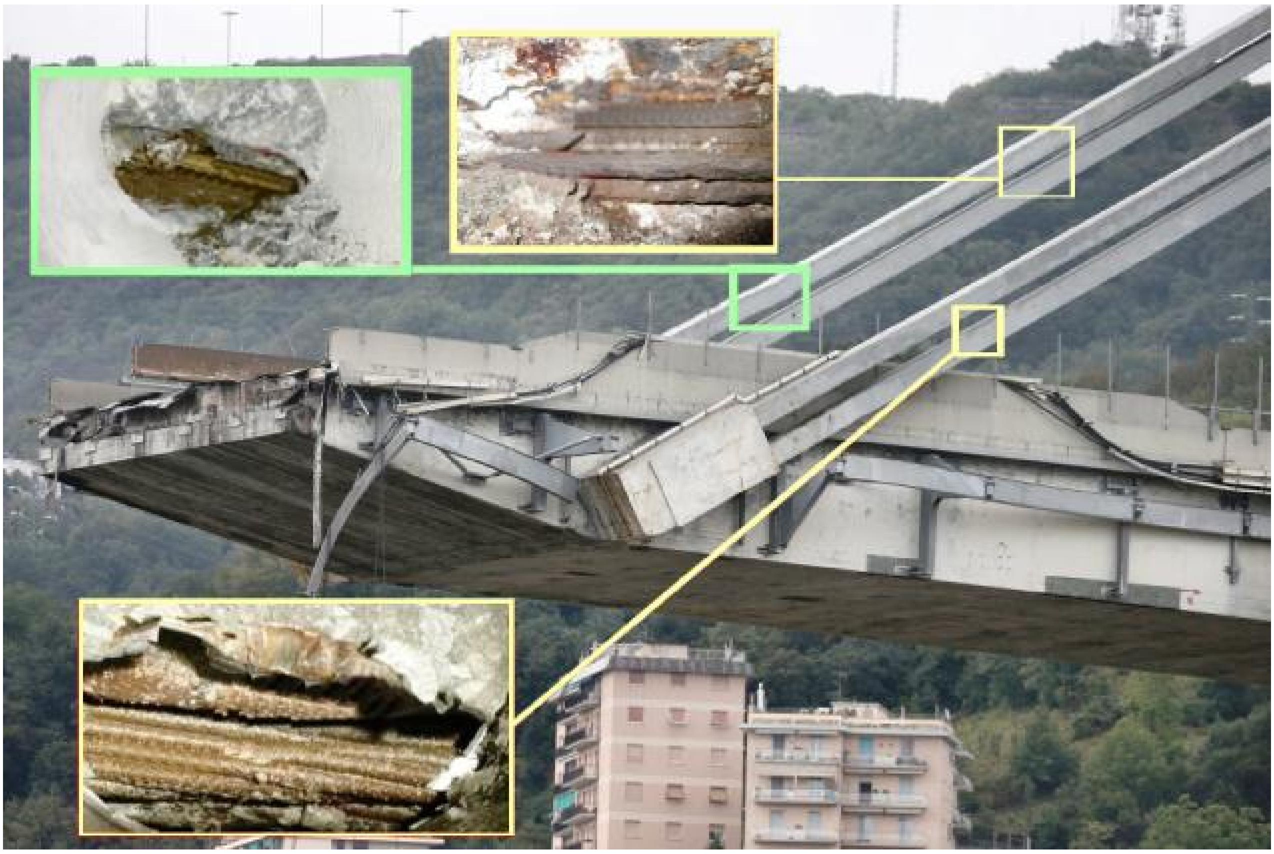

Figure 4 [Source Spea Engineering - January 2016] Diagnostic investigations on the stays of stack 9 and stack 10. The carrot carried out shows oxidation in the strands, corrosion and breakage of prestressing cables. The protective sheath is oxidized inside. Corrosion of the internal tie rods in the stay of the pile 10. The carrot investigates only secondary armor [Note 3].

