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Forensic Reconstruction of the Explosion that Occurred at the Cordero Flour Mill, Cuneo, Italy

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This paper contains the forensic reconstruction of a powerful explosion that occurred in a flour mill in Italy in 2007. The mill produced wheat flour and was organised over 4 floors inside a very old building. The explosion occurred just after a tanker had been loaded with flour which was to be delivered to customers. Since the truck was loaded with a slight excess of flour, a small amount was sent back to one of the silos, via pneumatic transport, through a rubber hose connected to a steel pipe. The explosion destroyed the building and killed 5 workers.

Through an analysis of the collected evidence, the testimony of the witnesses and an examination of the debris, the causes and dynamics of the explosion are here described. It was recognised that the explosion was ignited because of an electrostatic arc that occurred in the pneumatic transport duct. Signs of the explosion in the duct were evident because of the deformation that was provoked by internal overpressure. The triggering discharge occurred at the joint between the hose and the pipe. The pipe deformations were coherent with calculations of an internal pressure increase according to EN 14491.

The explosion propagated to a flour silo and then to the whole building through the elevator case, and resulted in many secondary explosions. The explosion dynamics are here described and the lesson that have been learned are also proposed.

1. Plant description

The Cordero Mill, in which the accident occurred in 2007, was a flour mill with a production of more than 0.2 t per day. It was located in a rectangular masonry building in the town of Fossano. The building consisted of a central four storey plus a basement; the products warehouse and the offices were located in a more recent three-storey construction.

The main building, in which the production area was located, was organized in four main sections, separated by brick thick walls. Access to the area was through a hoist and an internal staircase.

The production area which was located in the “B” rooms, while the “A” rooms were used as floor storage areas and for the preparation of the wheat for milling operations can be seen in Figures 1 and 2, which represent the ground and the top floor of the main building.

1.1 The Production Process

The wheat was taken from the grain bins located outside the main building and sent through an elevator, to a pre-purification operation. The wheat was then immediately watered, brushed and sent to a resting bin.

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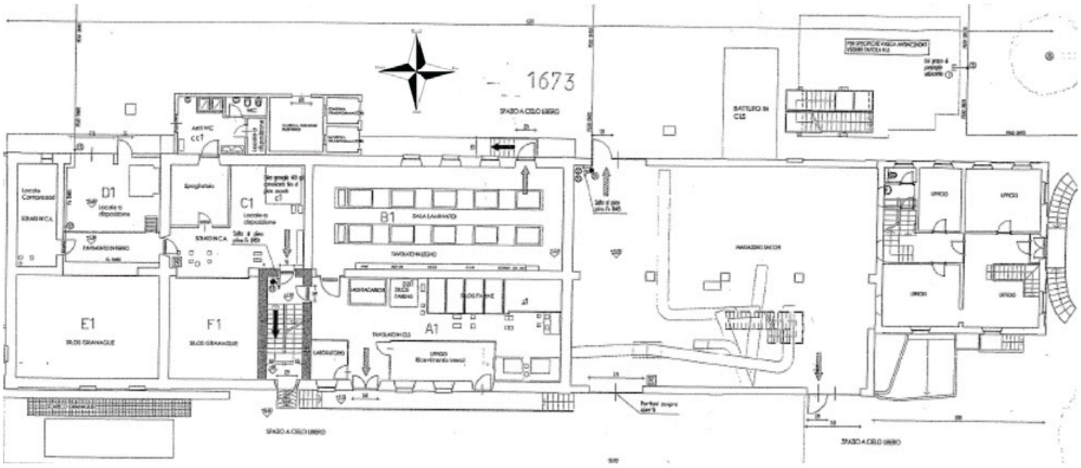