- Diagnostic investigations on prestressed concrete beams
- Reflectometric measurements on prestressing rods

The state of conservation of the tie rods antennas 9 and 10 was acceptable; however, the results of the reflectometric tests showed a slow trend of degradation of the cables constituting the tie rods (reduction of total cable area from 10% to 20%)

There was been material leakage during the period 2011-2016, perhaps as a result of the October 4, 2010 flood. But the Morandi viaduct is not on the list of urgent interventions. Consequences: detachment of the concrete cover, carbonation and oxidation of the reinforcements. Networks were placed to avoid material losses.

Figure 5 Firefighters and many engineers have immediately found traces of explosion

2. Accident description

On 14 August 2018 at around 11:36 local time (09:36 UTC), during a torrential rainstorm, a 257-metre (843 feet) section of Ponte Morandi collapsed. Eyewitnesses reported that the bridge was hit by lightning before it collapsed. The exact number of vehicles involved has not yet been ascertained: certainly 35 cars and 4 trucks have been declared fallen from the bridge.

The collapse of the Morandi viaduct is not caused by structural failure: the elements collected and which are presented here as in a classic probative incident do not prove the structural collapse as the first cause of the collapse of the viaduct. Firefighters and many engineers have immediately found traces of explosion.

The images on August 14, 2018 were very clear. Firefighters run on a surface covered with gravel and small rubble in the whole area of the Polcevera viaduct, Cornigliano side.

In this area the i have also collapsed roofs of some warehouses under the Morandi Viaduct, where it remained above blocked the green truck.

These are evidence of an explosion: the ruins are completely different from those found in cases of structural collapse. Two distinct collapses that have happened in a few minutes.

The first collapse was on the Cornigliano side, a collapse that also caused damage to the underlying sheds. The second collapse was determined by the number 9 pile that yielded as it was no longer counterbalanced

Figure 6 Firefighters run on a surface covered with gravel and small rubble in the whole area of the Polcevera viaduct, Cornigliano side

3. Causes

The webcam of “Autostrade per l'Italia” (the largest operator of toll roads in Italy) clarify the dynamics of the viaduct Morandi collapse.
From the integral video [Note 4] we know how fast the vehicles were going and therefore where they were at the time of the disaster. A white tanker is in transit on the motorway section, it is direct south. It is followed by a green truck.
In the video at 00:55 - a yellow truck uses about 35 to 40 seconds to enter the bridge section that subsequently collapsed. As can be seen from the webcam images this truck is near battery 9 after 50 seconds. The white tanker truck [Figure 7, Vehicle A] transits at 2:11 minutes - at 3:00 minutes, it is on the roadway then collapsed.
In fact, at 2:28, the tank trailer has just passed the curve - and at the minute 2:36 is exactly in the position where the green truck will lock up.

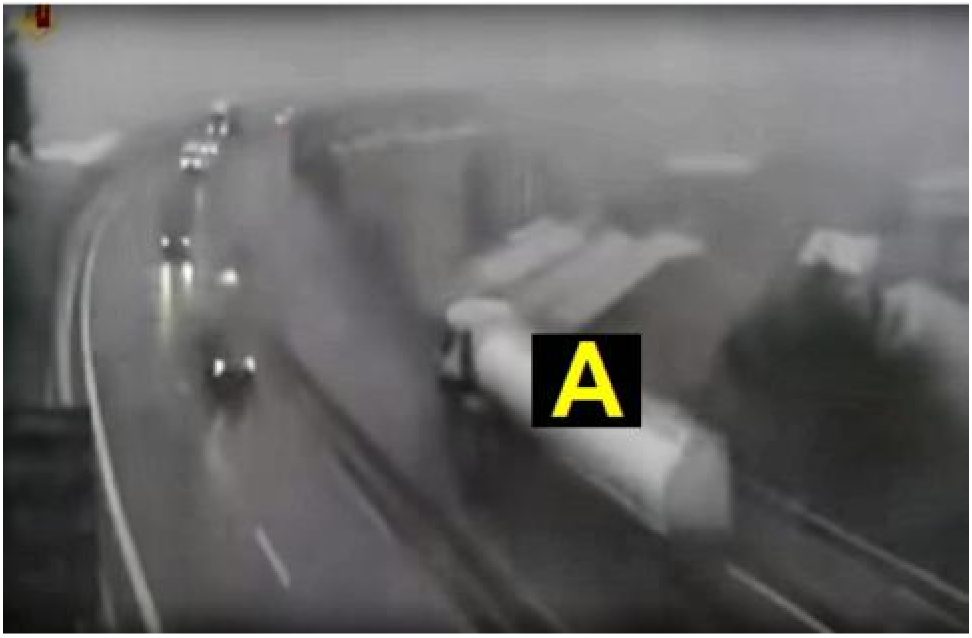

Figure 7 A white tanker is in transit on the motorway section, it is direct south.

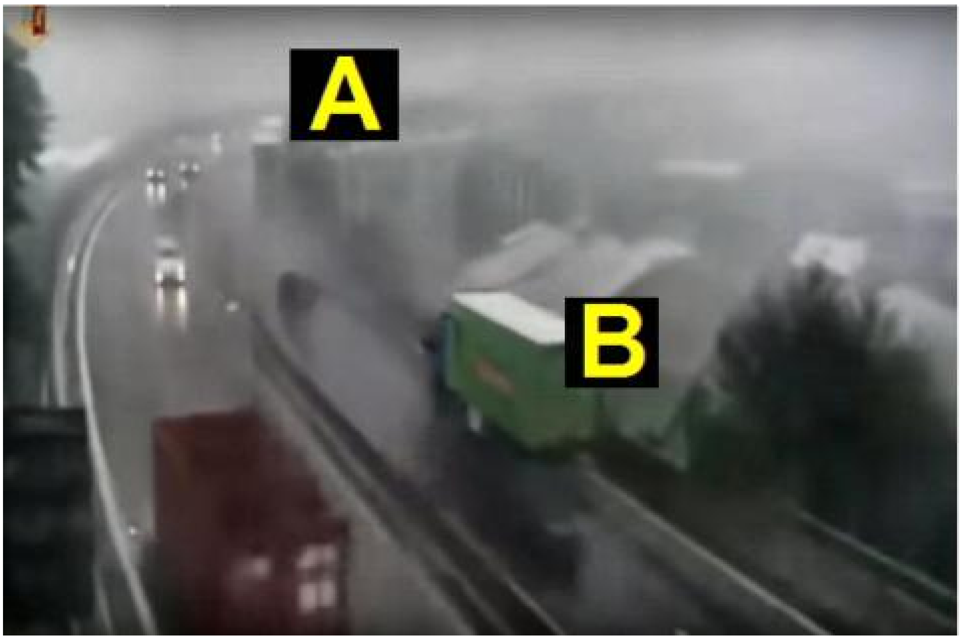

Figure 8 The green truck is in transit on the motorway section, it is direct south.

At 2:37 minutes the Alba red truck passes - preceded by the truck with metallic spool - total weight 44 tons: both will fall under the Polcevera viaduct.
The traffic along the roadway which immediately collapsed is very slow and advances at a lower speed than that used in the curve of the first section of the viaduct.
The explosion is visible at 3:41.
The green truck passes at 3:10 - it stays a few meters from the collapsed section.
And in the webcam [Note 5] under the pylon 9 you see a sudden glow.
Immediately after the bridge deck is translated and then collapses.