Figure 1: Plan of the ground floor

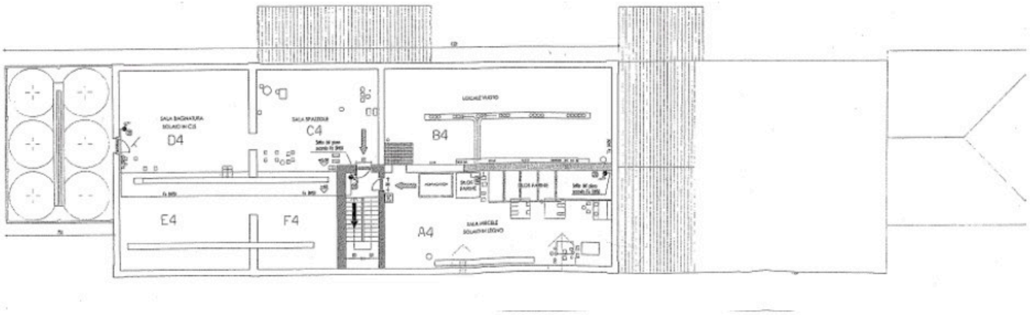

Figure 2: Plan of the top floor

The wheat was then moved to a metallic bin on the second floor, weighted and conveyed through a cochlea's system, to the mills in B1, where, after several passages, each of which was followed by separation in the plansichters on the basis of the granulometry, flour was obtained. The flour was then conveyed, through bucket elevators and cochleas and stored in the flour-warehouses in the area A.
The flour was loaded onto vehicles using bucket elevators, cochleas and finally left to fall free. If necessary, it was unloaded from tankers through the pneumatic conveying system, made up of a compressor on the vehicle itself, a rubber hose and a fixed steel pipe located inside the area A. This duct went from the basement, in A0, and after a first horizontal part, proceeded vertically, until it arrived at the top of the flour-warehouses. It went through areas from A0 to A4, where several ramifications and diverter valves distributed the flour to the different warehouses.

2. Technical enquiry and Collection of Evidence

One of the Authors (LM) was charged with the role of technical expert by the Judge during the trial. The enquiry was carried out more than one year after the accident, while an enquiry was made by the technical experts, charged by the Public Prosecutor and by the defence, immediately after the event. The Authors of the present paper had to face the challenge of conducting an enquiry more than one year after the accident had occurred. The main difficulty they had to face was a result of the fragility of the evidence that made much of it no longer representative at the moment of the surveys. To deal with these aspects, they used the evidence that was collected during the first technical enquiry (mainly photographs) and conducted some on site surveys. The technical enquiry hence involved the following activities:

- Site surveys (some still representative metallic debris was retrieved),
- Interviews with witnesses,
- Documentation analysis, including previous technical reports and photographs.

The only evidence that was (in part) representative was some metallic debris from the piping and machinery that was stored in a huge heap. The building and the site had undergone important alterations due to safety requirements. Much of the evidence connected to the combustible, partly burned materials was also unavailable, although photographs taken during the former technical enquiry were still available.

3. Damage

Because of the explosion, most of the main building of the mill underwent a significant, but not complete, collapse, in the areas marked as A and B in the plan (Figure 2 a/b). Other parts of the building suffered from less (areas C and F) or very slight (areas D and E) structural damage.

Figure 2 Damage to the main building: a) southern face; b) northern face

In particular the collapse that occurred in the basement of all the B rooms and of the relative equipment should be pointed out: plansicthers, mills, cyclones, cochleas and elevators ducts. Most of the equipment was not involved in the fire and it still shows the original paintwork. The north wall collapsed completely, while the internal ones were damaged, but remained in their original position. The internal staircase was still in its original position, even though its stability was totally compromised.

The equipment and walls in the A area of the basement mainly showed signs of fire, which had burned in the area over a long period. The equipment in this area did not show any sign of internal overpressure, while the ceiling of area A0 was damaged by internal overpressure. The same applies for the A1 area (Figure 1), as well as for the hoist bay, which appeared to be destroyed by internal overpressure. The overpressure from the hoist provoked major damage to the structures on the Southern side of the building. The rooms in the A areas of the intermediate floors were completely destroyed: the roofs and the perimetral walls. The upper hoist slab was also wrecked.