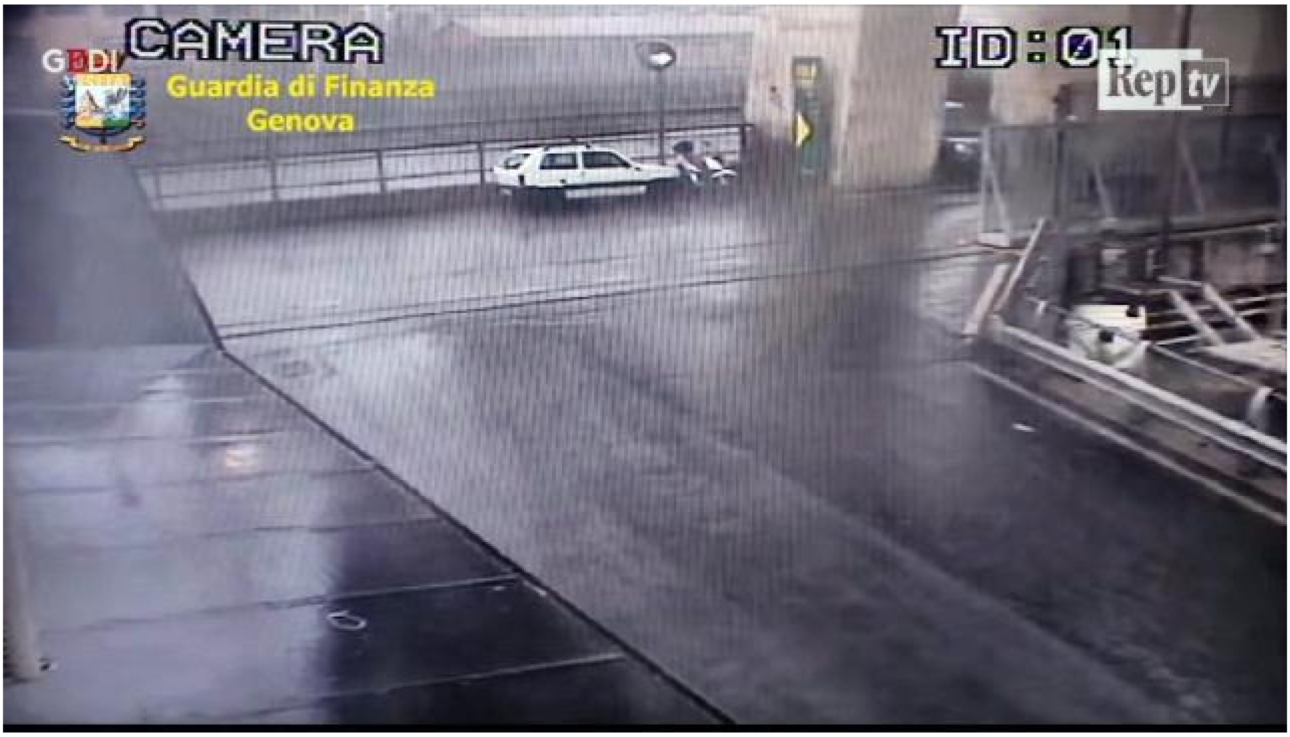

Figure 10 In the webcam under pylon 9, you see a sudden glow: at the top, the reflection of the viaduct on the wet roof. This is a relevant image that helps to determine the speed at which the bridge collapses and the provenance of the debris. This image explains the early phases of the collapse

4. Available evidence

This white truck tank is the key to solving the collapse of the Polcevera viaduct. By observing the images is clearly visible the tractor of the tank between the debris of the bridge.