Some interesting evidence came to light from the status of the pipe used to transfer the flour from the trucks to the warehouses. Some parts of this duct were found in their original position, while some parts had been retrieved from the debris heap and some were lost.

The steel pipe was characterized as shown in Table 1. The flanges were located as in Table 2.

Table 1: Characteristics of the unloading pipe

Pipe	Characteristic
Diameter	100 mm
Flanges	**Characteristic**
External diameter	155 mm
Holes	6
Interaxe distance	130 mm
Flange thickness	4 mm
Hole diameter	8 mm
Bolts	M6/M8

Table 2: Flanges along the unloading pipe

Component	Cumulative pipe length [m]
First flange	1.62
Second flange	4.36
Third flange	6.95
Pipe end	12.39

The flanges showed the typical deformations caused by high internal pressure, which produced much higher stresses to the material than the elastic limit and thus creating a permanent deformation.

4. Accident dynamics

The accident was caused by a very complex dynamics sequence of dust explosions: a primary explosion triggered a sequence of secondary ones. The dynamics described hereafter is coherent with the state of the sites and the declarations of the witnesses.

The day the accident occurred, a delivery had to be made to a confectionery company. The tanker was loaded, as usual, by gravity, using a bucket elevator and a specific cochlea. At the end of the loading operation, an extra amount of product was loaded. The operator unloaded this surplus, pneumatically conveying it back to a silo located in the flour-warehouses. During this operation, the tanker discharge device was connected to the pneumatic transport line through one of the tanker hoses. The unloading system, thus, consisted of two metallic conductor bodies, the truck and the pipe, separated by an insulating one, the hose (6 m long). The two conductors were not equipotential, since the truck was not connected to a grounding system, while the pipe instead was grounded.

The status of the control valves onboard the tanker (Figure 4) showed that the operation was carried out at a low flour flow rate, thus with a low concentration of flour in the duct (near or within the lower flammability limit).

It is well known that the pneumatic conveying of dust causes of the accumulation of electrostatic charges, and these can be released in the form of electrostatic sparks, in particular as a propagating brush discharge (Glor, 1988). Whether this kind of discharge could trigger the explosion of a dust cloud is still a matter of doubt: Glor (1988) and Eckhoff (2003) are certain it can, while others Authors consider this mechanism possible (Nifuku, 2003).

In the present case, the charge accumulation occurred due to the friction of the dust in the rubber duct (or even during the loading procedure). When the flour reached the metal pipe at the end of the hose, it found a discharge point and a propagating brush discharge was generated. The discharge occurred between the flour suspension in the pipe and the pipe wall, and a primary explosion was triggered inside the duct. The pressure front propagated along the duct, and escalated due to the confinement.

The mechanical strain produced the deformation of the duct flanges, as can be seen in Figure 5.

The dynamics of the explosion propagation was therefore certainly complex. The deformation of the flanges compromised their sealing capacity, thus creating venting openings for the pressure and the flame front and this led to the propagation inside areas A, over the three floors.

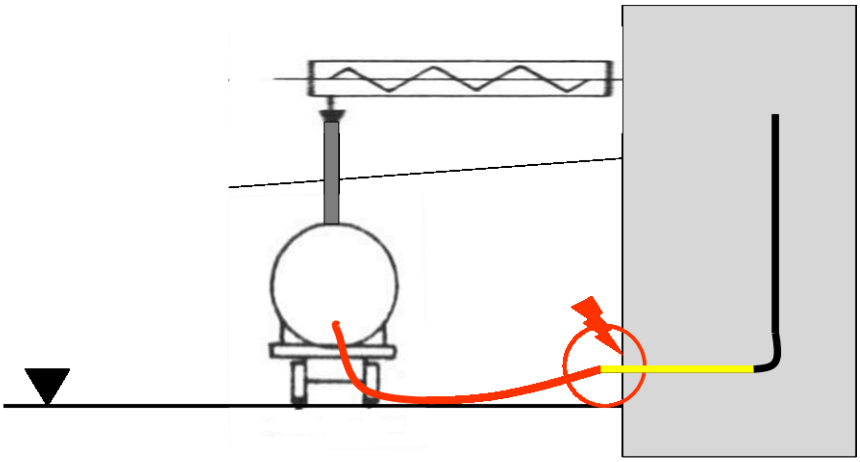

Figure 3 Simplified representation of the unloading operation with the triggering location.