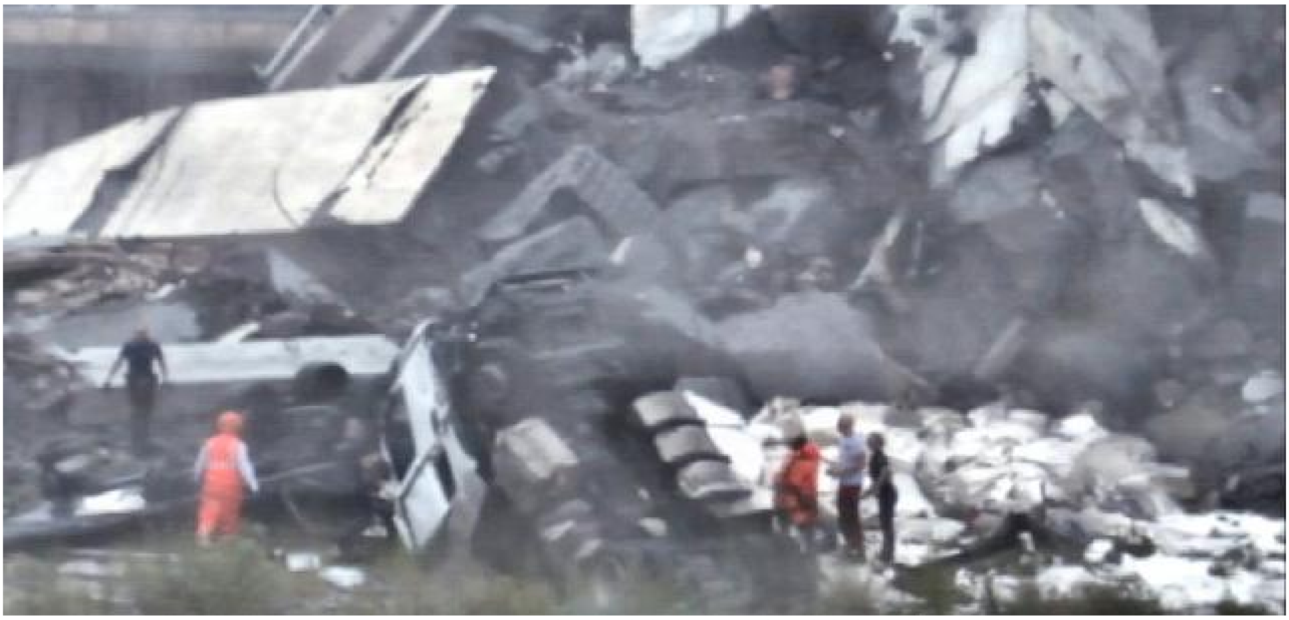

Figure 11. The tractor of the tank between the debris of the bridge.

Figure 12. The tractor of the tank between the debris of the bridge and now debris area under investigation

It is a semi-trailer with a cistern elliptical for fuel or ADR [Note 6]. The all-aluminium metal tank, about 20 meters long in transit on a bridge during a violent storm, attracts lightning. The tank truck are provided by the static grounding system [Note 6]. The connection resistance discharges to earth the electrostatic charges that can be created during the use of the tank (for movement of fluid or flow of liquids inside the flexible tubes of discharge). The Italian legislation prohibits the loading and unloading of ADR truck tank in the event of storms. Grounding is a metal strip (usually in copper), often visible, unhooked, dragged, touches the asphalt. The Truck Grounding Connection Line [Note 7]. perhaps forgotten without - has brought the ignition.

The "Cloud to Ground negative lightning" downward already very probably has struck the suspension tower, perhaps one of the tie rods on the top of the pylon 9 and the ascending "stepper leader" lightning has been generated in terms of positive, faster return discharge and intense: it propagated causing the explosion of the truck tank.

A positive lightning "stepped leader" and ascending has a speed of one hundred thousand km per hour and determines electric discharge in the order of 100 kA.
This lightning is invisible due to the speed that characterizes it and for this it does not appear in any of the camera images but in the return discharge it determines n short luminous flash and a detonation. The loud bang heard by all the witnesses.
Some witnesses cited the rumble, maybe a lightning, everyone saw the collapse.
Someone [Note 8] declared that he had arrived at a sheltered spot, stopped and descended from the vehicle; he heard a roar and then a strong movement of air that pushed him against a wall.
On 14 August 2018 there is a weather alert on Genoa: there are lightning strikes in the area. A lightning storm lights up Genoa for the whole night [Note 9].

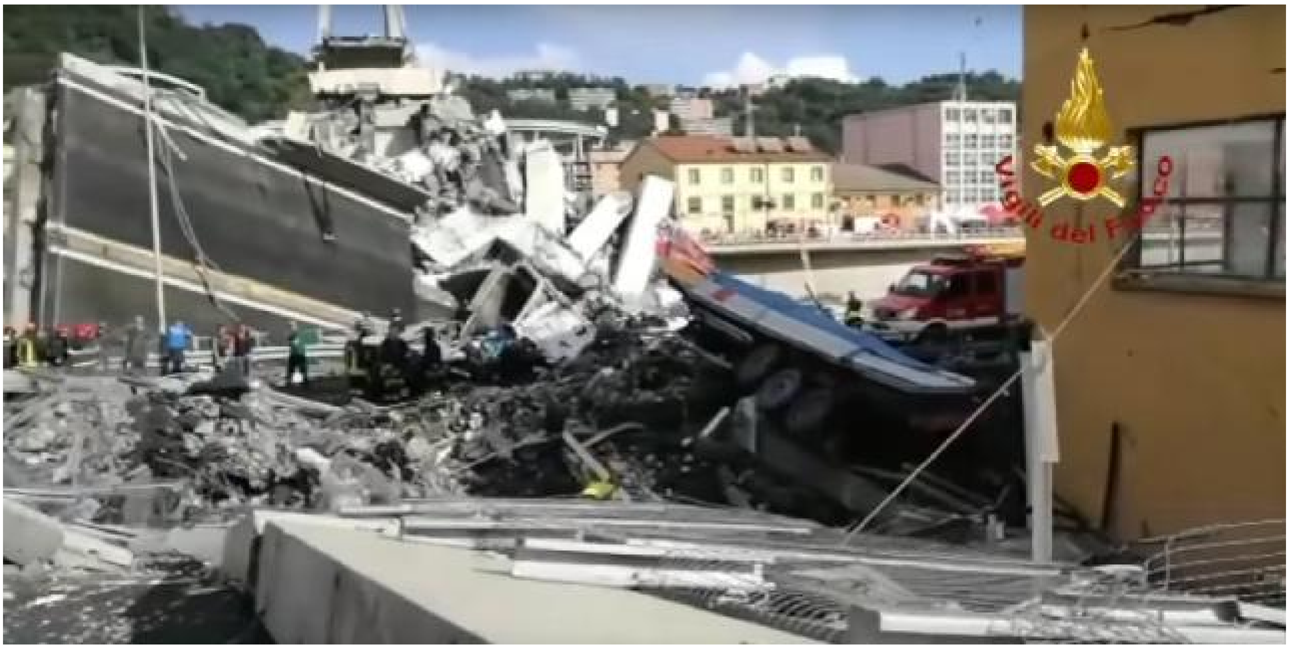

Figure 13 Collapsed roofs of some warehouses under the Morandi Viaduct

But no one imagines - because this has never happened before - that the motorway transit must be stopped for the ADR tanks.
There are no lightning rods on the pylon of the Morandi Viaduct.
The truck tank explosion caused the movement the Morandi Viaduct and a detachment Gerber saddle, resulting in the collapse of the bridge deck on the Cornigliano side.