Figure 4 The tank after the accident

The flame front reached the silo where the flour was being conveyed almost immediately. A large amount of suspended flour was present because of the reloading operation inside the silo, and a very strong secondary explosion therefore occurred inside the silo.

The explosion did not occur in the steel silo, which can be proved from the fact that none of the pieces of wreckage showed signs of deformation due to internal overpressure. The explosion instead occurred in one of the wooden silo, but no damage could be observed because the subsequent fire destroyed all the wooden silos.

The explosion and the rapid increase in the pressure in the headroom led to two effects. First, the pressure front descended the hoist bay, and arrived at the basement: this can be confirmed by the fact that the top of the hoist bay was overturned, the hoist door in room A1 was projected and a part of the ceiling of room A0 was overturned. The second, clearly visible effect, was the collapse of the roof and of the walls of the upper parts of the building, with the projection of fragments to long distances.

The explosion propagated from the A areas, to the B ones, through the compartmentalization doors, and to the storage areas.

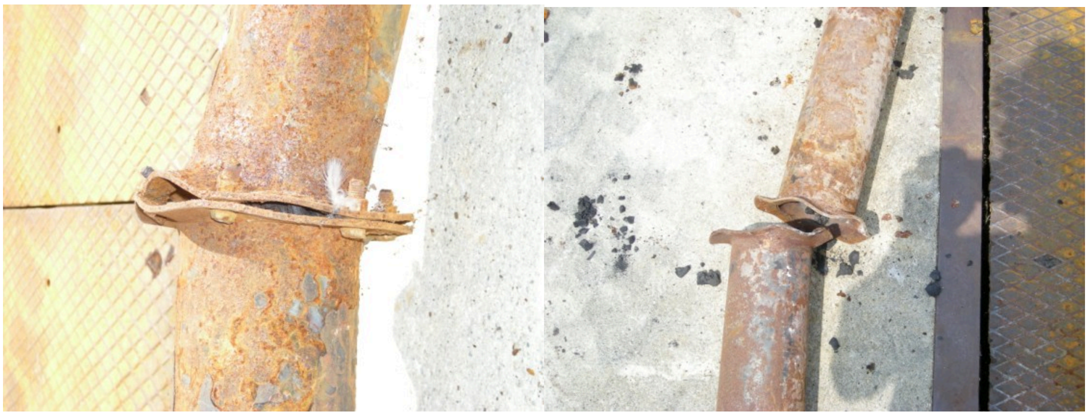

Figure 5 Flanges of the flour discharge pipe

The pressure front was accompanied by the flame front, which triggered a widespread fire. This fire, which involved most of the combustible materials (structures, equipment and flour, even though this last was in the sacks store).

5. Lessons learned and conclusions

The event that occurred in the Cordero Mill on 16th July 2007 was caused by a dust explosion phenomenon characterized by very complex dynamics.

A primary explosion was triggered in the pneumatic flour conveying duct from the tanker to the silos, due to an accumulation of the electrostatic charge, caused by the creeping of the flour against the internal wall of the rubber hose that was utilized. The accumulated electrostatic charge was discharged at the metallic pipe at the end of the rubber hose, thus creating a "propagating brush discharge".

A propagating brush discharge occurred between the flour in the pipe and the metallic wall and it triggered a primary explosion inside the pipe. The triggering point was identified inside the pipe next to the connection between the hose to the pipe.

Several pieces of equipment were not supplied with any explosion prevention or suppression system, although they were mentioned in the risk assessment document.

None of bucket elevators, which were also heavily damaged by the event, was equipped with an appropriate system to vent possible explosions or with a explosion suppression system. As far as the operation carried out at the moment of the accident are concerned, if the vehicle had been grounded, it would have reduced the charge accumulation during loading operations.

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