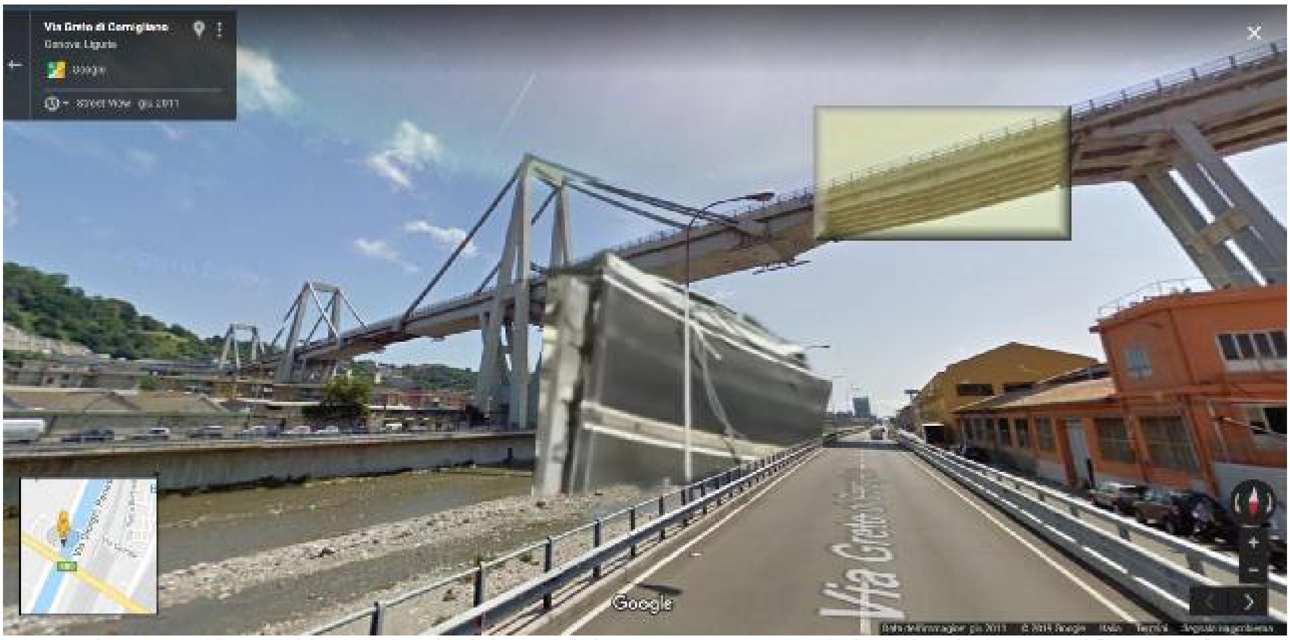

Figure 14 The position of the deck beyond the street lamp Cornigliano bank river road [Nota 10]

Here we see the deck bridge crashed to the ground with roto-translation on the horizontal axis In the same instant the first girder had collapsed due to the separation of the Gerber saddle.
Without support, the remaining part of the deck hung a few moments on the tie rods of the pile 9 which in some moments was then collapsed.
On the ground remains the tractor, it will have been pushed and dropped in the explosion. The tank is exploded and we cannot find it.
The tractor is blackened. A logo on the vehicle door and little else. Another white lorry near but no trace of the tank.
A tank twenty meters long and carrying on average 41 thousand litres of fuel or ADR liquids has disappeared.
The collapses are usually vertical.
But in this case the explosion triggered a different dynamic and therefore in the first collapsed deck section the affected area is greater than that exactly on the vertical of the viaduct.
The explosion was a terrible fatality, a lightning “stepped leader” interested the deck while - just at that moment – passed a tank truck loaded with ADR or fuel and, decisive fatality, that drive with the grounding system unhooked in the wet roadway.

4. Available evidence

The bridge deck is turned: a road bridge with a width of 18 meters that collapses in an instant but that during the collapse turns 90 °.
An unusual and extraordinary event.
What force is needed to rotate and move an objects of a 36 meter long, 18 meter wide and weighing 916 tons?
Webcam under pylon 9: at the top the viaduct deck reflection on wet roof. This is a relevant image that helps determine the speed at which the bridge collapses and where the debris comes from.
This image explains the first several phases during collapse**.**

5. Conclusion

This destruction was a terrible fatality and possibly avoidable fatality: the motorway operator did not think - with an orange weather alert and an electric storm warning in progress - to implement all the existing procedures to loading and unloading of tanks.
There is a lot of work on climate change policy, but much less on the relationship between road safety and weather conditions.
The climate is changing and we need to develop security protocols.

[Note 1]
Retrofit: the arrangement of new external cables from the bridge crosspiece to the top of the antennas. Some steel cable ties connected to the bridge crosspiece and to the top of the antenna have been placed along the stay by means of steel anchor blocks.

[Note 2]
In 1992, during a 90-meter control at the top of the pylon number 11, on the tie rods on the Genoa side (north side), the cement had left a portion of steel uncovered and this had led to the dissolution corrosion of about 30% of the strands.
The actions to which the load-bearing steel of the rod worked (about 7,000 kg) were far below the resistance capacity of the steel that constituted it (15,000 kg).

[Note 3]
Bridge description: the balanced system area consists of three cable-stayed piles (pile 9, 10 and 11) joined together by pre-compressed reinforced concrete cables. All three cable-stayed batteries are made up of four basic elements: antenna, easel, deck and tie rods. The main viaduct has the following theoretical spans:
- one 43.00 m span
- five 73.20 m spans
- one 75.313 m span
- one 142.655 m span
- one 207.884 m span
- one 202.50 m span
- one 65.10 m span

Tie rods on the stack: distribution of the pull in the consolidated suspension system:
stays made of prestressed concrete (Genoa side) (7 560 T (kN)
3 + 3 secondary external cables (Genoa side) (7 560 T (kN)
6 + 6 main external cables (Genoa side) (17 040 T (kN)
stays made of prestressed concrete (Savona side) (6 420 T (kN)
3 + 3 secondary external cables (Savona side) (6 420 T (kN)
6 + 6 main external cables (Savona side)) (17 040 T (kN)

The spans, of such a different length, find their conceptual link in a series of prestressed concrete decks, all of the same span 36.00 m long, simply supported by a series of special systems, amongst which we may distinguish the following two different basic types : - The system supporting the smaller spans, consisting of two inclined piers connected at the top by a double cantilever girder of variable length. The whole in reinforced concrete, carried by a foundation raft which in turn rests on drilled piles 110 cm in diameter of a length variable up to 40.0 m. The balanced system for the main spans. Such system consists of a three-span continuous girder resting on four supports, with two end cantilevers giving support to the above said 36.00 m beams. The two external support of the three-span girder are provided by the anchorages of two prestressed stay-cables passing over a mast (suspension tower) located on the axis of the system.
The mast top is 90.00 m above the ground and about 45.00 m over the roadway deck. Each balanced system consists of : 1. A reinforced concrete ribbed foundations raft resting on drilled piles 150 cm in diameter. 2. A special reinforced concrete trestle consisting of four "H" shaped bents laid side by side and connected to each other by cross elements. The tops of the trestle give elastic supports to the deck girder.
3. A mast, or Suspension tower ("Antenna") made up of four inclined legs with adequate connections in both directions (longitudinal and transversal) so as to form a true and proper frame, but such as to keep independent the tower itself from the trestle-deck system. 4. A continuous deck-girder of prestressed concrete, of cellular type, with top and bottom slab and six longitudinal ribs, resting on the trestle referred to

point 2. The connection between the deck and the stay-cables is achieved through a stiff cross girder, also in prestressed concrete, whose projections on each side of the deck provide the anchorage of the two stay-cables passing over the top of the mast at an elevation of 9,000 m above ground. Finally, concrete envelopes were cast around the cables; the function of these shells, as we know, is, in addition to protecting the steel, also reduce the elongation of the cable during the passage of moving loads because the hulls themselves have been prestressed.

[Note 4]
Polcevera viaduct: the webcam of "Autostrade per l'Italia" (the largest operator of toll roads in Italy) https://www.youtube.com/watch?v=t4JY3UidLLU
https://www.ilfattoquotidiano.it/2018/09/26/ponte-morandi-nessuna-manomissione-dei-filmati-di-autostrade-la-polizia-diffonde-il-video-integrale-prima-del-crollo/4651206/
http://www.ilsecoloxix.it/p/multimedia/genova/2018/09/26/ADIbKQrB-integrale_autostrade_telecamera.shtml

[Note 5] http://www.ansa.it/sito/videogallery/italia/2018/08/20/il-momento-del-crollo-ripreso-dalle-telecamere-collocate-sotto-il-ponte_401a0c5a-bb0b-44dc-b80c-8909db8ad8db.html

[Note 6] The classes of dangerous goods according to ADR are the following: Class 1 Explosive substances and articles, Class 2 Gases, including compressed, liquified, and dissolved under pressure gases and vapors, Flammable gases (e.g. butane, propane, acetylene) …

[Note 7]
The system establish if the connection resistance between the tank truck and the verified earth ground is 10 ohms or less. 10 ohms is the benchmark requirement repeated in several international standards, the most prominent of which is the American NFPA 77 "Recommended Practice on Static Electricity" and Europe's Cenelec CLC/TR 50404:2003 standard

[Note 8]
Declared statement https://www.youtube.com/watch?v=5FLs-nZQXiw

[Note 9] The statement by ARPA Liguria (Regional Environmental Protection Agency) states "At the moment there remains an extensive storm structure on the Ligurian Sea accompanied by intense electrical activity whose trajectory is constantly monitored by the operations center. »

[Note 10] Cornigliano bank river road https://goo.gl/maps/1iSuahc9JrJ2

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